NATIONAL AQUACULTURE RESEARCH AND DEVELOPMENT STRATEGIC PLAN

OVERVIEW

Federal legislation[1] has outlined government support and policy for aquaculture[2] development in the Nation through the following actions:

1. Declaring a national aquaculture policy to encourage development in the United States,
2. Calling for the establishment and implementation of a national aquaculture development plan, and
3. Encouraging aquaculture activities and programs in both the public and private sectors of the economy that will result in increased aquacultural production, coordination of domestic aquaculture efforts, conservation and enhancement of aquatic resources, and creation of new industries and job opportunities.

The legislation emphasizes the need for government-wide coordination of national activities regarding aquaculture, and to this end, it established a Federal interagency aquaculture coordinating group within the Office of Science and Technology Policy that operates as the Joint Subcommittee on Aquaculture (JSA). Currently, the JSA functions as the Interagency Working Group on Aquaculture (IWGA) under the Life Sciences Subcommittee of the Committee on Science of the National Science and Technology Council.

The IWGA prepared this Strategic Plan as a coherent framework to help shape, focus, and coordinate interagency research and development (R&D) efforts on the highest-priority strategic goals and crosscutting objectives over the midterm (5–10 years) that will encourage aquaculture development in the Nation, as cited under law. The Plan strengthens the primary function of the IWGA, which is to increase the overall effectiveness of Federal aquaculture research, technology transfer, and assistance programs.

VISION

A globally competitive, technologically appropriate, and diverse aquaculture sector in the United States that meets increasing demand for seafood and products that are affordable and meet high standards for safety, quality, and environmental stewardship, with maximum opportunity for profitability and economic growth. A critical element of this vision is that the aquaculture sector develops in concert with natural ecosystems that support recreational, fishery, and environmental services needs.

PLAN FRAMEWORK

This Plan aligns with the Administration's outcome-oriented goals for multidisciplinary research, international collaboration, and new approaches for accelerating technology commercialization

[1] The National Aquaculture Act (Public Law 96-362, 94 Stat. 1198, 16 U.S.C. 2801, et seq.) and the National Aquaculture Improvement Act (Public Law 99-198, 99 Stat. 1641)

[2] The Act defines aquaculture as the propagation and rearing of aquatic species in controlled or selected environments. For purposes of this plan, aquaculture is defined as the propagation and rearing of aquatic organisms for commercial, recreational, or public purpose.

and innovation and key aims in the National Bioeconomy Blueprint, under development[3]. Transformational solutions are required in order for aquaculture to overcome numerous critical challenges and to realize the tremendous opportunities of expansion for commercial enterprises, stock-enhancement programs and species and habitat restoration. These solutions depend on new scientific knowledge as well as strong public-private collaborative partnerships and a bold vision to optimize societal and scientific benefits from our Nation's collective capacity for R&D in aquaculture.

The Plan identifies nine strategic goals:

1. Advance Integration of Aquaculture Development and Environmental Conservation
2. Employ Genetics to Increase Productivity and Protect Natural Populations
3. Improve Aquatic Animal Health
4. Improve Production Efficiency and Well-being
5. Improve Nutrition and Develop Novel Feeds
6. Increase Supply of Nutritious, Safe, High-quality Seafood
7. Introduce Innovative Production Systems
8. Create Skilled Workforce and Effective Technology Transfer
9. Integrate Economic and Social Sciences

Each goal, along with its outcomes, milestones, and performance measures, is described in detail below.

The Plan creates an interagency collaborative and multi-disciplinary R&D framework to advance and realize the Nation's opportunities for a vibrant, future-oriented aquaculture sector. It provides a roadmap for these strategic goals and essential interagency organization to support the national policy to encourage aquaculture in the United States through coordination with the Office of Science and Technology Policy and the National Science and Technology Council.

Monitoring performance will rely on collecting data on agency investments biannually under each strategic goal and reporting qualitative and quantitative outcomes toward achieving these goals. There is an opportunity to establish baseline data on productivity measures for major aquaculture species. Data will be collected from the Department of Agriculture National Agricultural Statistics Service and the Department of Commerce National Oceanic and Atmospheric Administration to monitor trends in the aquaculture sector. Major breakthroughs and discoveries under each strategic objective will be reported biennially by agencies under each strategic goal so that results are broadly disseminated and applied. Success stories and model collaborative partnerships will be highlighted and reported. Because of the diversity of aquaculture and the broad distribution of R&D investments across this sector, performance measures will track progress under each of the strategic goals.

[3] Building a 21st Century Bioeconomy, Mary Maxon and Mike Stebbins, http://www.whitehouse.gov/blog/2011/10/12/building-bioeconomy (accessed 2 January 2012).

Actions taken to implement the Plan will lay a foundation of scientific knowledge and innovation to address critical challenges that are likely to arise over the next 5 to 10 years. In particular, the Plan is intended to

- communicate a bold vision and coordinated Federal R&D commitment that encourages the development of aquaculture in the Nation, as cited under current law;
- identify critical research needs, technology gaps, and priorities for innovative research that will lead to ground-breaking ideas, concepts, approaches, technologies, and capabilities and a robust foundation to advance U.S. technological and environmental leadership in aquaculture;
- enhance coordination and communication among executive departments and agencies to maximize the effectiveness of government R&D resources;
- support the function of the JSA to increase the overall effectiveness and productivity of Federal aquaculture research, technology transfer, and extension and assistance programs;
- encourage research teams composed of multiple science disciplines that employ system-level approaches and new skills to address complex challenges;
- strengthen mechanisms to engage partners in industry, academia, non-governmental organizations, States and tribes concerning government R&D priorities, programs, and planning processes; and
- integrate science and state-of-the-art knowledge in revising existing rules and development of new regulations and policies to support the responsible and sustainable expansion and operation of aquaculture nationally.

Executive departments and agencies conducting aquaculture R&D should engage industry, academia, and other non-Federal stakeholders in support of government planning and performance of the Federal aquaculture R&D portfolio and implementation of this Plan.

