Action Plan
National Program 106 - Aquaculture
(2015-2019)

Goal: Aquaculture is the production of aquatic animals under controlled conditions for all or part of their lifecycles. Interest in aquaculture production is on the rise because of limits to harvest of wild caught seafood and increases in demand for seafood and other products of aquaculture. The ability for U.S. aquaculture producers to meet that demand requires development of technologies to reduce the cost of production while maintaining and improving product quality. Producers, processors and breeders are in need of systems that maximize aquatic animal production, reduce environmental impacts, increase market competitiveness, sustain producers, and earn consumer confidence. Research in the disciplines of genetics, nutrition, health, and physiology will support the biological improvement of animals, while ecology, water quality, engineering and food science will support the improvement of systems and products to ensure sustainability.

The vision for ARS aquaculture research and technology transfer is *to support a thriving domestic industry based on improved genetic stocks and scientific information on biotechnologies and management practices to ensure a high quality, safe supply of healthful seafood and aquatic products.*

The research in this Action Plan is intended to develop and ensure an abundant, safe, and affordable supply of seafood products for the 300 million U.S. consumers produced in a healthy, competitive, and sustainable aquaculture sector, a sector supported by more than 4,300 aquaculture farmers producing in excess of $1 billion dollars worth of goods annually.

<u>Aquaculture Program Components</u>

- Selective Breeding, Directed Reproduction, and Development of Genomic Tools
- Nutrient Requirements and Alternative Sources of Protein and Lipid
- Health of Aquatic Animals
- Sustainable Production Systems
- Product Quality and New Products

COMPONENT 1: Selective Breeding, Directed Reproduction, and Development of Genomic Tools

Genetic improvement of fish and shellfish populations is a key strategy for increasing efficient production in a sustainable manner. The rate of improvement is hindered by a lack of well defined phenotypes, inadequate understanding of component traits and interrelationships among traits, incomplete understanding of the molecular basis of phenotypes and trait interactions, lack of methods to model and evaluate candidate traits for selection, and inefficient strategies to incorporate genomic data into breeding programs. Another hindrance to progress is the inability to move novel forms (alleles) of genes between populations. To facilitate genetic improvement, new knowledge of the genome and its interactions with environmental factors must be acquired in a comprehensive framework pertaining to animal growth, adaptation, health and well-being, reproductive efficiency, nutrient utilization, conversion of feed to animal products, and product quality.

These efforts will be significantly enhanced with the use of appropriate genomic tools. Public involvement in the construction of these resources is critical to ensure development of breeding and management tools for aquaculture producers and to provide researchers access to these tools to spur further science and technology development.

Problem Statement 1A: Genomic Tools and Genotype to Phenotype.

Significant public resources have been devoted to developing genomic and bioinformatic infrastructure for catfish, rainbow trout, and Atlantic salmon over the past 10 years, with oysters, yellow perch, and striped bass generally lagging behind. These efforts have culminated in significant improvement in the genomic information for these species available in the public domain, yet considerable work remains to enable modeling of how genotype controls phenotype. Through functional genomic and proteomic approaches, scientists will be able to improve characterization of genes and pathways controlling key phenotypes that will enable more targeted and rapid improvement of performance. ARS is focused on filling in the significant gaps that exist in the bioinformatic infrastructure and providing the scientific community with the genomic and proteomic data needed to support further research. This research will focus on the application of genomic tools to understanding physiology and informing and enhancing genetic improvement.

Research Needs:

Research is needed to develop physical genetic maps of catfish, rainbow trout, and Atlantic salmon and genetic linkage maps for other aquatic species. In particular, the identification of genomic variation associated with specific traits and associated genetic markers should be a major focus of research over the next 5 years. Scientists need develop a full and comprehensive array of full-length cDNAs for understanding and annotating genes in functionally important tissues under differing environmental conditions and developmental stages. This research will be useful for ascertaining alternative splicing of genes and fully exploring gene function and regulation.

In addition, there is need for further development of gene expression/modification tools to a commercially available level, such as small RNA (e.g. RNA interference, gene silencing).

