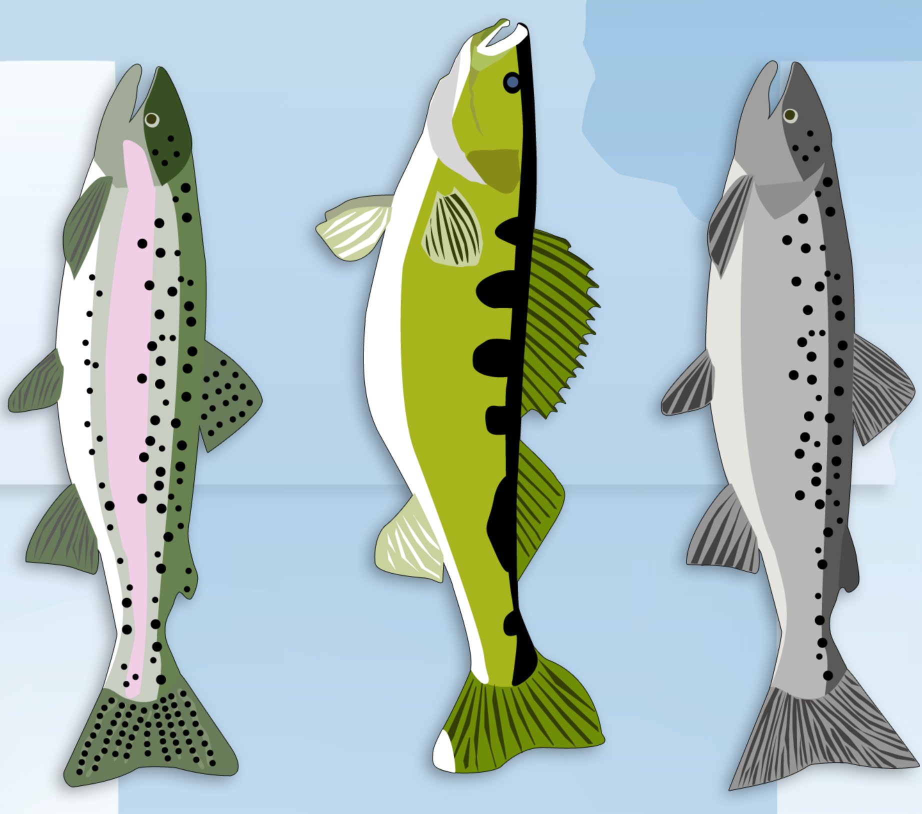
Food-Fish Aquaculture in Minnesota

Synthesis of the 26-27 April 2017 Workshop

Hosted by the
University of Minnesota
Sea Grant College Program

Prepared by
Sharon Moen, Donald Schreiner,
Jessica Coburn & Nicholas Jacob



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Cover design: Chris J. Benson
Proofreaders: Deborah Bowen, Marie Thoms
Contact: Donald Schreiner, Fisheries Specialist, Minnesota Sea Grant, schr0941@d.umn.edu

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Minnesota Sea Grant
31 West College St., Room 132
Duluth, MN 55812
Email: seagr@d.umn.edu
Phone: (218) 726-8106
www.seagrant.umn.edu

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Executive Summary

Producing baitfish and providing fish for stocking are the major fish-rearing activities in Minnesota. Recently, interest in food-fish aquaculture and aquaponics has increased. Consumer demand for locally grown, safe and healthy food, along with technological advances in aquaculture production strategies over the last 10 years, provides exciting potential for the growth of aquaculture in Minnesota. This potential led to the question Minnesota Sea Grant set out to answer during a workshop in April 2017:

"Can an environmentally responsible and sustainable food-fish aquaculture industry be established in Minnesota?"

The answer to the workshop's question, is "yes," but it will take a balanced, thoughtful and collaborative approach among many stakeholders. A follow-up question, "What might be the best ways to proceed?" can be answered with:

- A market analysis
- A state aquaculture plan
- State support
- Transparency and collaboration among industry and state regulatory agencies

This first-ever workshop in Minnesota addressed the status, trends and future for raising food-fish such as Walleye, trout and shrimp. Attendees represented national, regional and local expertise in food-fish aquaculture and aquaponics. Participants included growers from the upper Great Lakes states, staff from Minnesota state agencies that license and regulate aquaculture programs and a variety of businesses interested in learning more about the aquaculture industry. Though the food-fish aquaculture and aquaponics industries are presently limited by Minnesota's winters, the potential for their growth in Minnesota, with accompanying increases in local economies and jobs, is exciting.

This synthesis captures the main points discussed by presenters, panel members and participants. The workshop was composed of keynote presentations, expert panels and breakout sessions in which workshop participants contributed to focused discussions. Videos of all keynote presentations are available online from Minnesota Sea Grant. The results of this workshop are the first step in an exciting process to develop an economically viable and sustainable food-fish aquaculture industry in Minnesota while minimizing risk to natural aquatic systems throughout the state.

The workshop was organized around three themes. A brief summary of major findings and future directions for food-fish aquaculture in Minnesota by theme area follows.

Theme 1: Prioritizing Production Strategies and Species for Food-Fish Aquaculture in Minnesota

A wide variety of strategies and species were discussed. The consensus of the participants is as follows:

Production Strategies

Recirculating Aquaculture Systems (RAS) were the most popular fish rearing technique discussed, followed by flow-through systems. Dug and natural ponds were thought to be ineffective since they rely on ambient water temperatures making production of food-fish in Minnesota's cold climate a lengthy process. Net pen use in public water would likely be viewed negatively by the public and anglers. There may be some potential for net pens in private mine pits.

Aquaponics, the combined rearing of vegetables and fish, was discussed as an aquaculture method, but little research has been done to calculate the economic viability of a medium- or large-scale facility. Superior Fresh farms (Hixton, Wisc.) is using a decoupled method of aquaponics to grow Atlantic Salmon where the plants and animals are grown in separate buildings.

Shrimp aquaculture facilities are being developed in south-western Minnesota using an intense shallow water raceway system with zero water discharge. In these systems, biofilters remove nutrients; the salt remains inside of the system to be reused.

Species

Walleye was identified as the most preferred species discussed. Unfortunately, aquaculture systems have not yet been developed for their commercial production. However, the Northern Aquaculture Demonstration Facility (Bayfield, Wisc.) reports exciting results from experiments with Walleye and hybrids (Saugeye) in RAS.

Yellow Perch was also preferred, but consistent rearing and economic returns were concerns.

Atlantic Salmon and Rainbow Trout are species with established markets that are well-adapted for growth in cool and cold environments. Rainbow Trout are raised in Minnesota for a few local markets and both Atlantic Salmon and Arctic Char are being reared in an aquaponics facility.

There was much interest expressed for a budding shrimp industry in Minnesota. If trū Shrimp can produce the volume expected for the anticipated cost, the Midwest will have a local source of a highly preferred seafood.

Theme 2: Identifying Research Needs and Information Gaps

Participants identified many research needs and information gaps related to aquaculture in Minnesota with priority given to two broad categories: 1) social and economic issues, 2) biological questions/issues.

Social and economic issues

- Industry needs a state-wide business plan
- Aquaculture industry needs a market study to determine purchasing decisions of customers, species preference, price sensitivity, demand for local fish, and industry growth potential
- Market information needs to be collected on an ongoing basis so trends can be detected and predictions can be taken into account
- Consumers need unbiased information on aquaculture so they can make informed decisions, best done at point of sale
- Consumer perceptions and expectations for Minnesota aquaculture need to be determined
- A technically trained and widely available workforce must be available

Biological questions/issues

- Nutrition (proper feed stocks) need to be determined for each species at each life stage
- Broodstock development for species such as Walleye (year-round availability of gametes)
- Selective breeding for healthy fast-growing fish in a variety of facilities
- Expanded fish disease detection and control, new innovative treatments
- Continued advances in technology for facilities (RAS, bio-filters, thermal regulation, energy efficiency, water conservation, waste treatment, etc.)
- Advances in, and implementation of, biosecurity practices to reduce disease issues

Theme 3: Examining Policy and Regulatory Issues

Participants suggested that the regulatory climate for food-fish aquaculture in Minnesota was fair, supportive and allowed flexibility. There was concern expressed about high fees required to obtain a discharge permit from the Minnesota Pollution Control Agency.

Prioritized actions

- Conduct a market analysis to determine if food-fish aquaculture in Minnesota can become economically viable and sustainable
- Develop a Minnesota Aquaculture Association that can work on policies and foster success in the industry
- Create a Minnesota Aquaculture Plan that outlines a path forward
- Hire a state aquaculture coordinator who represents the state agencies involved in aquaculture to foster communication and assist with the development of a viable food-fish aquaculture industry in Minnesota
- Create funding streams, grants and fee structures that support the food-fish aquaculture industry in Minnesota
- Work with citizens to improve the social license for aquaculture in Minnesota

Foreword

By Donald Schreiner, Fisheries Specialist, Minnesota Sea Grant

Aquaculture involves the breeding, rearing, and harvesting of animals in all types of water environments including ponds, rivers, lakes, and the ocean. Historically, producing baitfish and providing fish for stocking were the two major fish-rearing activities in Minnesota. More recently, interest in food-fish aquaculture has increased along with interests in aquaponics. Aquaponics, a combination of aquaculture and hydroponics in semi-closed systems, allows water to flow between fish tanks and plant-growing beds so that the fish waste can serve as plant nutrients. The growth of aquaculture and aquaponics has expanded the demand for more specific information on how these activities might best be developed in cool and cold climates like Minnesota.

Specifically, growers are interested in which strategies and species may be best suited for aquaculture ventures in Minnesota, and what potential markets might best support the industry. In addition, Minnesota regulatory and management agencies must be prepared for the development of new and diverse forms of aquaculture and aquaponics at various scales. A major objective as aquaculture and aquaponics businesses develop in Minnesota is to minimize risk to the productive and highly valuable natural aquatic systems for which Minnesota is known.

Minnesota Sea Grant identified 2017 as a critical year to increase communication between the food-fish aquaculture and aquaponics industries and the state agencies that regulate those industries so common understandings and productive relationships could be established. Food-fish aquaculture and aquaponics in Minnesota is currently limited by the nature of the state’s winter climate. Increasing consumer demand for locally grown, safe and healthy food, along with the technological advances in aquaculture production strategies over the last ten years provides exciting potential for growth of aquaculture in Minnesota with accompanying increases in local economies and jobs.

In April 2017 Minnesota Sea Grant held the first-ever workshop in Minnesota to address the status, trends and future for raising food-fish such as walleye, trout and shrimp. The purpose of the workshop was to kick-start Minnesota's fledgling food-fish aquaculture industry. Workshop participants were represented by national, regional and local experts in food-fish aquaculture and aquaponics, growers from the upper Great Lakes states, staff from Minnesota state agencies that license and regulate aquaculture programs and a variety of businesses interested in learning more about the growing aquaculture industry. A major question posed to workshop participants was:

Can an environmentally responsible and sustainable food-fish aquaculture industry be established in Minnesota, and if so, what might be the best ways to proceed?

The major themes of the workshop were to:

- Prioritize production strategies and species for food-fish aquaculture and aquaponics in Minnesota.
- Identify research needs and information gaps to address for successful food fish aquaculture and aquaponics in Minnesota and other Upper Midwestern states.

- Identify policy and regulatory issues that promote food security and an environmentally responsible aquaculture and aquaponics program in Minnesota.

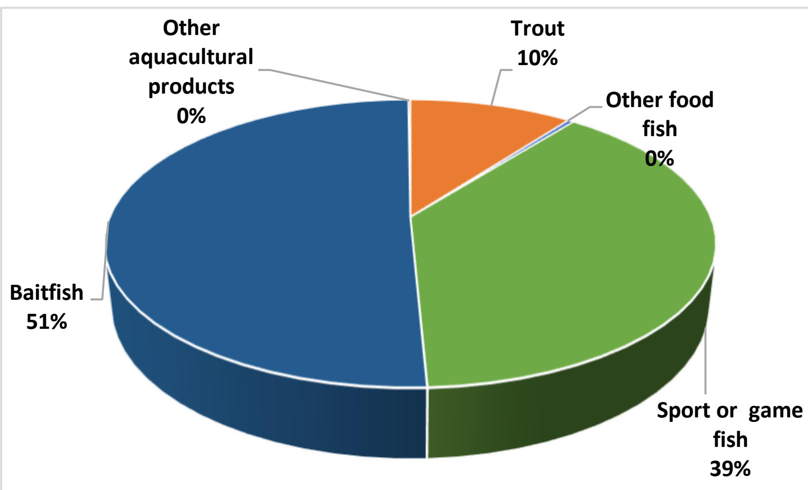
The workshop began with an introductory presentation and two overview presentations on the present status of aquaculture in the United Statess. Keynote presentations were given for each of the three major theme areas, followed by a panel of experts who discussed their perspectives on each theme, and a breakout session in which participants were divided among four different groups for more focused discussions. Questions for each breakout group were prepared to initiate discussions and focus the conversations. Participants were also encouraged to brainstorm and develop creative responses to questions related to each theme area. Each breakout group had a facilitator and a recorder and after the breakout sessions were completed each group's information was summarized and reported back.

This synthesis captures the main points discussed by presenters and panel members. It also summarizes the discussions from the breakout groups centered on each of the major themes. Capitalization of fish names follows the format of the American Fisheries Society. Findings and future directions for food-fish aquaculture in Minnesota are described in the conclusion. Videos of introductory addresses and keynote workshop presentations are available online at Minnesota Sea Grant.

Minnesota Sea Grant's Role in Aquaculture – *a summary of remarks made by John A. Downing*

Director of Minnesota Sea Grant John A. Downing introduced himself and Sea Grant explaining that the National Oceanic and Atmospheric Administration's Sea Grant College Program has awarded millions of dollars in aquaculture grants to help coastal communities maintain a safe and sustainable local seafood supply. Sea Grant's investment focuses on research and technology transfer to support and expand America's aquaculture industry. He said in Minnesota, Sea Grant seeks to help grow food-fish aquaculture so that it is profitable, efficient, environmentally neutral, innovative, sustainable and responsible.

Pointing toward a University of Minnesota Extension website designed to strengthen local food economies, localfoods.umn.edu, Downing said he envisions a day where Minnesota aquaculture and aquaponics products are integrated into the state's local food network. Why? Because he and many others view locally grown food as having better flavor, better variety, fewer contaminants and a deeper connection to nature than industrially produced similar products. He also pointed out that locally produced foods typically have smaller carbon footprints and greater nutritional value because processing and shipping are minimized. Buying locally grown produce strengthens the local economy, builds community and negates fears that the products might reflect a food system that exploits people.



Aquaculture in Minnesota was worth $11.2 M in 2012; 23 in nation, 104 facilities. 2012 U.S. Census of Agriculture (Minnesota).

Downing foresees opportunities in Minnesota aquaculture and addressed ideas such as food security in the frames of human history and a future of climatic uncertainty. He said an aquaculture industry would be compatible with the current food preservation trends; adding that he thought it could be beneficial to create commercial co-ops for processing and food hubs to aggregate the marketing potential of small businesses.

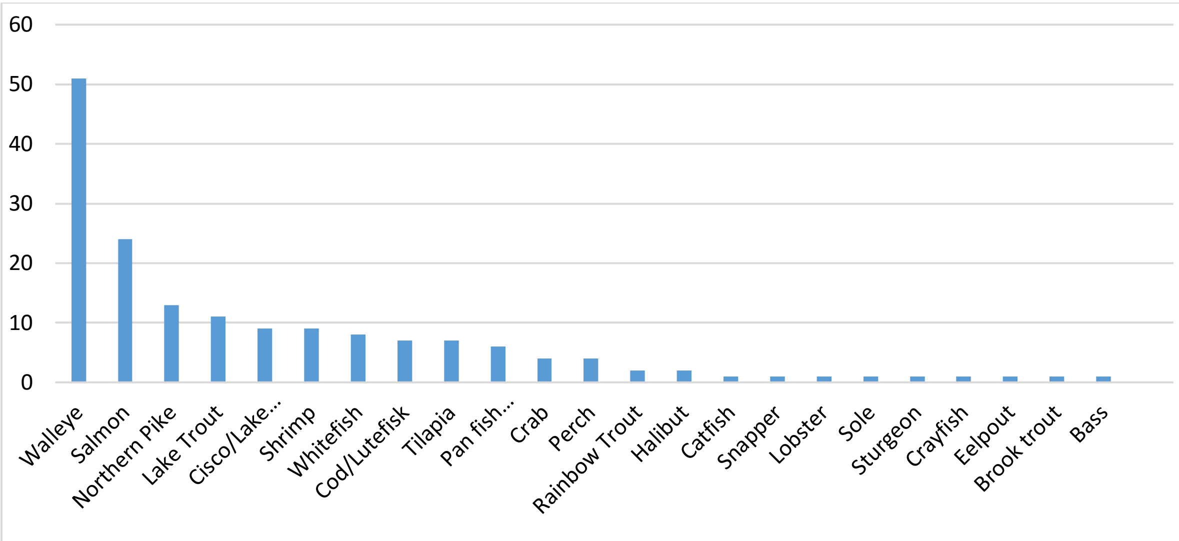
Aquaculture in Minnesota was worth $11.2 M in 2012, said Downing. That sum primarily reflects the production of baitfish and sport fish for stocking. In Minnesota, food-fish shows up mainly in the form of trout.

Of the protein that Americans eat, Downing reported that seafood comprises a meager 76 grams (2.7 oz.) per week on average, mostly in the form of shrimp. According to the U.S. Department of Agriculture (USDA), over half of the consumption of seafood in the U.S. in 2014 involved only three groups: shrimp (27%), salmon (16%) and canned tuna (15%) (Kantor 2016). Downing said the world's average fish consumption is 20 kg (44 lbs.) per year; in the U.S., it's 6.8 kg (15 lbs.).; in the Midwest, it's 4.5 kg (10 lbs.). Downing reasoned, there are 5.5 million people in

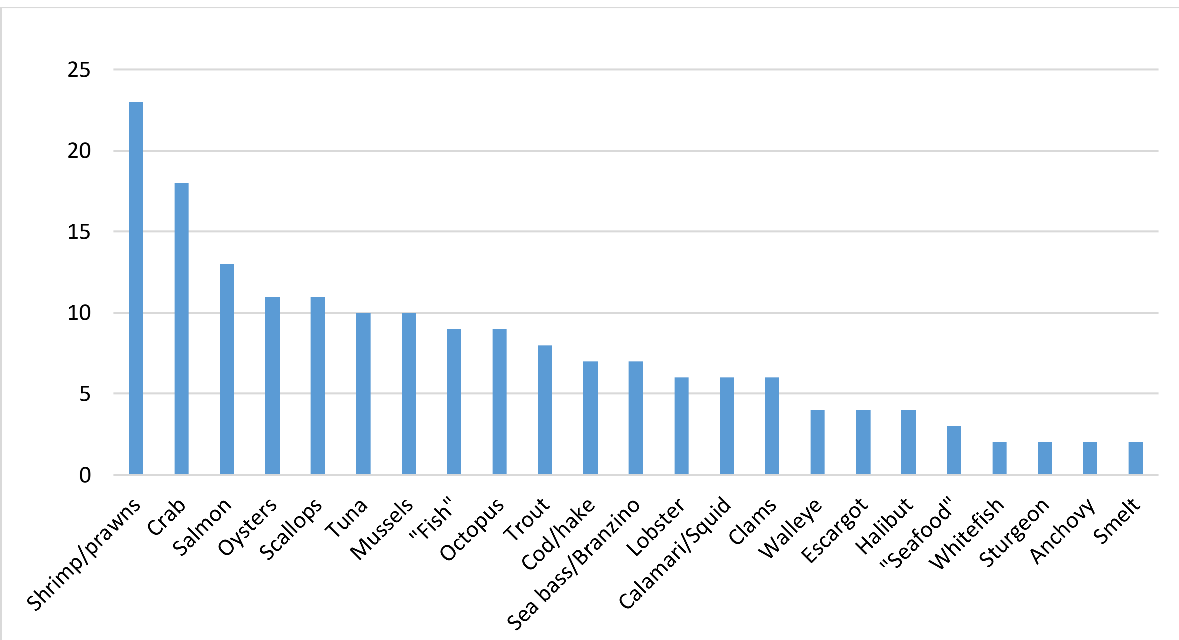
Minnesota and tons of seafood are and will be eaten in the state each year; there is great potential for a food-fish aquaculture industry here.

Downing shared the results of two Google searches he conducted. One sought species of fish and seafood most used in recipes related to Minnesota or published by Minnesotans. The other sought species of fish and seafood found on 70 restaurant menus in Minneapolis.

Fish and seafood recipes published by or about Minnesotans based on a Google search conducted by John A. Downing, 2017, not counting "My 100+ Favorite Walleye Recipes."



Fish and seafood on 58 Minneapolis menus based on a Google search conducted by John A. Downing, 2017.



This exercise led Downing to ponder an idea attributable to economist Paul Samuelson (1948), revealed preference theory. This theory posits that consumer preferences manifest as "utility," the satisfaction gained by using, owning or doing something, and that consumers tend to maximize utility balanced by budget restraint. Downing applied revealed preference theory to comment on fish and seafood use in Minnesota with empirical data. He found that Walleye by far outranked other species as the most popular fish in Minnesota-related recipes. Shrimp/prawns led the list of species that turn up on the menus of Minneapolis restaurants, of which 12 of 70 offered no fish or seafood.

Downing concluded saying that Minnesotans tend to think of seafood in terms of local species. He restated the huge potential for a robust aquaculture industry in Minnesota before rearticulating the mission for the workshop: Identify the tools, approaches and science needed to help a successful food aquaculture industry in Minnesota. He said it will be important to:

- Prioritize species and strategies
- Determine research needs
- Locate policy and regulation problems

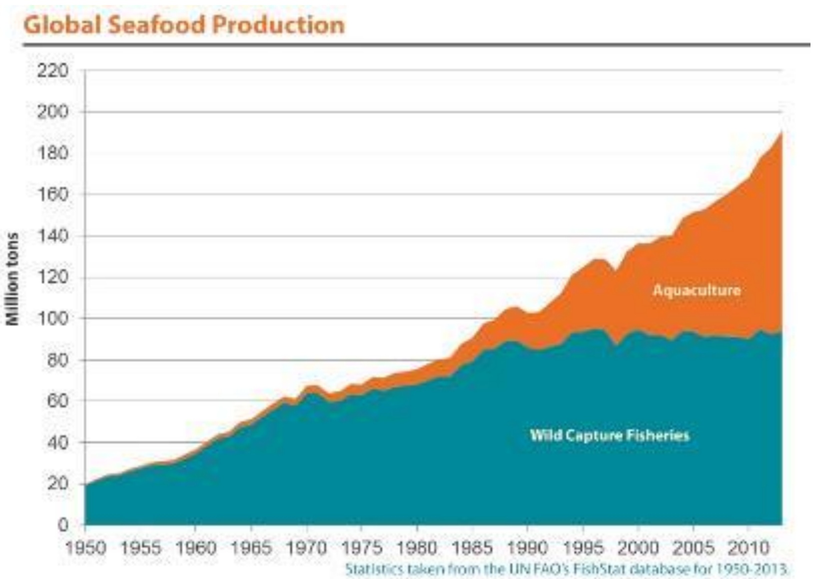
When asked why people would buy Walleye when they can go fishing and catch the fish, Downing suggested markets and chefs purchase imported Walleye and other fish and seafood because they need a dependable supply. The challenge, he said, is aggregating aquaculture products into a U.S. network that can supply supermarkets and restaurants with a consistent and sustainable suite of fish and seafood.

When asked about ethnic and socioeconomic dietary preferences between people, Downing, said that different cultures will certainly favor different fish species and that such cultural diversity is a boon for diet diversity. This question was followed by a discussion of American consumers' relative caution in preparing seafood and their interest in seeking restaurant fare that they wouldn't necessarily prepare at home.

When a participant pointed out that 80% of shrimp is imported from Asia, and South and Central America, and the other 20% is caught from the Gulf of Mexico, Downing agreed that the import market is gigantic. Because the percentage of imported seafood that is inspected is small and there is no real guarantee that seafood items listed on a menu match what turns up on the plate, he thinks people will pay a premium to buy known and locally grown products. "Minnesota already has a brand of 'clean, fresh and natural,'" said Downing. "Minnesota-grown anything would seem to overcome barriers."

The Role of the U.S. Department of Agriculture in Aquaculture - *a summary of remarks made by Caird Rexroad III*

In 2017, "Do right, feed everyone," was the charge U.S. Secretary of Agriculture Sonny Perdue gave to employees of the USDA, which includes Caird Rexroad III, the National Program Leader for Aquaculture within the USDA's Agricultural Research Service.



Global seafood production shown in million tons of wet weight both in wild capture and aquaculture for each year from 1950 to 2013.

Rexroad presented information suggesting research is the USDA's primary role in aquaculture, a billion-dollar industry in the U.S. He said that though the nation has the natural and other resources to conduct aquaculture, it produces only 1.5% of the farmed seafood sold in a market dominated by countries in Asia, particularly China. He said many wild fish stocks are currently fished at or over capacity; meanwhile the world should expect to feed nine billion people by 2050. To help do that, he and others at the USDA are studying ways to better use aquatic resources for protein production.

Rexroad suggested that aquaculture might be a good way to produce protein in a sustainable way since aquatic animals are 10-20% more efficient than land animals at converting energy to protein and that one acre of farmed mussels can produce 50 to 1000 times more edible protein than one acre of grazing land for cattle.

