Strengthening Strategic Genetic Resources for Livestock, Poultry and Aquatic Species in the United States

USDA National Genetic Resources Advisory Council

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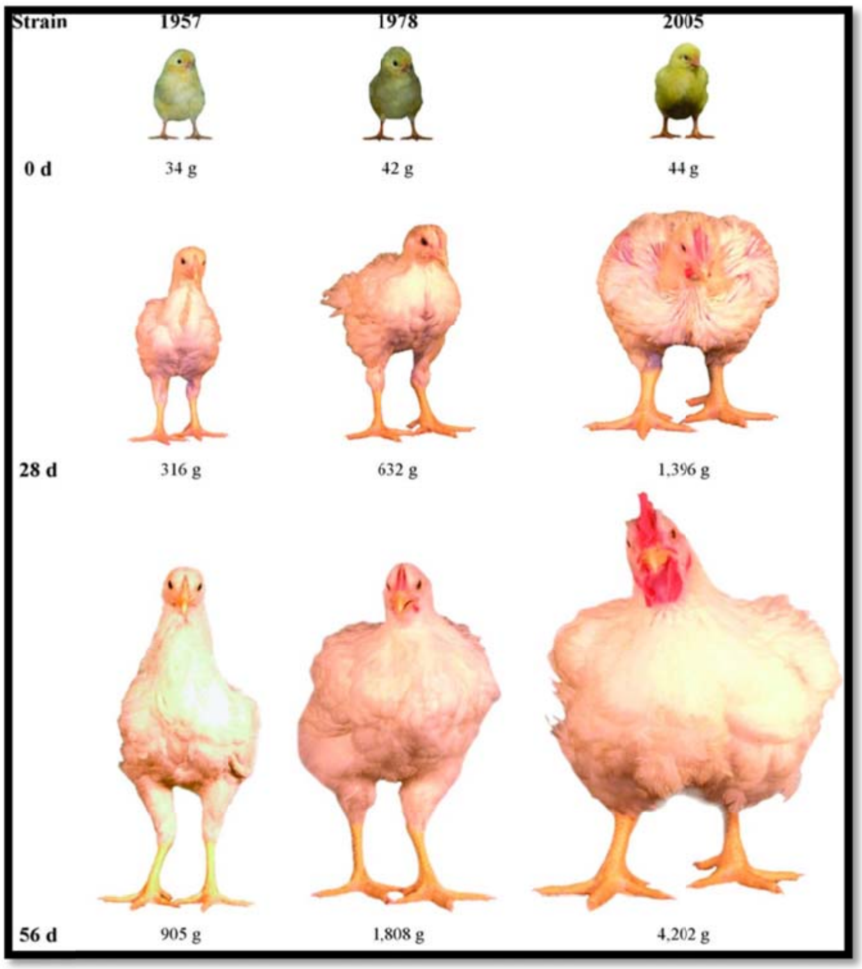

Executive Summary

Globally, the United States is the primary provider of high-producing animal genetic resources for food production. In essence, the animal sectors of US agriculture have become a new center of global genetic diversity. Although this provides benefits, it also presents challenges. For example, increases in animal productivity have resulted in a contraction of genetic diversity placing these resources at risk in a variety of ways including the emergence and spread of genetic mutations that are lethal or counterproductive.

Safeguarding these valuable genetic resources is paramount to protect the future of animal breeding in the USA for further genetic advances and improvement of global food security. To provide genetic resource security the USDA has established a gene bank for livestock and aquatic genetic resources. As most of these genetic resources are owned by the private sector, gene banking has and will continue to require public-private partnerships. To date the USDA-ARS collection in the National Animal Germplasm Program contains more 1 million samples of germplasm and various tissues from more than 50,000 animals. Through a publicly accessible database (Animal-GRIN) stakeholders can view this collection and information about the various animal populations and the animals themselves. To date the collection has been used to address a variety of industry and research problems.

The USDA NAGP collection of animal germplasm is the world's largest, but substantial efforts and additional support are required to fully secure the future of US genetic resources and animal improvement. In this document a set of recommendations have been developed to further strengthen US efforts to secure and maintain genetic variability for future use. These recommendations seek to make USDA's efforts more comprehensive and facilitate closing of gaps in genetic conservation efforts. The document suggests strengthening: the National Animal Germplasm Program, increasing the scope of activities for emerging aquatic genetic resources, working with small and disadvantaged livestock producers to conserve genetic resources and increase their capacities to produce livestock more profitably, and support the scientific community's efforts to establish, maintain, and use important research populations that contribute to numerous food security initiatives.