Anticipated Products:

Trout
- Complete reference genome assembly
- Improved physical and genetic linkage maps
- Functional genomics tools

Catfish
- Complete reference genome assembly
- Improved physical and genetic linkage maps
- Functional genomics tools

Hybrid-Striped Bass
- Begin genome assembly
- Improved physical and genetic linkage maps
- Functional genomics tools

Yellow-Perch
- Functional genomics tools

Atlantic Salmon
- Functional genomics tools

Oysters
- Contribute to genome assembly for Atlantic oysters
- Improved physical and genetic linkage maps of Atlantic oysters
- Functional genomics tools

Potential Benefits:
The development of genome-enabling tools and reagents will facilitate the continued genetic improvement of aquatic animal production systems. These tools will be used to identify the functional role and interactions of gene products in production animals. Better understanding of the underlying biology will allow improved management and enhance accuracy of selective breeding.

Problem Statement 1B: Define Phenotypes and Develop Genetic Improvement Programs.
Farm production systems focus not only on weight gain, but also on efficient conversion of nutrients into muscle. Identification of the genes and pathways leading to improved growth, nutrient utilization efficiency and product quality are important for maximizing the ability to improve these traits in the production environment. In addition, identifying stressors and stress pathways that negatively impact production and how they can be mitigated will improve growth efficiency as well as animal well-being.

The application of quantitative genetics theory to animal populations of livestock and poultry has produced significant genetic improvement in particular components of performance, such as the doubling of milk production per cow or the doubling of meat yield in poultry over the past 25 years. Meanwhile, aquatic animal genetic improvement has lagged behind, hindered by the small numbers of families evaluated, lack of phenotypic information, and weak selection pressures. Researchers will take advantage of the increased scope and power of computing platforms and the large family sizes available for many aquatic animals by applying them to expanding pedigreed phenotypic data sets. Genetic evaluation and improvement programs can improve through the elucidation of genetic parameters and interrelationships among traits, development of objective multi-trait breeding goals, and the availability of genomic resources for trait characterization at the molecular and physiological level. These genetic improvement programs will focus on animal production and well-being and emphasize the use of strategies that will reduce cost of production and improve product quality.

Identifying environmental conditions that allow animals to thrive in their respective production systems is critical for sustainable and profitable production. Enhancing well-being will allow animals to maximize their growth potential. This requires an understanding of genotype x environment interactions, as well as a comprehensive understanding of factors affecting growth, nutrient efficiency, and stress.

Research Needs:

Research is needed to expand knowledge of the factors affecting nutrient utilization in aquatic animals, as the genetic and physiological bases for variation in growth and feed efficiency are not well defined and needs further study. Scientists need to understand the pathways of protein retention and fat deposition. An understanding of the genes and metabolic pathways involved in nutrient assimilation and how nutrient balance affects these pathways is also required. Scientists need to understand how stress affects growth, health, and reproductive performance. Identifying how stress impacts performance will suggest ways to enhance overall growth efficiency and animal well-being. Research in genome variation, functional genomics, and proteomics will yield new diagnostic and genetic evaluation tools regarding specific genes and gene interactions, and this new molecular information will be incorporated to maximize genetic improvement. Additionally, new approaches to use molecular information from the whole genome will be investigated and validated to determine if and how they can be employed in genetic selection and breeding programs to target improvements of specific desirable traits.

Anticipated Products:

Trout

- Genetic improvement of production traits (growth, nutrient efficiency, fillet yield, resistance to disease)
- Whole genome approach to selection
- Identify genetic markers for production traits

Catfish
- Genetic improvement of production traits (growth, nutrient efficiency, fillet yield, resistance to disease)
- Whole genome approach to selection
- Identify genetic markers for production traits
- Evaluation of genotype x environment effects (including diet)

Hybrid-Striped Bass
- Genetic improvement of production traits (growth, nutrient efficiency, fillet yield, resistance to disease)
- Identify genetic markers for production traits

Yellow-Perch
- Genetic improvement of production traits (growth, nutrient efficiency, fillet yield, resistance to disease)

Atlantic Salmon
- Genetic improvement of production traits (growth, nutrient efficiency, fillet yield, resistance to disease)
- Whole genome approach to selection
- Identify genetic markers for production traits

Oysters
- Genetic improvement of production traits (growth, resistance to disease)
- Identify genetic markers for production traits

Potential Benefits:
Complex traits will be better defined allowing more targeted genetic improvement to be attempted. These traits include the most important to enterprise profitability, such as feed efficiency and disease resistance. Moreover, better accuracy in identification of elite genetic seed stock will allow the rate of genetic change to accelerate. Enhancing genetic improvement programs by defining and adding traits will enable producers to better exploit the genetic potential available and determine the best environments and diets for more profitable and sustainable aquaculture.