BACKGROUND

Role of Aquaculture

Aquaculture is a set of practices for the husbandry of aquatic organisms that we rely on for many functions and that distinguish it from commercial fishing. Commercial aquaculture is anticipated to contribute more than half of the world's seafood by 2012[4]—seafood that is high in protein and healthful omega 3 fatty acids and contains many essential vitamins and minerals. Aquaculture, both private and public, is also used to help restore endangered, threatened, and depleted commercially and recreationally fished species and to address essential fish habitat, shoreline protection and water quality concerns (such as oyster restoration and aquatic plant recovery activities). Regional planning mechanisms to support future marine aquaculture development, which include these and associated resource use issues, are addressed in the National Ocean Policy and Strategic Action Plans for the National Ocean Council[5].

[4] FAO Fisheries and Aquaculture Department. World aquaculture 2010. FAO Fisheries and Aquaculture Department. Technical Paper. No. 500/1. Rome, FAO. 2011. 105 pp.

[5] National Ocean Policy and Strategic Action Plans for the National Ocean Council [http://www.whitehouse.gov/administration/eop/oceans].

As we move into the second decade of the 21st century and beyond, a compelling case can be made for increasing scientific and technical knowledge to use aquaculture to grow safe and nutritious seafood in the United States; create new jobs, from coastal communities to the agricultural heartland; and foster sustainable aquaculture practices. Aquaculture, in conjunction with wild-harvest fisheries, will help to meet the growing demand for seafood and provide alternatives to increasing fishing pressure on fragile wild fish stocks. Aquaculture can generate prosperity in new ways while conserving and enhancing the Nation's natural resources and providing a safe, sufficient, and nutritious supply of seafood for the country and for export markets. Aquatic species are highly efficient, with feed conversion rates that compare favorably with terrestrial animal production.

Aquaculture Sector Status

Globally, aquaculture has evolved dramatically since Federal legislation was enacted in 1980 and 1985[1]. While wild fish harvest has stabilized, aquaculture has driven growth of the seafood sector, influenced product diversity, and found ways to address both economic development and environmental conservation goals in diverse aquatic ecosystems. The sector is knowledge and technology driven and continues to innovate and adapt to societal needs for nutritious food, good jobs, and sustainable production. The United States has bountiful freshwater and marine natural resources, plentiful feed grains produced in the heartland, a world-class aquaculture R&D infrastructure, and scientists, pioneers, and entrepreneurs to drive innovations and novel discoveries. The potential for sustainable growth of the aquaculture industry is indisputable. Today, however, the United States is a minor producer, supplying only about 5 percent of the seafood consumed domestically[3].

The primary economic rationale for a Federal investment in R&D is that, without such support, the private sector cannot adequately fund certain types of research needed to advance the industry in the United States[6]. The aquaculture industry is composed of many independent farmers (more than 4,300) and small businesses that produce dozens of different species in many diverse production environments[7]. Domestic aquaculture development does not have the support of a large commodity check-off program (i.e., a payment or a tax on sales of agricultural goods that finances a generic commodity marketing program, such as exists for milk, beef, and soybeans), though there are a few very limited feed check-off programs in some States. With an increased investment in R&D, this fragmented industry can meet its potential and reduce the Nation's dependence on imports and growing trade deficit in fisheries and aquaculture products $10 billion recorded for 2010)[8]. The top aquaculture-producing countries have all had considerable public sector support for aquaculture development.

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[6]"Promoting Research and Development: The Government's Role" Chairman Ben S. Bernanke, At the Conference on "New Building Blocks for Jobs and Economic Growth," Washington, D.C., May 16, 2011 http://www.Federalreserve.gov/newsevents/speech/bernanke20110516a.htm

[7] Census of Aquaculture (2005) issued October 2006, Special Studies 2002 Census of Agriculture http://www.agcensus.usda.gov/Publications/2002/Aquaculture/AQUACEN.pdf (accessed Sept. 30, 2011).

[8] Department of Commerce, NOAA Fisheries, Office of Science and Technology, US Foreign Trade, Current Fisheries Statistics No. 2010-2, Imports and Exports of Fishery Products Annual Summary, 2010. http://www.st.nmfs.noaa.gov/st1/trade/documents/TRADE2010.pdf (accessed 3 January 2012).

The broader aquaculture sector in the United States includes non-profit and nongovernmental organizations, companies, states, and tribes engaged enhancing and restoring aquatic species important to recreational and commercial fishing, threatened and endangered species, or habitats such as oyster and coral reefs.

The vision for renewed aquaculture expansion in the United States over the next 5 to 10 years calls for bold and coordinated actions to

- develop technically advanced, environmentally compatible, and sustainable production systems and techniques;
- improve domestication and productivity of species of economic importance;
- develop new and emerging species and novel products with strong market demand; and
- exploit our competitive advantages through responsible and integrated use of our natural genetic diversity and water and feed resources for production of public goods and environmental services, such as healthy foods, strong populations of wild stocks, and healthy ecosystems.

It is vital to connect critical links in seafood supply chains from farmers and fisherman to consumers, incorporating all the support industries: feed and equipment manufacturing, harvesting and processing, distribution, and retail.

Aquaculture Economics and Jobs

Our current trade deficit in seafood products and food security considerations highlight the need for increased domestic aquaculture production. The United States is a major consumer of aquaculture products and the third largest seafood market in the world. However, as noted above, commercial aquaculture within the United States supplies only about 5 percent of the seafood consumed domestically[3]. We import approximately 85 percent of our seafood[3], with half being produced through aquaculture outside of the United States [7]. Demand for seafood in the United States will grow as a result of a growing population and increased consumer awareness of seafood's health benefits. The *2010 Dietary Guidelines for Americans*[9] published by the Departments of Agriculture and Health and Human Services provides a science-based recommendation that Americans double their consumption of highly nutritious seafood from a wide range of species as a healthy food choice. Future increases in seafood supply will come from foreign aquaculture, increased domestic aquaculture production, or some combination of the two. As the growing middle class in many emerging economies consumes more seafood, quality seafood products may not be as readily available from other countries in the future and they may cost more, dramatically impacting seafood-dependent businesses and consumers.