Strengthening Strategic Genetic Resources for Livestock, Poultry and Aquatic Species in the United States

Livestock and aquatic genetic resources underpin our ability to feed our nation, and provide the basis for continued US leadership in exporting genetic resources around the world. The United States contains and utilizes a vast array of animal genetic resources by a broad spectrum of stakeholders ranging from large-scale commercial agriculture, small and disadvantaged farmers, and Native American peoples. Across this spectrum animal genetic resources are consistently utilized to increase the quantity and efficiency of livestock production ensuring that consumers have nutritious low-cost foods and producers have sustainable profitability.

While geneticists and breeders have successfully improved animal productivity through genetic resource utilization there has been a long-term contraction in effective population size across all livestock species which has reduced the genetic resource base. For example, beef cattle numbers have decreased to approximately 32 million breeding cows, a low that is equivalent to 1952 levels. Inventories of sheep (5.2 million) and goats (2.1 million) continue long-term declines. These larger industry-wide trends are also observed among various species and breeds, for example, the 34% decrease in Angora goat numbers from 2004 to 2016 is critical as Angora play an important role in the west Texas livestock sector and are the Nation's primary source for mohair.

The USDA-ARS National Animal Germplasm Program (NAGP) provides essential services to production industries for livestock and aquatic species by assessing genetic diversity, collecting germplasm and tissues, and preserving genetic resources in the world's premier animal gene bank in Fort Collins, Colorado. Working through a dynamic network of industry and public sector participants, germplasm accessions from 3,497 different livestock and aquaculture breeders across the United States have been secured in the collection since 2000. Although a large number of genetic diversity assessments have been made and substantial germplasm has already been placed in the national collection, the current efforts need to continue and be expanded to address new and emerging issues in animal agriculture, especially for emerging sectors in aquatic species.

This document was drafted by members of the National Genetic Resources Advisory Council (NGRAC) after extensive discussion. In formulating the document and recommendations, input was sought from approximately 45 livestock and aquaculture experts representing industry, universities, non-governmental organizations (NGOs), and government agencies. The document identifies and suggests possible approaches that will lead to greater protection and utilization of genetic diversity among animal species that are used for food and fiber production for large-scale commercial agriculture and small and disadvantaged farmers. This document has been divided into major thematic efforts that require additional support to augment existing USDA-ARS programs, and includes a list of recommendations. Examples are provided below to illustrate main themes that come from established livestock industries and aquaculture.

Background

Livestock and poultry in the US generate farm gate receipts of approximately $100 billion annually and it is expected to grow over the next 10 years (Figure 1). The demand for meat and dairy products in domestic and international markets is expected to remain strong and, as a result, production of all of these will increase over the projected period (USDA, 2016). A similar situation also exists for aquatic species with even greater growth potential in the coming decade (described below).

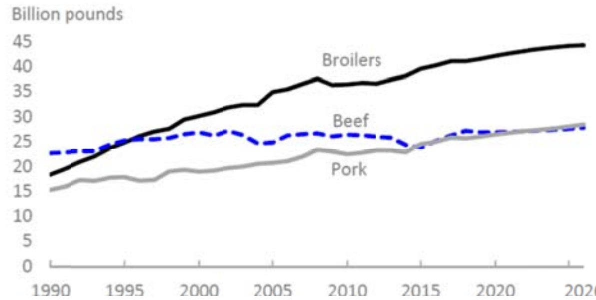

Figure 1. Red meat and poultry production in the US.

In general, the size of livestock populations has decreased, in part due to increased productivity (Figure 2). The current dairy cattle inventory is 9.3 million cows, with an equal number of replacements being raised. The US swine breeding herd consists of 5 million sows that produce 112 million market pigs annually. In addition, the $45 billion broiler industry produces more than 36.9 billion pounds of meat annually from chicken lines (e.g., Cobb500) which can reach market weight in less than 63 days.

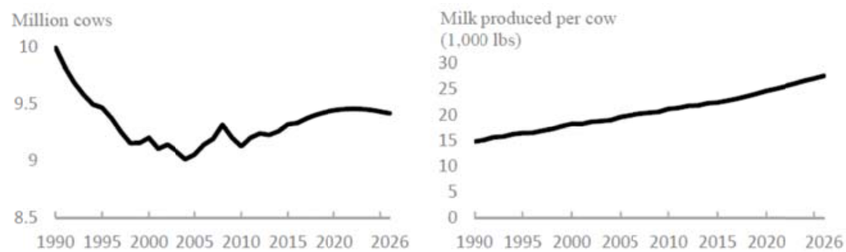

Figure 2. Dairy herd and milk production per cow in the US.