Problem Statement 1C: Enhance Aquatic Animal Reproduction.
Improving reproductive efficiency and success is a critical need for the production of many aquatic species. Managing this process will require an understanding of basic neuroendocrine regulatory mechanisms. The effects of handling fish on their reproduction and gamete quality need to be better understood to minimize problems arising from animal management. In addition to these efforts, research will focus on improving suboptimal fertilization rates and poor development during early life stages. Research on the physiology of the larval stages of aquatic species will improve larval survival. Other opportunities for improving reproductive performance include developing tools and technologies to predict when broodfish become sexually mature, as well as developing strategies to control spawning. In addition, ARS scientists will develop methods to control the sex of aquatic animals and to make the production

of hybrid gametes (eggs and sperm) more efficient. By improving reproductive success, research can significantly increase spawning efficiency, fingerling production, and profitability.

Research Needs:

Basic research is needed to enhance the understanding of neuro-endocrine regulatory mechanisms and gonadal development and function. Research will also help better understand the impacts of environmental stressors on successful gamete production, fertilization, hatch, and survival for aquatic species. Research is needed to identify management strategies, including the use of hormones, to enhance reproductive output and quality, since optimal requirements are not always met for fish species in captivity. The ability to induce spawning and produce quality gametes several times per year is a critical need for many species. Other research work is required to improve egg quality, which requires understanding basic processes involved in the assembly of the egg and needs of the developing embryo.

Anticipated Products:

Trout

- Characterize and improve egg quality, hatch, and survival

Catfish

- Characterize and improve egg quality, hatch, and survival
- Develop methods to predict and control sexual maturation
- Improve hormonal treatment strategies to improve efficiency of producing hybrids

Hybrid-Striped Bass

- Characterize and improve egg quality, hatch, and survival
- Develop methods to predict and control sexual maturation
- Improve hormonal treatment strategies to improve efficiency of producing hybrids

Yellow-Perch

- Characterize and improve egg quality, hatch and survival
- Develop methods to improve efficiency of reproduction
- Improve methods to produce monosex populations

Oysters

- Identification of critical developmental stages and environmental requirements for improving reproductive performance and larval success

Potential Benefits:

Increased reproductive success will lead to more stable and economical production of animals. Producing monosex populations and hybrids should improve farm productivity and may also increase the uniformity growth rates and body conformation. Meanwhile, the ability to produce eggs and juveniles throughout the year will lead to better use of production space and support year round harvest.

Component 1 Resources

The following ARS locations have research projects addressing the problem statements identified under Component 1:

- Franklin, Maine;
- Kingston, Rhode Island;
- Hagerman, Idaho;
- Leetown, West Virginia;
- Milwaukee, Wisconsin;
- Newport, Oregon;
- Stoneville, Mississippi; and
- Stuttgart, Arkansas.

COMPONENT 2: Nutrient Requirements and Alternative Protein and Lipid Ingredients.

One of the largest input costs to aquatic animal production is feed. Small changes in diet formulation can significantly affect the price of diets. Therefore, a thorough knowledge of the nutrient requirements for optimum growth and performance at all life stages is important for efficient production of aquatic animals. Additionally, development and evaluation of novel feed ingredients is vitally important to provide feed manufacturers flexibility to improve formulations when some commodities increase in cost. As the chemical composition and nutrient bioavailability of feedstuffs are determined, less costly feeds can be formulated based on nutrient requirements and the relative costs of different ingredients.

Problem Statement 2: Determine Nutrient Requirements and Evaluate the Nutritional Value of Alternative Sources of Protein and Lipid.

Specific nutrient requirements must be met to realize the performance potential of farmed aquatic animals. For many species of aquatic animals, the nutrient requirements are not well defined, and where they are defined, the information may not be relevant to the high performance, nutrient dense feeds available today, or to the rapidly growing, selectively bred animals. Furthermore, as more non-traditional protein- and lipid-based sources become available, research is needed to optimize delivery of limiting amino acids, fatty acids, or other limiting nutrients.

Past data is generally for a single stage of production and not partitioned into nutrient requirements for various stages of production. Following the lead of other more developed animal production sectors, development of stage-specific diets is needed, such as larval development, grow-out, and reproductive stages. The effect of nutrition on reproductive performance is of growing concern, requiring research to optimize broodstock diets as well.

