USDA AGRICULTURAL RESEARCH SERVICE

ARS NATIONAL PROGRAM 106

AQUACULTURE

RETROSPECTIVE PANEL REVIEW FOR THE YEARS 2013 TO 2017

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EXECUTIVE SUMMARY

A retrospective review of the ARS NP106 Program for Aquaculture for the years 2013-2017 was conducted in 2018 by an independent panel of experts. Spreadsheets, presentations, and other Program-provided materials that summarized NP106 research accomplishments and background information (budget allocations, publication lists, etc.) for the review period served as reference sources for the review panel and were the basis for the panel's review comments. The review comments fell in two categories: 1) Responses to General and Specific Questions provided by the National Program Leader; and 2) Ratings for each of the Problem Statements in the five Component areas of NP106's 2015-2019 Action Plan.

The Panel's conclusions were as follows:

SECTION 1A. RESPONSES TO GENERAL QUESTIONS

1) Did we do what we said we would do?

NP 106 scientists were very successful in meeting the expectations outlined for the three discipline-related components (genetics, nutrition, and health) and in production systems. They were less successful in the number, quality, and impact of results stemming from the Product Quality/New Products component. Of course, progress in the latter area may have been constrained by budget allocations and changes in research priorities.

NP106 research during the period for the most part addressed the Problem Statements in each Component and successfully met the challenges of delivering Anticipated Outcomes outlined in the Action Plans.

2) How well did we do it?

As a whole, the Panel agreed that the Program had accomplished its research mission exceptionally well, particularly in the areas of genetics and fish health. The fish nutrition program lacked consistency in innovation from the beginning (very innovative and relevant research) to the end (less innovative and relevant) of the review period. The sustainable production systems program area has done its work consistently well with high marks for relevancy but with less innovation than possibly needed for industry to keep advancing. For Product Quality/New Products, the Panel felt that, although the Program area made significant advances in off-flavor prevention and detection as well as product attributes, there were several projects that lacked relevance and practicality.

3) What was the impact?

There is no question that NP106's research program for aquaculture is the model for aquaculture research in the United States and possibly the world because of the expansiveness of its research including the disciplines, species and production systems

covered; its close ties, interactions, and relevancy to the industry; its reputation, as evidenced by the reliance of other academic, government, and industry laboratories on its partnership in research, and its publications and other products; and its adaptiveness to emerging issues.

4) Were customer's needs met?

NP106 has done an outstanding job interacting with the aquaculture industry, identifying what and where the most critical research needs are, and developing research programs that address both basic and applied science issues associated with those needs. Moreover, the speed at which NP106 scientists can react to emerging problems faced by the industry and solve them is noteworthy in itself.

5) Do we solve problems and/or make significant progress towards challenges in animal production?

NP106 scientists accomplish both very well. Their research addresses many of the current and upcoming issues faced by the national aquaculture industry. In their very competent and thorough planning and implementation process, NP106 scientists make significant progress toward expected outcomes and also often find solutions to certain issues. The program also has the foresight and capability to develop research plans that are more strategic in nature, addressing potential issues in the far future.

SECTION 1B. RESPONSES TO SPECIFIC QUESTIONS

1) Was NP106's research relevant to the needs of the industry and food animal production?

NP106's research in almost all cases closely followed the respective Action Plans developed with *a priori* input from the relevant industry stakeholders, and much of the research was conducted in collaboration with industry or on commercial farms. This was evident from programs developing strains of fish resistant to specific pathogens in concert with industry, developing practical vaccines, incorporating genomic selection methodology from livestock to application in trout and catfish, developing feed alternatives to fish meal and incorporating those ingredients into practical diets for Atlantic salmon and hybrid striped bass, adopting long-range plans for development of production systems for catfish, and to refine detection and prevention techniques for geosmin and 2-methylisoborneol off-flavors in fish reared in ponds and in recirculating aquaculture systems.

2) Was NP106's research innovative?