In the U.S., he said people purchase their seafood with discretionary funds with an eye toward price and quality. Consumers also care about safety, health, nutrition, sustainability and local production. Even so, 90% of the seafood consumed is imported while only 5% is produced through domestic aquaculture. The lack of domestic aquaculture contributes to the $14-billion seafood trade deficit in the U.S. (Great Lakes Environmental Assessment and Mapping (GLEAM) 2017)

When speaking of opportunities, Rexroad shared ideas for increasing food-fish production in the U.S. through aquaculture:

- Net pens could be used to rear fish in Great Lakes waters (Several Canadian companies do this in Georgian Bay and the North Channel of Lake Huron) (GLEAM 2017)
- The U.S. has access to an oceanic Exclusive Economic Zone that is larger than its land mass

- Land-based aquaculture operations including ponds, raceways and recirculating systems could be constructed almost anywhere

He applauded the nation's capacity for innovation and technical developments in agriculture and noted the U.S. is a major producer of ingredients for fish food, a situation that could be leveraged into the U.S. becoming a major producer of fish feeds. He also talked about increased opportunities for U.S. aquaculture associated with a changing consumer base including U.S. consumers seeking locally sourced foods, U.S. Dietary Guidelines (ODPHP) recommending increased fish consumption and the potential for increasing seafood exports from the U.S. to a growing middle class in Asia.

The immediate challenges for aquaculture in the U.S., he said, were high production and processing costs; the burden of regulatory compliance, especially for small business; and competition from other countries. Additionally, other industries compete for the soy, corn and fishmeal needed for fish feed. He felt that the growing U.S. aquaculture industry might be wise to address public perceptions and the industry's access to water resources.

Regarding U.S. aquaculture, federal regulations and management tools are in place to ensure environmental protection and seafood safety, which is not necessarily true of seafood imported from other countries. These regulations and tools are shared by the U.S. Environmental Protection Agency (EPA), the U.S. Food and Drug Administration (FDA) and the USDA. Other agencies also play a role in how food-fish aquaculture is conducted in the U.S. The National Oceanic and Atmospheric Administration's Aquaculture Policy and 10-Year Vision are also germane to federal perspectives on aquaculture (NOAA Fisheries 2011, Sea Grant Association 2016).

Rexroad said that a major priority for the USDA is developing new tools for managing aquatic animal health. The USDA's Aquaculture Research Service puts effort toward defining nutrient requirements for farmed species with respect to available and sustainable feeds. NOAA and the USDA's National Institute of Food and Agriculture put effort toward working with new species. Another priority is improving the culture of species already adapted to production; this includes refining genetic management practices and production systems to enhance efficiency, product quality, animal welfare and environmental security.

Rexroad went on to talk about the Interagency Working Group on Aquaculture, a coordinating group authorized by the National Aquaculture Act of 1980 with a goal of producing a more coordinated and consistent federal regulatory process that will protect ocean fish and water quality, and increase efficiency, transparency and predictability in making permit decisions. The working group, composed of representatives from many agencies, strives to increase the effectiveness and productivity of federal aquaculture research, regulation, technology transfer and assistance programs. This aspiration is reflected in the USDA National Strategic Plan for Federal Aquaculture Research (2014-2019), which defines nine research goals:

1. Advance Understanding of the Interactions of Aquaculture and the Environment
2. Employ Genetics to Increase Productivity and Protect Natural Populations
3. Counter Disease in Aquatic Organisms and Improving Biosecurity

4. Improve Production Efficiency and Well-Being
5. Improve Nutrition and Develop Novel Feeds
6. Increase the Supply of Nutritious, Safe, High-Quality Domestic Seafood
7. Improve Performance of Production Systems
8. Create a Skilled Workforce and Enhance Technology Transfer
9. Develop and Use Socioeconomic and Business Research to Advance Domestic Aquaculture

In "An analysis of nearly one billion dollars of aquaculture grants made by the US Federal Government from 1990 to 2015", co-authors David Love, Irena Gorski and Jillian Fry report that federal grant funding for aquaculture had a 37-fold return on investment since 2000 (2017). By contrast, Rexroad said spending on publicly funded agriculture research yields only about a 10-fold return on investment (Fuglie and Heisey 2007).

Citing the 2013 USDA Census on Aquaculture, he said that U.S. aquaculture's top five species, in order of revenue, include:

1. Catfish (Blue, Channel, hybrids); $376M
2. Oysters (Pacific, Eastern, *Olympia*, *Kumamoto*); $180M
3. Rainbow Trout; $110M
4. Clams (hard surf, manila, geoduck); $123M
5. Alligators; $62M

In the foreseeable future he said that Americans could be eating cultured fish such as Sablefish, Atlantic cod, Sixfinger Threadfin, Chub, Yellowfin Tuna, Florida Pompano and Barramundi.

Rexroad leads the aquaculture work conducted through the USDA's Agricultural Research Service, whose research priorities are directed by Presidential initiatives, Congress and stakeholders. The Service's mission with respect to aquaculture is *to conduct high quality, relevant, fundamental, and applied aquaculture research, to improve the systems for raising domesticated aquaculture species, and to transfer technology to enhance the productivity and efficiency of U.S. producers and the quality of seafood and other aquatic animal products.* Currently, this mission encompasses 18 projects, 47 scientists and a budget of about $31M. It is conducted through five components:

1. Selective Breeding, Directed Reproduction, and Development of Genomic Tools
2. Nutrient Requirements and Alternative Sources of Protein and Lipid
3. Health of Aquatic Animals
4. Sustainable Production Systems
5. Product Quality and New Products

Most of the current effort is applied to trout and salmon but other species of interest include catfish and their hybrids, Striped Bass and their hybrids, oysters and tilapia. Approaches are varied and span everything from genomics to host-pathogen-environment interactions to feed formulation to aquatic engineering.

Rexroad went on to talk about the USDA's National Institute of Food and Agriculture (NIFA), which provides about $21M annually in competitive grants to roughly 30 research, education and extension projects. NIFA also runs special grant competitions for applied aquaculture research projects that address program priorities. Additionally, NIFA's Small Business Innovation Research (SBIR) Program awards competitive grants to small businesses that want to address problems and opportunities in agriculture. There are currently no programs specifically for research in aquaponics but investigators can send aquaponics proposals to existing NIFA funding programs.

Rexroad ended by reiterating the abundant opportunities for expanding aquaculture in the U.S. Though he acknowledged that regulatory challenges are limiting, he said major progress will require public-private partnerships. Regarding research and development, he introduced the formula:

GxExMxP (Genetics x Environment x Management x Post Harvest)

He suggested much work could be done to better understand genetics (domestication, selective breeding, chromosome set manipulation, monosex populations), environment (optimizing production systems, water quality), management practices (biosecurity and animal health, stocking density, nutrition) and post-harvest questions (product quality, healthfulness, lipid profile, flavor, pigment). Additionally, he suggested social factors, such as consumer values, economics and marketing, would benefit from more study.

Acknowledging what he heard about the potential for Walleye aquaculture in Minnesota, Rexroad said it was an important message to take back to the USDA Agriculture Research Service. "We want to employ scientific approaches to expand responsible use of our natural resources to meet the nutritional demands of a growing global population," he said.

Rexroad responded to two questions following his presentation. The first was a query about how the USDA's Agriculture Research Service interacts with universities. Rexroad addressed it by saying that USDA's NIFA program works most closely with universities but that the Agriculture Research Service's laboratories are often co-located near universities and frequently collaborate on projects. The other question was related to Congressional enthusiasm for aquaculture. Rexroad said he doesn't think Congress is particularly excited about aquaculture as a whole but they've encouraged Agriculture Research Service to work to support the expansion of aquaculture in the Gulf of Mexico and on shellfish genetics in the Pacific and Atlantic coasts. He said other federal agencies and programs don't yet seem to be echoing the enthusiasm for reducing the seafood trade deficit voiced by the Secretary of Commerce, who clearly sees aquaculture as a major part of the solution.

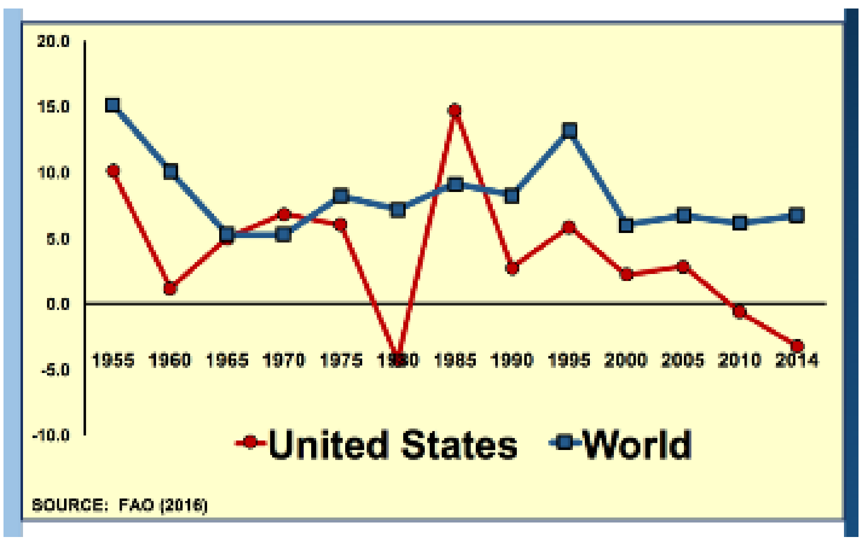
U.S. Aquaculture: Reality, Perceptions and Possibilities - *a summary of remarks made by Carole Engle*

"I want to paint a picture of a disconnect …," said Dr. Carole Engle, Editor-in-Chief of the Journal of the World Aquaculture Society, aquaculture economist and co-owner of Engle-Stone Aquatic$ LLC. That is how Engle began a presentation about aquaculture in the U.S. She explained that the nation is one of the largest seafood markets, not because its citizens eat great quantities of seafood per capita, but because the U.S. has a large population that is relatively affluent. The U.S. also has tremendous expertise in raising fish, well-developed infrastructure for raising fish and an impressive diversity of species in its aquaculture operations. The nation also has research infrastructure, resources and intellectual capacity through land grant universities and the USDA's Agricultural Research Service.

"We are doing what the new USDA secretary wants, and we are doing it right," said Engle. She followed by saying that U.S. aquaculture products are generally considered to be environmentally safe and profitable. "The U.S. is producing sustainable, safe fish through aquaculture...that's a fact," she said pointing to the "Best Choices" options on the Monterey Bay Aquarium Seafood Watch Consumer Guide. "All U.S. farmed fish are "best choice."

The disconnect Engle noted at the start of her presentation is best relayed on a graph she offered showing how the growth rate of U.S. aquaculture is falling in comparison to the rest of the world.

Much of this relative lack of growth can be traced to global competition within the catfish aquaculture industry, particularly competition with Vietnam. Engle said Vietnamese farmers were aware of the catfish trends in the U.S. and were able to grow fish for less because Vietnamese regulations are laxer and labor is cheaper.



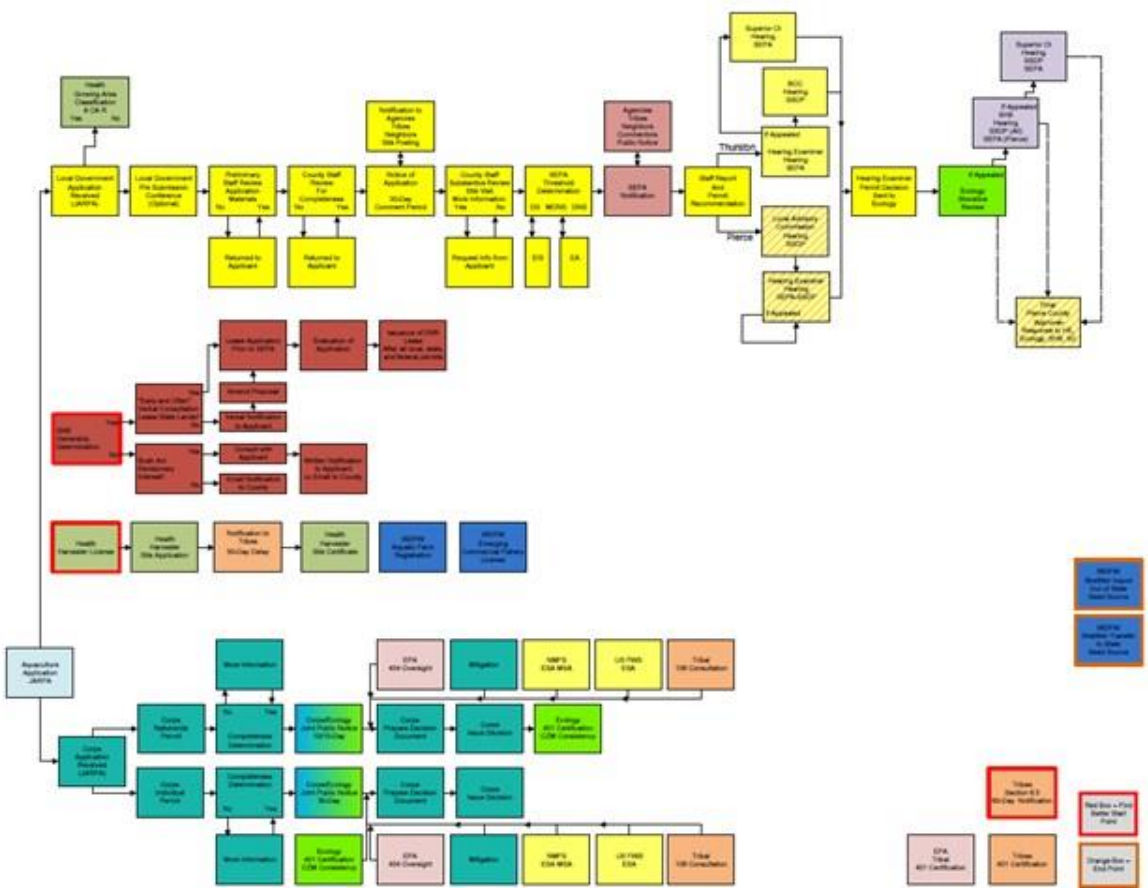
Five-year growth rate of U.S. (red circles) and world (blue squares) aquaculture from 1955 to 2014.

The good news, she said, is that the U.S. catfish industry is reigniting with new products and renewed demand for U.S.-raised fish. Trout aquaculture production has been stable, but sea vegetables like kelp and fish such as tilapia are becoming more popular aquaculture targets, as are crustaceans. Overall, however, Engle said that U.S. aquaculture is not living up to its potential, given the availability of resources and expertise.

To illustrate why U.S. aquaculture is struggling, Engle talked about shellfish growers who must "go through a very extensive permitting process that is just crazy.” The shellfish aquaculture industry cannot keep up with demand due to the burden of regulations passed down by 22 agencies, she explained. “Shellfish growers want to produce safe seafood but they would like seafood from overseas to be held to the same high standards. They don’t want to work with 22 agencies to stay in business nor do they want to report the same information to multiple agencies.” (e.g. shellfish growers must take the water temperature and record it on three different forms to send to three different agencies each week.)

Engle went on to talk about the origins of the regulations saying that societal expectations for an enterprise (aka social license) drive constituents to ask lawmakers to make laws. From what she’s witnessed, factions of society view aquaculture in negative ways. Engle perceives nongovernmental organizations (NGOs) depicting aquaculture operations as polluters and government officials as viewing the industry as one that must be regulated. Many aquaculturalists see themselves as farmers and command respect for the pride they take in their business. She noted that consumers generally view the word “farmer” favorably but “farming” more negatively.

Permitting process for west coast shellfish. SOURCE: Governor’s Office for Regulatory Assistance, State of Washington.



Engle suggested the issue is one of misperception and the spread of misinformation. To exemplify her point, she told the story of a third-generation fish farmer who actively sought information at scientific meetings and who complied with regulations. Evidently a new inspector accused the farmer, who was doing nothing wrong, of breaking state and federal water quality laws. The perception: the new inspector was hired without proper education and asked to write up more violations in an environment increasingly hostile toward aquaculture. Engle said that social license and acceptability of aquaculture certainly varies among states and that she couldn’t comment on what the social license for aquaculture might be in Minnesota.

The U.S. imports nearly all of the seafood its citizens consume. Fish is no longer thought of as a food caught locally. Most of it comes from developing nations that have very little governance and regulatory structure. Engle said that if everyone would pay double for locally raised fish U.S. aquaculture would boom, but she recognized that seafood sales are typically based on price and that public perception has fueled an opposition to aquaculture. Consequently, people are purchasing potentially unsafe seafood, and embracing policies and taking stances that are exacerbating the U.S. seafood economic deficit.

Later in the day, presenter Chris Weeks made a point to agree with Engle that the U.S. has a significant aquaculture problem. For aquaculture to move forward, he reiterated that the social license for farmed fish needs to improve.

Theme 1 - Prioritizing Production Strategies and Species for Food-Fish Aquaculture in Minnesota

Presentations and discussions within this portion of the workshop were geared toward identifying the most promising species and production strategies for Minnesota aquaculture. Presenters included:

Keynote speakers

- Steven Summerfelt, Director of the Aquaculture Systems Research with The Conservation Fund's Freshwater Institute; **Increasing Farmed Fish Production: Prioritizing Production Strategies & Species**
- Chris Hartleb, Professor of Fisheries Biology and Director of the Northern Aquaculture Demonstration Facility (NADF) at University of Wisconsin-Stevens Point; **Aquaculture Production Strategies and Species**

Panel members

- Greg Fischer, Facility Operations Manager of NADF; Closed-system Aquaculture
- Chris Weeks, Extension Specialist with Michigan State University Extension; North Central Regional Aquaculture Center; Open-system Aquaculture
- D. Allen Pattillo, Fisheries Extension Specialist III with Iowa State University; North Central Regional Aquaculture Center; Aquaponics
- Michael Ziebell, Managing Director, trū Shrimp; Intensive Land-based Shrimp Production

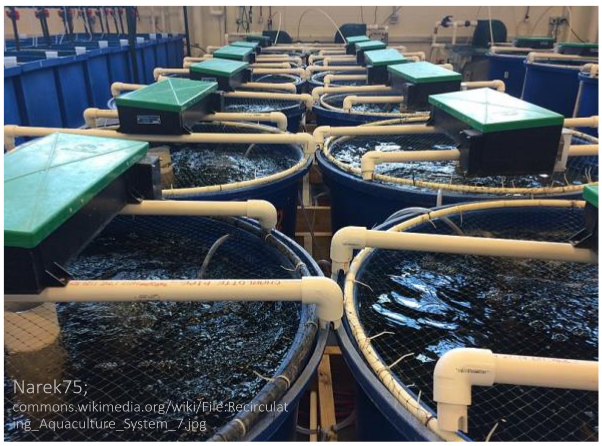
For the purposes of this synthesis, the presentations have been sorted into a review of types of aquaculture production systems and a review of food-fish species that might be best suited for aquaculture in Minnesota.

Production Strategies for Aquaculture in Minnesota

Although aquaculture systems are diverse in design and function, they can be parsed into three general categories.

Open aquaculture refers to fish farming in ponds or larger natural water bodies using gear such as net pens.

Semi-closed aquaculture refers to the land-based production of a species in which water is exchanged between the farm and a natural waterway. Flow-through raceways fall into this category.



Closed aquaculture, epitomized by recirculating aquaculture systems (RAS), refers to the technique of raising aquatic species on land by implementing recirculation technology. Cycling water through filtration processes and returning it back to the aquaculture system aids in maintaining water quality and ensures minimal exchange with natural waterways. Ponds and raceways can also fit within this category if they use recirculation technologies.

Combinations of semi-closed and closed aquaculture systems are common and the combinations are limited only by the imagination of the farmer. Workshop presenters and participants discussed each of these general systems but focused on ponds, RAS, aquaponics and raceways.

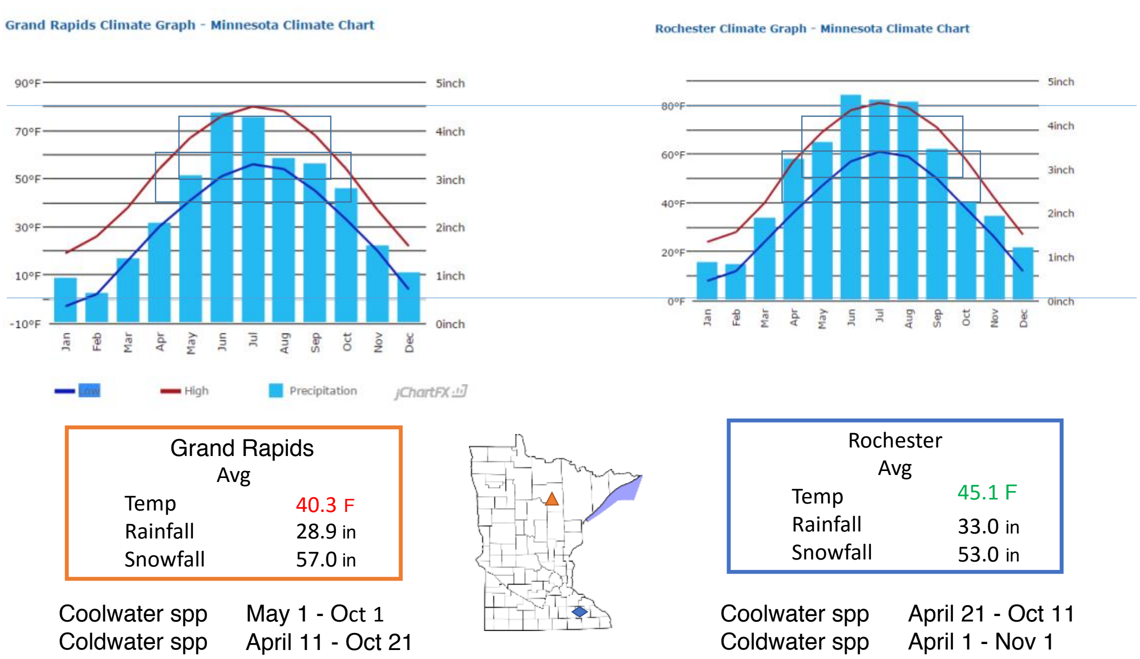
Ponds: Ponds provide an enormous global production of catfish, tilapia, shrimp and carp. In the U.S. alone, farmers raise 200,000 metric tons (220,462 U.S. tons) of catfish per year in ponds, said Steve Summerfelt. Chris Hartleb agreed, adding that aquaculture ponds are the primary production system worldwide, in the U.S. and in the Midwest. What makes ponds so desirable for aquaculture, said Hartleb, is that during the production season they can grow fish more quickly at low densities and with less stress. Aquaculture ponds generally rely on groundwater and, to a lesser extent, surface water. The resulting effluent can be contained and ponds are economical, costing less than $5K/acre in some cases. Construction of dug ponds is the primary cost with soil type influencing that cost. Soils that are 10-20% clay are ideal for holding water. Lacking such soil, many pond operations put down manufactured liners, which can drive the capital outlay up to RAS-like prices ($7.50 – $8.60/m^2 ($0.70-$0.80/ft^2); $75K/hectare ($30K/acre)). Hartleb also suggested that installing liners was not an easy feat.

Being outdoors, ponds only allow seasonal fish growth in northern climes like Minnesota, said Hartleb. That translates to 120-200 days per year and a two-year production cycle for most food-fish species. Pond aquaculture requires management from filling to draining. A farmer needs to manage minerals, biological oxygen demand, aquatic vegetation and alkalinity. Pond fertilization is necessary to create a food web for young fish, and aeration and liming might also be needed to maintain water quality.

Hartleb said that property, water and permits are necessary for pond aquaculture. In Wisconsin aquaculture has not historically been considered agriculture so more agencies are involved in permitting than might be involved in other states. Permitting depends on who owns the land and water, and whether the pond is natural or artificial. Properly siting where the waste discharge goes is important, especially with respect to nearby wetlands.

Chris Weeks spoke about traditional aquaculture systems (raceways and ponds). He offered a Minnesota Department of Natural Resources map of spring-fed water sources and said a map of aquifers is also available, emphasizing how important spring-fed water is to aquaculture endeavors. Maps like those the DNR provides can help new businesses properly site ponds and raceways relative to water depth and quality characteristics. He suggested that geology also matters and sandstone areas are good at moving water. He noted that Southern Minnesota looks like it may be a very profitable area, but almost no aquaculture businesses are there. (The state has three large fish hatchery facilities in this area that use ground water; there is some concern about agricultural chemicals found in the spring water.) He talked about the two zones of Minnesota: Northern and southern, with specific reference to their perfect temperatures for cold- and cool- water species.

Average climate graphs for Grand Rapids and Rochester, MN. Blue bars are average precipitation, average daily high is shown with the red line, and daily low with the blue line.



Weeks suggested commercial fish farmers would benefit if there were technologies to extend the Minnesota growing season for as little money as possible. He said this might mean using RAS. It could also mean focusing the industry on southern Minnesota to gain about 20 additional growing days relative to northern Minnesota or reevaluating which species to raise. To optimize which species to raise, Weeks recommended starting with the K.I.S.S. (keep it simple, stupid) principle and a serious review of water conditions, local climate, species characteristics and the species market potential. He recommended a reasonable aim would be to sell the fish based on Kroger or Meijer prices.

Recirculating Aquaculture Systems (RAS): Steve Summerfelt's presentation focused on RAS as a production system. RAS usually consist of fish tanks that send water containing fish waste to filters. These filters remove compounds such as ammonia and solids before returning the water to the tanks. Captured nutrients can be used to support plant growth (see aquaponics) or can be directed to a wastewater treatment plant. RAS recycle 80-90% of the water they hold. Consequently, these systems greatly diminish the amount of water required to produce fish, which is often a problem for sustaining land-based aquaculture systems. Also, by recirculating the water, fewer nutrients are released making it easier for businesses to meet state phosphorus discharge limits. In northern climates like Minnesota, water is typically heated during most of the year to enhance fish growth. Major energy savings occur within RAS systems as they recirculate heated water, making it more feasible to rear species that require warm water year round. Reusing water is viewed by the public as sustainable and socially acceptable.

The primary downside to RAS are the high initial investment cost. Despite the initial expense, the return on investment for these systems can be high. The main question Summerfelt gets about RAS, including one from a workshop participant, is, how to make the capital costs of RAS more affordable. He explained the capital expenses for a RAS are about 80% higher than traditional ocean net-pen systems but the gap is narrowing. In the U.S. the capital price of a RAS is about two times the price it is in Norway. Summerfelt said he is hoping to eventually see an economy-of-scale price drop but right now banks are leery of loans to fish farms because of lack of proof they can succeed. He said farmers in the U.S. are buying European technology, not because it is better, but because they can get loans from the Bank of Denmark.