Research Needs:

Research is needed to determine nutrient requirements and nutrient availability for aquatic animals fed non-traditional sources of protein and oil. Research on the optimization of formulation of broodstock diets, will ensure reproductive efficiency of these high value animals. Other research is required to develop methods to utilize genomic tools for evaluating metabolic responses to varied levels of nutrients including the utilization of co-products from bio-fuel processing and fish processing and plant oil.

Researchers will need to work toward improving the nutritional value of alternative protein sources through the use of better processing methods. Research will be necessary to develop feeding strategies to reduce demands for live feeds and to meet the requirements of larval fish growth and development. Pond-based culture of juveniles also requires the further evaluation of feeding strategies, such as when to bring fish out of the hatchery, when to provide feeds, and how to maximize the value of proper pond fertilization.

Anticipated Products:

Trout
- New sustainable sources of ingredients to provide dietary protein and lipids
- Enhanced methods for ingredient processing to improve nutritional value
- Define nutrient requirements and digestibility for fish fed diets with non-traditional protein and fat sources
- Define nutrient requirements at different life stages
- Improved broodstock diets

Catfish
- New sustainable sources of ingredients to provide dietary protein and lipids
- Define nutrient requirements at different life stages
- Improved broodstock diets
- Develop economical feeding strategies

Hybrid-Striped Bass
- New sustainable sources of ingredients to provide dietary protein and lipids
- Enhanced methods for ingredient processing to improve nutritional value
- Define nutrient requirements and digestibility for fish fed diets with non-traditional protein and fat sources
- Define nutrient requirements at different life stages
- Improved broodstock diets

Yellow-Perch
- Define nutrient requirements at different life stages
- Develop feeding strategies to reduce need for live feeds
- Improved broodstock diets
- Develop economical feeding strategies

Atlantic Salmon
- New sustainable sources of ingredients to provide dietary protein and lipids
- Enhanced methods for ingredient processing to improve nutritional value
- Define nutrient requirements and digestibility for fish fed diets with non-traditional protein and fat sources
- Define nutrient requirements at different life stages
- Improved broodstock diets

Potential Benefits:
Research in this area will support the formulation of cost-effective diets that promote optimal growth at different life stages and reproductive performance, improved product quality, and production efficiency. Reduced reliance on fish meal and fish oil from pelagic capture fisheries will enable increased production of fish feeds for sustainable aquaculture production. Furthermore, increasing the number of high-quality alternative ingredients will provide flexibility in formulating least cost diets. Work to reduce the

requirement for live feed in larval to juvenile stages of some species will simplify culture and reduce costs of fry. In addition, improving survival and reducing costs through pond fertilization and feeding strategies could improve production efficiency and reduce fry costs.

Component 2 Resources

The following ARS locations have research projects addressing the problem statements identified under Component 2:

- Hagerman, Idaho;
- Stoneville, Mississippi;
- Milwaukee, Wisconsin;
- Stuttgart, Arkansas; and
- Franklin, Maine.

COMPONENT 3: Health of Aquatic Animals.

Health management strategies, technologies, and bio-security plans that are safe for the environment and for consumers of aquaculture products are necessary to reduce disease-related losses. There is presently a lack of validated technologies for early and rapid detection, prevention, and treatment of diseases in production systems, which has hindered the growth and competitiveness of the U.S. aquaculture industry. Validated diagnostic tools that can be used in production systems to detect the disease agents in a rapid fashion are required. In addition to the need for diagnostics, effective control strategies and therapeutants are required to manage outbreaks, given that only a few drugs are approved for treating sick fish. Further research is also needed to provide new, effective vaccines and methods for mass vaccination of aquatic animals. This vaccine work would benefit from new molecular tools. For example, sequencing pathogens to identify regions of similarity among many strains of the pathogen may aid in producing vaccines that offer broad protection. Additionally, molecular tools enable researchers to examine thousands of host genes and, with appropriate experimental design and use of genomic tools, localize genomic regions associated with innate and acquired immunity.

Problem Statement 3A: Improve Understanding of Host Immunity, Immune System Evasion by Pathogens, and Disease-Resistant Phenotypes.

Identifying molecular pathways of the host involved with innate and acquired immune responses and understanding the mechanisms of immune system evasion to prevent disease will present new strategies for controlling disease. Conducting experiments on animals with divergent response to disease challenge can reveal the genetic sources of variation that correlate with innate and/or acquired immune status. In addition, understanding the immune response of animals to vaccination, variation in vaccine responsiveness, as well as mechanisms of protection, will suggest ways to deploy multiple lines of protection.