A large component of increased productivity, particularly for swine and poultry has been the ability to intensify management and operations through concentration (Figure 3). This has facilitated genetic progress. For chicken (egg laying and broiler) and swine production, industries have focused on specific breeds from which they have developed commercially available lines. For chickens, egg production is based on the Leghorn (white bird/white egg) and Rhode Island Red; while broiler production tends to be based on Plymouth Rock and Cornish breeds. Swine production is currently being based upon the Yorkshire, Landrace and Duroc breeds.

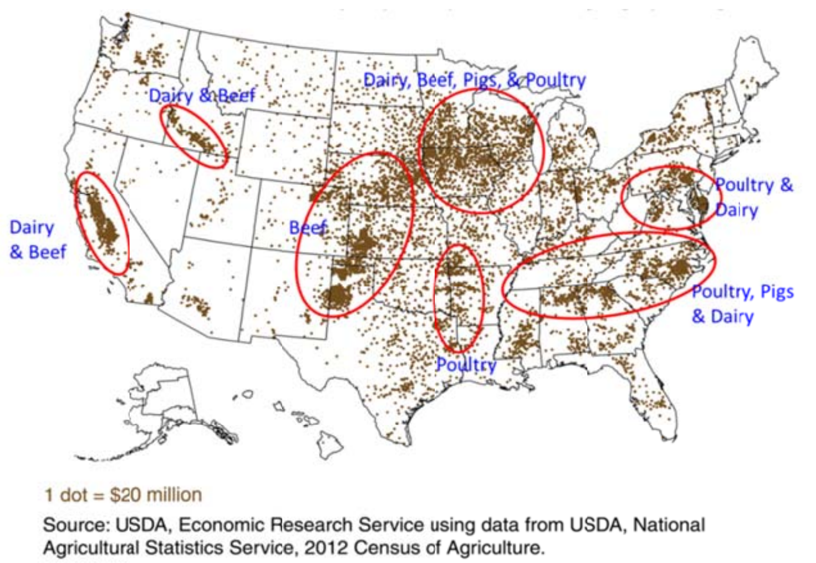

Figure 3. Market value of livestock, poultry, and their products sold in 2012. Red circles indicate major species produced in a geographic region.

Duroc is used as the paternal and terminal sire breed where it is estimated that 60% of all pigs marketed are sired by this breed. The distribution of livestock and poultry production is diverse, underscoring the need for genetic diversity to cope with different environmental and management conditions.

Aquaculture is even more diverse than livestock or poultry production, and this diversity translates into organism-specific requirements often seen as geographic or environmental limits on production (e.g., rainbow trout require cold, clear water). The USDA Economic Research Service (ERS) has noted a rise in aquaculture production due to steady increases in demand and declining wild harvest of many seafood species. In 2014 the value of US aquaculture was $1.3 billion from freshwater and marine sources. This includes production from five major species groups for freshwater (catfish, striped bass, tilapia, trout and crawfish) and five marine groups (salmon, oysters, clams, mussels, and shrimp). Most marine harvest value comes from fisheries of the Atlantic (49%), followed by fisheries of the Pacific (37%), and Gulf of Mexico (14%).

Economic Impact of Genetic Resources

The pronounced gains in livestock productivity have been achieved via genetic improvement and this is entirely based upon having access to genetic variability. Over the past 30 years 50% of the increase in milk production (from 15,000 pounds/lactation to 24,000 pounds/lactation) has been due to genetic improvement. The increase in litter size, from 8 pigs per litter to 10 pigs per litter from 1994 to 2014, which results in an extra 6 pigs per sow per year has been the result of producer-directed genetic change. Similarly, remarkable industry-sustaining gains have been achieved by selecting for weight gain in broiler chickens (Figure 4). All of these biological changes have benefitted US livestock industries by making production more profitable and biologically efficient resulting in greater consumer savings and increased global food security.