Aquaculture is becoming an increasingly integral source of safe, sustainable seafood for consumers worldwide, even as long-term supplies from wild-capture fisheries remain flat. In 2010 [3], U.S. consumers spent $54.0 billion in foodservice and $25.8 billion in retail seafood sales. The top 10 species presently consumed domestically represent about 90 percent of the

[9] U.S. Department of Agriculture and U.S. Department of Health and Human Services. *Dietary Guidelines for Americans, 2010.* 7th Edition, Washington, DC: U.S. Government Printing Office, December 2010.

total seafood consumption; 6 of these species come from farmed or a mixture of farmed and wild sources.

Compared with U.S. industries in manufacturing, agriculture, and fisheries, aquaculture is relatively small and at an early stage of development. The annual farm-gate sales of private domestic aquaculture production were $1.4 billion in 2007 and were dominated by small businesses with limited private-sector R&D capability. Aquaculture in the United States offers opportunities for economic development to support livelihoods and the well-being of people in rural inland and coastal areas. It can create an estimated 75,000 to 100,000 direct and indirect jobs with every 1 million metric tons of production because of its significant economic multiplier factor[10]. Ultimately, growth of aquaculture-based enterprises will be driven by favorable economic outlooks in markets, the pace of technological advances, lower investment risks, greater regulatory certainty, and reliable access to suitable culture sites for long-term sustainable growth and competitive development. Aquaculture development, particularly in rural coastal and inland communities, is consistent with and supportive of the White House Rural Council objectives of strengthening rural communities and promoting economic growth[11].

Research and Development Capacity

Most aquaculture businesses are small. Compared with agri-businesses or large corporations in other agricultural sectors, few domestic aquaculture businesses have internal R&D capabilities. At the same time, many small businesses are entrepreneurial and pioneer new systems, species, products, and technologies. Federal laboratories and competitive grant programs facilitate public-private sector partnerships through grants or cooperative R&D agreements to co-discover and co-develop innovations. Federal and State governments have made significant investments in human resources and aquaculture research facilities over the past 30 years. The United States has world-class laboratories and internationally recognized scientists that contribute to aquaculture advancements domestically and globally. Public universities have faculty trained in specialized aquaculture-related fields, and the United States has trained hundreds of domestic and international students who have become highly productive scientists and educators or high-level government leaders and policy-makers. These individuals have collectively contributed to the phenomenal trajectory of aquaculture growth worldwide.

Federal agencies have national aquaculture research and science centers and satellite facilities that support intramural foundational aquaculture research, which generates scientific knowledge and applies it to industry development. Regional aquaculture centers address multistate-level problems with regional expertise in research and extension education through competitive projects requiring multistate participation. In addition, Federal and State agencies have competitive, extramural grant programs that are critical to advancing scientific knowledge, developing new tools and technologies, and solving critical problems for broad benefits in

[10]Knapp, Gunnar (2008). "Potential Economic Impacts of U.S. Offshore Aquaculture," in Rubino, Michael (editor). Offshore Aquaculture in the United States: Economic Considerations, Implications & Opportunities. U.S. Department of Commerce; Silver Spring, MD; USA. NOAA Technical Memorandum NMFS F/SPO-103. 263 pages.

[11] White House Rural Council objectives of strengthening rural communities and promoting economic growth (http://www.whitehouse.gov/administration/eop/rural-council)

commercial aquaculture and stock enhancement. Federal programs facilitate public-private partnerships to bring new aquaculture products and technologies to the marketplace.

Great challenges in the Federal R&D enterprise in aquaculture stem from the multitude of aquatic species, systems, environments, stakeholders, user conflicts, and emerging issues and a wide range of critical problems. The R&D facilities and specially trained workforce represent the core Federal capacity and competency required for transformational changes that are anticipated in the future as pressures mount in such areas as the need for more aquaculture products, multiuse conflicts regarding natural resources, rising costs for feed ingredients and energy, climate change influences on aquatic ecosystems, and public policies that adapt to these changes. The implementation of this Plan requires Federal resources to maintain our Nation's core R&D capacity and competency for current and future generations and to expand high-performance programs to deliver quality public goods and services associated with aquaculture development and stock enhancement for the Nation.

Collaborative Research and Development

Considering the complexity of challenges and opportunities in commercial aquaculture and stock enhancement, as well as the aforementioned diversity of species, products, culture environments, systems, and stakeholders, no single agency or department has an adequate depth of R&D resources or capabilities to provide for the needs of a growing domestic industry. As aquaculture advances into new economic opportunities in the United States, the aquaculture sector and the public expect Federal agencies to collaborate, communicate, and cooperate in areas of common interest and investment. The future grand challenges and current specific challenges identified in this Plan require new collaborative approaches across scientific disciplines, institutions, agencies, and public and private sectors and new non-governmental partnerships to effectively and efficiently create opportunities for domestic aquaculture to expand and prosper.

This Plan provides a vision and framework, linked with R&D, to evaluate and solve critical constraints and provide a strategic and coordinated approach. The Plan outlines the role for the Federal R&D portfolio to benefit from new synergies and strengths across each sector and larger scale investigations due to increased collaboration among agencies and, importantly, with the private sector. The JSA provides an interagency mechanism to not only develop this Plan, but to also create incentives and processes to strengthen important interagency collaborative R&D and monitor performance and progress of aquaculture innovation, commercial sector development, and wild population and habitat conditions.

Research and Development Integration

Although the nine strategic goals of the Plan align with disciplinary fields of science, effective application of aquaculture R&D innovations clearly depends on the successful integration of new and diverse knowledge of multidisciplinary-dependent systems development and improvements. For example, new strategies in water quality management, increased aeration, and dissolved oxygen availability have led to improved growth rates of channel catfish, better feed efficiency, shorter time to harvest, and fewer undersized fish carried over the winter, resulting in reduced costly mortality. Improving dissolved oxygen availability has numerous economic benefits that can reduce overall production costs and potentially lead to changes throughout the industry. A

consequence of improved catfish production with higher aeration rates could be improved predictability of yield that reduces risk for farmers and creates new investment opportunities. The objectives and results of research can become part of an integrated process for overall improvements in productivity and sustainability. Such improved aquatic animal production systems need to be sustainably integrated into higher-level systems such as agribusiness for seafood production and natural resource management for mitigation strategies and stock enhancement.