The research performed by NP 106 scientists was in many cases highly innovative. Examples include the 'genotyping by sequencing' approach, which was applied to wild and domestic blue catfish to develop thousands of markers (SNPs) for parentage/kinship determination, use of the "one health" approach to host-pathogen interactions, adaptation of biofloc methodology to enhance striped bass and tilapia production, and development of

a more efficient hatching tank design for catfish. On the other hand, the Panel felt that innovation declined in the Nutrition Component from the beginning to the end of the review period and was a concern in the Product Quality/New Product program area.

3) Did NP106's research advance the science?

NP106 scientists made significant advances. These included developing the genomic platforms and utilizing that information for genomic selection in rainbow trout and catfish for the first time in aquatic species. Other examples, among the many possible from this Program, include sequencing, assembling, and annotating the *Crassostrea virginica* genome; integrating genomic and genetic studies from both the host and the pathogen side and exploration of the immunological basis of disease resistance in breeding programs; developing a 75K SNP chip for genomic selection in channel catfish; and demonstrating the feasibility of gene editing as a useful tool in aquacultural genetics.

4) Was NP106 responsive to emerging issues associated with food animal production?

The Panel found that, because of NP106's close relationship with industry, it is very aware of emerging issues, and because of the Program's philosophy to be adaptive and flexible, it was found to be very quick in responding to those issues. A case in point was the development of effective vaccines for two emerging pathogens that were threatening the trout industries in North Carolina (*Weissella ceti*) and Washington state (*Lactococcus garvieae*). Also, NP106 research led to multiple design options to move water with greater efficiency and less maintenance in split-pond catfish production.

5) Did research in NP106 impact other government, university, and/or industry programs?

Collaborations between ARS scientists and government, universities and industry were numerous, diverse and broad. This is one of the most important aspects of USDA ARS programs since it keeps ARS scientists updated in terms of technology, the latest trends in the field and current problems in industry.

NP106 research is directly integrated into other government, university and industry research programs. During the review period, NP106 had a total of 7 Cooperative Research and Development Agreements, 75 Material Transfer Research Agreements, and filed 4 patents.

6) Were new or improved scientific methods and approaches developed and transferred or published?

NP106 scientists developed many new or improved methods and approaches that were transferred to other user groups and/or published. Their close association and collaborations with both academic and industry partners and their willingness to share data and information are conducive to technology transfer. In addition, it is obvious that

ARS scientists are strongly encouraged to publish their results in peer-reviewed and popular journals or industry newsletters as well as to participate in scientific and industry-sponsored conferences and meetings.

7) What was the quality of NP106's published work?

The quality of NP106's published work is very high based on the array of science journals in which they are featured. The quantity of publications may have slightly decreased over the review period, but at an average of two peer-reviewed publications per scientist per year, is still notable.

8) Did NP106 provide key tools, databases, and infrastructure for other animal production researchers?

NP106's most significant contributions were in the fields of genetics and fish health. In particular, the genomic sequences for rainbow trout, the Eastern oyster, channel and blue catfish, and Atlantic salmon stood out among the many tools developed by ARS scientists.

9) Did NP106 form effective partnerships with research cooperators and successfully leverage additional resources for its activities through these partnerships?

Much of the evolution of pond culture systems, such as the split-pond and biofloc technology, and development of the hybrid catfish industry could not have occurred without industry's support and cooperation. As another example, NP106's very successful and productive recirculating aquaculture research program would not have been possible without the cooperation of the Conservation Fund's Freshwater Institute.

NP 106 has demonstrated the strength and incredible utility of research partnerships with universities to expand its science enterprise. This is particularly evident with the research partnerships between smaller NP106 units and universities such as the ARS Hagerman Lab with the University of Idaho and the Columbia River Intertribal Fisheries Commission for genetics and nutrition studies of rainbow trout.

As still another example, ARS has developed key partnerships with other government agencies. A good example would be the joint research program with the US Fish and Wildlife Services laboratory at Bozeman, MT, the University of Arkansas, and Texas A&M University.