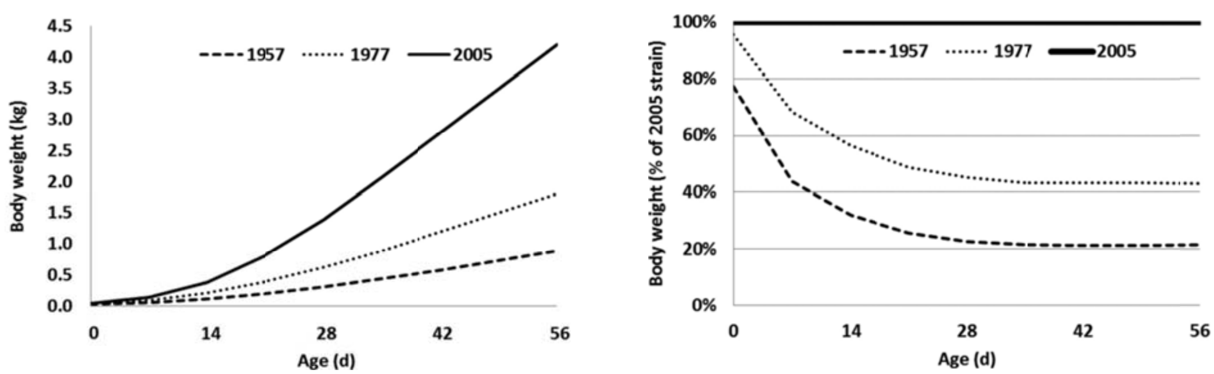

Figure 4. Absolute (left panel) and relative (right panel) body weights of mixed-sex broiler chickens (University of Alberta Meat Control unselected) since 1957 and 1977, and a modern breed (Ross 308 broilers).

In addition to serving domestic livestock sectors, breeding companies are actively engaged in lucrative markets based on exportation of genetic resources. For example, it is estimated that 50% of global broiler chicken production is based on genetics developed by a single US company. For bovine genetics the US is globally predominant. In 2016 the US exported ~ $142 million of bull semen for use in other countries vs. domestic sales of $20 million.

Genetic Base

Growth projections made by USDA-ERS are made under an assumption of continued genetic progress and therefore highlight the need for access to genetic diversity to continue the historic increases in production efficiency. Fortunately, the US has a broad array of genetic resources as a result of breeder sampling across geographic regions over time. This accumulated diversity has in turn been refashioned in accordance with industry demands and has led to development of new breeds and populations. As a result of this vibrancy, many of the breeds developed or extensively modified in the US have become the most prevalent in the world, for example, the Duroc pig, Leghorn chicken, and Brahman, Holstein and Hereford cattle. That said, there is an overall contraction in genetic diversity that started with the initial formation of breeds in the 1700's. *In order to maintain or improve upon previous success, genetic resources must be actively surveyed, evaluated, maintained, and utilized. This is not possible for animals without fully functioning, comprehensive, germplasm repositories. In that context, repository activities that support exploitation of germplasm and genetic resources constitute a strategic resource for the US and the basis for its agricultural industries.*

As stated above, dairy cattle breeding has been enormously successful in improving milk production via genetic selection. Currently over half the increase in milk production per cow is due to genetic improvement alone. In 2016 the U.S. exported more than $142 million in cryopreserved dairy semen. Highlighting this genetic flow are bulls such as Jenny-Lou MRSHL Toystory-ET, born in 2011, with 155,740 daughters in 28 countries. Evaluation of genetic resources suggests that there are few remaining alleles in the global population that have not already been catalogued and accessioned. This situation suggests that the US could be considered as the current center of origin for commercially important animal genetic diversity, which makes it all the more important to protect the genetic variability available across the country. In addition to commercially important breeds, the US contains a wide variety of breeds that harbor potentially useful alleles or allelic combinations that are not yet exploited. Such populations can be found among producers with varying levels of sophistication and operation size, in university research populations, and in geographically isolated populations. For example, Chirikof Island, in the Aleutian Islands of Alaska, is home to feral cattle thought to have originally come from Russia more than a century ago; these cattle represent a unique opportunity for understanding how natural selection influences cattle viability under extreme climates.

Another example of valuable genetic diversity is the Duroc breed, which was developed in the United States and is one of the most genetically diverse pig breeds in the world. Comparison of genetic composition from feral pigs in Guam and two different Hawaiian Islands indicate unique linkages to China and an unknown source when compared to commercial and rare breed populations in the continental US (Figure 5). This example illustrates the vast array of genetic resources potentially available for the livestock, poultry, and aquatic sectors to capitalize on for future genetic improvement.

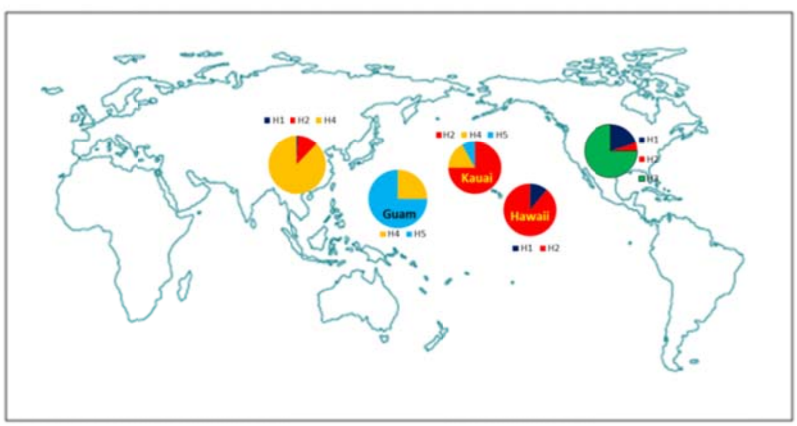

Figure 5. Frequencies of Y chromosome haplotypes from geographically distinct pig populations.