Research Needs:

Molecular tools such as transcriptome sequencing, quantitative real time PCR, sequencing technologies, and proteomics for use in evaluating the immune responses of animal tissues exposed to key pathogens. Additionally, animals with resistant/susceptible phenotypes need to be investigated to understand the mechanisms and location of genes (quantitative trait locus, or QTL) leading to reduced mortality. Using genetic variations in response to vaccination, researchers can select for good responders and identify gene correlates for vaccine efficacy. This will require close collaboration with genetics and breeding programs.

Anticipated Products:

Trout

- Identify genetic markers related to immunity
- Identification of microbial genes and pathways critical for pathogenesis (bacterial cold water disease, columnaris)

- Better understanding of the immune response of resistant and susceptible lines (bacterial cold water disease, columnaris) and key environmental factors (such as temperature, fed/fasted)
- On farm trials with animals that have demonstrated improved resistance to pathogenic bacteria
- Quantification of family variation in vaccination responsiveness

Catfish
- Identify genetic markers related to immunity
- Identification of microbial genes and pathways critical for pathogenesis (ESC, columnaris, A. hydrophila)
- Better understanding of the immune response of resistant and susceptible lines (ESC, columnaris) and key environmental factors (such as temperature, fed/fasted)
- Quantification of family variation in vaccination responsiveness

Hybrid-Striped Bass
- Identify genetic markers related to immunity
- Identification of microbial genes and pathways critical for pathogenesis (columnaris)

Yellow-Perch
- Identify genetic markers related to immunity
- Identification of microbial genes and pathways critical for pathogenesis (columnaris)

Atlantic Salmon
- Identify genetic markers related to immunity

Tilapia
- Identify genetic markers related to immunity
- Identification of microbial genes and pathways critical for pathogenesis (streptococcus, columnaris)

Oysters
- Identify genetic markers related to immunity

Potential Benefits:
Information on immune system components will provide targets for intervention to enhance immune system responsiveness. Animals with positive response to vaccination will be identified, forming an animal resource for locating the immune system pathways or components correlated with enhanced responsiveness. Additionally, animals with enhanced resistance will be identified and will form the basis of select disease-resistant lines. Identification of genes and markers related to immunity will also aid in locating genetic markers to reduce mortality.

Problem Statement 3B: Control of Pathogens and Prevention of Disease
Methods and reagents to rapidly detect pathogens and diagnose diseases in aquatic species are still unavailable or have not been applied at the farm. Microbial genomic sequences, or

particular diagnostic regions of the genome, will be important tools for pathogen identification and understanding pathogenesis. Once pathogens have been identified, strategies are needed to identify effective treatments, understand their pharmacokinetics, and apply therapeutants to control them. For these studies and for testing host resistance and responsiveness, disease challenge protocol development for key pathogens is necessary.

Aquaculture producers have few vaccines available to prevent infectious disease agents. Although some vaccines exist, their use on the farm is not always economically feasible. Ultimately, vaccine research must result in a product that is safe, easy to administer, and effective on the farm. The development of new vaccines will require techniques such as killed, modified-live, DNA, and recombinant technologies. Novel approaches for development of vaccines may be employed with information obtained from microbial genomics and proteomics. Additionally, for vaccination to be feasible for many fish species, strategies for mass vaccination are needed, such as vaccination through immersion as juveniles or eggs or through feed.

Research Needs:

Molecular tools, including pathogen genome sequencing, are needed to develop validated rapid and automated methods, both microbiological and immunological, for detecting infectious disease agents and toxins in aquatic animals. Studies on the factors contributing to how, when, and where disease outbreaks occur are also needed. As for control, researchers will be required to identify compounds that can be used as therapeutants and to develop methods of mass delivery.

There is a need for the development and testing of vaccines in the laboratory for safety and effectiveness. This will require researchers to evaluate many strains of recognized pathogens through genetic screening and microbial sequencing and endeavor to develop strategic vaccines offering broad protection against pathogen classes. Techniques should also be investigated on how to apply vaccines and medicines using mass delivery strategies in on-farm trials.

Another area of growing interest and potential is the use of immunostimulants and understanding of the microbiome in host animals. Research into the variations in metagenomes, and ways to enhance protection against pathogens through use of immunostimulants is relatively new and active.