Summerfelt was emphatic that it is necessary to keep RAS water free of pathogens. Because the water remains in the system, an introduced pathogen might easily spread through all the tanks. Nevertheless, he said RAS are easier to keep pathogen and disease free if high-quality biosecurity procedures are implemented. This is because they are completely indoors and the groundwater supplies used in most freshwater RAS exclude obligate pathogens, those viruses, bacteria, fungi and other species that must pass through at least one parasitic or disease-causing stage to complete their life-cycle. This means RAS fish tend to be healthier and survive better than they might in other aquaculture systems. It also means that farmers can reduce or eliminate the need for vaccines, antibiotics and pesticides. Summerfelt said by using RAS, farmers can often also avoid losses and the costs of mitigating the systems for sea lice, viruses and other scourges that plague salmon raised in saltwater. Indoor RAS also prevent predators like mink and cormorants from damaging yields.

Summerfelt said RAS represent a small but rapidly growing segment of U.S. aquaculture production and that their scale is increasing. RAS can yield up to 8000 tons of fish per year under one roof (smolt/post-smolt salmon and food-sized fish). He said it is worth noting that many RAS are used for keeping broodstock, and producing smolt and post-smolt.

He stated that Minnesota and Wisconsin are ideal environments for raising Rainbow Trout, salmon (Atlantic, Coho) and Arctic Char in RAS. Not only are there plentiful freshwater resources but the groundwater ranges from 8-10 ^{0}C (46-50 ^{0}F) north to south, which is ideal for such coldwater fish.

The northern states also have strict phosphorous discharge limits necessitating permits, which a RAS can achieve with the right selection of technologies. "We have the technology," he said. "We've been studying RAS for two decades." In fact, Summerfelt said that water treatment technologies can clean water in a RAS enough to reuse it and the change of water temperature is perfect for salmon. Water recirculation within a RAS often produces an approximately 3-5 ^{0}C (~7 ^{0}F) temperature rise. In essence, the 8-10 ^{0}C (46-50 ^{0}F) groundwater temperature warms to near 11-15 ^{0}C (52-59 ^{0}F) in the RAS. The actual increase in temperature depends on the intensity of water reuse among other factors. Temperature gain in the summer often requires chilling within the RAS.

RAS water treatment technologies can reclaim nutrients in a way that the manure can be thickened into biosolids and used on land to raise crops such as alfalfa or in an aquaponics system.

Summerfelt mainly talked about freshwater RAS but he also mentioned those that operated with seawater. Seawater RAS are more difficult and costly to run. They require more flow, larger processes and more money. Additionally, he said there is a higher risk for pathogens entering the system through a seawater intake from surface waters. Compared to freshwater, in seawater RAS:

- O_2 (oxygen) saturation is 20% less
- CO_2 (carbon dioxide) removal efficiency is 20% less
- Nitrification is 30-60% degraded
- Low-dose O_3 (ozone) can create toxic bromine in brackish-seawater if not carefully dosed
- High SO_4 (sulfate) in seawater can produce toxic H_2S (hydrogen sulfide)
- Corrosion resistant materials are required

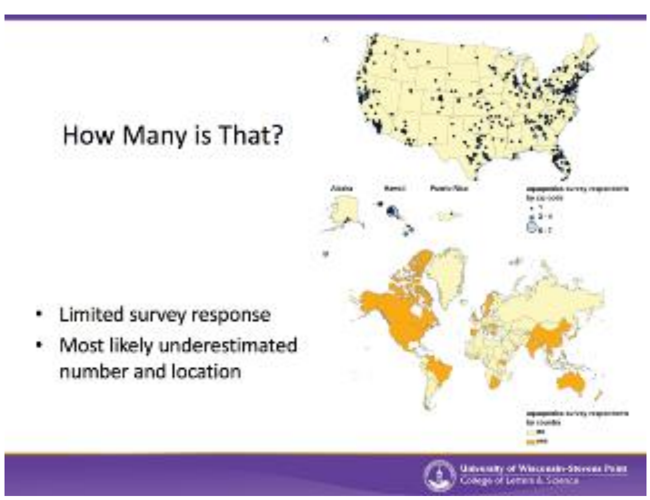
During the second day of the workshop, Summerfelt added that using freshwater reduces capital costs to salmon production by maybe 30% in comparison to saltwater production.

Greg Fischer broadened the workshop's understanding of RAS by talking about a partial-reuse RAS he works with at the Northern Aquaculture Demonstration Facility of the University of Wisconsin-Stevens Point. He and his colleagues are working with the technology to grow Atlantic Salmon brood stock to provide a U.S.-based egg source. They are focusing their RAS research on coldwater species that rapidly grow to market size (1kg (2.2lbs) in less than 17 months), and produce high-quality fillet yields of over 50% that can fetch a good market price.

Aquaponics, Coupled and Decoupled: Aquaponics systems allow fish and plants and, by necessity - bacteria - to grow simultaneously and synergistically. Chris Hartleb suggested aquaponics had many positive attributes including that the systems were integrated, soilless and free of biocides. The systems use water, space and labor conservatively while yielding both vegetable and protein crops in a year-round production cycle uniting aquaculture and hydroponics. Although most production does not occur in big cities, aquaponics systems can meet the socioeconomic challenges of urban and peri-urban environments that suit the recent local food movement.

Aquaponics has its obstacles, however, and because it is a relatively new pursuit in its modern form, research results about the techniques of growing fish and plants together are limited. Hartleb was forthright about the high initial costs and the difficulty of obtaining financing. He said that enthusiasm is greater than the knowledge about aquaponics and most aquaponics systems are dissimilar. The dissimilarity creates a lack of "proof of concept" success stories making lending agencies baulk. Meanwhile, zoning and permitting in cities is complicated, Hartleb said, as he talked about the lengths to which Chicago and Milwaukee went to make aquaponics businesses possible in their jurisdictions. In the marketplace, the return on investment for food grown through aquaponics pales in comparison to organic products grown in other systems.

Hartleb said in aquaponics systems, a farmer is also raising a bacterial culture and if that bacterial biofilter aspect fails, then the whole system fails. He explained that the system works because many of the nourishing elements fish and plants require are similar and they can provide them to each other through their metabolic inefficiencies and outputs. The fish produce waste that is converted to ammonia by bacteria. Nitrifying bacteria then turn the ammonia into nitrite and then nitrate. The plants are able to grow by using the nitrates dissolved in the water, which in turn filters the water that can be returned to the fish tank.



Location and quantity of aquaponics survey respondants from 2015 Love et al.

Hartleb talked about coupled and decoupled aquaponics systems. In coupled systems, plants and fish share the same water through a connection of piping and pools. A coupled system works well in warmer climates. In the upper Midwest, Hartleb said a decoupled system, like the one Superior Fresh maintains, makes more sense because water temperatures can be managed with more flexibility. In a decoupled system, the fish tanks are separated from the greenhouse; the nutrient-rich fish water is piped to the greenhouse as needed. A decoupled system allows farmers to raise coolwater species because they don't have to necessarily heat or cool the water as it flows between the greenhouses and fish tanks.

Hartleb talked about a recent email survey sent to aquaponics producers around the world that showed most growers started their aquaponics system within the past 5 years (2013-2017). The resulting journal article (Love et al. 2015) also showed that most aquaponics systems were scaled for home or farmer's market production. To some extent the survey also reflected the distribution of aquaponics producers, of which there are over 800 in the U.S. This survey confirmed that modern aquaponics is still a new food production system and that large-scale commercial production systems are in their infancy. Dozens of new commercial aquaponics production businesses are being constructed and Hartleb said it wouldn't be long before it becomes clear if commercial aquaponics in its current form can become a significant food production system.

Allen Pattillo also talked about aquaponics, saying that even a small classroom-sized system with a 0.5 m^2 (5.4 ft^2) growing area could offset about $600 in lettuce and add more value if it included herbs. He shared an interest in biophotonics, a general term for techniques dealing with the interaction between biological factors and photons. He suggested understanding biophotonics will advance the aquaponics industry and that the best fish and plant choices for aquaponics depend on water temperatures. "Stick to leafy greens that you can harvest every 30 days if you use cool water," he said. "Warmer water is better for basil and tilapia." He also said fruits and berries, especially strawberries, are potential aquaponics plants and that maybe growing cucumbers, tomatoes and flowers like nasturtiums for the cut flower market could be profitable.

Raceways, Flow-Through and Floating Systems: Traditional flow-through raceways yield about 20,000 metric tons (22,046 US tons) of trout per year in the U.S., said Summerfelt. Though the presenters didn't talk much about flow-through raceways, this type of aquaculture system exists in Minnesota. According to a publication by Masser and Lazur (SRAC Publication No. 170), the need for large volumes of good quality water is the principal reason raceways have been limited to sites with large springs. "In general, water cannot be economically pumped through raceways; it must flow through them by gravity," the authors say. These enclosed channel systems have advantages, including:


Superior Raceway Systems

- higher stocking densities (0.28-0.42 fish/m^3 (10-15 fish/ft^3))
- reduced manpower
- ease of feeding
- ease of grading
- ease of harvest
- precise disease treatments
- collection of fish wastes
- less off-flavor

Disadvantages include the need for flow rate and water quality to remain relatively stable over time. Also, diseases spread more rapidly because of the density of fish and operators need to obtain state discharge permits and meet water quality standards through continuous monitoring of effluent.

Michael Ziebell discussed “super-shallow raceways” for growing shrimp. His company, trū Shrimp is structured around the patented Tidal Basin Technology, which combines a flow-through growing system with RAS technologies. The shrimp harbor will initially introduce salt, but will recapture the salt by constructing a complete wastewater treatment plant. “We want to get the salt back,” Ziebell said. “It is money!” He said a stack of eight tidal basins is referred to as a “reef” and the “reefs” add up to a “shrimp harbor.” He said the important concepts in this system are shallow water (30.5 cm (12 in)) deep, constant flow and aeration. The company expects to have a full production harbor operating in Minnesota by 2018 and to be selling shrimp in 2019. The shrimp harbor includes a 3.6 ha (9 ac) building, 17 ha (42 ac) of water surface and 159M liters (42M gal) of water. Ziebell calculates shrimp production costs will hover around $5.50-$6.60/kg ($2.50-$3/lb.). Robotic feeders will travel up and down the raceways and trū Shrimp is working toward automated processing in collaboration with a turkey processing company. The objective is not only to cut the shrimps’ heads off but also to devein them, Ziebell said. He expects one shrimp harbor to produce 3.6M kg (8M lbs.) of shrimp a year; some shrimp could reach 35 g (1.2 oz.), which is large he said.

Floating raceways might also be characterized as cage aquaculture. Floating raceways (aka in-pond raceways) require ponds and built floating docks attached to fish cages, said Chris Hartleb. In them, fish can be produced in higher densities year-round and harvested with ease. The ponds themselves act as filters and even if the pond is frozen, farmers can still access the fish should they choose to do so. Floating raceways are costly ($4500 per raceway; $21K/year operating cost) and are mostly side businesses for dairy, cranberry or other farmers. Using Yellow Perch as an example, Hartleb said fish in floating raceway systems grow in winter while those in traditional aquaculture ponds lose weight in similarly cold environments (like Wisconsin).

Cages and Net Pens: Chris Hartleb suggested cages and net pens are impractical in the Upper Midwest because of the size of the water body needed for the business to be sustainable. Though the investment for net pens and aquaculture cages is modest and harvesting fish raised this way is relatively easy, raising fish in high densities in net pens has negative connotations in the eyes of the public, and may not be allowed under state regulations, he said. Net pens have been used experimentally in some unique situations such as abandoned mine pits in Minnesota (Hora 1999) and Ontario, but growers were not successful for a number of reasons.

Species with Aquaculture Potential in Minnesota

The conversations about species most likely to support the aquaculture industry in Minnesota focused on salmonids (Atlantic Salmon, Arctic Char, Rainbow Trout), Walleye and shrimp.

Alluding to Minnesota, Wisconsin and the Dakotas, Steve Summerfelt said, "This is a farm-fish desert. This is the bread basket; this is where the feed industry is; this is where we have freshwater; there's so much potential!" He pointed out that economic success depends on market and business development but there is no doubt that food-fish production in environmentally sustainable land-based operations is possible, especially as the capital and operating costs are being reduced through better technology and efficiencies. Summerfelt said that governments in other countries have helped to fund new aquaculture businesses but that in the U.S. it is difficult to raise the potentially tens of millions of dollars necessary for building large commercial-scale RAS facilities. He said the requirements for fish farming are that it be biologically feasible, technically practical and economically viable. These requirements lead him to think that Rainbow Trout and other salmon species, particularly Atlantic Salmon, are going to be Minnesota aquaculture's best bets.

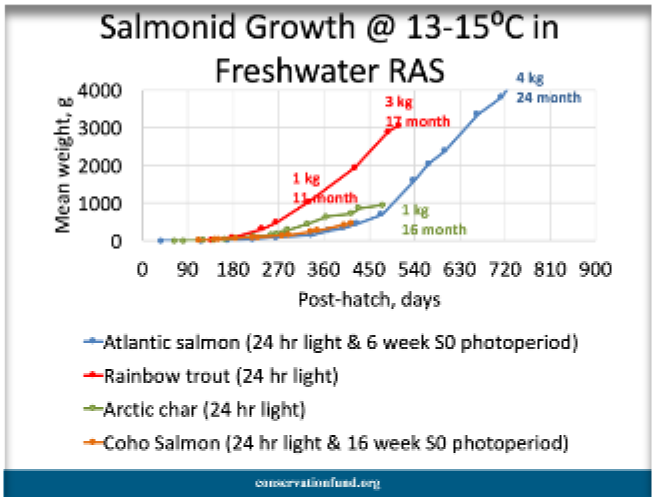
Coldwater Species

Salmon and Trout: Summerfelt said that the Atlantic Salmon industry needs to be able to raise smolt and post-smolt salmon on land and that Norway, recognizing that sea life is changing, is spending billions of Norwegian krone on research and the country's researchers are publishing scores of journal articles to advance Atlantic Salmon aquaculture.

With respect to being biologically feasible, aquaculture operations need a year-round egg supply so that harvesting can be done weekly. He said that Atlantic Salmon eggs are, indeed, available year-round. They are Certified Pathogen Free (CPF) and all-female germplasms can sometimes be obtained, which is desirable because female salmon are less likely to mature than male salmon. Someone asked why, with regard to farmed Rainbow Trout being almost all females, don't consumers ask questions about genetic engineering? Summerfelt responded by saying that there is no genetic engineering required to produce an all-female population, the previous generation is treated with a well-regulated and well-studied hormone. However, beyond the FDA approval issue, there is often consumer pushback and intense interest in food production that is amended, modified or edited.

> **A process for producing all-female trout and salmon** - feeding methyl-testosterone to the fry of the previous generation creates neo-male milt that can be collected when these fish mature. Each of these neo-male sperm are haploid, carrying only an x-chromosome. When milt from a neo-male fertilizes an egg (always x-chromosome), the progeny are all-female. These progeny, which have never been exposed to methyl-testosterone, are then cultured to market size. Methly-testosterone has been restricted by the U.S. Food and Drug Agency. It's Summerfelt's understanding that methyl-testosterone can only be used domestically if the researcher/farmer has an approved INAD (Investigational New Animal Drug).

Summerfelt continued by saying that similar egg supplies are needed for Rainbow Trout, Yellow Perch and Walleye. Ideal fish for aquaculture are hearty, grow rapidly, mature early and are suited for a biomass density of 80-120 kg/m^3 (5-7.5 lbs./ft^3). They have a low feed conversion ratio (FCR) and don't require fishmeal for grow out; fish oil remains a critical component of their diet. Their harvest quality needs to match consumer expectations for color, texture and flavor profile. Generally, this means they would be depurated (cleansed) in a geosmin-free finishing system during their last 5-14 days so they don't taste earthy upon harvest.



Blue, red, green, and orange represent Atlantic Salmon, Rainbow Trout, Arctic Char, and Coho Salmon respectively.

To be technically practical an aquaculture business would use proven production technologies that meet permit requirements and achieve environmental and social acceptance. A facility must also be reliable and be able to withstand environmental challenges such as flooding and exceptionally cold outdoor temperatures.

To be economically viable, Summerfelt said consumer demand needs to be strong and the market price high. A realistic capital investment should be reflected in a strong business plan that also explains a robust internal rate of return. He said some businesses carefully pick species and location to match and please investors.

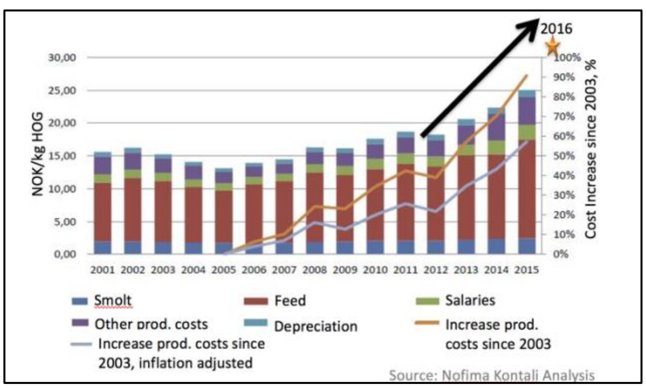
Summerfelt said the fish species most likely to meet the three criteria for success (biologically feasible, technically practical, economically viable) are:

- Strongest (year-round CPF eggs; reasonable market)
    - Atlantic Salmon
    - Rainbow Trout/Steelhead (all female, lowest production costs)
- Potential (CPF eggs 1-2x annually, slower growing)
    - Arctic Char (all female)
    - Coho Salmon (all female)
- More challenging (limited eggs that are not CPF, slower growing, potential for contracting the fish disease columnaris)
    - Walleye and hybrids (Saugeye)
    - Yellow Perch

Summerfelt expounded on why he thought Rainbow Trout and Atlantic Salmon had so much potential for aquaculture. Pointing to a graph showing growth rate, he said that in a freshwater RAS he has averaged Rainbow Trout weights of 1 kg (2 lbs.) in 11 months from hatch. He reported that growth rate varies between production systems with a RAS yielding marketable fish faster than raceways. Although Rainbow Trout, a salmonid from the Pacific coast, can be sold at a variety of sizes they are typically sold at about 0.45 kg (1 lb.). Most Rainbow Trout produced in the U.S. are produced in serial-reuse raceways in Idaho. There is also significant production of Steelhead in net pens in the Columbia River; and, at least two commercial farms are producing large Steelhead in RAS in the states of Washington and New York. They can be sold without pigments but in their Steelhead form, ruby red pigments (astaxanthin) are often an ingredient in their final diet. A recent trend has seen farmed fish have lower levels of omega-3 and higher levels of omega-6 fatty acids, but that they are still an excellent source of omega-3 fatty acids. "It depends upon what you feed the fish," he said.

Steelhead and Rainbow Trout are both *Oncorhynchus mykiss*. In aquaculture, *O. mykiss* that are labeled as Steelhead are raised to 1-5 kg (2-11 lbs.) and fed astaxanthin to produce a ruby red color in their fillet, similar to that found in nature. Rainbow Trout in aquaculture are typically unpigmented and harvested at less than 1 kg (2 lbs.); sometimes these smaller fish are also fed a pigmented feed and sold as a ruby-red trout.

The potential for Atlantic Salmon aquaculture in the U.S. is exciting in Summerfelt's estimation. The salmon market is valued at ~$2.2B. He considers it a significant problem that only about 4% of the 500K metric tons (551K US tons) of Atlantic Salmon consumed in the U.S. in 2015 was a U.S. product. Though most of the Atlantic Salmon Americans eat comes from Chile, Norway is actually the biggest producer of salmon in the world, raising over 1M metric tons (1.1M US tons) a year (globally, there is 1.8M metric tons (2M US tons). In fact, NASDAQ keeps a salmon index reflecting the total export of Atlantic Salmon out of Norway; the index shows that the price of salmon had doubled, to $8 per kilo (~2 lbs.), in the last three years. Norwegian production costs are a modest $3.50/kg ($1.60/lb.), plus the cost of shipping at ~$2/kg ($0.90/lb.), which creates a margin of potential profit for domestically reared salmon. In Chile, production costs are a bit higher at $4.60/kg ($2.10/lb.), said Summerfelt. Fish exported from Norway come with details about the antibiotics used, which is a selling point.



Norwegian salmon production costs.

Norwegians are currently battling multiple challenges to sustain their ability to farm salmon, not the least of which is sea lice. Typically, they raise a fish to 100 g (3.5 oz.) on land, then grow them out in huge ocean net pens stocked with 200,000 fish until it is time to slaughter and sell them (~18 +/- months later). The cost of feed is by far the most expensive part of the operation.

To farm Atlantic Salmon in Minnesota, Summerfelt suggested purchasing eggs from commercial suppliers (as found in Iceland, the UK and Norway) and extoled the virtues of using a RAS that includes both smolt and grow-out capacities, and substantial water treatment technology. He also said fish farmers would need to consider the mechanism for harvesting, processing and distributing the products.

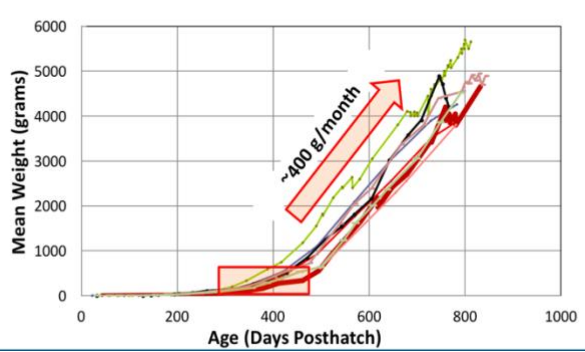
Continuing to explain why RAS in Minnesota would be ideal for Atlantic Salmon, he talked about the region's favorable groundwater temperatures (generally less than 8^0C (47^0F)) and how maybe some cooling would likely be needed in summer but otherwise the cycling of groundwater probably keep the fish in their ideal water temperature (11-15^{0}C (52-59^{0}F)).

According to research at the Freshwater Institute, Atlantic Salmon can grow 400 g (14 oz.) per month in freshwater during the grow-out phase. Atlantic Salmon can reach 4 kg (8.8 lbs.) in 24 months, said Summerfelt.

Summerfelt co-authored a study published in Aquaculture Engineering, Comparative economic performance and carbon footprint of two farming models for producing Atlantic salmon (*Salmo salar*): Land-based closed containment system in freshwater and open net pen in seawater (Liu et al. 2016). In it, he and his co-authors found that:

- The cost of producing salmon in RAS is approximately the same as the cost of producing them in traditional open net pen systems, when excluding interest and depreciation.
- The return on investment for traditional open net pen salmon farming is twice that of farming them in RAS, when land-based produced salmon are sold at a 30% premium.
- The carbon footprint of salmon produced in RAS delivered to market in the U.S. is less than half of that for salmon produced in Norway in open net pen systems then delivered by air freight.

Salmon growth in freshwater recirculating aquaculture systems. Salmon showed consistent growth after 500g, independent of feed type, density, or strain. Source: conservationfund.org



Summerfelt said that RAS for salmon grow out could address market needs. It would provide consistent production every week of the year in a local, fresh and highly traceable way. In fact, Closed-tank production of Atlantic Salmon is ranked "best choice" by the Monterey Bay Aquarium, which lists other Atlantic Salmon sources as "good alternatives" or "avoid." The Freshwater Institute produced about 20 metric tons (22 US tons) of fish per year during Summerfelt's research.

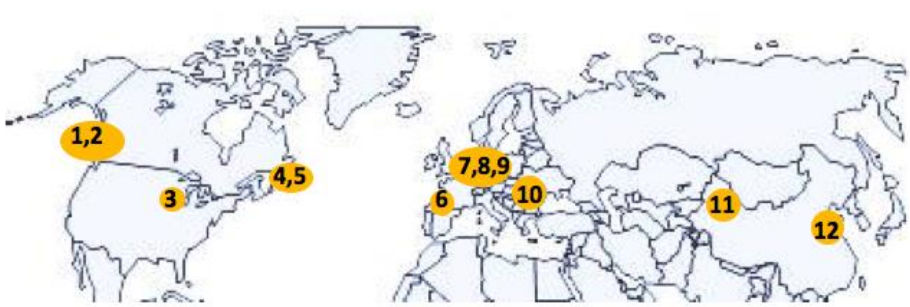
During later presentations, Chris Weeks said that Rainbow Trout are seriously underrepresented in Minnesota's aquaculture scene. Meanwhile, Greg Fischer suggested that, though Atlantic Salmon aquaculture holds the most promise, Arctic Char is a species absolutely worth considering. He reported an ability to grow market size char in 12 months by starting them in cold water and then moving them to warm water, which helped to boost their growth. "The problem is eggs," he said. "You can't get them year-round."

A variety of participants and speakers at the workshop acknowledged that year-round egg availability is critical for the success of food-fish aquaculture ventures.

Fischer answered questions from an audience intrigued with the idea of raising Arctic Char. "What's the draw?" someone asked. "If this area gets warmer and the well water becomes warmer, what does it mean?" The draw, replied Fischer, is that Arctic Char serve a niche market as a unique menu item. He said they command fairly high market prices because of their scarcity and exotic-sounding name. Since the char would be raised in a RAS, he said the water temperature could be easily managed.

Fischer recommend against farming Brook Trout as a food-fish because there is currently no market for them. Allen Pattillo mentioned that trout have been raised in some aquaponics ventures using raceways and decoupled systems.