Connection Between Regulations and Research and Development

As evidenced by its current ranking as the fastest-growing animal protein sector worldwide[7], aquaculture must become a more important contributor to the solution of future food challenges in the United States and globally. Increased production will depend on new breakthroughs and discoveries from R&D investments that directly improve productivity. Equally important for some sectors are new visionary policies and regulations that address environmental protection and also enable permitted access to new aquatic sites for commercial and restoration activities. Existing and new regulations across multiple Federal agencies can create disincentives and uncertainty for investment, permitting, and operation.

Regulations have been cited as barriers to aquaculture development in the United States for more than 30 years[12,13]. New science discoveries and state-of-the-art knowledge should be used to inform and create regulations to support dual outcomes of responsible economic development and environmental conservation. Federal, state, and local jurisdictions in the United States administer many laws and regulations designed to protect and maintain environmental quality and wild stocks of fish, protect human health and safety, and advance other social goals. These accumulated regulatory requirements, however, have created an often lengthy, uncertain, and costly process for commercial and restoration aquaculture permit applicants. Because of the curbing impact of numerous regulations and policies on expansion, the public value from domestic R&D investments can be limited in the United States while benefits are realized by foreign competitors that have less onerous and restrictive regulation. Policies and regulations to protect and restore our Nation's natural resources for future generations can be compatibly aligned with our Nation's opportunity as a world leader and model for sustainable aquaculture production. Such improvement in regulation is consistent with Executive Order 13563, "Improving Regulation and Regulatory Review"[14].

STRATEGIC PLAN GOALS

STRATEGIC GOAL 1: ADVANCE INTEGRATION OF AQUACULTURE DEVELOPMENT AND ENVIRONMENTAL CONSERVATION

[12]National Research Council. 1978. Aquaculture in the United States: Constraints and Opportunities. A report of Committee on Aquaculture, Board on Agriculture and Renewable Resources, Commission on Natural Resources, National Academy of Sciences. 123 pp.

[13] Jensen, G.L. 2007. The evolutionary role of Federal policies and actions to support the sustainable development of aquaculture in the United States. Pages 179-207 *in* P.S. Leung, C.S. Lee and P. O'Bryen, editors. Species and System Selection for Sustainable Aquaculture,. Blackwell Publishing, Ames, Iowa.

[14] Executive Order 13563 of January 18, 2011, Federal Register / Vol. 76, No. 14 / Friday, January 21, 2011 / Presidential Documents, pg. 3821; http://www.gpo.gov/fdsys/pkg/FR-2011-01-21/pdf/2011-1385.pdf (accessed 2 January 2012).

The demand for sustainable practices that minimize harm to the environment, native species, or the potential for future production resonates globally in all agricultural production sectors, including aquaculture. Aquaculture is broad-based, producing animals and plants for food, recreation, bio-energy, and protection and recovery of threatened and endangered species and habitats. Successful aquaculture depends on ecosystem services such as the availability of clean water and nutrient cycling to process or reuse wastes and co-products. In addition, aquaculture production can have a variety of effects on the environment, depending on species, production system, and location. In the United States, aquaculture's environmental performance has improved dramatically during the past 20 years, driven by the need for efficient use of resources (due to rising costs of fuel and feed), public awareness of environmental issues, application of science-based best management practices (BMPs), technological innovation, knowledge about proper siting of facilities, and evolving aquaculture-specific environmental regulations at State and Federal levels.

Commercial aquaculture production in the United States operates under some of the most stringent environmental requirements in the world; likewise, Federal agencies adhere to sound science and BMPs when fulfilling their recovery and restoration missions. Aquaculture in the United States will continue to innovate and refine "environmentally sustainable" practices in response to competitive pressures to reduce costs (especially of feed and energy), environmental regulations, competition for sites, market demand for certified products, limiting freshwater supplies, and competing uses for the nation's coasts and waterways. Restoration of bivalve shellfish and recovery of threatened and endangered species provide a variety of ecosystem services and public and economic benefits.

Outcomes

- Enable sustainable aquaculture that provides jobs, products, and services in harmony with healthy, productive, and resilient freshwater and marine ecosystems.
- Ensure that Federal agency decisions concerning aquaculture are science based.
- Advance scientific knowledge concerning aquaculture and the effects of aquaculture on the environment; associated environmental challenges and benefits of aquaculture.
- Develop knowledge and tools to monitor influences in aquatic systems from global climate factors and ocean acidification for adaptive strategies for aquaculture development.

Milestones

- Expanded science knowledge that provides the necessary ecological and technological data, tools, and analyses to (1) effectively and efficiently improve and manage aquaculture development and species restoration, and (2) monitor, assess, and address any unacceptable adverse environmental effects of aquaculture.
- Practical models and spatial planning tools for inland, coastal, and marine ecosystems that predict the carrying capacity for various cultured aquatic species and consider the cost and feasibility of ecosystem-level management to appropriately site aquaculture activities and reduce or eliminate any potential adverse environmental effects of new and ongoing aquaculture activities.
- Innovative, efficient, and improved designs of, and operating methods for, aquaculture production systems that reduce energy and feed consumption per unit of output, avoid

potential unacceptable adverse environmental effects, and generate net environmental benefits.
- Identification and expansion of ecosystem service benefits of commercial and public aquaculture (e.g., water quality and habitat restoration due to shellfish planting and harvest operations, shellfish restoration).
- Development of innovative approaches to sustain financing of aquaculture activities that create and maintain ecosystems services (e.g., nutrient trading).
- Monitoring and assessment of the effects of climate change and ocean acidification on aquaculture and development of adaptation strategies.

Performance Measures
- Biological-physical-chemical models developed and utilized in coastal-zone marine spatial planning, permitting, and conservation planning.
- BMPs developed and disseminated for existing, new and expanding aquaculture operations.
- Case studies developed examining impacts and benefits of common aquaculture practices.