To test treatment efficacy and prevention of disease, controlled challenges with key pathogens will need to be developed.

Anticipated Products:

Trout

- Develop improved challenge model for Weissella
- Pathogen genome sequencing
- Vaccine development and optimization for prevention of diseases
- Improved understanding of infectious diseases of trout (e.g. Weisella, columnaris) and development of control measures

Catfish
- Pathogen genome sequencing
- Vaccine development and optimization for prevention of diseases
- Identify optimal temperatures to vaccinate fish for ESC
- Improved understanding of infectious diseases of catfish (Aeromonas hydrophila, Ichthyophthirius multifilis, Flavobacterium columnare, Edwardsiella ictaluri, E. tarda and E. piscicida) and development of control measures

Hybrid-Striped Bass
- Improve efficiency of treatment of striped bass eggs with CuSO4
- Examine the effects of treating water with CuSO4 as a means to control Columnaris
- Develop improved challenge models

Yellow-Perch
- Develop improved challenge model for columnaris
- Improved understanding of the risk to aquaculture of Viral Hemorrhagic Septicemia

Atlantic Salmon

Tilapia
- Improved understanding of infectious diseases of tilapia and development of control measures
- Vaccine development and optimization for prevention of diseases

Oysters
- Improved understanding of infectious diseases of oysters and development of control measures

Potential Benefits:
Sequence information on microbial genomes will permit better identification of the pathogens and improve understanding of pathogenesis and virulence factors.

Vaccines hold the potential to greatly reduce the need for other therapeutants (*e.g.*, antibiotics), improve the economic returns of aquatic animal production by requiring less reactive drug use, and reduce the environmental impact by reducing use of antibiotics and other antimicrobial compounds. Improved biosecurity should lessen the frequency and dispersion of disease problems, improve animal well being, and increase system productivity and reliability.

Component 3 Resources
The following ARS locations have research projects addressing the problem statements identified under Component 3:
• Auburn, Alabama;
• Hagerman, Idaho;
• Leetown, West Virginia;

- Newport, Oregon;
- Kingston, Rhode Island;• Stoneville, Mississippi; and
- Stuttgart, Arkansas.

COMPONENT 4: Sustainable Production Systems.

Aquatic animal producers are continually challenged to produce fish, shellfish, and crustaceans efficiently and economically. Producers must have the necessary information and technology to meet consumer desires for fish and shellfish products. To that end, production technologies must be developed to optimally produce animals in existing and new facilities and environments. Performance of aquatic animal production systems can also be improved through the development and application of innovative biological and engineering approaches.

Aquatic animal production systems range from low energy/trophic level production to super-intensive systems. Although production intensity varies widely among systems, optimal production efficiency is required for profitability. Optimal utilization of production inputs, including water, feed, and mechanical energy and minimization of waste outputs requires knowledge of the interactions among inputs, culture species, production environment, and economics; however, these interactions are not understood fully.

The marketplace for foods coming from animal muscle is competitive, requiring new and improved aquaculture products to meet consumer demands and expectations, maintain market share for aquatic animal products, and sustain "aquatic products as food" industry growth. New methods need to be developed to enhance the sensory and nutritional qualities of aquaculture products. In addition, there are great opportunities to enhance the utilization and value of lower valued materials that result from fish processing as feed and food ingredients

Problem Statement 4A: Improve Technologies for Recirculating and Flow-through Production Systems.

Recirculating aquaculture systems are dependent on fixed equipment and large energy inputs and thus have high costs of capital and operation. In return for high energy expenditures, however, the water quality within recirculating systems is constant, waste is contained and highly managed for optimal fish production and health, barriers are in place to prevent escape of fish and entry of pathogens, and water use is efficient. Strategies for reducing energy and water requirements are important for these systems.

On the other hand, flow-through systems, such as those typically used in rainbow trout production, have the advantage of low energy inputs and abundant water supplies at the cost of reduced water quality and water quality control. These quality and control disadvantages are the result of water in raceway systems being serially used as it passes down an elevation gradient on its way through several raceway steps. For flow-through systems, the challenge is to maintain or expand production in limited or even declining water supplies.

Depending on the system employed, the production of (live) feeds for first feeding stages within many culture systems is either a critical gap or a high cost. There is a significant need to address this bottleneck by improving each of these systems to optimize production of feed organisms for larval fish and shellfish.