SECTION 2. RATINGS OF PROBLEM STATEMENTS IN THE 2015-2019 ACTION PLAN

COMPONENT 1. SELECTIVE BREEDING, DIRECTED REPRODUCTION, AND DEVELOPMENT OF GENOMIC TOOLS

PROBLEM STATEMENT 1A: GENOMIC TOOLS AND GENOTYPE TO PHENOTYPE

Review Team Rating: HIGH IMPACT

NP106 scientists completed or collaborated with research partners to complete reference genome assemblies for rainbow trout, catfish, and the Eastern oyster, and well-annotated transcriptomes for striped bass and white bass, which form the foundation upon which all future progress under this component will be based. In trout and catfish, they utilized next-generation DNA sequencing to detect 10's to 100's of thousands of sequence variants (e.g. SNPs) genome-wide; many of these markers are associated with phenotype and/or trait performance. For catfish, trout and Atlantic salmon, high throughput genotyping platforms, SNP 'chips', or other marker panels were developed to determine parentage/kinship and/or to predict performance with respect to traits associated with body growth, fillet yield and resistance to bacterial diseases and parasites. These markers and tools were deployed to selective breeding programs, and in several cases on commercial farms (see next section). In trout, this genome-based prediction of 'breeding value' for selection was shown to be far superior to traditional pedigree-based methods with respect to resistance to bacterial cold-water disease. Overall, the NP106 researchers made excellent progress in all areas covered by this problem statement.

PROBLEM STATEMENT 1B: DEFINE PHENOTYPES AND DEVELOP GENETIC IMPROVEMENT PROGRAMS

Review Team Rating: HIGH IMPACT

The DNA markers and marker-detection platforms developed under Component 1 were immediately adopted in research and breeding programs for detecting parentage and pedigree and to identify markers associated with performance regarding key traits such as growth and resistance to disease. Said markers were promptly exploited for genomic selection to improve resistance to bacterial cold-water disease in trout, susceptibility to sea lice infestation in Atlantic salmon, and growth and carcass yield in both channel and blue catfish. The genetic improvement program for Eastern oysters was launched with genome sequencing, the discovery of significant line X site interactions and a genetic basis for predator avoidance behavior. Overall, NP106 made outstanding progress in meeting the goals of Problem Statement 1B.

PROBLEM STATEMENT 1C: ENHANCE AQUATIC ANIMAL REPRODUCTION

Review Team Rating: HIGH IMPACT

NP106 scientists made significant advances in the field of fish reproduction. The accomplishments were wide in scope including developing practical protocols for

inducing ovulation and maturation in channel catfish, evaluating sire effects in blue X channel catfish hybrid crosses, and preserving blue catfish sperm for improved germplasm and preservation of genetic material. Scientists performed some pioneering research on epigenetics in which they discovered that striped bass fertility was correlated with sperm DNA methylation at 171 differentially methylated regions between low and high fertility spermatozoa. In still another spinoff from the genome sequencing advances referred to in Problem Statement 1A, NP106 scientists discovered through transcriptome analysis that trout eggs of low, medium, and high survival differentially expressed transcripts. These two more basic science accomplishments provide still more promising tools for fertility research and broodstock selection.

COMPONENT 2. NUTRIENT REQUIREMENTS AND ALTERNATIVE PROTEIN AND LIPID INGREDIENTS

PROBLEM STATEMENT 2: DETERMINE NUTRIENT REQUIREMENTS AND EVALUATE THE NUTRITIONAL VALUE OF ALTERNATIVE SOURCES OF PROTEIN AND LIPID

Review Team Rating: MEDIUM IMPACT

NP106 scientists are addressing contemporary issues within nutrition by evaluating alternative feed ingredients for targeted species. Work on defining nutritional requirements appears to have been deemphasized in this reporting period. Significant variation between project periods and within periods was apparent. For example, research programs focused on catfish reported more accomplishments than other species groups in both project periods and that program was incorporating innovation in nutrition studies during the 2010-2015 period by examining molecular mechanisms of growth related to nutrient intake. Programs focused on rainbow trout and Atlantic salmon did not report the same level of accomplishments in materials received by the review committee, although one subcomponent (selection of trout strains that can elongate and desaturate n-3 fatty acids) might have a significant impact in the future. Programs focused on tilapia were comparatively active, particularly given the funding levels across species groups. Work on bluegill, yellow perch and hybrid striped bass appears to have a much smaller emphasis within ARS programs.