This situation is even more prevalent in aquaculture species, as the strains and commercial populations in production are recently derived from wild populations, and thus tremendous unexploited genetic diversity still exists and needs to be catalogued, maintained, evaluated, and utilized. For example, developmental work in disease resistance or expanded commercialization of hybrid catfish has the potential to significantly improve production and profitability.

Genetic Trends for Animal Industries

All livestock and poultry species and breeds share a common genetic resource problem to varying degrees: there is a global contraction in genetic diversity. In the *Second Report on the State of the World's Animal Genetic Resources for Food and Agriculture* (2016) an effective population size (N_e)of less than 50-100 animals was considered to be an indication that a breed could be undergoing a contraction in genetic diversity that could negatively alter its ability to compete among national and global markets. To appreciate this concept we only need to look at Black Welsh Mountain sheep, Oberhasli goats, and Holstein dairy cattle, which all have an N_e of less than 50 animals. While Black Welsh Mountain and Oberhasli have small *in-situ* populations (less than 5,000 animals), the Holstein is the most populous dairy breed in the world (with ~ 8 million head in the US alone). For large breeds such as Holstein this has manifested itself as a significant reduction in effective population size (genetic diversity) to the equivalent of ~35 animals, despite millions of individuals. The recent finding that US Holstein only have two distinct Y chromosome variants and the observation of fertility problems indicate how limited genetic diversity can impact the productivity of major breeds.

Likewise, commercial poultry production is dependent upon highly uniform lines of meat and laying chickens. There is a general agreement that genetic variability has become limited in these populations. Additionally, data show that only a limited proportion of genetic variability can be recovered by crossing such populations. The swine industry has focused heavily on using the Yorkshire, Landrace and Duroc breeds. However this industry has also been receptive to using other breeds like Berkshire as consumer demand shifts in meat quality have occurred. All dairy breeds, except Guernsey, have effective population sizes of less than 100 animals. *Given the large actual sizes of Holstein and Jersey populations, and the other examples above, this clearly underscores the point that the declining genetic diversity of populations within major breeds is a significant concern that needs to be monitored and efforts to ensure genetic resilience are essential to long-term robustness of these populations.*

This is especially relevant because tight financial margins make the use of commercially inferior breeds or lines unsustainable for nearly all commercial dairy cattle breeders. Moreover, there are around 50 beef breeds in the US, and of these there are only approximately 13 breeds that have a substantial commercial presence. Based upon annual registrations of purebred cattle between 2000 and 2015 there has been an average contraction in population size of about 36% for 9 of the breeds and an average decrease of 17% for all 13 breeds. The population contraction within beef breeds presents an additional insidious loss of diversity that is not largely recognized in the industry. The breeds undergoing contraction are also rapidly losing their breed identity because of crossbreeding programs in an attempt to meet short-term market demand for Angus-like traits. Thus by responding to temporary market shifts, breeders can be undermining the long-term stability of pure-bred cattle. This situation clearly demonstrates yet another need for well-established germplasm repository activity to protect valuable genetic resources.

Therefore, the general conclusion from evaluating genetic diversity at the breed level is that population size *per se* is not indicative of genetic variation, and that maintenance of genetic diversity for all breeds should be an existential concern for animal industries and the USDA-ARS. There are a number of actions that need to be taken given the small effective population sizes for many breeds and the available infrastructure at the industry level to support management and utilization of genetic resources.

Aquaculture in particular is confronted with significant opportunities and challenges in management and utilization of genetic resources. In aquatic species genetic differences between production and wild populations are generally small because of short domestication periods. However, due to large array of biotechnologies that are used to implement genetic changes in aquatic species (well beyond what is possible for mammalian species), there is great potential for genetic bottlenecking to occur at a rapid pace. For example, even using traditional breeding methods it is possible for single matings to generate thousands (e.g., trout or catfish) or millions (e.g., striped bass or oysters) of progeny. As a result effective population size could rapidly decrease. Additional technologies such as hormonal sex manipulation (e.g., producing XX "neomales"), chromosome set manipulation (e.g., polyploidy and monosex inheritance), and the ease of producing hybrids (such as the channel catfish x blue catfish hybrid which now comprises most of the industry) can also create rapid changes in the genetic structure of commercial populations.