Land-based salmon grow-out in RAS already stocked with fish. From Steve Summerfelt's presentation, conservationfund.org



1. KUTERRA (Canada)	**2. Golden Eagle Aqua** (Canada)	**3. Superior Fresh** (USA)	**4. CanAqua** (Canada)
5. Sustainable Blue (Canada)	**6. BDV** (France)	**7. Langsand Laks-Atl. Sapphire** (Denmark)	**8. Danish Salmon** (Denmark)
9. Swiss Alpine (Switzerland)	**10. Jurassic Salmon** (Poland)	**11. Xinjiang Ehe** (China)	**12. Shandong Oriental** (China)

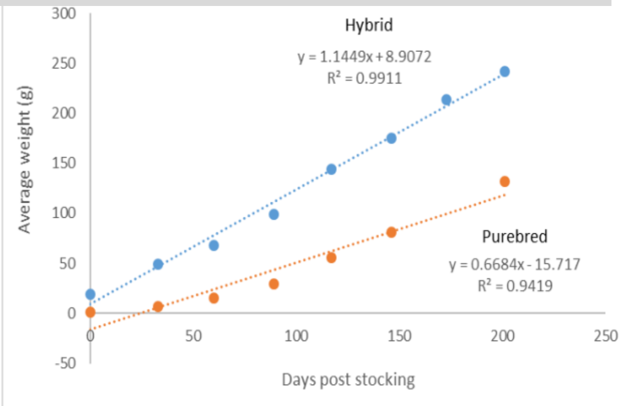
Land-based trout grow-out in RAS already stocked with fish. From Steve Summerfelt's presentation, conservationfund.org

1. Taste of BC, 100 MT (Canada)	**2. Riverence, 100 MT** (USA)	**3. Bell Aquaculture, 1000 MT** (USA)	**4. Hudson Valley 1200 MT** (USA)
5. Fifax AB, 3000 MT (Finland)	**6. Danish Model Farms, 16,000 MT** (Denmark)	**7. Hayashi, 200 MT** (Japan)	

Coolwater Species

Walleye, Sauger and Saugeye: Chris Hartleb said that Walleye are typically farmed using a pond-tank-pond method. Fish for stocking are harvested at one year while those destined for market are harvested in their second year. People are starting to raise Walleye in RAS and the good news, said Hartleb, is that Saugeye, a Walleye-Sauger hybrid, can be harvested from a RAS in 9-15 months. Greg Fischer, who works with Hartleb at the University of Wisconsin-Stevens Point's Northern Aquaculture Demonstration Facility, said they were able to grow 0.57 kg (1.25 lb.) Saugeye in a RAS in 12 months. Fischer said Saugeye might also have potential for aquaponics.

Growth of hybrid (Walleye female x Sauger male) vs Walleye in a RAS. From Chris Hartleb's presentation



There are hurdles to raising Walleye and their hybrids, however, including swim bladders that don't inflate and cannibalism. Hartleb said that true starter diet for Saugeye hasn't been developed and that husbandry practices need to be perfected, including managing turbid water, surface spray, in-tank lighting and maladaptive clinging behavior. Walleye and Saugeye aquaculture requires special equipment, said Fischer. The extra costs could be worth it, though, since the hybrids consistently outperformed pure Walleyes.

Fischer elaborated on rearing Saugeye. He said that this hybrid, which also occurs in nature, can be reared intensively in and out of season. Soon, he expects photoperiod and temperature manipulation will produce broodstock that can spawn year-round. Saugeye can be reared on an entire cycle of commercial feeds and exhibit high growth rates and good feed conversion rates. They can also fetch good market prices, he said. More details about Fischer's work with Saugeye can be found in the online presentation, Intensive production of hybrid Walleye (*Sander vitreus* x *S. canadense*) in a recycle water system.

Walleye and Saugers at the University of Wisconsin-Stevens Point, Northern Aquaculture Demonstration Facility spawn out of season as early as February and as late as June due to photoperiod and temperature manipulations. European Pikeperch have also been manipulated to spawn throughout the year.

Hartleb said there seems to be a Minnesota market for fillets and petite fillets; grocers want larger fillets to match consumer demand while restaurants want the smaller ones for single dinners and fish fingers.

Workshop participants seemed interested in developing a Walleye and Walleye hybrid aquaculture industry in Minnesota. Allen Pattillo said raising Walleye in aquaponics systems would be possible. Summerfelt cautioned that Walleye harvested from lakes are typically larger than farmed Walleye, which could be a problem for marketing.

Yellow Perch: Chris Hartleb said the primary market for Yellow Perch is within 50 miles of the Great Lakes. Females produce a unique gelatinous strand of eggs, called a "ribbon," which is useful for aquaculture. The ribbons can be more than 6-feet long and are proportional to the size of the female. Farmed perch are often grown in a pond-tank-pond method. Eggs hatch and then are moved to a pond, then feed-trained in tanks after which they are put back in ponds and raised on commercial food. People are starting to produce perch in RAS but diseases and low tolerance to the levels of total suspended solids make this challenging. It is also difficult to find broodstock for RAS conditions. In general perch exhibit highly variable growth rates and their larval stage remains somewhat of a difficulty as they can be cannibalistic and prone to developmental deformities. Female only populations tend to fare better than mixed-gender populations. Allen Pattillo suggested that in aquaponics settings "it's not looking good for Yellow Perch."

Warmwater Species

Panfish: Sunfish are typically reared in ponds for stocking and food in one and two years, respectively, said Hartleb. With respect to RAS aquaculture, sunfish can adapt to crowding and poor water quality; monosex male populations and hybrid crosses fare better. The fish are able to spawn multiple times each year, including out of season. If they are raised in a cage near a bass, they tend to be motivated to grow bigger faster, Hartleb reported. Sunfish accept commercial diets of about 35% protein including vegetable protein. Unfortunately, their fillet yield is low at only about 30% of their weight. In aquaponics systems, Pattillo said bluegills need to go on pelleted diets.

Largemouth Bass: Hartleb said that this species is mostly grown as sportfish by the pond-tank-pond method. They are slow growing, requiring two or three years to reach 0.68 kg (1.5 lbs.), and can be cannibalistic. Farmers have worked with different strains while research on nutrition has lagged. Like the sunfish, Largemouth Bass have a low fillet yield.

Culture factor	Range
Temperature	64 - 90°F (17 - 32°C)
Dissolved oxygen	3 – 10 mg/L
pH	7 – 8
Ammonia-N	0 – 0.04 mg/L
Nitrite-N	0 – 0.8 mg/L
Hardness	50 - 350 mg/L
CO_2	0 – 30 mg/L

Tilapia: Tilapia is the fourth most consumed fish/seafood in the U.S., following shrimp, canned tuna and salmon. Hartleb said the market is dominated by foreign imports and three species (Nile, Blue and Mozambique). Monosex male populations are most productive. Tilapia are well suited for RAS production (70% of the industry in the U.S.). In RAS facilities, tilapia have shown wide tolerance ranges for crowding and disease, and the off-flavoring that can accompany RAS grow-out can be remediated in five days. In the U.S., nurseries are separated from the grow-out facilities, said Hartleb. Tilapia can be sold in a variety of forms, from live to "individually quick frozen." The challenges are uniformity of size, a dearth of processing facilities and a market crowded by low-priced foreign imports.

Shrimp: The first species of shrimp to be commercially farmed in Minnesota is the White Pacific Shrimp. Proof-of-concepts tests from trū Shrimp suggest that a 35 g (1.25 oz.) shrimp can be reared in 140 days said Michael Ziebell, trū Shrimp managing director; this spans from larvae to dinner table. Ziebell was asked if trū Shrimp was hatching their own shrimp now. He said "no" but they are building a hatchery because getting larvae from Florida is inconsistent. Land-based shrimp aquaculture is being conducted in New York City through Eco Shrimp Garden, in Indiana through RDM Aquaculture and elsewhere. Saltwater production in aquaponics is not conducive to plant growth, said Allen Pattillo. Outside of aquaponics systems he said, "I'd really like to crack shrimp aquaculture. Growing shrimp in garages has lots of potential but salt can be a problem."

Other Species: Baitfish and fish for stocking dominate Minnesota aquaculture. Even so, raising carp species, especially Koi and goldfish as ornamentals, could be a valuable proposition in Minnesota, said Allen Pattillo. They command a good price and can easily be raised in home aquaponics systems. As far as food-fish, Pattillo suggested maybe Barramundi (a.k.a. Australian Sea Bass) has aquaponics potential. He said it is important to consider how a species choice will impact licensing (native vs. non-native) and how to best match cold-, cool- and warmwater fish with plants in aquaponics systems.

Summary of Small Group Discussions about Production Strategies and Species

After experts shared their perspectives on production strategies and potentially successful species to use in Minnesota food-fish aquaculture, workshop participants broke into four groups to discuss what they heard and directions for further inquiry. Despite differing approaches, the groups agreed on many methods and species that could enhance the future of Minnesota's aquaculture industry.

Of the production methods discussed, Recirculating Aquaculture Systems (RAS) were most popular. An economist from one of the groups offered that data about the success of different sized RAS is sparse. Other members from the group hypothesized that because the cost of constructing a RAS is so great, larger-scaled systems would theoretically yield fish at a cheaper cost per pound.

Members of all of the breakout groups had a wide variety of species that they said could succeed in RAS in Minnesota. Among those were Atlantic Salmon, Rainbow Trout, Arctic Char, Walleye, Saugeye and Yellow Perch. The high market value of these species makes them economically feasible.

One group spent a fair bit of time discussing the challenges of raising some of these species due to a lack of broodstock. While Rainbow Trout eggs are available year-round from U.S. suppliers, Walleye, Yellow Perch, and Saugeye eggs are not consistently available throughout the year and their broodstock are not highly developed. Atlantic Salmon eggs, although relatively simple to obtain, need to come from overseas; Arctic Char eggs are not consistently available to support an aquaculture business.

In addition to RAS, raceways or flow-through systems were discussed as having been successful for cultivating many fish species and costing half to one-third of a RAS. Phosphorus discharge standards can be hard to meet when raising fish in raceways or flow-through systems, especially around the Great Lakes where the discharge limits are especially strict. One group discussed implementing a full-reuse or partial-reuse system, similar to a RAS, to make raceways more likely to meet discharge limits and to also conserve water.

Another conversation centered around the idea that flow-through systems typically require a natural spring and most available springs are used or, in some cases, exploited. It is usually more economically feasible to grow coldwater species in flow-through raceway systems, because these systems use groundwater (springs) which tend to be cooler. One group pointed out that Idaho is able to produce a lot of Rainbow Trout in a way that complies with the water-quality regulations. Engle reported that the North Carolina trout industry, which is substantial, is based mostly on surface water, with treatment systems removing phosphorus and other waste prior to discharge.

Driftless Fish Company, operating near Rochester, MN, has been raising 11,360 kg (25,000 lbs.) of Rainbow Trout annually and plans to increase that to 45,450 kg (100,000 lbs.) by 2018. Rainbow Trout are a species proven to succeed in these systems. MN DNR staff noted that raising non-native species in raceways would require a special permit. Nonnative fish such as Atlantic Salmon or Arctic Char could potentially pose a threat to native species in Minnesota waterways.

Aquaponics was discussed as a farming pursuit that has been gaining popularity. Although aquaponics is an ancient practice, not much research has been done to calculate its economic viability on a medium or large scale. In addition, large-scale success has been scarce. According to one group, Chicago has a harsh saying for aquaponics: the 12-6-3=3 axiom. Evidently, of the 12 aquaponics businesses that started in Chicago, six went out of business, three switched to hydroponics, and three are still in operation; this is a low rate of success. Many agreed that more research needs to be done on the bacteria, biosecurity hazards and the potential risk of raising plants in fish waste. In most aquaponics systems, the money makers are vegetables and fruit. Because the plants are not grown in soil, USDA organic certification is controversial. Gaining organic certification allows aquaponics companies to compete in the organic food market, where the prices better reflect production costs. It remains unclear whether aquaponics systems could produce fish at affordable prices.

Superior Fresh farms in Hixton, Wisconsin, is using a decoupled method of aquaponics to grow Atlantic Salmon. Waste nutrients produced by the fish are condensed and pumped to the plants. Superior Fresh advertises zero discharge of its production water, having achieved a 99.9% recycling rate. Many members from all of the groups said that decoupled systems housing coldwater fish species could be the future of aquaponics in Minnesota’s cold climate. This is because coldwater fish need a water temperature that is colder than the plants, so the cost to heat and cool the water between the two entities would not make warm water species profitable. Members of one group mentioned that excess heat from nearby processing plants could be used to heat water if warmwater species were desired in a coupled system, but it seems that decoupled systems were favored at the workshop.

Cold- and coolwater species that might be considered for decoupled systems included Rainbow Trout, Atlantic Salmon, Walleye, Saugeye and Yellow Perch. There are few success stories indicating which species might be the best. For a connected system, warmwater species, like tilapia, would be best as no temperature change between the plants and fish would be required. An economist in one of the groups said that tilapia produced in Minnesota would not be able to compete with low-cost foreign imports or with large farms in the southern U.S. that have climates with more suitable growing conditions. The amount of energy required to keep water temperatures warm enough for tilapia is a specific disadvantage for Minnesota growers.

In a discussion about using net pens in lakes or in mine pits, participants reiterated that net pens are one of the cheapest systems to install. Net pens require a special permit in Minnesota according to members of the group. Some at the workshop maintained that net pens should be permissible in the Great Lakes. Many anglers, conservationists and fisheries biologists are worried that diseases from farmed fish could travel to the wild populations or that the nutrient loads associated with net-pen aquaculture would damage the Great Lakes. Sport anglers, state agencies and fish farmers have clashed for years over this topic. Many suggested that the farmers and fishermen could work together. The Great Lakes are deficient in some nutrients due to invasive species, so adding nitrogen and phosphorous through net-pen aquaculture could be beneficial, some said. Even with this controversy, Canada has been using net pens in the Great Lakes since the mid- to late-1980s (GLEAM). Most agreed that if net pens were to be implemented in the Great Lakes, they would most likely succeed if they held Atlantic Salmon, Lake Trout, or a different native coldwater species. Proper siting of net pens would be critical if they are to survive the high wave conditions often found in the Great Lakes.

Using net pens in abandoned mine pits was also discussed, although the idea was not popular. This method was tried in Chisholm, Minnesota, by a company called Aquafarms (Great Lakes Water Quality Board 1999). They quickly exceeded their National Pollutant Discharge Elimination System (NPDES) permit and over 20,000 Minnesota Pollution Control Agency hours went into dealing with this facility according to one group. The nutrients loaded into the system were considered threats to groundwater, water quality, and human and environmental health (Axler et al. 1996).

Shrimp aquaculture was talked about in the frame of using an intense shallow water raceway system with zero water discharge. In these systems, biofilters remove nutrients, but all the salt remains inside of the system. The only salt that leaves is in the product and its feces. Possible problems include the amount of salt needed for these systems and if the salt could actually be reused. Another problem is similar to the problems in the RAS; if a disease outbreak occurs, the whole system is at risk of infection because of the constant circulation. The system's biofilters could cause a problem. Biofilters are composed of many microorganisms that filter out nutrients from the system. If a biofilter dies, the system is at risk of killing its shrimp or fish due to a lack of filtration. So far, the only product that has been hypothesized to succeed in these shallow water systems is shrimp. With time and research, other saltwater species may eventually be successfully farmed on land in Minnesota.

Participants talked about outdoor growing ponds, the most widespread fish rearing practice in Minnesota. Minnesota has a large baitfish industry that relies on ponds to raise products for Minnesota's large sport fishing industry. In addition, fish such as Walleye are raised from fry to fingerlings in these ponds for stocking. Raising food-fish in ponds was suggested by some of the groups but it faces many challenges. According to a member of one of the groups who researched Walleye for more than three decades, it takes a Walleye three years in a pond environment to reach market size while in a RAS or raceway system, the fish could be marketable in one year. Another problem is that the ponds would need to be properly oxygenated as winterkills could devastate fish populations. Some hypothesized that one could raise fish to fingerling size outside and then move them indoors to an RAS. This sounds good in theory, but a fish disease specialist from one of the groups stated that fish from the outdoors would likely bring diseases inside creating a biohazard. Not much research has been done on the economic viability of outdoor growing pond systems for food-fish. It seems that Walleye and Yellow Perch would be the species best suited for outdoor growing ponds.

Societal views on aquaculture systems and the species produced were considered critical to the success of food-fish aquaculture in Minnesota. Each species and system has a different level of societal acceptance that influences its market viability. Of the systems mentioned, there was not broad consensus on which the public might favor. Two groups said that RAS would garner the most societal acceptance as they are contained and disease free. Others cited studies indicating that consumers want fish that are raised in outdoor systems because it seems more natural. It was noted that net pens were vehemently rejected by the public in Michigan, so moving that idea forward might also be difficult in Minnesota. Almost everyone agreed that more research is needed to demonstrate which systems consumers prefer. There was also agreement on the need to educate the public on the quality and safeness of farm-raised fish. Aquaculture is, at times, perceived in a negative way due to questionable practices in other countries and because the public tends to prefer wild-caught fish. Almost everyone agreed that education is an essential part of growing a large aquaculture industry, not just in Minnesota, but in the U.S.

RAS: Greenhouse Gas and Waste

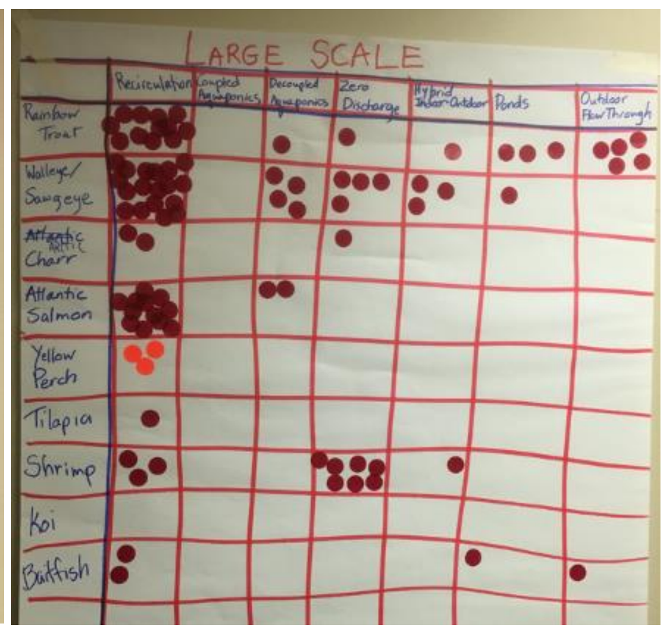
Clark and Tilman (2017) report that RAS produce higher greenhouse gas emissions per gram of protein than other aquaculture techniques and non-trawling fisheries. Additionally, RAS wastes generally go to a publicly owned wastewater treatment facility. A large aquaculture facility might quickly overwhelm a small municipal sanitary district. Since the economics are still unproven and there are few large RAS facilities, questions about environmental costs and social license should factor into RAS's desirability as an aquaculture technique (Carole Engle, personal communication).

In terms of marketability, Walleye seemed to be the fish of choice for Minnesota and many of the experts felt that farm-raised Walleye would have a place in the Minnesota market. With the high consumption of Walleye in this region, farm-raised Walleye might fit in well with consumer demand. Another option discussed was the faster-growing Walleye hybrid, the Saugeye. Although Saugeyes appear naturally in the wild, it is unclear how one could legally label the hybrid on packaging. Experts in two groups suggested that if Saugeye could be labeled as

Walleye, it would be very successful. DNR staff talked about another challenge to farmed Walleye: the potential revenue loss for Red Lake Tribe's commercial fishers. A glut of farm-raised Walleye could run indigenous commercial Walleye fishermen out of business, which would not be socially accepted. Others hypothesized that fish farmers could work together with the Red Lake Tribe to ensure that farm-produced Walleye were processed at the Tribe's facilities. Walleye seemed to be a favored aquaculture option because it has a market and potential for cultivation.

Others said that Rainbow Trout and Atlantic Salmon could fill a market niche as they have more of the prized omega 3 fatty acids that consumers prefer. Rainbow Trout already live in many bodies of water in Minnesota, so like Walleye, Rainbow Trout could be marketed as a locally grown favorite. In addition to the salmonids, many said that locally grown shrimp would have a place in the Minnesota market. Members from one group restated that 90% percent of the shrimp in the U.S. are imported. Shrimp may have a niche in combatting imports while being produced as a sustainable locally grown option. Overall, while many more species were mentioned such as Coho Salmon, Arctic Char, Lake Herring, Whitefish, sturgeon, crayfish, tilapia, Bluegill, and Barramundi, the experts seemed to think shrimp and three coldwater species (Walleye, Rainbow Trout and Atlantic Salmon) have the best potential to succeed in a Minnesota aquaculture industry.

What production strategies and species were participants most excited about in both large- and small-scale systems? Here is how they voted:



Theme 2: Identifying Research Needs and Information Gaps

The second of the three workshop themes sought to illuminate areas where Minnesota cool- and coldwater aquaculture for food-fish could be helped by research and better information. The presenters included:

Keynote Speakers

- Chris Hartleb, Professor of Fisheries Biology and Director of the Northern Aquaculture Demonstration Facility (NADF) at University of Wisconsin-Stevens Point, Aquaculture Research and Information Needs
- Steven Summerfelt, Director of the Aquaculture Systems Research with The Conservation Fund's Freshwater Institute, Increasing Farmed Fish Production: Prioritizing Research and Needs

Panel Members

- Caird Rexroad III, National Program Leader for Aquaculture within the USDA's Agricultural Research Service; Genetics and Domestic Strains
- Robert (Bob) Summerfelt, Professor Emeritus, Iowa State University; Feed and Nutrition
- Nick Phelps, Director of the Minnesota Aquatic Invasive Species Research Center, University of Minnesota; Fish Health
- Carole Engle, Editor-in-Chief of the Journal of the World Aquaculture Society, aquaculture economist and co-owner of Engle-Stone Aquatic$ LLC; Social, Economic and Marketing Considerations for Aquaculture

Though each of the invited speakers gave discrete presentations, their deliveries have been parsed into five categories for the purposes of this synthesis:

1. Sociopolitical and Economic Challenges
2. Biological Questions
3. Environmental Risk
4. Unique Aquaponics Challenges
5. Technology

Sociopolitical and Economic Challenges

Consumers, Producers, Regulations and Economics: Chris Hartleb started the exploration of food-fish aquaculture research needs and information gaps with an economic discussion. He said insurance companies and financial institutions ask to see examples of successful aquaculture or aquaponics systems before they dare to sign paperwork. This makes obtaining startup funds or loans for expansion challenging since it remains difficult to demonstrate success, especially in aquaponics. He said the next wave of ecopreneurs are working to make aquaponics profitable.

On the sociopolitical front, U.S. consumers prefer high-value fish that are healthy and healthful, meaning, among other things, that they are not laden with mercury or other contaminants. According to Hartleb, consumers seem to prefer the idea of locally available fish but the U.S.

seafood market is still 90% dominated by foreign imports of which the U.S. Food and Drug Administration only has the resources to inspect 2-3%. Local marketing efforts are needed, he said. Consumers have stereotyped large aquaculture ventures as polluters that produce products laced with unacceptable levels of antibiotics; this is a difficult stereotype to overcome, said Hartleb. Meanwhile, the permits and regulations related to aquaculture are complex, he said, citing research by van Senten and Engle (2017) reporting that for aquaculture there are "… greater than 1,300 laws promulgated at local, state and federal levels."

To ease regulations, Wisconsin lawmakers are working to define aquaculture as agriculture, which would provide more freedom for businesses to manage land and water. A workshop participant offered that Homegrown Minneapolis has made fish farming possible by supporting small businesses and working to fix the zoning problem of warehouses in Minneapolis.

Hartleb suggested there is room for a better understanding of how to encourage the economic success of new businesses through research and research funding. Steve Summerfelt added ideas about stimulating aquaculture businesses with tax credits, government subsidies, foundation support and mentoring.

Carole Engle discussed success, failure and "the dismal science" of economics. During her career, Engle found aquaculture businesses succeed or fail as a consequence of a sequence of strategic decisions made by the company's leadership. She said failure is most often the result of:

- Not understanding the business. (The owner pursues something aside from being the solution to a customer's problem. For instance, selling fish through a pay-lake is a recreational business, not aquaculture.) Business owners must understand their business on a deep level, said Engle.
- Unrealistic market projections. "There are too many stories like this," said Engle giving an example of a fish farmer who raised hybrid Striped Bass for $8.80-11.00/kg ($4-5/lb.) and expected to sell them for $16.50/kg ($7.50/lb.). Instead, he got $5.50/kg ($2.50/lb.) and his aquaculture business failed. "Prices change constantly," she said. "Quite a few people start out with over-optimistic market projections and the volume they can produce."
- Mistaking a business for a hobby. "Fish farmers have to sell fish, not just enjoy watching them eat," said Engle. She said if a fish farmer doesn't have the skillset or time to manage an aspect of the business, they should maybe hire someone who does.
- Under-capitalization. Engle said that people sometimes forget to save money for future problems and a delay in returns. She has seen businesses fail due to timing issues and unforeseen costs.
- Inexperienced management. "You may know fish," said Engle, "but do you know social media, financing, accounting and marketing?"
- Unexpected antipathy in some sectors of the community. Engle said it is important to recognize why and when some people will oppose an aquaculture business. She said insurance agents and attorneys who deal with political and permitting issues can be handy, if not necessary in some cases.

"Aquaculture is disadvantaged by lack of continuous market research," said Engle. "We don't have information about prices about different species in different markets over time. This is a problem! How can you price your fish?" She said answering economic questions would help fish farmers estimate risk, cash flow and market timing. She recommended conducting and compiling marketing studies on an annual basis in key markets like Minneapolis and Chicago and then conducting a more in-depth analysis of demand and supply for key products and markets including competition every 5-10 years. "Who is the competition? What is the existing price? How can you occupy a niche? You need to be asking yourself these questions," she said. Critical information on aquaculture products includes:

- 10-year average price
- Minimum price
- Price fluctuation throughout the year
- Facts about the customer base and key markets (every 5-10 years we need quantitative study of consumer demand and preferences)
- How the product sells in supermarkets versus restaurants versus elsewhere
- Sources of the product and its substitutes (where's it coming from and at what price?)

Engle also said there needs to be detailed cost analyses using average and worst-case outcomes like those done for U.S. agriculture. She said enterprise budget analyses need to be standardized so that the industry can manage cash flow and risk with good estimates for scales of production of different species in different systems. Periodic surveys could help detail the social perceptions held by regulatory agencies and the public about aquaculture.

Engle was asked to expound on the perils of aquaculture ventures anticipating a high price for their products: "With a high price point market, people think they can sell fish for $15 dollars a pound. Then the prices crash and their business fails. Have you had any experience with this?"