Research Needs:
For flow-through systems, research is needed to improve aeration, water quality related to "off-flavor," continuous water quality monitoring systems, dynamic process control systems, and automation technologies to increase aquaculture production system reliability, efficiency, and cost effectiveness. Additionally, research is needed to maximize waste removal and production per unit of water used. For recirculation systems, research to improve energy efficiency is vital. Research is required to identify the critical parameters for fish performance and well-being when reducing water exchange, and sensitivity analysis to model the inputs and outputs needed to determine factors with greatest impact on cost of production. Further, research is needed to develop improved systems for growing and delivering live feed for fish with small larvae and larvae that do not accept prepared feeds.

Anticipated Products:

Trout
- Increased application of water quality monitoring and process control technology to improve efficiency of production
- New tools and methods to analyze aquatic animal production systems and manage off-flavors

Atlantic Salmon
- Defined criteria for optimal water quality for salmonids in recirculating systems.
- New technologies to reduce energy costs and increase energy efficiency in recirculating systems.
- New tools and methods to analyze aquatic animal production systems and manage off-flavors.

Potential Benefits:
Increasing levels of automation will lower the cost of labor and improve the cost competitiveness of domestic aquaculture products. Improved efficiencies in production and waste removal will maximize production per unit of volume. With lowered energy demands and increased optimization of recirculating systems, systems that tightly control the fish culture environmentally, limit the ingress and egress of pathogens, and fit into systems integration plans for waste capture/utilization will emerge. Finally, developments in microparticulate and larval feed production can support the growth of species that require live feeds.

Problem Statement 4B: Enhance Control of Pond-Based Ecosystems to Maximize Production and Product Quality.

Aquatic animal pond production systems, the dominant fish culture system in the United States, range from low intensity to super-intensive systems. Optimal utilization of production inputs, including water, feed, and energy requires knowledge of the interactions among inputs, culture species, production environment, and economics; yet these interactions are not understood fully.

Improving product quality requires understanding the effects of rearing and harvesting practices on product quality. Pond-based culture systems are common for catfish and striped bass, and for these large pond systems, often greater than 10 acres, the magnitude and scale of treatments to make any change is large, so there is a critical need for research in smaller systems that can be verified in large commercial scales. To promote fish production industry profitability, there is also a need for manipulation of pond microbial and phytoplankton communities to control product flavor, predation of larval or juvenile fish, and predation of larger fish and shellfish by birds.

Research Needs:

Research is needed to develop new or improve existing pond systems for aquatic animal production using innovative, non-traditional approaches that result in optimized production, increased economic competitiveness, and reduced environmental impact. Additionally, studies to determine combinations of production inputs (e.g. feed and aeration) that optimize product quality within economic, engineering, and biological constraints are needed to identify bottlenecks and opportunities for improved efficiencies. Improved aeration, water quality monitoring systems, dynamic process control systems, and automation technologies would increase aquaculture production system reliability, efficiency, and cost effectiveness. Investigations to determine the relationship between rearing and harvesting practices on product quality are needed. To enhance and improve pond management, research is needed to control the phytoplankton species making up the photosynthesizing biomass in the pond and reduce off-flavor in fish. Strategies for remediation of off-flavor compounds should be further developed.

Anticipated products:

Catfish

- Improved efficiency of pond-based ecosystems
- Develop new aerators to improve the efficiency of aeration to ponds
- Recommendations for the use of Biofloc technology to improve water quality
- Recommendations for grading hybrids during production cycle to improve production
- Recommendations for stocking fry into ponds to improve survival
- Strategies and/or compounds for favoring the beneficial or neutral phytoplankton species or selectively reducing the abundance of harmful and/or undesirable phytoplankton to reduce levels of "off-flavor" compounds.

Hybrid-Striped Bass

- Improve efficiency of pond-based ecosystems
- Recommendations for the use of Biofloc technology to improve water quality

Potential Benefits:

Technology development to improve fish pond systems will lead to increased production intensity, reduced variation in yields, and control of the nutrient outputs from fish production. Better product quality will result from improved rearing and harvest strategies. Reducing the negative impacts of undesirable phytoplankton blooms to

decrease off-flavor episodes and reduce oxygen demand during the night in ponds would improve the efficiency of pond production.

Problem Statement 4C: Develop Shellfish Systems to Maximize Productivity and Environmental Compatibility.