COMPONENT 3. HEALTH OF AQUATIC ANIMALS

PROBLEM STATEMENT 3A: IMPROVE UNDERSTANDING OF HOST IMMUNITY, IMMUNE SYSTEM EVASION BY PATHOGENS, AND DISEASE-RESISTANT PHENOTYPES

Review Team Rating: HIGH IMPACT

The ARS team has made significant advances in the understanding of pathogen genomics and virulence factors and in the characterization of disease-resistant phenotypes. Overall, the Program did an excellent job with a very high number of publications in solid journals mostly focused on pathogens. Functional immune studies were perhaps lacking. Most of the work was performed at the gene level using 'omics approaches. Complementary approaches at the protein and cell level would be beneficial including collaborations with new partners at other academic institutions.

PROBLEM STATEMENT 3B: CONTROL OF PATHOGENS AND PREVENTION OF DISEASE

Review team rating: MEDIUM-HIGH IMPACT

This problem statement included use of chemotherapeutants and antibiotic alternatives to eliminate fish pathogens during outbreaks as well as development of vaccines to prevent outbreaks. Several outstanding projects and accomplishments were reported within this subcomponent. Three new vaccines were developed and rapidly implemented in the field. The rapid development and implementation have already contributed to halting or significantly reducing disease losses in U.S farms. Further research should be devoted to alternatives to antibiotics and drugs with reported resistance.

COMPONENT 4. SUSTAINABLE PRODUCTION SYSTEMS

PROBLEM STATEMENT 4A: IMPROVE TECHNOLOGIES FOR RECIRCULATING AND FLOW-THROUGH PRODUCTION SYSTEMS

Review Team Rating: HIGH IMPACT

NP106 scientists have developed a strong and very productive partnership with scientists from the Conservation Fund's Freshwater Institute. During the 5-year period of this review, the partnership has produced significant advances towards improving the commercialization of recirculating aquaculture systems for salmonid production. Relevance, innovation, and advancing the science of RAS have been noteworthy characteristics of this program.

PROBLEM STATEMENT 4B: ENHANCE CONTROL OF POND-BASED ECOSYSTEMS TO MAXIMIZE PRODUCTION AND PRODUCT QUALITY

Review Team Rating: HIGH IMPACT

Two strong characteristics of this research program are the relevance of the science it conducts and its successful transfer of technology through close relationship with industry. It has been very successful in both areas, in part also because of the maturity of the program and its ability to attack issues incrementally over protracted periods of time.

The Review Team recommends that follow-up research be conducted to determine whether the initially high impact results are sustainable.

The successful history of this research program illustrates that, for cultured species with a multi-year growth cycle, it is imperative to fund projects through to harvest as commercial conditions continuously vary and may not be apparent in single-year studies.

PROBLEM STATEMENT 4C: DEVELOP SHELLFISH SYSTEMS TO MAXIMIZE PRODUCTIVITY AND ENVIRONMENTAL COMPATIBILITY

Review Team Rating: MEDIUM-HIGH IMPACT

Despite its limited size, this primarily West Coast research group was very successful in achieving the anticipated outcomes for the problem area. This was possible in part because of the strong partnerships that the program has developed with universities, industry, and state agencies in the region. The discovery that oyster aquaculture has minimal effects on the eelgrass community at the landscape level was highly significant for land-use management decisions at the state level while the recruitment model for burrowing shrimp will play a large role in developing integrated pest management plans for the oyster industry.

COMPONENT 5. PRODUCT QUALITY AND NEW PRODUCTS

Review Team Rating: LOW-MEDIUM IMPACT

The principal accomplishments in the Component were in consolidation and compilation of detection techniques and thresholds for off-flavor in catfish and salmonids and determining flesh characteristics of catfish through a trained sensory panel and use of a mechanical texture analyzer. While the discoveries were relevant for industry, the projects in this Component generally lacked the innovation, scientific rigor, and overall impact observed in the rest of the program. The Panel urges a careful review of the overall mission of this component.