Engle replied, "It is common and prevalent. Demand and choice have a big influence. When the supply is coming from one producer they can maybe get $15 dollars a pound. When another producer comes into the market, the prices change because there are more options. What we really need is trend and yearly tracking data. Where do you go to look at a ten-year average to see where prices flow? It doesn't exist. People need to plan for average or low prices and have capital to withstand losses and low price points. Don't take all your profits and go to Vegas."

Education: From workforce training through consumer education, Hartleb suggested that there's much to be done in the way of closing gaps on education. "You can produce all the fish you want, but if no one wants to buy them, what kind of business is that?" He included economic and sustainability education related to different systems and species on his list of ideas for advancing the industry.

He talked about training the next generation of fish farmers at the University of Wisconsin-Stevens Point's Northern Aquaculture Demonstration Facility in Bayfield and its sister facility, the Aquaponics Innovation Center in Montello, Wisconsin. UW-Stevens Point is the only university in Wisconsin that offers a minor in aquaculture. Hartleb said the university offers semester-long college aquaponics courses that have trained 400 students in six years, a three-day master class that attracted 1,400 students and is the only professional aquaponics certificate in the nation. Engle reiterated that more support is needed for people entering the aquaculture business. "Since it comes down to an individual's strategic decisions, what information can we provide to the decision makers?" she asked.

Summerfelt suggested increasing consumer education by leveraging the capacity of nonprofits to explore the benefits of eating U.S. and locally produced seafood, and seafood in general. He said consumer education could increase seafood consumption per capita. He pitched the idea of creating mentoring programs for start-up aquaculture businesses with companies such as Cargill or Pentair. Organic standards for farmed fish and produce from aquaponics systems are also needed, he said.

Fish Fraud: Fish fraud is common and is an "… economically motivated adulteration that undermines economic honesty, consumer confidence, public health and sustainability," said Nick Phelps, assistant professor with the University of Minnesota. Given that the vast majority of seafood is imported, he recognized the clear need to grow more food-fish within the U.S. He conducted a survey of 350 restaurants and found that salmon was mislabeled 40% of the time and tuna 20%. People ordering Walleye, for the most part, got the species they ordered. "This is a drastic change," he said, noting that a decade earlier about 40% of the Walleye were mislabeled. He also pointed out that the federal government is working to stop fish fraud and that by doing so, they are improving consumer confidence and health.

Questions about the consequences for mislabeling in fraud cases and who is responsible prompted Phelps to say that during his research, which was funded by the Food Protection and Defense Institute at the University of Minnesota, he didn't investigate at what juncture the fraud occurred, only that it did somewhere along the way. He said his visits to supermarkets and restaurants were unannounced and he simply bought fish as a consumer. He did not do trace-backs but he did ask where the supermarket or restaurant bought the fish and its country of origin. Even so, he could not detect a trend. "My guess is that it is happening at the restaurant level or very close," he said. "We interviewed throughout the chain and no one wanted to be the regulator." He said most people thought the U.S. Food and Drug Administration was responsible for regulating fish fraud. "But that is too high up to be regulating at the restaurant level," said Phelps, adding that the FDA doesn't have the capacity to inspect more than a tiny fraction of the seafood. Phelps found that fraud was higher when fish didn't show fish skin and could be masked by seasonings. In the consumer focus groups he led, Phelps found that participants tended to lump seafood together, not discerning the differences and the complexities.

Biological Questions

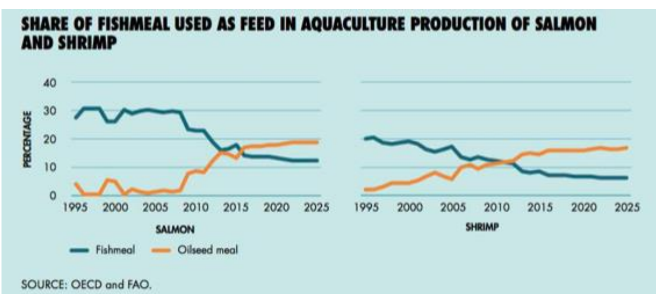
Nutrition: Hartleb emphasized that fish nutrition deserved time and attention. He said that species-specific diets do not yet exist and there is room to develop alternative fish feeds as well as better starter feeds and life-stage feeds. Aquafeeds, he said, are what the U.S. might need to focus on to be competitive in the global market. Citing research about the environmental impacts of feeding crops to farmed fish (Fry et al, 2016), he said that substituting plant protein for fishmeal may not be as sustainable as conventional wisdom suggests; he said it is a subject that could bear more research. Hartleb suggested that there is also room for exploring how probiotics can become part of fish diets. Evidently there is a push for this in Europe.

Protein and lipid composition (%) of commercial aquafeeds; from Bob Summerfelt's presentation.

	Rainbow Trout[1]		Atlantic Salmon[2]	
	Protein	Lipid	Protein	Lipid
Starter feed	52-53	18-20		
Fry	50	18-22	55	17
Grower	40-47	24 (16)[3]	48	24 (30)[4]
Broodstock	48	20	45	24

[1] **Bio-Oregon Catalog 2015** www.bio-oregon.com
[2] **FAO 2017** http://www.fao.org/fishery/affris/species-profiles/atlantic-salmon/atlantic-salmon-home/en/
[3] **Zeigler**
[4] **Ewos**

Fishemeal vs oilseed meal used as aquafeed for salmon and shrimp; from Bob Summerfelt's presentation citing OECD and FAO.



Steve Summerfelt also spoke about fish feed. "Atlantic Salmon, Rainbow Trout and Walleye don't require fishmeal in their grow-out diets," he said, adding that it would be wise to develop practical and locally sourced protein options for fish out of plants like peas, lentils, soybeans and their protein concentrates.

Steve's father, Bob Summerfelt, Professor Emeritus at Iowa State, concurred, adding plant substitutes for fishmeal like corn gluten meal, rapeseed (canola), linseed (flax), sunflower seeds, etc., to the list. Both Summerfelts also talked about land-animal sources of protein including byproducts of the beef, poultry and porcine industries. Bob Summerfelt said that using cow parts could be risky because of prions related to mad cow disease. Both presenters also suggested the aquaculture industry could benefit from investigations pertaining to microbial meals, nut meals and insect meals. Steve Summerfelt said more work needs to be done on aquafeed's impact on water quality, waste production, salmonid growth, feed conversion ratios, survival and fillet attributes.

Steve Summerfelt had similar comments about lipid alternatives. "Did you know that feed companies substitute many other lipids for fish oil?" he asked. "Some might not be able to be digested by the fish." Both Summerfelts mentioned that feeds could include lipid alternatives made from rapeseed, soybean, linseed, genetically modified oilseed crops, *Spirulina* microalgae and poultry fat, among other things, adding that the industry needs information on calibrating the right balance of lipids so fat isn't aggregating in the fishes' guts or being released in feces. The industry also needs feed formulations that maximize omega-3 fatty acids and other elements that are known to provide humans with a healthy meal. Bob Summerfelt said that the target in new formulas is to maximize omega-3 fatty acids and to balance the omega-3:omega-6 ratio. Steve

Essential fatty acid content of plant oils and animal fats; from Bob Summerfelt's presentation.

Lipid source	Σn-6	Σn-3	n3:n6 ratio
Beef fat	3.1	0.6	0.19
Pork fat	10.2	1.0	0.1
Chicken fat	19.6	1.0	0.05
Corn	58.0	0.7	0.01
Soybean	51.0	6.8	0.13
Canola (rapeseed)	20.2	12.0	5.94
Flax (linseed)	12.7	53.3	4.2
Anchovy	1.3	31.2	**24.0**
Herring	1.0	15.7	**15.7**
Menhaden	1.5	25.1	**16.7**
Salmon (AK wild)	2.1	31.4	**15.0**

Summerfelt suggested that examining the fat content of fillets of trout raised in different conditions on different feeds would be valuable.

Bob Summerfelt agreed that research opportunities are abundant in the area of fish nutrition. There are about 40 nutrients required in a fish's diet that are provided through fishmeal and fish oil, including omega-3 fatty acids, he said. Fish nutrients are primarily proteins, lipids, carbohydrates, vitamins and minerals, but amino acids like methionine and lysine are also essential and provided through fishmeal and fish oil. One of the fasted growing segments of the aquafeed industry is developing amino acid and vitamin additives, he said.

The aquafeed industry is growing rapidly and expected to continue to do so, said Bob Summerfelt, adding that 2022 predictions suggest the fish-feed industry will have grown to be worth $156B. He referenced The Future of Aquafeeds (Rust et al. 2011), a NOAA-USDA Alternative Feeds Initiative publication which expounds upon alternative dietary ingredients to reduce the amount of fishmeal and fish oil in aquaculture feeds while maintaining the human health benefits of eating fish. Expressing the need for research in this area of aquaculture, Bob Summerfelt said that substitutes for fishmeal and fish oil are incomplete or not digestible at this time. Currently, feed is composed of about three-quarters wild-caught fish such as anchovies and herring, and one-quarter fish scraps. About 60-70% of fishmeal and 90% of fish oil goes toward aquafeeds.

Any substitutions for fishmeal and fish oil require evaluation, said Bob Summerfelt. He said the pioneering ARS Digestibility Database helps fish farmers and aquafeed producers to formulate diets based on the bioavailability of nutrients in replacement feeds. High levels of indigestible fiber depress growth and increase fecal bulk. To make plant fibers and protein more accessible, adding enzymes to feed might be necessary. Negative side effects of plant-based fishmeal substitutes include antinutrients in plant matter, potential contamination with mycotoxins and increased phosphorous discharge in effluents. Also, the amounts and balance of amino acids and vitamins in plant matter requires scrutiny.

Breeding and Genetic Manipulation: Steve Summerfelt talked about needing research to refine the methods for producing all-female and non-maturing populations while improving growth and preventing fillet quality from declining. It will be necessary to safeguard intellectual property associated with germplasm lines and put effort into the biological containment of cultivated strains of fish.

Regarding research needs, Steve Summerfelt said the aquaculture industry needs standard operating procedures for applying methyltestosterone so that none of the compound escapes. Treating tilapia fry with methyltestosterone is a simple way to produce all-male stocks, which grow to a larger and more uniform size than mixed sex or all-female tilapia populations (Megbowon and Mojekwu 2014).

Steve Summerfelt referenced Wong and Zohar (2015), who state, “Farming reproductively sterile fish is the most environmentally sustainable approach to ensure complete bio-containment in large-scale aquaculture operations.” Wong and Zohar developed a method of treating embryos with compounds to stop stem cells from forming gonads. “This is huge,” said Summerfelt, “A sterile fish is ideal for growing and for the environment because it doesn’t put energy into reproduction. Additionally, this method is not genetically modifying the fish.”

On the subject of triploidy as a way of developing Atlantic Salmon aquaculture stocks that are both sterile and all-female, Summerfelt said this research was requested by the industry to minimize the risk of farmed fish escaping and spawning with wild fish. In the ocean, triploid fish could be problematic and in general, they don’t fare as well. However, they might be able to thrive in a RAS’s controlled environment.

Caird Rexroad weighed in on the subject of genetics. “Breeding programs have made huge progress for agriculture; we need to bring this for aquaculture,” he said, adding that traditional breeding has already halved the harvest time for Norwegian Atlantic Salmon over the last 40 years while improving feed conversion efficiency, survival and product quality. He noted that hybrid catfish crosses originating in the 1960s are now yielding fish that can grow 25-50% faster than traditional Channel Catfish and recent genomic approaches to selecting Rainbow Trout have improved disease resistance from 30% to 60% in a single generation.

Rexroad suggested that manipulating fish genes through biotechnology – including transgenics and gene editing – is currently not practical for the U.S. food-fish market due to regulations and consumer values. “But biotechnology offers a great deal of potential,” he said, noting that the controversial genetically modified (GM) food-fish, AquAdvantage Salmon, requires 25% less feed. The U.S. Food and Drug administration approved AquAdvantage Salmon for human consumption but not for sale in the U.S.; the GM salmon can be sold in Canada.

When asked about the future of GM salmon in the U.S., Rexroad talked about the beneficial qualities and improvements in animal welfare that genetic modification can offer. He said opposition stops the sale of what has been a thoroughly researched and expensive process, adding that though gene editing has plenty of potential, the new technology does not have clear regulation yet. “We have to see where it goes over the next few years,” he said. Rexroad’s research is invested in selective breeding, which is accepted by the public. A member of the audience suggested that clarity in terminology would help the public discern the differences among words like genetically modified, gene editing, genetic improvement, sterile vs non-sterile, etc. Rexroad agreed that industry and government need to do this to help consumers understand the final product.

He said the gaps in information about genetics tend to be species-specific due to biology and the species’ histories of domestication. Efforts are particularly focused on optimizing genetics as part of a production system, highlighting the fact that genetics programs are expensive and raising a species like catfish is extremely different from raising a species like trout. Even raising the same fish species can take multiple forms. “Would the strain developed for raceways do equally well in a RAS or a pond?” he asked. “Can we afford to optimize strains for every production system, or do we look for the fish that performs the best in a variety of systems?”

He recommended selective breeding programs should select the top 10% performers. Food-fish aquaculture might be advised to create breeding programs that seek to improve traits associated with yield, production efficiency, product quality, healthfulness and animal welfare. He said breeding can change biology of fish to adapt to certain feeds; fish that typically eat fishmeal could develop disorders or diseases from plant-based diets unless they are adapted through selection. Some salmon pick up color better than others: this trait can be managed by selective breeding. Breeding programs can encompass everything from domestication, mass selection, family-based selection, marker- and genomic-enabled selection, among other methods. Rexroad said breeding programs might focus on traits such as:

- Growth, feed efficiency, disease resistance, stress tolerance, omega-3 profile, etc.
- Feed choices affecting production based on breeding; choose the right feed mix for your fish
- Temperature regime
- Uniformity; important for predictable processing and production

Diploidy is still today’s norm for production, said Rexroad. However, he said the industry could invest more energy into technologies such as triploidy, chemicals that control reproduction and gene flow, ways to minimize the environmental impact of escapes and protecting commercial breeding investments. Rexroad said work could also be done on domestication, chromosome set manipulation and producing monosex populations. He also talked about hybrid vigor, saying, Striped x White Bass and Blue x Channel Catfish crosses have proven to be effective in aquaculture.

Rexroad said currently one company, Troutlodge, Inc, produces 90% of Rainbow Trout eggs available in the world. Many fingerling producers pay attention to genetics, the question being: “how will we get these genetic benefits to food-fish farmers?” He said that public-private partnerships with organizations such as the USDA’s National Center for Cool and Cold Water Aquaculture in West Virginia, Hagerman Fish Culture Experiment Station at the University of Idaho, and the Aquaculture Research Institute at the University of Maine are all potential partners. At institutions like these, innovative technologies can move from the lab to the field while minimizing risks to individual fish farmers.

Fish Health, Biosecurity and Flavor: Several presenters suggested aquaculture would benefit from more research on fish health with the greatest need in pharmaceuticals and biosecurity.

With regard to the health of fish in closed-containment aquaculture facilities, Summerfelt said that research to exclude or treat obligate and opportunistic pathogens and parasites should be ongoing. Related to that, he specifically mentioned that the industry needed ways to minimize treatments and their cost, and technologies that use methods other than antibiotics. He said that improving production environments might also help to control pathogens and parasites. Further, he talked about how, despite improved vaccines and broodstock, the environment has inhibited fish growth. He said in Norway researchers are racing to produce a marketable salmon in one year. “If they can get fish out of the system in one year, that would be huge,” he said of the endeavor.

Growth and survival of fish are not yet idealized for all environmental aspects of RAS technologies. Steve Summerfelt, conservationfund.org

Feed	Photoperiod	Density	Temp	O_2/CO_2	TSS	Pathogens	Growth
Ideal	Ideal	Ideal	Realized	Ideal	Ideal	Ideal	Ideal
Realized						Realized	
				Realized			Realized
	Realized	Realized					
					Realized		
Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad

To refine the optimal culture environments, Summerfelt said more studies need to look into the water chemistry, natural hormones that accumulate, population density, photoperiods and swimming speeds. Most RAS don’t capitalize on all of these factors so fish growth is less than ideal. Growth is what makes the money, so fish farmers would value information on how to fine-tune these factors, said Summerfelt, noting that for some species in some systems better information is available; for instance, salmon and trout grow better in RAS if they are exposed to light 24 hours a day. “Businesses make choices in technology and don’t always make the maximum ideal choices,” said Summerfelt “We see the response in performance.”

Nick Phelps discussed fish health starting with emerging pathogens. “The University of Minnesota is poised well for this,” he said. Estimating and managing risk in aquaculture is his background. He thinks there is fertile ground for more research in early detection of diseases, disease pathology, monitoring and control recommendations.

Phelps answered a question about research being done on fish microbiomes. He said he has conducted some studies to promote the growth of beneficial bacteria and reduce the abundance of harmful bacteria, as have researchers at UW-Stevens Point, Iowa State University and elsewhere.

Phelps said that the recent and rapid expansion of aquaponics has led to food safety concerns. Though aquaponically produced foods are perceived as safe, they might not be. “Fish aren’t the problem,” he said. “It’s rodents, people and other warm-blooded animals.” This risk is similar to problems with leafy vegetables grown in other systems.

When asked what pathogens were associated with aquaponics, Phelps said the worst bacteria is on ready-to-eat produce and that overall bacteria counts, aeromonads, salmonella, *E.coli* and *Listeria* were among the pathogens found.

Phelps said that pathogens, with respect to fish health, could be broken into three categories of concern:

1. Regulatory
2. Production
3. Potential

Pathogens of regulatory concern such as viral hemorrhagic septicemia virus (VHSV) and infectious pancreatic necrosis virus (IPNV) might be best combatted with improved best management practices for biosecurity strategies and rapid response. Keeping viruses such as these out of a production system is important, said Phelps, but when they do get in, the industry needs rapid response strategies to keep captive fish stocks from collapsing.

Pathogens of production concern like *Flavobacterium columnare* and aeromonads fly under the radar of statutes and regulations but can still bring an aquaculture business to its knees, said Phelps, citing struggles experienced by Bell Aqua, Minnaqua and a state hatchery. Though he said he would love to avoid vaccines and therapeutics, they seem necessary for advancing aquaculture along with probiotics to prevent problems.

He said pathogens of potential concern, like the 15 novel pathogens found in the last four years, need to be tackled with improved surveillance, diagnostics and risk assessment. Of the 15 novel viruses, he said not all are problematic but classifying them is challenging.

Phelps was asked how many novel viruses are being encountered. He said it is hard to keep track because of the recent spate of active surveillance, but finding 15 hasn't been surprising since nobody has really looked before. "The more we look, the more we find," he said, adding that scientists are working to figure out how the virus spreads across and within systems, and their impotence. Phelps said the novel viruses move with their hosts but it is unclear if they are species-specific.

In some cases, aquaculture systems can produce off-flavor in their products. The most common off-flavor compounds found in cultivated fish are 2-methylisoborneol (2-MIB) and geosmin, which are secondary metabolites released by microorganisms such as cyanobacteria or actinomycetes that exist in most aquaculture systems. Steve Summerfelt talked about technologies to remove 2-MIB and geosmin and related research needs regarding UV, O_3 (ozone), advanced oxidation and biological remediation with microbes that remove 2-MIB and geosmin or compete with actinomycetes. He also said it would be valuable to learn more about how swimming speeds and dissolved oxygen could be manipulated to maximize gill ventilation during depuration, the process of purging biological contaminants (such as geosmin) and impurities (such as biosolids) by placing aquatic animals into clean water.

Environmental Risk

Net pens are not permitted in the Michigan waters of the Great Lakes and are non-existent in other U.S. Great Lakes states. This is primarily due to lack of social acceptance because of poor water quality and potential disease challenges associated with concentrated fish waste. Escapement into wild stocks is also a major concern.

In terms of using groundwater for aquaculture, Hartleb said, "It's a fight over who gets to use the water and then where the water goes?" Growers face off against conservationists and fishing enthusiasts over the regulations for high-capacity wells.

Putting social license and regulations aside, Steve Summerfelt mentioned that Minnesota could potentially raise fish in net pens in Lake Superior in the fashion of salmon in Washington state's Columbia River.

Aquaculture is often perceived as a vector for spreading aquatic invasive species, said Phelps. Though it is unlikely fish will escape, he said the risk is "on our radar." He said an aquatic invasive species certification program for aquaculture might be helpful but primarily the concern with regard to spreading invasive species through aquaculture is for farmed baitfish (See: AIS-HACCP, Gunderson and Kinnunen 2004). Most food-fish in Minnesota will most likely be raised in closed systems outside of flood zones. A member of the audience asked Phelps to elaborate on how aquaculture is not a risk for spreading aquatic invasive species. He said that there is a gradient of risk and that the key is to keep vigilant about the risk and make improvements as more information and tools become available. He said farms that implemented biosecurity measures are at lower risk of contamination and for spreading unwanted species.

Unique Aquaponics Challenges

The major challenges to aquaponics include market competition with respect to products and whether or not a system should be coupled or decoupled. Separating the fish from the plants provides more options for fish species but adds the expense of heating and cooling. Geothermal or solar heating systems may reduce these expenses. Complying with regulations in some areas may also restrict aquaponics growth.

At this time, the fish side of aquaponics is 90% tilapia and Hartleb said there is a great opportunity for more diversity among fish species. Workshop participants asked Hartleb if *Streptococcus*, a genus of bacterium that has killed scores of farmed tilapia, can be better controlled in a decoupled aquaponics system. The answer to this question remains unclear.

One of the bottlenecks to the growth of aquaponics is increased species diversity. This is because there are just a few nurseries that provide tilapia, and very few or no providers of Walleye and other fish species. Hartleb said the industry would benefit from out-of-season and indoor production of fry to increase availability and reduce biosecurity risks. Aquaponics ventures tend not to purchase fish from outdoor growers because of biosecurity risks and there are few indoor sources for fry of species like Walleye.

Diseases of both fish and plants are challenges as is the need for science-based education. Hartleb quipped that you can't create a successful aquaponics business by watching YouTube videos. Most grants for aquaponics fund plant research, viewing fish as fertilizer and in many cases an economic loss. "Aquaponics is viewed as horticulture," said Hartleb, adding that this view slows the speed at which the aquaculture component of aquaponics can develop because conditions are kept for plants, often leaving fish in less-than-ideal growing conditions.

Steve Summerfelt also talked about the need for more information and research related to aquaponics. He said it would be valuable to determine how chronic exposure to potassium at levels around 50 ppm affects the growth, feed conversion ratios, survival and welfare of salmon and trout. Determining what ion (other than chloride) would most efficiently reduce NO_2-N toxicity would also be useful.

Hartleb suggested that since fruits and vegetables produced through aquaponics compete with those from the organic market, one way to increase profits might be to obtain USDA organic certification. It is controversial but at this time still possible for aquaponically grown produce to gain USDA organic certification. The USDA has not created organic standards for fish.

Technology

With respect to how technology could be improved, Summerfelt focused on reducing capital and operating costs through economy-of-scale and improved energy efficiency. Both could necessitate better design and standardization of equipment and construction. For example, removing CO_2 is the largest energy sink within RAS; the necessary building ventilation also loses heat to the atmosphere. Using a CO_2 scrubber in closed-loop air system to minimize building-air exchange could reduce energy costs, as could technologies to recover energy from ventilated air. Additionally, Summerfelt mentioned research could help optimize, simplify and reduce the cost of membrane biological reactors to reclaim water, alkalinity and ions.

As information technology advances, Summerfelt said automation could be improved in aquaculture facilities. He envisioned that machines could monitor inventories and stocks, manage feed in large tanks and assess and control water quality. Possibly the industry could capitalize on data management through integrated cloud-based platforms and someday, farmers could be using technologies like facial recognition to better track individual fish.

Another way technology could improve aquaculture is through hydraulics, Summerfelt said. He talked about using hydraulics to improve fish transfer and handling within the production system, as well as using technologies to improve fish handling pre-slaughter to optimize product quality.

Walleye in Particular: Robert (Bob) Summerfelt, Professor Emeritus from Iowa State University, spoke about basic research, like understanding the roles of genetics, nutrition and the environment in the occurrence of deformities and diseases. He also talked about Walleye.

He acknowledged that while farming Walleye as a food-fish was biologically and technologically feasible in Minnesota, it may not be economically viable. Minnesota farmed Walleye would compete with the oldest and largest Walleye commercial fishery in the U.S. (Red Lake Reservation, Minnesota) as well as Canadian Walleye and European Zander. He said farm-reared Walleye produce smaller fillets than wild-caught and that the industry would also need to combat fish fraud since it has been shown that many “Walleye fingers” are actually made of Pollock, an ocean species.

Developing domesticated Walleye broodstock through selective breeding would help production. Bob Summerfelt said that if Minnesota wants to cultivate a food-fish farming industry around Walleye, the industry needs a dedicated propagation specialist to cultivate strains that can spawn out of season and to develop methods for producing all-female populations and hybrids.

When asked to describe out-of-season spawning related to cold banking, Bob Summerfelt explained cold banking is a way to hold fish during winter (Harder et al. 2014). He said Walleye can be kept in cold water from August through June. Their resulting slow metabolism reduces their interest in food and oxygen needs so they can be kept in higher densities. Though they use some body fat for maintenance, they remain in excellent condition. Cold banking provides an alternative to multiple spawning. Bob Summerfelt said that spawning could be extended by maybe two months with temperature control. He said that Walleye can be made to spawn two (one natural, one early) and possibly three times a year. A fourth spawning is problematic but he suggested it might be possible to combine out-of-season spawning and cold banking manipulations to achieve that end. He said there are also problems with certain diseases, like columnaris, in Walleye that might be addressed through selective breeding programs.

Summary of Small Group Discussions about Research and Information Needs

Attendees participated in one of four breakout groups to discuss questions on prioritizing research and information needs. The groups supported research on a variety of topics pertinent to advancing food-fish aquaculture in Minnesota. The discussions were fluid and often seamlessly and simultaneously addressed these questions.