STRATEGIC GOAL 2: EMPLOY GENETICS TO INCREASE PRODUCTIVITY AND PROTECT NATURAL POPULATIONS

Unlike in much of terrestrial agriculture, wild progenitor populations still exist for the wide variety of cultured aquatic organisms. Likewise, domestication in most commercial aquatic species is only a few generations advanced in even the most intensively cultured species. Thus, aquaculture has the unique opportunity and responsibility to conserve natural (wild) populations while increasing the availability of nutritious and safe seafood and other products for consumers. To support the growth of seafood consumption in the United States and worldwide, domestication and genetic improvement of the agronomic traits of cultivated species is a critical R&D need. Furthermore, there is tremendous opportunity to apply genomic advances to agronomic improvement. Desirable production traits include disease resistance, fast and efficient growth, increased product yield, and lower input costs. Currently, fewer than 15 percent of all animals produced in aquaculture have been agronomically improved through selective breeding; many juveniles or seed stocks are directly harvested from wild populations or are the offspring of wild parents.

As genetic changes are made in cultured populations, the nature and likelihood of interactions of domesticated animals farmed in close proximity to wild populations must be understood in order to minimize potentially adverse impacts. Aquaculture faces the dilemma of domesticating and enhancing the agronomic traits of aquatic animals for commercial production while learning best science-based practices to successfully integrate commercial interests with protective measures for natural populations. Modern Federal efforts for stock restoration and recovery of imperiled species and stocking for recreation programs currently strive to minimize genetic impacts on wild stocks by ensuring that genetically appropriate animals are released into native waters. There could be opportunities for commercial companies to raise aquatic species for public restoration and recreation purposes, in addition to products for commercial markets.

Outcomes

- Define and conserve genetic variation and diversity in designated wild populations.
- Measure, monitor, and control the risks and potential genetic impacts of cultured populations on designated wild stocks.
- Use breeding and other genetic tools to rapidly improve the agronomic and production traits of aquaculture species.

Milestones

- Defined distribution of genetic variation within and between populations of interest for commercialization, augmentation, restoration, or recreation that will assist decision-making on which populations have the most potential for economic development or which natural populations are most sensitive to environmental perturbation and responsive to habitat restoration.
- Development and refinement of genetic risk models to aid in science-based regulation and management of commercial and public aquaculture activities.
- Development of techniques to reduce the risks of undesired genetic impacts on natural populations that can adversely impact sensitive native species or biodiversity priorities in natural systems.
- Development and implementation of genetic improvement programs with multitrait selective breeding for improved growth efficiency, specific disease resistance, and product quality that will maximize efficiency and sustainability of aquaculture and increase global competitiveness.

Performance Measures

- Population structure and sources of genetic diversity defined for key aquaculture species.
- Defined sources and magnitude of genetic impacts due to human activities on wild stocks.
- New tools for genetic improvement of farmed species and greater proportion of aquaculture-produced seafood from genetically improved populations.

STRATEGIC GOAL 3: IMPROVE AQUATIC ANIMAL HEALTH

Disease accounts for significant economic and ecological losses across the aquaculture sector. It is essential to control endemic, emerging, and catastrophic infectious diseases that cause commercial and restoration loss of aquatic animal production and restrict commerce and movement of live aquatic animals due to the potential spread of pathogens and parasites that cause disease. The National Aquatic Animal Health Plan (NAAHP) provides guiding principles and recommendations to industry, States, tribes and Federal agencies on actions to protect the health of wild and farmed aquatic animals (finish, mollusks, and crustaceans), to minimize the impacts of disease when they occur. While progress has been made in combating certain diseases through the use of vaccines and a limited number of approved drugs, significant losses still occur. The diversity of cultured aquatic species and associated pathogens and parasites is a significant challenge. There is great demand to improve the survival, growth, vigor, and well-being of cultivated stocks through improved technologies and practices. For example, a critical need exists to develop validated techniques for early and rapid detection of many diseases in order to prevent outbreaks and facilitate safe and timely commerce for the growth and competitiveness of U.S. aquaculture.

Research is needed to improve the characterization of causative agents of disease, their diversity, and basic epidemiological traits such as host and geographical range. Further, understanding of host immunity is needed in order to develop effective immuno-biologics, drugs, and pesticides that offer broad protection and improve mass delivery systems for these agents. Molecular tools allow new and comprehensive ways to examine host immunity and disease resistance and aid in the production of vaccines and development of specific pathogen-resistant broodstocks. Important targets for aquaculture animal health-related science and technology are to (1) increase the understanding of disease transmission dynamics, including carrier states, pathogen and parasite movements, and environmentally permissive factors; (2) advance the understanding of the interactions between cultivated aquatic species and natural populations from an aquatic animal health perspective; and (3) expand and standardize biosecurity practices within culture systems to reduce the spread of disease and optimize efficient disinfection.

Outcomes

- Develop improved surveillance and diagnostic technologies to support pathogen-free populations and broodstocks.
- Improve characterization of disease-causing agents, including genetic diversity, host and geographic range, and variation in pathogenesis and pathogenicity.
- Improve understanding of immunity using molecular tools and develop effective vaccines, drugs and probiotics for economically important species.
- Support and enhance public-private partnerships to identify, evaluate, and approve new aquatic animal drugs.

Milestones

- Increased availability of rapid, efficient, inexpensive, sensitive, and specific diagnostic and surveillance assays for detection and control of diseases to improve the competitiveness of aquaculture production, ensure biosecurity, and reduce impediments to domestic and international trade, as well as restoration efforts.
- Development of new tools to characterize pathogenic agents in terms of host specificity, geographic range.
- Development of new tools to identify and characterize host defense mechanisms important in immunity and to compare animals with resistant/susceptible phenotypes.
- Approval of well-designed, safe, and effective vaccines, drugs, probitoics, and pesticides that will improve the efficiency and competitiveness of U.S. aquaculture production.

Performance Measures

- Validated assays for disease detection, diagnostics, and surveillance and characterization of disease-causing agents that are widely used in laboratories and production sites.
- New and approved aquatic animal drugs, licensed biologics and vaccines, and registered pesticides for use in aquaculture.