Industry Structure

Unlike plants, genetic improvement for livestock and poultry is completely controlled by private breeders and there is little public-sector ownership of breeding populations. These breeders range in terms of herd size from a dozen to thousands of animals and their level of expertise is equally diverse. For aquatic species there are more public-sector breeding programs, but industry is increasingly taking over this role. Across animal lifeforms there is no ability to patent various populations that may be developed; and in most instances highly developed populations are treated as trade secrets. Thus, genetic advances are vulnerable to loss due to a lack of systematic incorporation of germplasm in repositories. For example, if commercial broiler breeding companies were to regularly deposit elite germplasm with the NAGP it would be much easier for them to resolve genetically mediated problems like white striping which lowers meat quality.

Commercial beef cow numbers dropped to one of the lowest points in modern history (i.e., 1950's level) during the 2008 to 2009 recession and have recently shown some recovery; however, it appears that calf numbers may not be increasing with this recovery, except for Angus. The sheep and goat industries have also contracted in size. Producer focus has shifted from larger to smaller operations and there has been a tendency for these industries to move toward the southeastern US. Due to the private nature in which genetic resources are held, the conservation of animals must be conducted in close collaboration with industry. Such collaborations take the form of germplasm collections for repository purposes, providing assessments to industry of the status of their genetic resources, technology transfer, and providing access to information (e.g., collection status, genotypes, and breed comparisons). These capabilities are not sufficiently available to meet the current needs.

Aquatic Species
A recent assessment of the genetic resources available to US aquaculture was presented in the *United States Country Report* to FAO for *the State of the World's Aquatic Genetic Resources*. According to that report, US aquaculture contributes directly to seafood supplies, and plays important roles in supporting commercial and recreational fisheries, conserving genetic diversity, and can assist in restoring threatened and endangered species. Aquaculture can be an important factor in maintaining healthy and productive freshwater, coastal, and marine ecosystems. It can assist in rebuilding of overfished wild stocks, restoring populations of endangered species, restoring and conserving aquatic habitats, balancing competing uses of aquatic environments, creating employment and business opportunities in rural inland and coastal communities, and enabling the production of safe and sustainable seafood. Technological advances that support expansion of aquaculture will require continued investment in genetic improvement programs, including application of breeding strategies originally developed for plants and terrestrial animals. Currently, approaches to broodstock development are species-specific and range from obtaining gametes from wild stocks, mass selection based on individual performance, family-based quantitative genetic selection, and marker-assisted and genome-enabled selection.

In addition to these approaches, some applications take advantage of specialized breeding technologies to optimize production efficiency, such as cross-breeding for heterosis (improved characteristics); chromosome set manipulation to produce triploids that focus energy towards growth instead of sexual maturation, and production of mono-sex populations that take advantage of sex-specific traits in growth characteristics. All of these approaches have demonstrated varying levels of effectiveness for adapting populations to production systems that provide consumers with quality seafood and non-food products. These and similar approaches are increasingly important for reducing antibiotic usage and production costs, formulating fish feeds with sustainably produced ingredients that maintain the health benefits provided by seafood, and adapting production animals to stresses associated with climate extremes. Continued development and application of these and newer technologies to additional species will enable responsible production of aquatic animals and enhance economic opportunities for the United States. The natural genetic resources of these animals, plus those developed by breeding programs, are currently not properly protected in repository settings despite the recent availability of suitable cryopreservation methods and systems for high-throughput processing.

Wild, Feral and Semi-domesticated Populations Used for Food Production
Wild, feral and semi-domesticated populations represent species such as: pollinators (i.e., wild honey bees or those raised by bee keepers), finfish (e.g., catfish, salmon, trout), mollusks (e.g., oysters, clams), pigs (especially on west Pacific Islands), cattle (found in the Aleutian Islands) and bison. *The rate at which these species are being used for food production is variable, but for many of these life forms wild populations are the basis for introduction of genetic variability into the populations that are directly used for commercial food production.* Furthermore, the role that many of these species play in supporting traditional lifestyles of Native American communities cannot be understated. Unfortunately, many of these lifeforms will be among the first to be impacted by climate change and other factors that degrade the environment.

Populations Held by Public Institutions
Across life forms there has been a steady contraction of research populations, principally due to the financial costs and shrinking budgets involved in maintaining these specialized lines.

Significant efforts have been made to secure these populations at the NAGP, and currently more than 120 research populations are being stored. It has been shown that cryopreserved storage of research populations is about 90% cheaper than maintaining these genetic resources as live populations, especially for poultry. That said, public institutions are unsure at this point in time how to best protect and utilize genetic resources that are being held in repositories. Therefore opportunities exist to develop new models for the formulation of research populations and their utilization.