1. What type of research will be required to move food-fish aquaculture forward in a sustainable manner in Minnesota and what research needs are of highest priority?
2. What major technical hurdles must be addressed for aquaculture to be successful in Minnesota and the Midwest?
3. Is information on food-fish markets (supply-demand), product value and consumer acceptance of farmed, locally grown food-fish available in Minnesota? If not, what types of information would be important to collect?
4. What can be done to increase the public’s understanding and acceptance of farm-raised fish in the marketplace and as a legitimate agricultural product (social acceptance)?
5. What are other questions related to this theme worth discussing?

1. What type of research will be required to move food-fish aquaculture forward in a sustainable manner in Minnesota and what research needs are of highest priority?

The groups considered it impractical, if not dangerous, to narrow research priorities down to one topic. Consensus built around the notion that studying the market as well as technical aspects of Minnesota food-fish aquaculture simultaneously would be a valuable pursuit; the research questions could be built together and respond to each other. Outstanding categories of research were “marketing and understanding consumer perceptions and demand” and “business models, best practices, and technical efficiencies.”

Across groups, participants prioritized **research into marketing, economic potential and consumer perceptions** as a first step as well as a long-term process to accompany consumer education and the industry as it develops. Comments and questions in this domain included:

- Nothing starts without a business plan; the Minnesota food-fish aquaculture industry needs to start with a business plan.
- The Minnesota food-fish aquaculture industry needs to know more about purchasing decisions, substituting species and price sensitivity.
- The Minnesota food-fish aquaculture industry needs to understand customer demographics in a way that would lead to economically productive products.
- What are people willing to pay for and at what price?
- Is the Minnesota food-fish aquaculture industry divvying up a small market or is it able to expand the customer base?
- What can proper branding achieve? Would a "Minnesota raised" campaign work for food-fish?
- What is the potential for growth? Within the Walleye market? Shrimp? Salmon? Perch? Other?
- The Minnesota food-fish aquaculture industry needs to understand perceptions about wild-caught versus farm-raised fish with respect to quality, taste and environmental impact.

An economically sustainable industry must also produce products efficiently and offer economic choices to consumers. Regarding **business models, best practices and technical efficiencies**, participants commented and asked:

- The Minnesota food-fish aquaculture industry needs to develop reliable broodstock for Walleye, Sauger and creation of hybrids. Without a consistent broodstock, you cannot provide a consistent product to the consumer.
- What are successful aquaculture businesses doing differently? How does the Minnesota food-fish aquaculture industry replicate that success?
- The Minnesota food-fish aquaculture industry needs to create a layered map that helps identify sites that have aquaculture potential.
- What are the best engineered systems and practices for Minnesota?
- The Minnesota food-fish aquaculture industry needs to continue to improve the efficiencies of RAS and other technologies.

Research to solve biological and biosecurity challenges also became points of discussion. Participants acknowledged that biological research will always benefit the industry and often contribute to efficiencies. Their areas of interest were:

- Nutrition for each species and life stage
- Broodstock development
- Breeding healthy, fast growing stocks
- Fish health

Participants were united in wanting to be sure that building up an aquaculture industry was done safely with best practices and policies that support sustainable businesses. Their concerns included a secure source for eggs and fry year-round, and not creating an increased risk of moving and spreading diseases and invasive species.

2. What major technical hurdles must be addressed for aquaculture to be successful in Minnesota and the Midwest?

The technical hurdle mentioned repeatedly was the lack of **broodstock.** Though species-specific research to support Minnesota and Midwest businesses could include a variety of coolwater and coldwater fish, more than one participant made a call **to focus on one species** rather than trying to tackle aspects of farming them all. Participants also recognized that focusing too narrowly on one species could be risky and that market research would help pinpoint the most viable species for food-fish aquaculture in Minnesota. Further discussions about the technical aspects of food-fish aquaculture involved:

Biological challenges

- Broodstock for Walleye, Saugeye and other species of interest
- Beneficial bacteria communities for biological filters
- Pathogen resistance, treatments and best management practices
- Nutrition by species
- Sustainable aquafeeds

Engineering

- Water stasis for shrimp and fish environments
- Energy- and labor-efficient indoor systems
- Improving RAS technologies
- Energy generation and conservation strategies that pair well with the aquaculture systems

Regulatory

- Regulation clarity related to working with multiple agencies
- The Minnesota aquaculture industry is too new and small to affect policy

3. Is information on food-fish markets (supply-demand), product value and consumer acceptance of farmed, locally grown food-fish available in Minnesota? If not, what types of information would be important to collect?

This question attracted much discussion. The consensus was that there is value in collecting relevant market information on an ongoing basis to monitor changes and trends. The information also needs to be disseminated broadly. Information gaps that came up include:

- Pricing and its range over a 10-year period
- Consistency of the market, including seasonality
- Information for different markets such as grocery, restaurant, institution
- Demographics
- Volume
- Species substitutes
- Consumer perception and preferences
- Investor perception

4. What can be done to increase the public's understanding and acceptance of farm-raised fish in the marketplace and as a legitimate agricultural product (social acceptance)?

While participants agreed on the importance of this question, conversations did not particularly focus on it. Conversations about public acceptance seemed to focus on understanding public perception through market research. Comments and questions included:

- Minnesota must address misconceptions and changing perceptions about aquaculture in the state.
- Can branding (like that done in Alaska) or certification help consumers understand the difference in quality and responsibility of Minnesota-grown aquaculture products?
- Education happens at the point of sale and can help provide outreach to the community. However, the seller has an economic bias, and may not be the most trusted source of information.
- Extension and education groups may be able to change public perception given a capacity to deliver messages in fact sheets, interviews, state fair booths, etc.
- To educate consistently without contradictions, a consensus on terms is needed (e.g. sterile, GMO, gene editing).
- Continued outreach to consumers; re-education is vital.
- A Minnesota food-fish aquaculture industry should not try to compete with a sustainably harvested fish industry.
- A Minnesota food-fish aquaculture industry will not win consumers without addressing the different perceptions of wild-caught quality and taste versus farm-raised quality and taste.
- The Minnesota food-fish aquaculture industry does not need more research on the effects of aquaculture on drinking water, but it does need more outreach and education.
- Using sustainable energy sources may help gain consumer confidence.

5. What are other questions related to this theme worth discussing?

Some considered it difficult to prioritize research without short-term and long-term goals; they suggested narrowing the focus. That being said, additional research priorities included developing a trained workforce that involves aquaculture technicians, processing facilities, aquatic veterinarians and nutritionists, engineers for aquaculture systems, sales and marketing teams, chefs around the state that cook fish well and University of Minnesota Extension support.

Critical Research Focus: When the presenters were asked to choose a research focus they think is critical for aquaculture in Minnesota and to grow the industry, they answered:

Consumer science and reeducation! The anti-aquaculture campaign has been too effective. People are almost brainwashed that wild is better and farmed fish are bad. Helping develop a nursery provider seems important as well. (Chris Hartleb)

Overcoming barriers - fungal infections, early maturation of males, off flavor, etc. - to producing more and better Atlantic Salmon in freshwater RAS. Minnesota aquaculture research would be

best advised to start by leveraging Minnesota's climate and water by focusing on the large-scale production technologies for Atlantic Salmon and Rainbow Trout while realizing there is a niche for Arctic Char, Coho Salmon and Walleye.
(Steve Summerfelt)

Domesticated broodstock and selective breeding programs are highly needed for Walleye if Walleye is to take off as a cultured fish in large quantities. But we need a sugar daddy who can put millions of dollars into this endeavor for a decade or more. For salmonids it took 2-3 years per generation off of 100 families to achieve domestic broodstock. Who is going to have a facility to do this type of selective breeding? (Bob Summerfelt)

Aquaculture producers must select the species they want to produce and the systems in which they will be raised. They must have access to a dependable and consistent supply of fish genetics that performs well in those systems. For species such as trout and Atlantic salmon, many choices exist; for species such as Walleye, these programs must be developed. This is an expensive endeavor often initiated through public/private partnerships as it requires establishing a selective breeding program that incorporates diverse genetics that is bred for superior performance over successive generations. This can be done in a way that benefits an industry and not just one or few producers. (Caird Rexroad III)

Fish health should be the focus for everyone. Perhaps improved best management practices would cover a lot of these overarching goals. Health! I'm surprised it isn't everyone's first. I think that is the lowest hanging fruit even though it is broad. (Nick Phelps)

An economist needs to develop an ongoing database of prices and enterprise budgets to go with it. An individual could do that every year and make it widely available. It would take a month or two of their time each year. (Carole Engle)

Theme 3: Examining Policy and Regulatory Issues

Presenters on policy and regulatory issues included:

Keynote Speaker

- Carole Engle, Editor-in-Chief of the Journal of the World Aquaculture Society, aquaculture economist and co-owner of Engle-Stone Aquatic$ LLC; Perspectives on Aquaculture Policy, Regulatory and Food-Security Issues

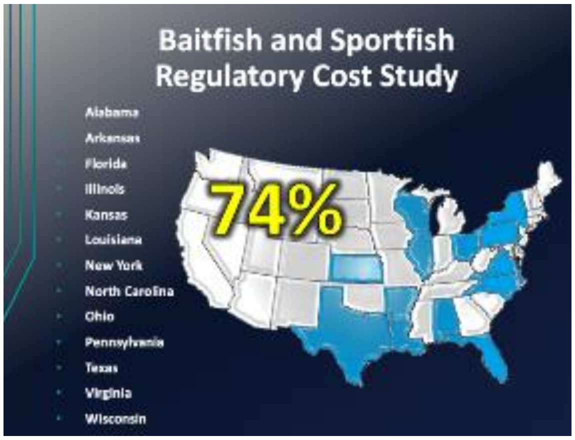
Panel Members

- Don Pereira, Chief of the Section of Fisheries, Minnesota Department of Natural Resources; Regulations and Permitting to Balance Aquaculture and Protection of Wild Fish Stocks
- Jeff Udd, Water Quality Permits Unit Supervisor, Minnesota Pollution Control Agency; Pollution Prevention and Standards for Aquaculture Effluent
- Valerie Gamble, Produce Safety Program Manager, Minnesota Department of Agriculture; Food Security Concerns for Minnesota Aquaculture Products
- Chad Hebert, Owner and operator, Urban Farm Project; Regulation and Policy Effects on a Small Aquaculture Business in Minnesota
- Zach Lind, Owner and operator, Driftless Fish Company; Aquaculture Complex Rehabilitation in Southeast Minnesota: Regulation and Policy

Perspectives on Aquaculture Policy, Regulatory and Food Security Issues

Carole Engle said, "I'm not talking about whether we should have regulations. We need them. We need some." Engle went on to say that though regulations are necessary and the aquaculture industry pushes for high environmental standards, perhaps the U.S. is over-regulated with more than 1300 regulations pertaining to aquaculture. She spoke of a study spanning 95 countries that found the U.S. has the third most stringent aquaculture-related regulations and second slowest growth rate for the aquaculture industry (Abate et al. 2016). Engle reported that Norwegian investigators found technical improvements on farms were hindered by regulations (Asche and Roll 2013). She said that economists believe laws and regulations are needed to internalize the costs of externalities, like pollution.

Over her career, Engle has been involved in a variety of regulatory issues with many federal and state agencies. When Engle started researching the regulatory angle of aquaculture, information was sparse and she was skeptical about the complaints she heard from fish farmers. However, she has come to understand that regulations can add up to create a real barrier to success. She said reform is necessary, recalling a favorite quip delivered by President Obama about salmon regulation in his 2011 State of the Union address (Shogren 2011).



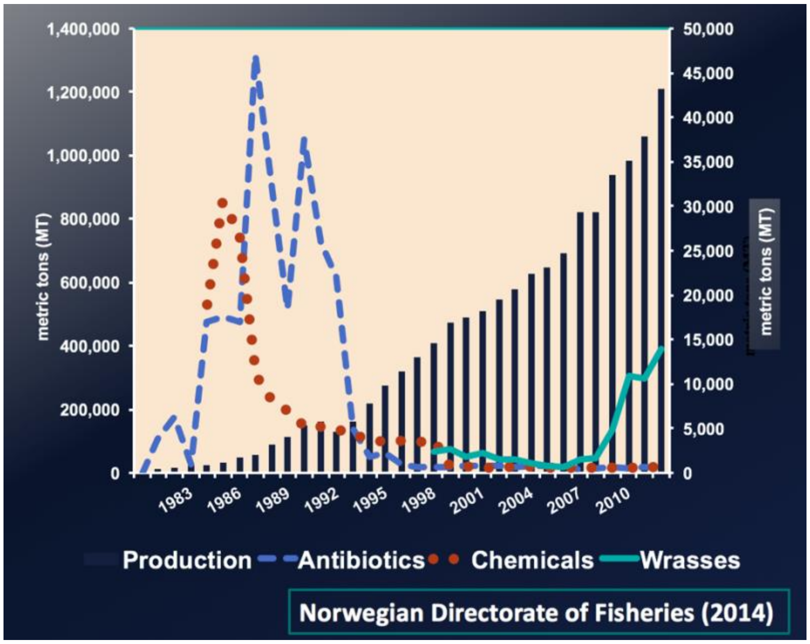
Engle and a colleague conducted a regulatory cost survey regarding the production of baitfish and sportfish to evaluate how over-regulation might be hurting the industry (van Senten and Engle 2017). Based on a surprisingly high response rate of 74%, she said the estimated total cost of regulations to the industry conservatively hovered near $12M/yr. Per farm, the cost was nearly $150K/yr.; per acre, the cost was $3,000/yr. "That is 25% of total costs," she said. Reflecting an economy-of-scale within the industry related to fixed costs, Engle said that small farms have higher regulatory costs per acre and higher costs per acre in general. The most expensive regulations pertained to the environment and, secondly, fish health. Of the regulatory costs, Engle said more than three-quarters were due to state regulations of which a third were mandated by federal agencies. Only 1% went toward permits and licenses. She said the remaining 99% were indirect costs such as time, market restrictions, access restrictions, changes to farming practices, etc.

Engle took a moment to talk about technical efficiency in aquaculture and how theoretical production levels are unachievable because of random error and inefficiencies. She suggested inefficiencies related to regulations are rampant in the aquaculture industry saying some fish farmers must keep up with multiple forms and permits covering the same details for different timeframes and for different agencies. She said regulations drove up costs of production by making it difficult for other farmers to pick up lost or foregone sales, by changing the rules of compliance, by requiring more labor to comply, and by the sheer number of permit and license renewals. Engle said that in the baitfish aquaculture industry it is clear that the regulatory environment is resulting in additional costs, restricted access to markets and lower farm efficiency. She suggested that regulations are particularly pushing small-scale and baitfish farms out of business.

Engle next talked about an almost-completed study related to shellfish farms along the west coast. She said the industry engages with agencies on multiple regulatory levels (county, state, federal) that frequently overlap. "The market for shellfish is incredible right now but the permit process is stopping the shellfish farms from expanding," she said. She explained that startup costs were prohibitively high due to needing attorneys and environmental consultants. Even then, she said it takes maybe five to 15 years to get a permit or permits to expand an operation. Engle said it bothers her that shellfish growers must specify equipment and supplies on permit applications but by the time the permits are approved five or more years later they can't capitalize on improvements in technology without going through another two to five years of waiting.

Regarding a trout-focused project in progress throughout the U.S., Engle said the remarkable part, so far, is the response rate the researchers are seeing on a difficult subject: a farm's financial details related to regulations. "It shows they care about regulations," she said of the trout farmers who responded to the complex survey.

Engle introduced the concept of a "wicked problem" as a problem that involves uncertainty, incomplete knowledge, lack of consensus, dynamic challenges and solutions that are slow in forming (Rittel and Webber 1973). She also introduced the concept through the work of three Norwegian researchers who interviewed people about the salmon industry and published "Fish farmers and regulators coping with the wickedness of aquaculture" (Osmundsen et al. 2017).



Graph showing the growth of salmon production in Norway and the dramatic decrease in the use of antibiotics and other chemicals over time.

With regard to uncertainty, Engle said the industry's effect on the environment comes up right away. She also pointed out that though aquaculture can pollute water, water can also poison aquaculture thereby making public policy an externality to aquaculture that also creates uncertainty. She commented that piscivorous birds on catfish farms could be considered an externality to aquaculture because the wetlands they would usually inhabit were subsumed by other activities.

Speaking about dynamic challenges, Engle pointed to a graph regarding the production of salmon in Norway, saying that salmon production has certainly grown while the use of antibiotics and other chemicals plummeted. Still, she noted, people believe farmed salmon is a product carrying undesirable elements because of history.

She said aquaculture technologies are developing rapidly and though regulators are often accused of using out-of-date information for decision making, they really don't have a mechanism for keeping up with the evolving technologies. She said, "If I were working in a regulatory agency, I wouldn't be able to keep up with information on how the industry is constantly changing and consequently address the right problems." She gave AquAdvantage salmon as an example of how regulators recently approved the genetically engineered fish as safe to eat but the public remains uncomfortable with dynamic change. "The industry has been changing and will continue to change due to dynamic nature of a relatively new agricultural business," said Engle.

She said that regulators and fish farmers frequently disagree on interpretation of the law and solutions to challenges but that whenever scientists, regulatory agencies and businesses work together, the systems they create are more stable and effective. Engle reiterated the story of the fish farmer and the inexperienced regulator that she told earlier in the workshop. She offered recommendations from Osmundsen et al. (2017) about what it takes to tackle wicked problems like the regulation of aquaculture. To be competent, regulators need adequate training about how to inspect products and systems. The regulatory system needs to be collaborative, adaptable, flexible and cost efficient. These elements can and should address the industry's competitiveness, sustainability, growth, risk management, and evolution, she said.

Speaking about imported seafood, Engle said, "Food safety is one thing; food security is another." She suggested that U.S. seafood isn't secure since almost all of it is imported and antibiotics like amoxicillin and enrofloxacin are used in Asian fish farms while remaining unapproved for such uses in the U.S. She cited a study that found 100% of farms in Vietnam used substances that are banned in the U.S. for farming *Pangasius*, a genus of shark catfish native to South and Southeast Asia; some of the banned substances are known carcinogens (Rico et al. 2013). "Problems like these have been reported for more than a decade, but we keep importing the seafood anyway?" said Engle. "There are some very compelling reasons for U.S. aquaculture, but how do we develop public support for aquaculture and get regulations fixed?" she asked.

In Arkansas, a state that embraces aquaculture, the public's perceptions of farm-raised fish has been aided by *Arkansas Grown Magazine*, which often highlights fish farms and aquaculture, as does the Arkansas Farm Bureau in its publications. Other state entities and media outlets also shed a positive light on aquaculture in the state. Engle reminded workshop participants that it takes ten positive comments to overcome one negative one. She suggested in states where U.S. aquaculture is viewed negatively, a concerted multi-fronted educational campaign needs to be mounted with three messages:

- This product is locally and sustainably grown
- This product complies to U.S. regulations and standards
- This product has freshness, taste and quality

Engle suggested that maybe Minnesota should develop an aquaculture plan modeled after existing plans. She said in Arkansas the process of developing the plan was maybe more important than the actual plan because it prompted a variety of agencies and constituents to work together. The plan was followed in five years by a progress report which provided a framework for continued progress.

A workshop participant asked if there might be a large aquaculture organization that could craft a universal reporting form to track permits, licenses and data. Engle responded that though she hasn't heard of an organization that would have such a broad scope, the USDA's Animal and Plant Health Inspection Service is developing an overarching form for reporting fish health details to multiple agencies (see Commercial Aquaculture Health Program Standards (CAHPS)). Such a program would help people like Arkansas fish farmers who might ship catfish to 30 different states. Engle said such farmers need to conduct various laboratory tests to comply to the rules of different states and something like CAHPS could compile the data on a single certification form that might be used by multiple states. "That would dramatically drop regulatory costs and aggravation," said Engle. "Even the ability to receive a certificate online and print it off would be a savings."

Participants asked Engle to expound upon improving the efficiency of regulations. She said turnover within agencies is possibly the biggest efficiency problem. A fish farmer might develop a working relationship with one regulator and when that person leaves the job, the farmer might never get a response. Engle gave examples of this: an agency didn't return permit application calls for over a year and agency personnel instructed fish farmers to call someone who had retired. She said efficiencies depend on the aquaculture methods used and vary by state. For baitfish the biggest cost of regulations is restricted market access because of universal concerns over the spread of diseases and aquatic invasive species. "When multiple agencies say they have jurisdiction over the transportation of live fish, there is a problem," she said. "But it all depends on industry." For trout aquaculture, Engle said waste discharge was a costly regulatory hurdle. She suggested regulatory agencies tend to defend their turf and getting them to coordinate their efforts would be hugely helpful, especially if they could agree on common forms.

For Washington state shellfish growers, Engle said the permitting process is still a fight. She said the growers don't mind the health regulations but the leases and site permits are causing trouble. The Shellfish Interagency Permitting (SIP) Team crafted a joint permit that was supposed to streamline permitting, but their solution was so complicated that Engle needed to spend several days trying to understand the information requests and the requirements. Engle told a story of an oyster farmer that got a call from a regulatory agency about eelgrass. The farmer had complied to an eelgrass set-aside requirement but the regulator was calling to say that now the eelgrass was bothering fishermen. Engle said the conundrum in this situation is who is responsible for the eelgrass. She hopes that issues such as this one can be resolved without penalties to the fish farmer.

A participant asked Engle about regulations regarding bringing fish across state lines. She said it depends on the species and purpose, with someone else adding that it also matters whether the fish is alive or dead.

Regulation and Permitting for Food-Fish Aquaculture in Minnesota

Regulation and Permitting to Balance Aquaculture and Protection of Wild Fish Stocks: Don Pereira, Chief of the Minnesota Department of Natural Resources (DNR) Section of Fisheries, talked about Minnesota regulations and permitting saying that aquaculture for fish-food production is a relatively new industry in the state. He said that it is important to grow the industry safely given Minnesota's deep cultural ties to its environmental resources and its sport fishing industry, which is worth $4B in direct and indirect economic impact. Managing Minnesota's fish costs $30-$33M annually and is funded almost entirely through the sale of fishing licenses.

“Everyone is biased. I admit I am biased as well,” said Pereira. “As a natural resource manager, I see risks maybe differently than you. I would weigh the escape of a captive animal differently than someone in the private sector. I think we need more research in biosecurity and in viable business models.” He said, “You are all good folks, but from the regulatory side, I see some ghastly bad behavior, too. I want to promote the industry, but also deal with the bad guys.”

Pereira said that the DNR has a significant role in aquaculture businesses even though aquaculture is a form of agriculture. The DNR issues Aquatic Farm Licenses and related licenses, and inspects fish farming operations. He said that the Minnesota Pollution Control Agency (PCA) is also involved because they issue related water discharge permits. The DNR and PCA work together, Pereira said. All DNR aquaculture facilities must comply with state regulations and obtain PCA permits as necessary.

In Minnesota, Pereira said fish farmers primarily raise baitfish and game fish for private stocking under 193 licenses. Pereira said popular farmed fish are Walleye, Fathead Minnows and suckers. “We processed several food-fish license applications last year,” he reported, mentioning that 34 licenses have been issued for food-fish aquaculture in the state.

With respect to the aquaculture industry, Pereira said the DNR is concerned about the spread of aquatic invasive species and how climate change will affect natural resources and the spread of pathogens. He said the DNR puts significant energy into keeping pathogens from spreading and requires certified disease testing on imported animals.

Pereira identified groundwater appropriations as an emerging concern in Minnesota. Keeping the future in mind he said that permits are beginning to be restricted or denied by the DNR’s Water Appropriations Permit Program because groundwater use is hovering around its sustainable capacity. He also said with respect to aquaculture, the DNR is interested in efforts aimed at preserving the genetic integrity of native strains, environmental risk assessments, biosecurity and support to help new aquaculture ventures succeed.

An ensuing audience-driven discussion had Pereira again acknowledging that the DNR would like to see Minnesota aquaculture industry grow without damaging the sports fishing industry by spreading diseases, invasive species or polluting water. “We’re very conservative because we have this huge other industry we want to protect,” he said. Other participants acknowledged that Minnesota has the advantage of a clean slate regarding aquaculture and that the industry could grow by learning from mistakes made elsewhere. “It sounds like our regulatory environment isn’t too onerous compared to other states,” said a participant.

Pollution Prevention and Standards for Aquaculture Effluent: Jeff Udd, Water Quality Permits Unit Supervisor for the Minnesota Pollution Control Agency (PCA), said the agency is involved in Minnesota aquaculture because the U.S. Environmental Protection Agency (EPA) authorized the PCA to issue National Pollutant Discharge Elimination System (NPDES) permits. With respect to fish farming, the PCA follows the (EPA) guidelines defining effluent limits for aquaculture operations, which reflect feed levels and production.

"We keep it simple by asking two questions," said Udd:

1) *"What is the scale of production?"*
2) *"Are you discharging to a surface water?"*

An NPDES permit is necessary when raising coldwater aquatic animals in ponds, raceways, or similar structures which discharge wastewater at least 30 days/yr., produce more than 20,000lbs/yr. (9kg/yr.); and feed more than 5,000 lbs. (2,272 kg) of food during the calendar month of maximum feeding. Warmwater fish are considered under different criteria. Udd said that the PCA infrequently deals with case-by-case NPDES permit considerations that are not specifically stated. If an NPDES permit is unnecessary, then simple notifications are required. He said that the PCA regulates with permits and aims to keep licensing on one form. The agency's wastewater operator certification is one way to ensure that people know how to implement the treatment systems properly, he said.

He said the PCA wants to:

- Follow the law
- Be reasonable ("We try," he said.)
- Hire compliance and enforcement staff who have good people skills, return phone calls, meet face-to-face and reduce frustrations

With respect to NPDES permits and aquaculture (and almost all industry permits), the PCA is mainly concerned with phosphorus. Udd says the way to get a permit is to work with a PCA staffer who generally treats the request on a case-by-case basis to allow for some industry flexibility. He noted that discharge differences exist between lakes and rivers, from north to south and by ecoregion. He said at the moment, less than ten NPDES permits related to aquaculture are for food fish; almost all are for DNR fish hatcheries. Udd commented that, in general, aquaculture facilities are using on land waste disposal and working with the PCA's land application of industrial by-products program and related licenses.