<u>STRATEGIC GOAL 4: IMPROVE PRODUCTION EFFICIENCY AND WELL-BEING</u>

Efficient, effective aquaculture production systems reduce inputs, operating costs, and wastes and create optimal conditions for animal growth, adaptability, and reproduction. Defining optimal conditions requires a comprehensive understanding of the physiology of early development, growth, stress response, and reproduction. Feeding for maintenance and growth is

the most economically demanding input cost in animal production. Achieving the desired partitioning of nutrients into the competing systems of muscle development, digestive metabolism, health maintenance, and reproductive development is critical for improving productivity and reducing waste. Stressors caused by social, nutritional, and environmental factors and their interactions must be understood in order to limit adverse impacts on animal well-being that lead to poor health, sub-optimal growth and production efficiency, poor product quality, and excess environmental waste.

Outcomes

- Improve reproductive efficiency and early-life-stage development methods to enhance survival and juvenile availability.
- Enhance feed efficiency to improve growth and nutrient retention and reduce waste products.
- Develop novel tools to define and reduce fish stress and the impacts of production system stressors on fish well-being.

Milestones

- New practices to improve reproductive efficiency and successful early-life-stage development that will enhance productivity and cost efficiencies.
- Efficient growth and feed use that will lower input costs and reduce loss of nutrients to the environment, thus improving environmental sustainability.
- Improved animal well-being and product quality for broader consumer acceptance.

Performance Measures

- Controlled reproduction and high survival through juvenile stages of production, making juveniles more available.
- Improved well-being and efficiency, resulting in reduced feed costs and waste generation per unit of production.

STRATEGIC GOAL 5: IMPROVE NUTRITION AND DEVELOP NOVEL FEEDS

Although supplies of the key aquaculture feed ingredients, fish meal and fish oil, have been relatively constant for more than 30 years, the resource is limited. Aquaculture worldwide currently uses over 90 percent of available marine oils and greater than half of available marine fish meals. Therefore, if the culture of finfish and shellfish is to increase worldwide, sustainably produced or derived alternatives to fish meal and fish oil must be found and feed ingredients need to be used more efficiently. Feed costs are approximately 40 to 70 percent of the variable cost of finfish and shrimp culture. A global challenge is to identify novel feed ingredients and develop nutritionally complete diets that support optimal performance and animal health. Synergies may be found by working with bio-fuel co-products as feed ingredients. Prepared feeds are the main source of essential nutrients necessary for optimal growth, reproduction, and health in commercially produced aquatic animals. Care must be taken to ensure that feeds do not become a source of compounds that adversely affect the health and performance of the cultured aquatic animals or human health when the animals are consumed or have unacceptable impacts on the effluent.

Food and Drug Administration approval of new aquatic animal feed ingredients will be a critical step in novel ingredient development. The long-chain, highly unsaturated omega-3 fatty acids in marine fish processed for fish meal and fish oil are not produced by these forage fish, but rather by marine algae. They then accumulate through the food web and are stored in aquatic animals after consumption of prey or food items. The feeds produced and provided to cultured animals can be prepared to contain desired levels of these human-health-benefitting fatty acids. Fish meal and fish oil can be screened and if necessary processed to remove any contaminants to ensure that the feed is free of contaminants such as PCBs and heavy metals.

Outcomes

- Source and develop new sustainable protein and oil alternatives for cultured aquatic animals (food production and stock enhancement).
- Source and develop feed ingredients and formulated diets that support optimal performance throughout the complete life cycle and across traditional and new species of commercial and restoration interest.
- Determine the consequences of changes to aquatic animal diet composition on consumer acceptance and human health and nutritional benefits.

Milestones

- Availability of complete diets for traditional and new aquaculture species, with reduced reliance on fish meal and fish oil and exploitation of new and improved feedstuff products and co-products made in the United States.
- Improvements in development of sustainable aquafeeds that define and support the nutritional value of fish and shellfish to human health and well-being.

Performance Measures

- Commercially available novel ingredients that reduce reliance on marine fish meals as dietary protein and lipid sources.
- Specialized feeds for critical life stages, early development, and breeding to improve survival and productivity of farmed aquatic animals.

- Larger selection of ingredients for diets to reduce price volatility of feeds.
- Improved feeds that provide enhanced nutritional benefits to consumers of aquaculture-produced seafood.

STRATEGIC GOAL 6: INCREASE SUPPLY OF NUTRITIOUS, SAFE, HIGH-QUALITY SEAFOOD

Aquaculture products are becoming more prominent in seafood supplies, with seafood ranked among the top food products traded globally. Aquaculture food products contribute scientifically proven nutrition and health benefits to American consumers. Also, restoration aquaculture can expand fish populations to further contribute to domestic fisheries. Increased consumption of farmed and wild seafood supports national priorities to reduce obesity, early childhood diabetes, and the risk of chronic disease related to food consumption and improves cognitive and cardiovascular function. There is increasing scientific evidence from human nutrition and medical research on the healthful benefits of seafood consumption.

Outcomes

- Increase the supply of nutritious, locally available farmed seafood products that are affordable and meet the highest U.S. food standards of safety, wholesomeness, and nutritional value.
- Improve understanding of the factors and attributes that drive consumer preferences and choices for aquaculture foods to align new products to consumer preferences from farms to the markets.
- Develop innovative methods, technologies, and approaches to improve product processing, shelf-life, and packaging that promote human safety and product quality.
- Develop analytical methods for affordable rapid detection of microbial and biological toxins, chemical residues, and human pathogens of highest concern for farm-raised product.

Milestones

- Contribution by domestic aquaculture products to doubling the weekly consumption of seafood through improved consumer understanding about quality and safety of U.S. aquaculture products and their human nutritional value.
- Availability of more research-based information on the nutritional and quality attributes of farm-raised food products for use by nutritional educators and health professionals to inform the public about aquaculture and its desirable food products.
- Improved tools and knowledge so that producers and processors can develop new value-added and product forms to improve supply-chain management efficiencies from farms to consumers.

Performance Measures

- Increased number of seafood product forms, leading to increased seafood consumption by Americans.
- Better consumer understanding of the nutritional and organoleptic value of farmed seafood to improve acceptance.
- Attention to product handling and uniformity along the entire value chain to reduce product variability.

- Improved microbial and chemical residue detection and avoidance practices that enhance the safety of farmed seafood.