Bivalve shellfish are a major production commodity in the United States. Although larvae are often reared in a hatchery, most juveniles and adults are raised directly in multi-use, coastal waters. Survival at various stages of rearing can be low, resulting in low harvest rates as a fraction of juveniles deployed. Production is also constrained by recent regulatory actions regarding siting resulting in the need for better understanding of the interaction between shellfish aquaculture production systems and the environment.

Research Needs:
Research is needed to determine and validate methods to reduce mortality caused by disease, predators, pests, and bio-fouling organisms. Research is also necessary to identify and quantify interactions between aquaculture practices and natural resources to benefit shellfish production and satisfy regulatory constraints. In addition, due to recent seasonal mortality events and ocean acidification concerns, it is clear that the effects and limits imposed on shellfish by temperature, other environmental factors, and the interactions of these stresses with pathogens need to be defined.

Anticipated Products:
- Environmentally compatible practices to combat predators and pests of shellfish, and treatments that selectively impede predators and bio-fouling organisms.
- Published science that the shellfish industry can use to complete environmental management plans and policy makers can use to develop science-based policy that sustains the marine environment.
- Identification of key environmental stressors.

Potential Benefits:
Production efficiency can be improved through efforts to reduce the loss of juveniles and adults in open production systems. In addition, authoritative scientific reports that can support environmentally compatible best management practices will reduce regulatory uncertainty for the shellfish aquaculture industry. Further, identifying genes affected by thermal stress and pathogens, and identifying genetic markers associated with more and less susceptibility to these challenges will suggest a methodology to understand disease progression and potential remediation strategies.

Component 4 Resources
The following ARS locations have research projects addressing the problem statements identified under Component 4:
• Hagerman, Idaho;
• Leetown, West Virginia;
• New Orleans, Louisiana;

- Newport, Oregon;
- Oxford, Mississippi;
- Stoneville, Mississippi;
- Stuttgart, Arkansas; and
- Franklin, Maine.

COMPONENT 5: Product Quality and New Products

Aquatic animal producers are continually challenged to produce fish, shellfish, and crustaceans efficiently and economically. Producers need to be provided with the necessary information and technology to meet consumer needs for the products they produce. To that end, production technologies must be developed that result in consistently high-quality products.

The marketplace for foods coming from animal muscle is competitive, requiring new and improved aquaculture products to meet consumer demands and expectations, maintain market share for aquatic animal products, and sustain "aquatic products as food" industry growth. New methods need to be developed to enhance the sensory and nutritional qualities of aquaculture products. In addition, there are opportunities to enhance the utilization and value of lower aquaculture co-products that result from fish processing as feed and food ingredients.

Lack of product consistency is a major concern for some species reared in aquaculture systems. The consumer demands consistently high-quality products, and when defects are detected, corrective actions must be taken. There is a need to improve the quality and increase the consistency of flavor, color and texture attributes in products. In addition to improvements in methodology used to evaluate quality, more information is needed on production factors that contributing to variation in product quality. In addition to improving product quality, there are opportunities to create new and improved products to meet consumer needs and to improve the economic viability of aquaculture industries, including opportunities to enhance the utilization of aquaculture co-products, such as making food and feed ingredients from viscera components, frames, skin, and heads.

Research Needs:
Methods need to be developed to measure quality attributes such as off-flavors, color, and firmness. Production system practices that affect these quality parameters will need to be evaluated and used to develop systems that optimize product quality and uniformity. Economical methods are also needed to collect, preserve, and store valuable co-products from processed fish waste material until they can be further processed into alternative uses. Research is also needed for development of new product forms, such as designer products with enhanced human health benefits, highly unsaturated fatty acids, antioxidants, and vitamins.

Anticipated Products:

- Methods to measure attributes like color, firmness, meat weight, and taste in different products.
- Preharvest production practices that improve product quality attributes.
- New, value-added products from under-utilized co-products, such as belly flap, mince, skin, heads, and viscera components.

Potential Benefits:
Improving product quality by improving the traits important to U.S. consumers could increase the demand for domestic products. Furthermore, efforts to improve the

utilization of co-products will improve production efficiency and promote environmental responsibility.

Component 5 Resources

The following ARS locations have research projects addressing the problem statements identified under Component 5:

- New Orleans, Louisiana;
- Leetown, West Virginia;
- Franklin, Maine; and
- Newport, Oregon.