Food Security Concerns for Minnesota Aquaculture Products: Valerie Gamble, Produce Safety Program Manager for the Minnesota Department of Agriculture (MDA), said, "Our regulations kick in when the fish is dead. Then it becomes food." Food safety and inspection are the purview of the MDA. In the case of aquaponics, Gamble said the MDA is more involved in the entire production process because of food safety concerns about the plants and their risk of making humans ill. MDA regulations are implemented through inspections by the Food and Feed Safety Division, along with inspections from the U.S. Food and Drug Administration (FDA) in certain circumstances. The MDA office in St. Paul handles licensing while field inspectors work across the state.

Gamble went on to talk about the MDA's role in aquaculture, which includes:

- Facility and equipment sanitation
- Personal hygiene
- Seafood HACCP 21 CFR 123
- Produce Safely Rule 21 CFR 112

- Labeling 21 CFR 101
- Licensing statute MN Statute 28A

She said the MDA follows the federal rules developed by the FDA regarding the facility and equipment sanitation and personal hygiene. These include such things as training employees and maintaining an environment that does not contaminate food. Gamble said her team often fields questions about fish processing and Seafood HACCP regulations. She said aquaculture facilities are typically considered harvesters, not processors, so Seafood HACCP regulations don't apply, except by reference. They also don't apply if all the fish are sold to the end user. Treating otherwise unprocessed fish with carbon dioxide, bleeding, washing and icing is not considered processing and is therefore not subjected to HACCP regulations. Seafood HACCP regulations do apply if heading, gutting or packaging fish occurs on the farm.

Gamble talked about farmer's markets and on-farm production and how the complicated Produce Safely Rule 21 CFR 112 could apply. She said, "Know that the rule is there and that there is potential for that rule to apply to you. I want as many people to know about this as possible."

Gamble said the MDA regulates and inspects for fish fraud and misbranding. She said the agency doesn't have the capacity at this time to be more than reactionary about fish inspections and, at this point, species and safety/foodborne illness testing cannot be conducted in the MDA laboratory. She said a goal is to trace food borne illnesses to their sources.

A common question is, "Do I need a permit to sell fish?" Gamble said if you grew the fish or products you are selling, all food safety regulations apply but you do not need to pay a license fee. However, if you add anything … even salt … a license is necessary.

Regulation and Policy Effects on a Small Aquaculture Business in Minnesota: "There are a lot of regulators, but they are not a huge burden," said Chad Hebert, owner and operator of Urban Farm Project. Hebert thinks the burden of regulation likely depends on location but that the cities of Minneapolis and St. Paul encourage urban agriculture, particularly through urban agriculture amendments, Homegrown Minneapolis and the Metropolitan Council, which oversees sewers, the airport and other regional concerns.

He said that with respect to the MDA, the state constitution gives aquaponics producers latitude as long as production is being done safely. "As an aquaponics business we deal with the food safety regulations of fish and produce," said Herbert. He said he participates in FDA-approved seafood Hazard Analysis and Critical Control Point (HACCP) training and works with the MDA to meet vegetable food safety requirements. Herbert also offers a fish processing class.

Hebert says he has two DNR licenses – one for fish sales and one for a fish hatchery. All that was required was that he fill out a form and pay the fees. "Overall the DNR is very supportive and not a hurdle," he said. "They always answer the call." He said if a fish farmer was bringing in a different species they might have to present information on biosecurity protocols that will be held to additional scrutiny. He said the difference between a DNR hobby license and hatchery license is the volume of sale.

Hebert said, “New regulations through the Food Modernization Safety Act could bring many dramatic effects to farming and my business. Another big deal is buying insurance; the pool of options is small and costs are high.” Seafood and juice, he said, are viewed as food-borne illness risks.”

Aquaculture Complex Rehabilitation in Southeast Minnesota - Regulation and Policy: Zach Lind, owner and operator of Driftless Fish Company that started in Spring Valley, Minnesota, inherited some problems when he bought the farm to raise Rainbow Trout eggs to harvest. The former operator cut corners which resulted in lawsuits. Lind said, “As soon as we bought the farm we called the DNR and they came out and walked the property with us and the environmental consultant we hired. That day we came to consensus.”

Like Hebert, Lind also says working with the DNR and obtaining licenses from them has not been a burden. “The main thing that affects us is the discharge permit,” he said. “It is not a matter of science or permitting, it is the money.” He said filing an application for an NPDES permit costs $9,300 and that it is a gamble. “We have to hire an environmental scientist and it takes a year. Even then, you might not get your permit but either way you don’t get the money back.” Lind expects to pay $15,000 for the permit and related environmental consultation. “This is the only specific regulation that is a hurdle for us,” he said.

Engle was surprised. “Wow. That’s the highest cost of any permit of any farm we’ve talked to,” she said.

Udd said that the NPDES permit fee of $9,300 is a PCA rule that went through the Minnesota legislature, which wants to fund the Clean Water Act through fees rather than state taxes. The NPDES permit fee is not scaled, so small fish farms and large fish farms pay the same $9,300. Udd said that only six or seven permits have been issued for farming fish and most of these are for hatcheries. Udd said, “There is not a broad group of facilities that have a threshold for needing them.”

The conversation turned toward water chemistry when a participant asked Udd, “Do NPDES permits have TMDLs for chlorides?” Total Maximum Daily Loads (TMDL) is a regulatory term in the U.S. Clean Water Act describing a plan for restoring impaired waters that identifies the maximum amount of a pollutant that a lake or river can receive while meeting water quality standards. Udd responded that the PCA monitors chloride but it is not regulated.

Staff from Superior Fresh, a large aquaponics facility in Wisconsin, asked about a summary for TMDL limits and wondered if there was a reference in Minnesota that might provide farmers TMDLs for different water bodies. Udd replied that the information is not pulled together yet but that the PCA has mapped ecoregions with respect to phosphorus limits. He responded to a follow-up question about infiltration saying that if fish farmers inject effluent into the ground they would need to conform to rules addressing groundwater standards.

After pointing out that Minnesota has a relatively smooth regulatory environment for aquaculture, more than one participant suggested the NPDES permit fee seemed like it could be scalable and a topic to take up with Minnesota legislators. “We need to consider the unintended consequences of what our regulations say and changes we might suggest,” someone said. Another said, “$9,300 is onerous for a small business and the history of the legislative paper shuffle is a trick. Do you <Udd> know of anyone at the state house who would support small businesses and would support the considerations of these permits?”

Udd replied that $9,300 was the cost of an individual permit and that every year there are proposals to streamline regulations, including those related to water quality. He said the fees have been in place since 2007 and there has been no discussion to reduce them. There is a state statute that agencies have to recoup their fees and Udd said the permit fees only pay for about 10% of the program. “User pays” is one of the considerations. He said, “I’m not sure that we have fees based on risks, we are mainly trying to pay for the costs of staffing.” Udd said that general permits, which have broader applications, are cheaper and faster but there needs to be a certain number of people involved in the general permit to make it cost-effective, which might not be appropriate for aquaculture at this time.

Another participant asked Udd where the trigger points come from that the EPA or the PCA use. He said they come from the EPA and are the same throughout the U.S.

Pereira said that the DNR had to increase aquaculture license fees to comply with the new regulations and to ensure game and fish funds are not used for aquaculture endeavors. He said the DNR spends a lot of money to permit and inspect ponds, and the people who have the ponds pay for it.

Engle asked Pereira about the business of regulations relating to water tables and groundwater. She said some western states give credit to fish farmers for injecting water back into the ground. Pereira said that an injection well would be the purview of the PCA but would likely involve an agreement between the DNR and PCA. Engle said, “I always wondered why Minnesota didn’t have an aquaculture industry. It is obviously the clean water fees.”

Summary of Small Group Discussions about Aquaculture Policy and Regulations

Participants divided among four groups to discuss solutions to regulatory and policy challenges. The top five priority actions emerging from the conversations were:

1. Build a Minnesota Aquaculture Association that can work on policies and foster success in the industry
2. Create a Minnesota Aquaculture Plan that outlines a path forward
3. Hire a State Aquaculture Coordinator to improve agency and fish farm interactions and efficiencies
4. Create funding streams and fee structures that support new food-fish farms and Minnesota aquaculture in general
5. Improve the social license for aquaculture in Minnesota

Minnesota Aquaculture Association: A rallying call went out to form a Minnesota Aquaculture Association. Participants noted that Wisconsin has an active organization, and Minnesota needs one. The association would be a point where industry, agencies, academia and others could discuss topics and share information germane to producing and selling food-fish in Minnesota. It would also provide lobbying capacity and could host an annual conference or workshop for people engaged in improving the business, similar to the one documented here. Some said an association should be led by industry, others said any stakeholders could lead the organization.

There are only 34 licensed food-fish producers in Minnesota and many are relatively new. "An association with even four people is still a start," said a participant. Participants mentioned models like the Minnesota Farmers Union, and lake associations and the "association of lake associations" (aka Minnesota Coalition of Lake Associations), particularly in light of including baitfish and sportfish growers in the Association.

Minnesota DNR's Aquatic Farm License Categories

Indigenous (Native) Species/Strains
Ponds or facilities may contain only fish that originated from Minnesota or a contiguous state, and may only contain fish species present in the surrounding watershed. Exceptions are possible ... For example, the DNR would usually approve licensing for Rainbow Trout ... Walleye must originate from Minnesota. If Walleye are to be reared ... north of MN Highway 210, they must originate north of Highway 210.

Nonindigenous Species/Strains
Ponds must be outside of a 25-year floodplain. If a nonindigenous species is considered high risk, a closed system may be required … Walleye from north of MN Highway 210 … may be used for waters south of Highway 210 and non-Minnesota sources.

Exotic Species/Strains (Aquatic Life from Outside of the United States)
Generally, closed systems will be required for private aquatic life not indigenous to the continental United States.

These categories and regulations help determine the types of aquaculture facilities that can be used and what the Minnesota aquaculture industry can become.

Some participants said that there is enough common ground so that a Minnesota Aquaculture Association could include food-fish growers as well as sportfish, baitfish and ornamental fish growers. Someone mentioned that the Michigan Farm Bureau is the largest advocate for aquaculture in Michigan saying, "After all, aquaculture is agriculture. Maybe you could start with the Farm Bureau in Minnesota." Funding for a Minnesota Aquaculture Association could come from association fees but many said that the government is going to have to help kick-start the organization. Someone mentioned that associations tend to have great relationships with government and that maybe it would be helpful to form an interagency council of stakeholders to manage regulations. Participants agreed that if fish farming is shown to be profitable then more people might enter the business making an association valuable. A loose association of fish farmers once formed in Minnesota, but it dissolved as did several similar partnerships. Currently, a White Sucker producers' association meets once a year.

Minnesota Aquaculture Plan: Many participants said that Minnesota needs an Aquaculture Plan that would likely first necessitate forming a Minnesota Aquaculture Association and developing a process. The Strategic Plan for Michigan Aquaculture might be used as a model. Participants said the plan could include a flow chart outlining steps for building new aquaculture businesses and other information to onboard people entering the industry. Someone suggested that new growers need information from successful existing growers and referenced the Michigan plan as an example. Participants also said the plan should address commercial fisheries and the baitfish industry so that conflict could be minimized. DNR staff noted that a document titled Aquaculture Best Management Practices for Minnesota (2011) exists but that it mainly addresses the bait fish industry.

Hire a State Aquaculture Coordinator: Participants said that a state aquaculture coordinator should be hired to facilitate communication. "Communication is the most essential thing," one participant commented. Currently, Minnesota doesn't have a food-fish representative in agriculture; maybe this is because there is really not much of an industry, yet, responded some. People suggested that the coordinator could provide open-source data and aggregate data, best management practices, permits, studies and rapid-response technical papers. Someone commented that "They keep treating aquaculture like agriculture but it's not. It's high-tech." Some said the coordinator could promote technology and facilitate interagency cooperation and agreement. Even better, some said, would be if this coordinator could consolidate agency responsibilities and license applications for food-fish aquaculture and possibly serve as a designated office to coordinate permitting. Ideas about automating application processes and streamlining reporting were shared, in part as a way to relieve staffing bottlenecks within agencies. Many commented the coordinator should be a state employee housed in one of the following agencies: Minnesota Department of Agriculture (MDA), Minnesota Department of Employment and Economic Development (DEED), Minnesota Department of Natural Resources (DNR). Participants suggested the coordinator would also work closely with University of Minnesota Extension, the University of Minnesota Sea Grant Program and the Minnesota Pollution Control Agency. The coordinator could possibly help to modify laws and policies that are outdated or redundant and offer farmer support to navigate the regulations.

Create funding streams and fee structures that support new food-fish farms and Minnesota aquaculture in general: People said it would be wise to seek grant funding from government and elsewhere to support food-fish aquaculture in Minnesota. Although unfunded at this time, language for a potential funding mechanism for small aquaculture businesses is in the state statute (MINNESOTA STATUTES 1991 SUPPLEMENT, Department of Agriculture; 17.49 AQUACULTURE PROGRAM AND PROMOTION). There were also discussions about ways to relieve the $9,300 NPDES permit fee through tax rates, tax credits, scaled fees, reduced fees or eliminating fees for new fish farms. Another idea was to base fees on pollutants. Someone suggested that the government should consider subsidizing "sustainability" instead of subsidizing agricultural pursuits that are more damaging to the environment or crops that aren't harvested. Funding for automation and funding to accelerate permit approval processes were also discussed.

Improve the social license for aquaculture in Minnesota: Participants said that aquaculture operations and products in Minnesota need to be better positioned as environmentally friendly, a good source of protein, sustainable, energy-efficient, etc. They said the identity of aquaculture and aquaponics is its basic selling point, especially to millennials who would likely support environmentally sustainable and Minnesota-grown labeling. Discussions acknowledged that attitude and behavior don't always match. Someone noted that supermarkets get excited about certification labels but certification might require a third-party audit.

Participants suggested the industry needs transparency, and an education and outreach campaign to schools and at retail meat counters. Species testing and DNA testing might help ensure that labeling is accurate which should bolster consumer confidence. Someone suggested the industry needs to screen for aquatic invasive species, too. It is clear that the industry can't be caught green-washing (i.e., claiming to be more environmentally responsible than is true). Some people noted that stricter regulations on imports might be wise given that only a tiny fraction of imported seafood is inspected and an even tinier fraction tested. Since the U.S. aquaculture industry doesn't benefit from anything like the National Pork Producers Council or the National Cattleman's Beef Association, some suggested that maybe partnering with outdoor recreationalists would improve farmed fish's social acceptance. One line of research was funded by a salmon association. The person who offered this said, "In promoting positive forms of aquaculture, you'll find some interesting bed fellows. You have to ask, 'Who would love us in this state because we're helping maintain the state resources?'"

With specific respect to Walleye and Saugeye, some said if you could legally market Saugeye as Walleye it would make a significant difference to the Minnesota aquaculture industry. Someone suggested Saugeye might be more marketable if it bore a label sporting a Walleye picture with "hybrid" written beneath it. Another participant said, "You can't affect policy without a united voice. If you don't have a voice you can't get the laws passed."

Another participant offered, "Pick Walleye so you can build support and put research effort behind it. This may win the approval of legislators." It might be possible, this person said, to flood the local market with farm-raised walleye, then proceed to sell the product nationwide. "The current market is met by Canadian sources and by the Red Lake Nation," he said. "We have to create a market beyond that while not cutting in on the profits of Native Americans who have been selling Walleye for years," He suggested existing tribal processing facilities might be willing to process the farmed Walleye. “The West Coast farms trout. The East and West coasts do shellfish. The South does catfish. We should do Walleye.” People agreed that if you are selling something the public likes and it solves a problem, it’s hard for legislators to say “no.”

Additional discussions brought focus on the importance of aquatic invasive species regulations and other biosecurity policies. These regulations affect interstate commerce but are viewed as necessary. There were comments about the potential for interstate standards when moving fish across state lines and someone mentioned that though Minnesota uses the health certification standards put forth in the Fish Health Blue Book (World Organisation for Animal Health 2017); regulations become more complicated in other states.

Some participants affirmed a desire for full-cost accounting, agreeing that aquaculture and agriculture should be sustainable and regulations should help bring price in line with costs. A participant said, “People have imposed social costs that are not reflected in price.”

An interesting discussion ensued about which Minnesota state agency should take the lead in aquaculture. “Why is aquaculture not part of the Department of Agriculture?” asked a participant. The answer stems from a 1980s history where most of the state’s aquaculture was being done by the DNR to stock sportfish. Someone asked if there were any benefits for aquaculture pursuits to be administered through the MDA. “Would fish be considered livestock? Would they be considered an agricultural product and a product of interstate commerce?” Some talked about how effluent is treated in RAS systems and that there is more precision during land applications and that fish waste should be agricultural waste, not industrial waste. Some said regulation under MDA is important because a state agency who runs a hatchery (DNR) should not have authority over commercial businesses. “We need to switch this part of regulation to MDA because aquaculture is agriculture,” said a participant. Commercial aquaculture is included in the Michigan Development Act so the industry is only regulated by the Michigan Department of Agriculture and Rural Development.

Discussions also suggested Minnesota aquaculture would improve if there were formal ways to:

- Promote technologies that are compatible with the recreational industry
- Regulate imported seafood better
- Stop or penalize common practices that damage the environment
- Find a focus for Minnesota aquaculture
- Classify fish waste as agricultural waste, not industrial waste
- Streamline outdated regulations
- Bring fish processors, chefs, retailers and wholesaler into the aquaculture discussion
- Process fish efficiently (lacking access to fish processing plants, someone suggested the Minnesota industry could form a processing co-op)
- Build a “Community Supported Aquaculture” program for aquaponics and aquaculture businesses like has been done elsewhere in the U.S.
- Obtain organic certification for farmed fish

Conclusions

Food-fish aquaculture has an unrealized economic and social potential in Minnesota. The primary barriers to the industry's success have been start-up costs, broodstock availability of preferred species available for food-fish aquaculture, lack of information about the market for aquaculture, economic incentives, and consumers understanding of aquaculture and their willingness to purchase more expensive locally produced aquaculture products over cheaper imports.

If Minnesota opts to encourage aquaculture and aquaponics in the state, legislators might consider viewing aquaculture waste as agricultural waste rather than industrial waste to simplify regulatory efforts. The state might also assemble a state aquaculture board made up of staff from regulatory agencies and representatives of industry. The board would communicate within and among government agencies and constituents and make recommendations on state aquaculture matters. The state might look toward the aquaculture plans and activities of Wisconsin and Michigan as models of how Minnesota might proceed to encourage aquaculture and aquaponics in the state.

To make aquaculture successful in Minnesota, the state and federal governments need to invest money in technology, research and business development. State and federal investments have allowed researchers to make great strides in raising Walleye/Saugeye in integrated aquaculture systems at the University of Wisconsin-Stevens Point Aquaponics Innovation Center. Still, the lack of broodstock, nutritional data on aquafeed and other fundamental information will continue to hamper the physical and financial success of Walleye aquaculture business ventures. Similarly, though research on producing Atlantic Salmon and Rainbow Trout in aquaculture facilities is more advanced, producing these species in Minnesota could be enhanced through business incubators, opportunities for technology transfer and advances in aquafeeds.

Through the workshop it became clear that market studies need to be conducted before the state, industries or individuals start, or assist with successful food-fish aquaculture businesses. The market studies need to investigate the economics of growing, processing and marketing the products and, equally, consumer attitudes, behaviors and demand for food-fish grown through local aquaculture and aquaponics.

The idea of developing an aquaculture association resonated with workshop participants. Though it was unclear how this association should coalesce, it became an important point of conversation toward the end of the workshop.

The answer to the workshop's driving question, "Can an environmentally responsible and sustainable food-fish aquaculture industry be established in Minnesota?" is "Yes," but it will take a balanced, thoughtful and collaborative approach among the many stakeholders. The follow-up question, "What might be the best ways to proceed?" can be answered with:

- A market analysis
- An aquaculture plan
- Transparency
- State support

Addressing the three major themes of the workshop succinctly, workshop participants prioritized RAS as the most promising production strategy and Atlantic Salmon, Rainbow Trout, Arctic Char, Walleye, Saugeye and Yellow Perch as the most promising species for food-fish aquaculture in Minnesota. Participants identified many research needs and information gaps with priority given to two broad categories: 1) marketing and understanding consumer perceptions and demand, 2) business models, best practices, and technical efficiencies. Lastly, participants identified and discussed policy and regulatory issues and prioritized the following actions:

1. Build a Minnesota aquaculture association that can work on policies and foster success in the industry
2. Create a Minnesota aquaculture plan that outlines a path forward
3. Hire a state aquaculture coordinator who can improve agency and fish farm interactions and efficiencies
4. Create funding streams and fee structures that support new food-fish farms and Minnesota aquaculture in general
5. Improve the social license for aquaculture in Minnesota

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Resources

International
United Nations Food and Agriculture Organization (FAO) Database:
www.fao.org/fishery/statistics/software/fishstat/en

World Organisation for Animal Health, Manual of Diagnostic Tests for Aquatic Animals:
www.oie.int/index.php?id=2439&L=0&htmfile=contributeurs.htm

World Aquaculture Society: www.was.org

Global Aquaculture Alliance: www.aquaculturealliance.org

National
USDA: www.usda.gov/topics/farming/aquaculture

- USDA Agricultural Research Service: www.ars.usda.gov
- USDA Economic Research Service: www.ers.usda.gov
- USDA National Institute of Food and Agriculture: https://nifa.usda.gov/program/aquaculture
- USDA Animal and Plant Health Inspection Service: www.aphis.usda.gov/aphis/ourfocus/wildlifedamage/operational-activities/SA_Aquaculture/CT_Aquaculture_index (also Commercial Aquaculture Health Program Standards; www.aphis.usda.gov/animal_health/animal_dis_spec/aquaculture/downloads/cahps_concept_paper.pdf).
- USDA National Center for Cool and Cold Water Aquaculture: www.ars.usda.gov/northeast-area/leetown-wv/cool-and-cold-water-aquaculture-research

NOAA

- NOAA Sea Grant: http://seagrant.noaa.gov/Our-Work/Aquaculture
- NOAA Fisheries: www.nmfs.noaa.gov/aquaculture/aquaculture_in_us.html
- NOAA National Ocean Service: https://oceanservice.noaa.gov/facts/aquaculture.html
- Interagency Working Group on Aquaculture (NOAA chairs the Aquaculture Regulatory Task Force under the Interagency Working Group on Aquaculture) www.nmfs.noaa.gov/aquaculture/policy/13_policy_and_reg_homepage.html

EPA

- National Pollutant Discharge Elimination System Aquaculture Permitting: www.epa.gov/npdes/npdes-aquaculture-permitting#permit

Congress

- National Aquaculture Development Act (16 USC 2801-2810; 94 Stat. 1198) -- P.L 96-362, approved September 26, 1980. http://extwprlegs1.fao.org/docs/pdf/usa2654.pdf
- National Aquaculture Development Plan, 1984: www.gpo.gov/fdsys/pkg/CZIC-sh34-f4-1984/pdf/CZIC-sh34-f4-1984.pdf

Regional

Wisconsin Aquaculture Association, Inc.: www.wisconsinaquaculture.com

University of Wisconsin-Stevens Point

- Northern Aquaculture Demonstration Facility (Red Cliff, Wisc.): www.uwsp.edu/cols-ap/nadf/Pages/UWSP%20Northern%20Aquaculture%20Demonstration%20Facility%20Home%20Page.aspx
- Aquaponics Innovation Center (Montello, Wisc.): www.uwsp.edu/cols-ap/aquaponics/pages/aquaponic-innovation-center-.aspx

Michigan Aquaculture Association: http://michiganaquaculture.org

A Strategic Plan for a Thriving and Sustainable Aquaculture Industry in Michigan: www.miseagrant.umich.edu/wp-content/blogs.dir/1/files/2012/09/2014-MAA-Strategic-Plan_Final_141215.pdf

University of Idaho Hagerman Fish Culture Experiment Station: www.uidaho.edu/research/entities/aquaculture

University of Maine Aquaculture Research Institute: https://umaine.edu/aquaculture

Minnesota

Minnesota Pollution Control Agency

- NPDES and SDS Permits: www.pca.state.mn.us/quick-links/npdes-and-sds-permits
- Land Application of Industrial Byproducts: www.pca.state.mn.us/waste/land-application-industrial-products

Minnesota Department of Agriculture – Food Safety: www.mda.state.mn.us/food/safety.aspx

Minnesota Department of Natural Resources

- Spring Inventory: www.dnr.state.mn.us/waters/groundwater_section/springs/msi.html
- Aquatic Farm License: www.dnr.state.mn.us/fishing/commercial/af.html
- Water Use Permits: www.dnr.state.mn.us/waters/watermgmt_section/appropriations/permits.html
- Aquaculture Best Management Practices for Minnesota 3.21.2011: http://files.dnr.state.mn.us/recreation/fishing/commercial/aqua_bmp.pdf

The University of Minnesota

- The University of Minnesota Sea Grant College Program: www.seagrant.umn.edu/aquaculture
- University of Minnesota Extension, local food economies: localfoods.umn.edu

Homegrown Minneapolis: www.ci.minneapolis.mn.us/sustainability/homegrown/index.htm

Aquaculture and Aquaponics Facilities

- Driftless Fish Company (Rushford, Minn.): www.driftlessfish.com
- Eco Shrimp Garden (Newburgh, New York): www.ecoshrimpgarden.com
- RDM Shrimp (Fowler, Indiana): www.rdmshrimp.com
- Superior Fresh (Hixton, Wisc.): www.superiorfresh.com
- trū Shrimp (Balaton, Minn.): www.facebook.com/truShrimp
- Urban Organics (St. Paul, Minn.): http://urbanorganics.com/

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Mor, S.K., N.B.D. Phelps, T.F.F. Ng, K. Subramaniam, A. Primus, A.G. Armien, R. McCann, C. Puzach and T. Waltzek, 2017. Genomic characterization of a novel calicivirus, FHMCV-2012, from baitfish in the USA. *Archives of Virology* doi:10.1007/s00705-017-3519-6.

Phelps, N.B.D., S.K. Mor, A.G. Armien, W. Batts, A.E. Goodwin, L. Hopper, R. McCann, T.F.F. Ng, C. Puzach, T.B. Waltzek, E. Delwart, J. Winton and S. Goyal, 2014. Characterization of the novel fathead minnow picornavirus. PLOS One 9:e87593.