STRATEGIC GOAL 7: INTRODUCE INNOVATIVE PRODUCTION SYSTEMS

The current production systems for aquaculture in the United States include pond-based systems (e.g., catfish production); raceway systems (e.g., rainbow trout); near-shore and offshore net-pens and cages (e.g., Atlantic salmon); intertidal, off-bottom, and long-line coastal shellfish production; freshwater and marine algae production systems; and recirculation systems (e.g., salmon smolts, yellow perch, tilapia, oyster spat). There are significant opportunities to improve the performance and productivity of aquaculture production systems through advanced innovative engineering and new technologies. There is significant potential to adapt technologies and engineering solutions that at present are commercially employed in other sectors of the economy, such as municipal wastewater treatment, medicine, information technology, and energy, and to develop new system-specific technologies to aquaculture systems. Concerns related to global climate change, energy costs, and competition for resources underscore the need for technologies that support a sustainable industry by continually reducing costs while conserving natural resources and the environment.

Outcomes

- Develop innovative and cost-effective production systems and culture technologies.
- Improve the performance of aquaculture production systems that are compatible and integrate with animal well-being and ecological factors.

Milestones

- Increased production efficiency and reduced production and operating costs from technological innovations in rearing, feeding, transporting, and harvesting fish and shellfish.
- Development of systems requiring less water, feed, and energy resources to contribute to sustainable intensification of aquaculture.
- Production of animals similar to those found in the wild through systems designed for species restoration.

Performance Measures

- Farm production levels increase by 50 percent, with input (feed, freshwater, energy) use reduced by 10 percent.
- Improve effluent treatment technologies to significantly reduce or eliminate the escapement of aquatic nuisance species of significant environmental concern and discharged effluents meet water quality standards.

STRATEGIC GOAL 8: CREATE SKILLED WORKFORCE AND EFFECTIVE TECHNOLOGY TRANSFER

Aquaculture is dependent on progressive science and technological innovation to be competitive in world seafood markets, sustainable in development, and compatible with evolving social expectations. Continued U.S. R&D leadership will require building a next generation of human capacity in diverse scientific fields to find solutions to scientific, economic, social, and management needs of aquaculture systems, natural resources, and 21st century communities.

Public education and understanding of new areas of science, contemporary issues, and performance of diverse aquaculture systems create a scientifically literate population leading to sound policy-making. Science-based information, integrated with new information delivery systems, offers new outreach opportunities to the public and the aquaculture community. The purpose of Federal and university technology transfer is to efficiently integrate ideas, inventions, and technologies developed with both public and private funds into the production sector in ways useful for adoption. Unlike many other production sectors, most support for aquaculture R&D originates from Federal sources. Encouraging private sector involvement through cooperative and collaborative research ensures the relevance of research investments. Federally funded technology transfer is facilitated by collaborative partnerships with the commercial and non-commercial aquaculture community through cooperative R&D agreements.

Research and extension scientists, private for profit and non-profitbusinesses, professional societies, and industry associations all share a need to exchange information. International scientific partnerships and global communications can also accelerate technology development. Innovative approaches and new partnerships must optimize public benefits by solving critical problems and focus on strategic regional and national goals. New public policy choices and consumer preferences also raise new technology questions and drive the direction of future educational needs. Long-term development and sustainability of aquaculture will be determined, in part, by effectively connecting science, industry, and society, using innovations in education and technology transfer along with efficient communications amidst the dynamic changes in technology advancements and global competitiveness.

Outcomes

- Enhance and stimulate aquaculture education and training.
- Expand technology transfer (from research to implementation) through integrated research, extension and education projects, patents, Federal laboratories, and non-governmental organizations.
- Develop effective communication strategies to disseminate best-available, science-based knowledge, tools, and technologies.

Milestones

- A prepared and trained workforce with critical specialized skills to support future technology-driven industry growth.
- Full use of effective technology transfer mechanisms such as patents, cooperative R&D agreements, licensing agreements, public-private partnerships, incubators, and extension education partnerships to encourage the co-development of future generations of technologies.
- Enhanced dissemination of information through improved information exchange platforms and use of new information and communication technologies to provide timely, objective, science-based knowledge regarding aquaculture and its diverse products.

Performance Measures

- Development of a database of educational opportunities that facilitates programs to assess industry priority research and education needs.

- Models of discovery, technology development, scale-up, and transfer to industry developed through research-extension-industry partnerships
- Employment increase of 15 percent in aquaculture production and processing industries.
- Aquaculture-related businesses increase, spurred by public-private partnerships, of 5 percent per year.

STRATEGIC GOAL 9: INTEGRATE ECONOMIC AND SOCIAL SCIENCES

As interest in commercial aquaculture production and wild species enhancement and restoration through aquaculture has increased, so too has debate about the potential economic and social effects of aquaculture. In addition, the economic viability of domestic aquaculture continues to be constrained by regulatory, environmental, economic, social, market, industry, and technological factors that have been cited since the 1980s[10,11]. Economic and social challenges can include complicated and uncertain regulatory processes, market competition affecting the prices domestic seafood farmers and fishermen receive for their products, competition with other users of aquatic resources, and impacts to diverse cultural traditions and values.

Global market forces, for example, create economic and social pressures. The United States has a global reputation as a leader in aquaculture innovation, technology, and environmental management. Over the past decades, numerous aquaculture technologies and husbandry practices with tremendous commercial potential were pioneered in the United States. Our scientists and entrepreneurs helped to invent and advance farming techniques for salmon, shrimp, trout, catfish, oysters, clams, and mussels. Other innovative aquaculture practices designed to enhance species for commercial and recreational use (such as salmon, trout, bass, and redfish) are restoring endangered or threatened species (e.g., salmon, trout, abalone and corals) and rehabilitating critical habitat and aquatic ecosystems (e.g., oysters). The economic and social issues related to both public and private sector aquaculture goals often coincide because the species produced overlap and there is a shared need for the technologies to improve production while reducing costs.