Information System Development

Information is fundamental to understanding genetic resources as well as for planning their future uses. The Animal-GRIN system was developed at NAGP and provides the backbone for animal genetic resources information, and will facilitate the long-term storage and public availability of animal genomic data generated by USDA funding. In addition, other countries have expressed a desire to use Animal-GRIN for their national genetic programs as well (e.g., Brazil, Canada, Mexico, Philippines, and Columbia). There are a number of components and interactions necessary for realization of a comprehensive germplasm repository that can be used to develop, maintain, and distribute genetic resources (Figure 6). The value of information (e.g., genomic analyses) and samples is magnified as more components are integrated for specific genotypes, individuals, populations and species within the repository system.

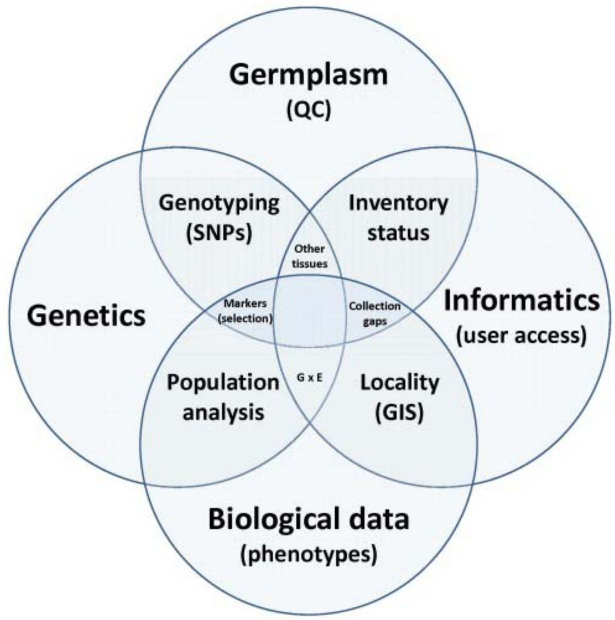

Figure 6. Collections can include a variety of tissues, and genotyping can be used for marker-assisted selection, to specify needs in the collection, or identify Genotype x Environment (G x E) interactions. As such, comprehensive repositories are much more than collections of samples. Information must be tightly integrated with inventory and be made available to user groups through a robust interface.

The Role of the USDA-ARS National Animal Germplasm Program

The NAGP serves as the lynchpin for conserving livestock, poultry, and aquatic species in the US and beyond. Since its inception in 1999 the program has been acquiring animal genetic resources and releasing selected material to industry and research communities. Globally it is recognized as the largest collection of animal genetic resources. Substantial quantities of germplasm and tissue are held by this program, approaching 1 million catalogued accessions. Livestock breeder involvement with acquisition of germplasm has helped keep project costs low, at approximately $1 per US livestock producer per year. However, as the program seeks to expand the genetic diversity of the collection, costs will increase due activities needed to identify and procure samples from unique individual animals among various populations. In addition to conserving genetic resources, the program works with a wide range of industry stakeholders to conduct genetic diversity assessments, makes recommendations for breeding programs, establishes cryopreservation protocols shared with different communities, and provides an internet-based information system (Animal-GRIN) which allows the public to view and evaluate germplasm in the collection. Future expansion of USDA activities for animal genetic resources should be based around strengthening of the NAGP and leveraging its successes in moving forward with conservation and utilization of animal genetic resources. This includes building upon the long-standing partnership with the Aquatic Germplasm and Genetic Resources Center of the Louisiana State University Agricultural Center which pioneered high-throughput processing at a commercial scale for aquatic species, as well as with other land grant universities.

Models for Further Advancements

Currently samples from more than 6,000 animals have been withdrawn from the repository for use by industry and research. Examples of what the availability of these samples has resulted in include:

- Reconstitution of a valuable research line of pigs resulting in new scientific findings on meat quality and human disease. Use of this line has been expanded to two universities;
- Reintroduction of Y-chromosome genetics lost from the current commercial population of dairy cattle. This was coordinated by a partnership among breeding companies, universities and NAGP;
- Reintroduction of lost genetic variability for corrective mating by breeders of rare breeds (e.g., Dexter and Milking Shorthorn);
- Development of new technologies such as genome-wide association studies (GWAS), and genetic diversity assessments. These have proven to be invaluable for researchers;
- Enabling of trout breeders to mate fall and spring spawning lines (which could not be otherwise crossed) to increase productivity and incorporate disease resistance;
- Identification of specific animals that are carriers for a lethal mutation in order to purge that mutation from current commercial cattle populations.