APPENDIX

List of Participants

(some people were unable to attend or unable to attend for the full workshop)

Sea Grant

Emma Wiermaa – Wisc. Sea Grant – University of Wisconsin-Stevens Point – NADF Aquaculture Specialist - ewiermaa@uwsp.edu

Ron Kinnunen – Mich. Sea Grant – Michigan State University – Fisheries Specialist – kinnune1@anr.msu.edu

Dr. John Downing – Minn. Sea Grant – University of Minnesota Duluth – Director

Don Schreiner – Minn. Sea Grant – University of Minnesota University of Minnesota University of Minnesota Duluth – Fisheries Specialist

Minn. Sea Grant – University of Minnesota – support staff – ~10

National USDA Aquaculture

Dr. Caird Rexroad – National Program Leader for Aquaculture, ARS, USDA – caird.rexroadiii@ars.usda.gov

North Central Regional Aquaculture Committee

Allen Pattillo – Iowa State University – Extension Specialist – pattillo@iastate.edu

Dr. Chris Weeks – Michigan State University – Aquaculture Specialist – weekschr@msu.edu

Minnesota State Agencies

MN DNR

Dr. Don Pereira – Fisheries Chief, MNDNR – don.pereira@state.mn.us

Sean Sisler – Aquaculture Specialist, MNDNR – sean.sisler@state.mn.us

Henry Drewes – Northwest Regional Fisheries Supervisor, MNDNR – henry.drewes@state.mn.us

MN PCA

Jeff Udd – Water Quality Permits Unit Supervisor, MPCA – jeff.udd@state.mn.us

Jeff Stollenwerk – Manager, Water Section, Industrial Division, MPCA – jeff.stollenwerk@state.mn.us

MN DOA

Andrea Vaubel – Assistant Commissioner, MDOA – Andrea.Vaubel@state.mn.us

Meg Moynihan – Principal Administrator, Organic/Diversification Program - Meg.Moynihan@state.mn.us

Valerie Gamble – Food Inspection Supervisor – Valerie.Gamble@state.mn.us

Academia

Dr. Nick Phelps – University of Minnesota – TC – Director, Minnesota Aquatic Invasive Species Research Center – Phelp083@umn.edu

Dr. Alex Primus- University of Minnesota – TC – Assistant Professor, Department of Veterinary Population Medicine – primu012@umn.edu
Dr. Richard Axler – Senior Research Associate, Center for Water and the Environment, Natural Resources Research Institute – raxler@d.umn.edu
Dr. Rolf Weberg – Director, Natural Resources Research Institute – rtweberg@d.umn.edu
Dr. Carole Engle – Manager Engle-Stone Aquatic$, Executive Editor for the Journal of the World Aquaculture Society – cengle8523@gmail.com
Dr. Steven Summerfelt – Director of Aquaculture Systems Research, Freshwater Institute – ssummerfelt@conservationfund.org
Dr. Chris Hartleb – University of Wisconsin-Stevens Point – Director NADF – chartleb@uwsp.edu
Greg Fischer – University of Wisconsin-Stevens Point – Manager NADF – Greg.Fischer@uwsp.edu
Dr. Robert (Bob) Summerfelt – Professor Emeritus, Iowa State University – rsummerf@gmail.com

Private Aquaculture/Industry Experts

Clarence Bischoff – Blue Water Aquaculture – clarence.bischoff@gmail.com
Brandon Gottsacker – CEO, Superior Fresh – brandon@superiorfresh.com
Michael Ziebell – CEO, trū Shrimp – Michael.Ziebell@trushrimpcompany.com
Dr. Jon Holt - Sr. Director of Technical Services, The trū Shrimp Company – Jon.Holt@ralconutrition.com
Dr. Jessica Fox – DVM, Technology Manager of Ralco Nutrition, Inc., The trū Shrimp Company – Jessica.Fox@ralcoagriculture.com
Chad Hebert – onechadmh@yahoo.com
Sam Menzies – Operations Manager, SPARK-Y – sam@spark-y.org
Zach Lind – Driftless Fish Company – zlind1434@gmail.com
Mike Higgins – CEO, The Fish Guys – mhiggins@thefishguysinc.com
Dr. Myron Kebus – DVM, WI Dept. of Ag. – Myron.Kebus@wisconsin.gov

Others

Leonard Prescott – Chief Executive Officer Eagle Visions – leonardprescott@me.com
Don Shelby – Blue Water Aquaculture Board Member – dgshelby@gmail.com
Dr. Ilze Berzins – DVM – ilze.k.berzins@gmail.com
Carol Russell – Russell Herder Consulting – carolr@russellherder.com
Harold Stanislawski – Project Development Director, AURI – hstanislawski@auri.org
Debbie Goettel – Hennepin County Commissioner, Mayor, City of Richfield –dgoettel@comcast.net

Commissioner Hardy – State Commerce or Representative
Governor Dayton's Office Representative

Summary of Evaluations by Participants

At the conclusion of the workshop, participants were asked to complete an evaluation. The response to some questions could not be easily summarized (open-ended questions) and some questions were not relevant to this synthesis. A summary of the responses to selected questions are provided below. Participants could choose multiple responses to the last two questions.

*Overall, how useful was this workshop for you?

Not Very Useful – 1 2 3 4 5 – Very Useful

Mean response was 4.3

*How well did organizing the workshop around the three theme areas address your overall understanding of aquaculture in Minnesota?

Very poor – 1 2 3 4 5 – Very well

Mean response was 4.5

*How well did the workshop answer the major question: "Can an environmentally responsible and sustainable food-fish aquaculture industry be established in Minnesota, and if so, what are the best ways to proceed?"

Very poor – 1 2 3 4 5 – Very well

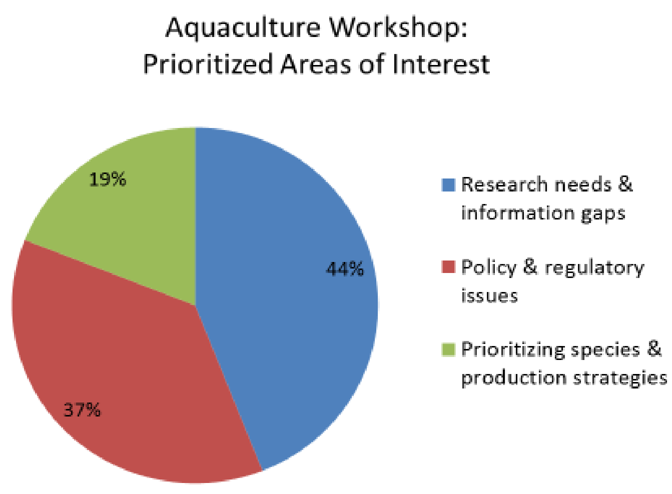
Mean Response was 3.6 - A number of participants stated that it was too early in the process to accurately estimate the response to this question.

*Could you please rank the theme areas that were most important to you from highest interest 1, to lower interest 3.

__Theme Area 1 - Prioritizing production strategies and species for food-fish aquaculture/aquaponics in Minnesota.

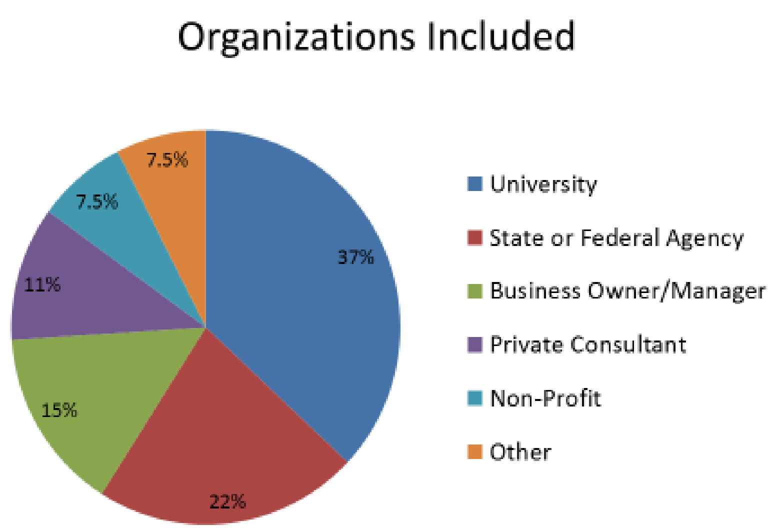
__ Theme Area 2 - Research needs and information gaps to address for successful food-fish aquaculture/aquaponics in Minnesota, and other Midwest states.

__ Theme Area 3 - Identifying policy and regulatory issues to promote food security and an environmentally responsible aquaculture/aquaponics program in Minnesota.



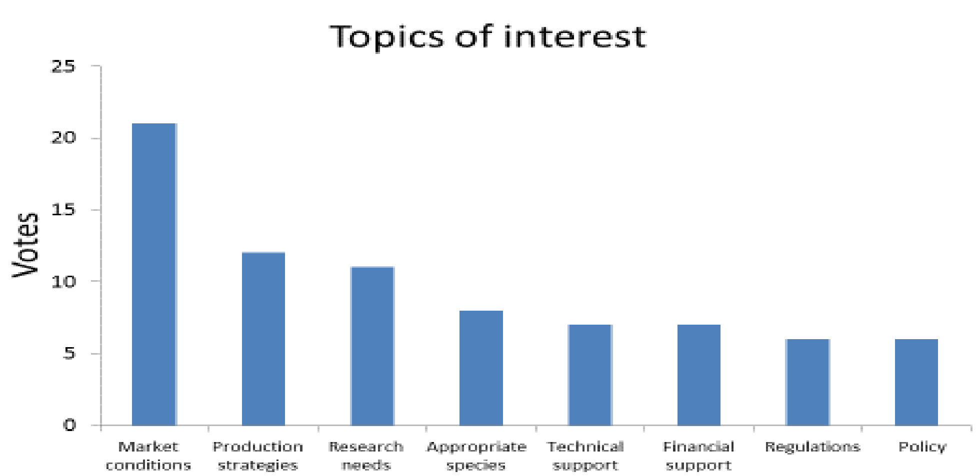
Which best described your organization?

___State or Federal agency
___Non-Profit
___Business Owner/Manager
___University
___Private Consultant
___Other



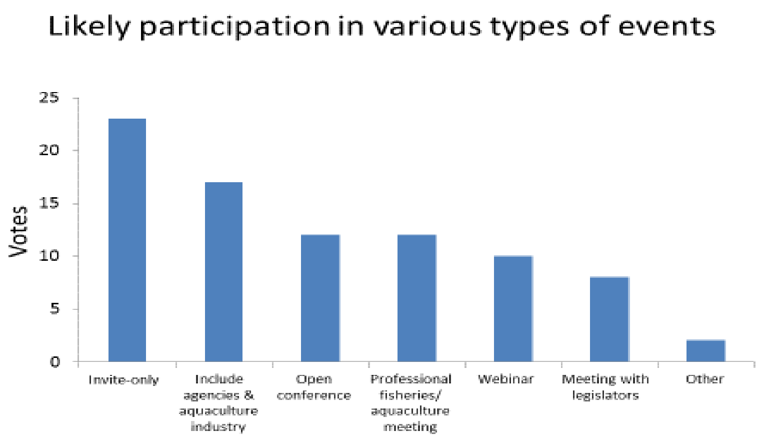
What topic areas in aquaculture/aquaponics would you like to learn more about based on what you learned from the workshop?

___Production strategies
___Appropriate species
___Research needs
___Market conditions
___Regulations
___Policy
___Technical support
___Financial support



In the future, what type of event do you think may be the best forum to transfer information on aquaculture/aquaponics that would foster responsible aquaculture development in Minnesota?

___Another invite-only workshop
___A conference open to all
___Webinars
___Meetings with legislators
___Meetings between agencies and the aquaculture industry
___Professional fisheries/aquaculture meeting
___Other:____



Minnesota Sea Grant
Aquaculture Workshop

University of Minnesota
Continuing Education and Conference Center
April 26-27, 2017

Agenda

Wednesday, April 26

Setting the stage

8:30 **Registration, coffee and refreshments**

9:00 Welcome and game plan
Don Schreiner, Fisheries Specialist, Minnesota Sea Grant
Cynthia Hagley, Environmental Quality Extension Educator, Minnesota Sea Grant

9:15 Participant introductions

9:45 ***Minnesota Sea Grant's role in aquaculture***
John Downing, Director, Minnesota Sea Grant

10:15 **Coffee break**

10:30 ***The role of USDA in aquaculture: An overview***
Caird Rexroad III, National Program Leader for Aquaculture, USDA Agriculture Research Service

11:00 ***National challenges in aquaculture***
Carole Engle, Manager, Engle-Stone Aquatic$

11:30 **Lunch**

Theme 1: Prioritizing production strategies and species for food fish aquaculture and aquaponics in Minnesota

12:30 Keynote: ***Cold water systems and species***
Steven Summerfelt, Director, Aquaculture Systems Research, Freshwater Institute, The Conservation Fund

1:05 Keynote: ***Cool water systems and species***
Chris Hartleb, Director, Northern Aquaculture Demonstration Facility and Aquaponics Innovation Center, University of Wisconsin-Stevens Point

1:40 Panel:
Open-system aquaculture
Chris Weeks, North Central Regional Aquaculture Center, Michigan State University Extension
Closed-system aquaculture
Greg Fischer, Northern Aquaculture Demonstration Facility, University of Wisconsin-Stevens Point
Aquaponics
D. Allen Pattillo, Fisheries and Aquaculture Specialist, Iowa State University; North Central Regional Aquaculture Center
Intensive land-based shrimp production
Michael Ziebell, CEO trū-Shrimp

2:40 **Break**

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Sea Grant

Agenda

Wednesday, April 26 continued

3:00	Small-group discussion
4:00	Small-group reports
4:30	Large-group discussion and preview of day two
5:00	Adjourn
5:30 - 8:00	**Social at Radisson Hotel Roseville**
	Salon A/B, 2540 North Cleveland Avenue, Roseville, MN 55113

Thursday, April 27

7:30 **Coffee and refreshments**

8:00 Reorientation and review of day one

Theme 2: Research needs and information gaps to address for successful food fish aquaculture/aquaponics in Minnesota, and other Midwest states

8:05 Keynote: ***Cool-water systems and species***

Chris Hartleb, Director, Northern Aquaculture Demonstration Facility and Aquaponics Innovation Center, University of Wisconsin-Stevens Point

8:30 Keynote: ***Cold-water systems and species***

Steven Summerfelt, Director of Aquaculture Systems Research,The Conservation Fund Freshwater Institute

9:00 Panel: *Genetics and domestic strains*

Caird Rexroad III, National Program Leader for Aquaculture, USDA Agriculture Research Service

Feed and nutrition

Robert Summerfelt, Professor Emeritus, Iowa State University

Fish health

Nick Phelps, Director, University of Minnesota, Aquatic Invasive Species Research Center

Social, economic and marketing considerations for aquaculture

Carole Engle, Manager, Engle-Stone Aquatic$

10:00 **Break**

10:15 Small-group discussion

11:15 Small-group reports

11:30 **Lunch**

Minnesota Sea Grant
Aquaculture Workshop

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Agenda

Thursday, April 27 continued

Theme 3: Identifying policy and regulatory issues to promote food security and an environmentally responsible aquaculture/aquaponics program in Minnesota

12:15 Keynote: ***Perspectives on aquaculture policy, regulatory and food-security issues***
Carole Engle, Manager, Engle-Stone Aquatic$

1:15 Panel: *Regulations and permitting to balance aquaculture and protection of wild fish stocks*
Don Pereira, Chief, Section of Fisheries, Minnesota Department of Natural Resources

Pollution prevention and standards for aquaculture effluent
Jeff Udd, Water Quality Permits Unit Supervisor, Minnesota Pollution Control Agency

Food security concerns for Minnesota aquaculture products
Valerie Gamble, Produce Safety Program Manager, Minnesota Department of Agriculture

Regulation and policy effects on a small aquaculture business in Minnesota
Chad Hebert, Owner and operator, Urban Farm Project

Aquaculture complex rehabilitation in southeast Minnesota: Regulation and policy
Zach Lind, Owner and operator, Driftless Fish Company

2:15 Break

2:30 Small-group discussions

3:30 Small-group reports

3:45 Synthesis and wrap up
Nick Phelps, Director, University of Minnesota, Aquatic Invasive Species, Research Center
John Downing, Director, Minnesota Sea Grant

4:30 Adjourn

Thank you for participating!

Support for this workshop comes from a competitive grant awarded to Minnesota Sea Grant from Oceanic and Atmospheric Research, National Oceanic and Atmospheric Administration, Department of Commerce. NOAA-OAR-SG-2016-2004772.

Minnesota Sea Grant is part of the National Oceanic and Atmospheric Administration's (NOAA) Sea Grant Program, which supports 33 similar programs in coastal states throughout the United States and Puerto Rico. It receives funding through the NOAA Office of Oceanic and Atmospheric Research and the University of Minnesota. The program partners with local, regional and national organizations and is an integral member of the Great Lakes Sea Grant Network.

Speakers

John A. Downing, Ph.D.
Director, University of Minnesota Sea Grant College Program; Research Scientist, University of Minnesota Duluth Large Lakes Observatory; Professor, Department of Biology, UMD

John's research and teaching dossiers concern many aspects of the aquatic sciences. His 150+ peer-reviewed books and journal articles cover diverse topics in limnology, marine science, environmental economics, and terrestrial ecology. He has founded and run several small businesses in the U.S. and Canada and has a long-standing record of success in securing research funding from federal, state, provincial, and local agencies. His family has conserved and managed a shore-habitat and forest area in northern Minnesota for 108 years.

Carole Engle, Ph.D.
Retired Chair/Director Aquaculture and Fisheries, University of Arkansas at Pine Bluff; Member/Manager Engle-Stone Aquatic$ LLC, Strasburg, VA

Carole has worked in aquaculture research, extension and teaching for more than 35 years, primarily through the lens of her expertise in economics and marketing. She has worked closely with aquaculture businesses around the world and values the contributions that science has made to the growth and development of successful aquaculture businesses. She is the editor of the Journal of the World Aquaculture Society.

Chris Hartleb, Ph.D.
Professor of Fisheries Biology and Director, Northern Aquaculture Demonstration Facility and Aquaponics Innovation Center, University of Wisconsin-Stevens Point

Chris has been a professor of fisheries biology, water resources, and sustainable and resilient food systems at the University of Wisconsin-Stevens Point for the past 21 years. He has a B.S. in biology from Rensselaer Polytechnic Institute, a M.S. in zoology from the University of New Hampshire and a Ph.D. in fish ecology from the University of Maine. He also coordinates the aquaculture minor and professional aquaponics certificate programs at UW-Stevens Point.

Caird Rexroad III, Ph.D.
National Program Leader, Cool and Cold Water Aquaculture Research, Agriculture Research Service, USDA

Caird has served in various roles since joining ARS in 1998 where his primary research focused on the use of molecular genetics in breeding programs seeking to improve production efficiencies of agriculture animals. He currently works in the Office of National Programs and oversees an aquaculture research portfolio that includes 10 laboratories across the nation. He has a B.S. in biology from Abilene Christian University and a Ph.D. in genetics from Texas A&M University.

Steven Summerfelt Ph.D.
Director, Aquaculture Systems Research, Freshwater Institute, The Conservation Fund

Steve is a professional engineer and holds a Ph.D. in civil engineering (environmental emphasis) and M.S. and B.S. degrees in chemical engineering. He is one of five recipients of the Aquacultural Engineering Society Award of Excellence. He is working on innovative technologies to increase farmed fish production in closed-containment systems that practically eliminate water pollution, minimize water use, improve freshness and safety and allow the farm to be located adjacent to the market.

Theme 1 Panel Members

D. Allen Pattillo, M.S.
Fisheries and Aquaculture Specialist, Iowa State University Extension; Outreach Extension Program Chair, North Central Regional Aquaculture Center

Allen has been the aquaculture extension program director at Iowa State University for the past six years, focusing on pond and aquatic plant management, aquaculture and mainly aquaponics. He has a B.S. in fisheries and aquaculture from the University of Georgia and a M.S. in aquaculture from Auburn University. He is currently on the board of the United States Aquaculture Society and has served as the president of the Iowa Chapter of the American Fisheries Society.

Gregory Fischer
Facility Operations Manager, Northern Aquaculture Demonstration Facility, University of Wisconsin-Stevens Point

Gregory is the facility manager at the University of Wisconsin-Stevens Point Aquaculture Demonstration Facility located near Bayfield, Wisconsin. Greg has worked with various university, state, tribal, private and federal agencies in designing, constructing and managing multi-species facilities for conservation and aquaculture purposes with a variety of cool and coldwater fish species. He has more than 25 years of experience with more than 20 different species of warm, cool and coldwater fish in various rearing systems such as recirculation, flow through and outdoor ponds.

Michael Ziebell, M.S.
Managing Director, CEO, trū-Shrimp

Michael earned his Bachelor of Arts from the University of Wisconsin-Parkside and his Master of Business Administration from the University of St. Thomas. Michael uses his extensive experience in the food industry with the Schwan Food Company to develop optimal solutions and hands-on implementation to produce safe and healthy shrimp for a growing world. Michael and his team are taking a highly strategic approach to provide a turnkey solution for future land-based shrimp production.

Chris Weeks, Ph.D.
Aquaculture Extension Specialist, North Central Regional Aquaculture Center, Michigan State University

Chris has been serving as an aquaculture specialist for the North Central Region since 2008. He obtained a B.S. degree in aerospace engineering from San Diego State, and M.S. and Ph.D. in fisheries and wildlife from Michigan State University. His experience includes strategic planning, business development, production system design and management, aquatic animal health, baitfish, regulations and aquatic nuisance species.

Theme 2 Panel Members

Nick Phelps, Ph.D.
Assistant Professor, Department of Fisheries, Wildlife and Conservation Biology; Director, Minnesota Aquatic Invasive Species Research Center, University of Minnesota

Nick has been at the University of Minnesota for 10 years, largely focused on the health and sustainability of wild and farmed fish populations. This has included efforts related to aquaculture research, outreach, diagnostic service and education. He earned a B.S. from Bemidji State University in aquatic biology, a M.S. from the University of Arkansas-Pine Bluff in aquaculture/fisheries and a Ph.D. in veterinary medicine from the University of Minnesota.

Robert Summerfelt, Ph.D.
Professor Emeritus, Iowa State University

Robert has diverse research interests in fish biology (telemetry, age and growth, physiology, diet, reproductive biology, parasites), aquaculture, aquatic toxicology, water quality and aquacultural effluents. Over the last 30 years, he has focused on the culture of walleye and has published numerous papers and book chapters on this topic. Robert is recognized as an expert on walleye production.

Theme 3 Panel Members

Valerie Gamble, M.S., R.S.
Produce Safety Program Manager, Minnesota Department of Agriculture

Previously Valerie worked for the Food and Feed Safety Division, Minnesota Department of Agriculture, in the food inspection program supervising and inspecting a variety of food businesses, including those that fell under seafood Hazard Analysis Critical Control Point (HACCP) and other state and federal regulations. She has a master's degree in geological sciences and worked for five years with organic and conventional farms and orchards in California, first directly with farms and then with the Agricultural Extension program at the University of California, Davis.

Chad Hebert
Owner and operator, Urban Farm Project, Minnesota

Chad has been operating the Urban Farm Project for almost 10 years. The Urban Farm Project is a small plot intensive farm focused around a recirculating aquaponics system. The main crop is yellow perch.

Zach Lind
Owner and operator, Driftless Fish Company, Spring Valley, Minnesota

Zach has been involved with farming in southeast Minnesota from a young age. After high school he went on to study mechanical engineering for a couple years, then was bitten by the aquaculture bug. He and his partners restored much of the old Minnesota Aquafarms facilities at five locations in southeast Minnesota. In spring 2017 they will harvest their first crop of rainbow trout for the food-fish market. Zach and his partners have additional plans in the works and are excited to be a part of this growing industry.

Don Pereira, Ph.D.
Fisheries Chief, Section of Fisheries, Minnesota Department of Natural Resources; Adjunct Professor of Fisheries, University of Minnesota

Don has a master's and a PhD. in fisheries. He has worked for the Minnesota Department of Natural resources as a fisheries research biologist, research leader, and more recently fisheries chief. Don is currently a commissioner with the Great Lakes Fishery Commission. He has published numerous journal articles and book chapters on a variety of fish management topics.

Jeff Udd, P.E.
Supervisor, Industrial Water Quality Permits Unit, Minnesota Pollution Control Agency

Jeff has worked at the Minnesota Pollution Control Agency for the past 15 years. He has been the supervisor of the Water Quality Permits Unit in the Industrial Division since 2009. Prior to working at the MPCA, Jeff worked for Cargill, Inc. in both Ohio and Nebraska, as well as Potlatch Corp in Cloquet, Minnesota. He has a B.S. in chemical engineering from the University of Minnesota Duluth.

Workshop Organizers

Don Schreiner, M.S.
Fisheries Specialist, Minnesota Sea Grant

Don is recently retired from the Minnesota Department of Natural Resources where he spent about 34 years managing wild fish stocks. During the last year he has been working with Minnesota Sea Grant on a limited basis providing outreach to Minnesota's citizens on a variety of fisheries topics that range from aquaculture to zebra mussels. Don has worked with Minnesota Sea Grant staff and an outside planning committee to organize this workshop on food-fish aquaculture in Minnesota. He hopes you find it interesting and valuable.

John A. Downing, Ph.D.
Director, University of Minnesota Sea Grant College Program; Research Scientist, University of Minnesota Duluth Large Lakes Observatory; Professor, Department of Biology, University of Minnesota Duluth

Facilitators:

John Bilotta
Minnesota Sea Grant
Cynthia Hagley
Minnesota Sea Grant
Ann Lewandoski
Water Resources Center
Jesse Schomberg
Minnesota Sea Grant

Recorders:

Jessica Coburn
Student, University of Minnesota
Nicholas Jacobs
Student, University of Minnesota
Sharon Moen
Minnesota Sea Grant
Marie Thoms
Minnesota Sea Grant