Globalization has affected U.S. seafood markets beyond the increasing trade deficit. A significant, but difficult to quantify, percentage of aquaculture imports are partly based on exports of U.S. technology, investment, equipment, and feeds. U.S. consumers have benefited from lower-priced, abundant seafood available year round and imported from more than 125 countries, in large part from farmed supplies. U.S. equipment suppliers, feed manufacturers, and foodservice and retail companies have also benefitted from foreign business, investments, and imported products. But reliance on imported seafood has costs and risks. The United States has not captured the economic opportunity of the production and processing segment of the value chain or the opportunity for added employment in these sectors. Furthermore, imported aquaculture products are not grown under U.S. environmental, social, and food safety laws, raising some concerns about food safety, global environmental impacts, and social effects of imported products. In addition, some U.S. aquaculture producers have been affected by low-cost imports of the same or similar products.

Some aquaculture activities are located in public waters rather than on private land, or in public waters adjacent or within the view of private land. Securing approval for a new commercial or restoration aquaculture project in public waters can be a difficult and lengthy process. There are

many competing uses of public waters such as tourism and recreation, fishing, shipping, oil and gas facilities, and marine protected areas.

The economic and social value of aquaculture for enhancement and restoration and the links among commercial, enhancement, and restoration aquaculture need to be better understood. For example, State, Federal, non-profit and commercial hatcheries produce fish and shellfish for release to enhance commercial fisheries (e.g., pink and chum salmon in Alaska); supply recreational species (e.g., salmon, trout, bass, and redfish); restore endangered, threatened, or imperiled species (e.g., salmon, trout, paddlefish, abalone, and corals); rehabilitate habitat (e.g., oysters, aquatic vegetation); and mitigate for public fisheries lost as a result of water projects. These hatcheries create substantial economic value (commercial and recreational fisheries and related industries) or generate monetary and nonmonetary benefits of species and habitat restoration. Although some programs have been quantified, the total economic value of captive propagation and stock enhancement in the United States has not been estimated. As an example, up to 40 percent of the annual Alaskan commercial salmon catch is derived from hatchery-released fish. Whether hatchery releases increase the number of fish available to the fishing industry or contribute to declines in wild stocks is an area of active and needed research[15]. More than 30 million Americans fished in 2006, spending an estimated $41.0 billion on those activities and stimulating local businesses[16]. Many of these anglers, and the resultant economic benefits, depend on hatchery-reared and -released fish for sport and recreation.

A recent regional study[17] estimated that recreational anglers contributed an annual economic benefit of $1.9 billion in the western region of the United States alone. These expenditures resulted in 26,229 full-time jobs in the region. The top trout hatcheries of the Fish and Wildlife Service generated more than 3.9 million angler days, directly supported more than 3,500 jobs, and resulted in $325.0 million in total economic benefits to local economies, with a 60:1 return on expenditures [18]. The 123 million fish (all species) stocked by the National Fish Hatchery System generated more than 13 million angler days in 2006. The economic benefit associated with aquatic habitat conservation has an annual estimated economic value of $1.9 billion and 45,000 jobs[19].

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Outcomes

- Identify and resolve key regulatory, policy, socioeconomic, and environmental constraints to improve the economics of commercial aquaculture and public stock enhancement and restoration in the United States.
- Develop economic models to evaluate the relative cost and value of major cost components of aquaculture production, such as feed, survival, transporting, harvesting, processing, value-added processing, distribution, and marketing.
- Determine new collaborative and economic opportunities between the aquaculture industry, the commercial fishing industry, and the conservation community (e.g. product marketing and employment crossover).
- Evaluate and report developments in seafood market demand and trends, identify opportunities for domestic industry.
- Develop socio-economic models to assess and report economic and social impacts of U.S. aquaculture in job creation and economic, environmental, and social development terms.

Milestones

- Socioeconomic research that influences, informs, and supports new legislation, regulatory actions, and other management actions; land use or coastal zoning and ocean spatial planning; economic incentive programs such as revolving loan, loan guarantee, or insurance programs; public-private partnerships to foster locally supported and designed aquaculture initiatives; and outreach and education efforts.
- Development of agricultural economic sensitivity analyses for major aquaculture species that inform existing models and indicate systems research priorities.
- Market research that enables aquaculture producers to better respond to major trends that affect the profitability or competitiveness of U.S. aquaculture.
- Expanded seafood market demand met by complementary domestic aquaculture and fisheries activity.

Performance Measures

- Identification and analysis of changes in major cost components of aquaculture production.
- Identification of types of production, species, or regions where aquaculture will generate net economic benefits.
- Assessment of the monetary and nonmonetary benefits of Federal stock enhancement programs aimed at species and habitat restoration.
- Recommendations for legislative or regulatory actions; land use or coastal zoning and ocean spatial planning; economic incentive programs such as revolving loan, loan guarantee, or insurance programs; and public-private partnerships to foster locally supported and designed aquaculture initiatives.

PLAN IMPLEMENTATION GUIDELINES

The JSA, under the National Science and Technology Council, will serve as the coordinating agent for implementation actions in the Plan, as defined in its mission to "increase the overall effectiveness and productivity of Federal aquaculture research, technology transfer, and assistance programs" under the National Aquaculture Act of 1980[1].

Specific implementation actions include the following:

- Federal agencies should develop specific plans for managing critical Federal assets that align with Plan priorities and customer needs.
- Federal agencies should prepare a plan that identifies the most critical assets needed to maintain a core capacity and competency for the Federal role in R&D based on needs of the broader user community.
- Departments and agencies conducting R&D should engage industry, academia, and other non-Federal stakeholders in support of government planning and performance of Federal aquaculture R&D.
- Departments and agencies should improve dissemination of Federal R&D results and lower the barriers that prevent technology transition from R&D to applications.
- Departments and agencies should identify and promote innovative policies, regulations, and approaches that complement and enhance Federal R&D investments in realizing applications in aquaculture activities and field operations.
- The JSA, with support from the National Science and Technology Council, should develop and implement measures to improve coordination and cooperation and lower organizational barriers among departments and agencies to maximize available Federal government resources for public value.
- The JSA should promote and facilitate the exchange of technologies and breakthroughs between departments and agencies to maximize the effectiveness of Federal aquaculture R&D investments and effective outreach to maximize public value.

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