These examples of previous efforts provide proven models for future opportunities mediated through the activities of the NAGP. Continuing the types of accomplishments listed above requires expanded effort to collect new and divergent genotypes that exist among our livestock and aquatic populations. This will require continued dialog and coordinated interaction with all levels of the livestock and aquatic industries to further collaborations with them in capturing genetic diversity. Expanded efforts to build, maintain, and utilize the collection will be critical for maintaining the security of various breeds and research populations, and as we look to the future and the increased use of biotechnologies (such as gene editing) the collection will continue to serve as a resource for exploration of gene function and can be used to correct unintended genetic problems that may occur. Advances in genomics (e.g., genomic selection) and the further development of genetic resource collections will also enhance the ability of stakeholders to assess new and more comprehensive measures of genetic diversity that will result in sustained improvement in utilization of livestock and aquatic species.

In order to continue moving forward, the following set of recommendations has been developed with input from industry and public-sector stakeholders. The recommendations are built upon a solid foundation of previous experience and success and are intended to maximize the future potential for strengthening of the strategic genetic resources of livestock, poultry, and aquatic species in the United States. The NAGP can play a central role in mediating these activities across the wide array of stakeholders in the private sector, government agencies, and academic institutions that are responsible for protecting, improving, and commercializing animal and aquatic genetic resources.

Recommendations

1. The role of NAGP encompasses all aspects of conserving animal genetic resources. Additional staffing and programmatic support are needed to improve: knowledge and use of genetic resources, reproductive technologies, and the Animal-GRIN information system. Augmentation of the program in such a manner will greatly improve procurement, management, and utilization through outreach to animal industries ($850,000/year).

2. The US has an opportunity to develop global leadership in managing aquatic genetic resources. Expanding the resources of NAGP for aquaculture and strengthening the long-standing partnership with the Aquatic Germplasm and Genetic Resources Center of the Louisiana State University Agricultural Center will accelerate necessary research, technology development, and training programs to expand repository activities and market creation for improved aquatic germplasm. This initiative would provide funding to hire one ARS scientist with technical support to provide research and outreach for fish farmers to leverage USDA-funded advances in genomics research and reproductive technologies. Such increased efforts will make US aquaculture substantially more competitive, influence development of integrated production systems, help protect industries from various threats including diseases, and lay the foundation for lucrative new markets for improved germplasm ($700,000/year).

3. Many of the producers holding diverse animal genetic resources fall into the categories of small and disadvantaged farmers. Significant efforts are needed to increase their access to and utilization of genetic, reproductive, and information technologies. Addressing this gap should be a combined effort of NAGP, the Livestock Conservancy, producer associations, and universities. A new funding category should be made available through the USDA Sustainable Agriculture Research and Education (SARE) program as a mechanism to support technology transfer ($700,000/year).

4. Feral and wild populations of cattle, pigs, sheep and all aquatic genetic resources hold unique gene combinations for future use. There is a need to quantify the genetic diversity held in such populations and define their utility under a variety of environments. Quantifying the genetic and phenotypic aspects of feral populations will require ARS to establish test populations at appropriate research locations. ($350,000/year).

5. Native American communities hold genetically diverse populations of livestock and aquatic species. With changing oceans, rivers, and grazing areas there is a critical need to ensure that these resources are conserved, and to develop mechanisms whereby Native Americans can prepare for and mitigate the impacts of climate variability ($1,500,000/year).

6. To strengthen the utility of research populations USDA-NIFA and ARS should lead efforts to ensure that research populations have germplasm and tissue samples backed-up in public collections such as NAGP, and that production and genomic data are deposited in public databases such as Animal-GRIN. This can provide community resources for universities and other groups to utilize in various research programs as needed. In addition, support is needed to enhance and expand the use of *in-situ* populations held by universities. Implementing such a program will ensure that the research community can develop populations to meet critical research objectives ($1,500,000/year).

7. Other programs in the US share common interests in genetic resources, and stronger links for protection of these resources through repository development are needed for integration across government agencies including USDA, NOAA, NIH, and USFWS ($200,000/year).

8. Industry information is not routinely available concerning production, supplies, prices, and economic value of animal genetic resources within and among species for livestock, poultry, and aquatic species. Therefore, the USDA Economic Research Service and National Agricultural Statistics Service should perform regular analyses to quantify the economic activity generated by the purchase, sale, and uses (including goods and services) of genetic resources via live breeding animals and resulting germplasm (semen, embryos, reproductive tissue) within breeds and populations among species groups. Analyses and reports such as these can be performed within NASS and/or ERS or through extramural agreements ($250,000/year).

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