

Conserving and reconstituting key animal genetic resources in an era of epidemic

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Introduction

Over the past decade numerous epidemics (e.g., avian influenza and African swine fever) and environmental disasters (e.g., flooding) have impacted livestock sectors in many countries (Satoshi *et al.*, 2022). These types of disasters create short- and long-term economic losses for the livestock sector. In the short term, disrupted national markets often lead to countries importing livestock products to meet consumer demands which in turn can displace national production for years after the disaster. Short and long term, the animal genetic resources (AnGR) base can also be severely impacted by such disasters; for example, Ling *et al.* (2025) demonstrated how disease and social unrest decreased the effective population size (N_e) of Mashona cattle in Zimbabwe. Given increasing threat levels across livestock species, the issue becomes what steps, beyond health remedies, countries should take to protect their livestock sectors and AnGR for further development of those sectors.

In general, countries are not prepared to respond to large scale disasters impacting their AnGR base; FAO estimated 70% of countries lack disaster-mitigation plans specifically addressing AnGR. Existing frameworks such as the Livestock Emergency Guidelines and Standards (LEGS) guidelines, and FAO emergency manuals—provide guidance on livestock disaster response but largely overlook AnGR. Furthermore, most existing gene bank collections have focused on a goal of reconstituting breeds to an N_e of 50. As a result, gene bank collections usually do not have sufficient germplasm to reconstitute populations on the scale needed after extreme disasters, therefore a paradigm shift is needed which requires increased numbers of animals and samples.

From a technical, policy, and operational perspective we have proposed actions needed for mitigating large scale genetic losses in case of disasters. In addition, we emphasize the complementary roles of in situ populations and gene banks, integrating lessons from case studies, global guidelines, and documented emergency events leading to a coherent framework for conserving and reconstituting AnGR under epidemic and other disaster conditions.

Materials & Methods

This study is based on extensive bibliographic sources such as FAO guidelines, national gene bank frameworks, scientific references and documented case studies of disease outbreaks and environmental disasters. The synthesis applies three analytical lenses—pre-disaster preparedness, post-disaster response, and enabling policy options—across both in situ and ex situ conservation contexts.

Pre-disaster. Literature and case studies were reviewed regarding management of live breeding populations, focusing on genetic diversity, adaptive traits, key herd mapping,

biosecurity protocols, and integration of early warning (EWS) and emergency response systems (ERS) for in situ populations. Global documentation on gene bank development, cryoconservation technologies, collection strategies, and risk-based sampling approaches were assessed for an ex situ perspective. Particular attention was given to germplasm types, sanitary requirements, replenishment strategies, and storage management relevant to emergency preparedness.

Post-disaster. Case studies were used to explore mechanisms of population recovery, genetic reconstitution strategies, breeding timelines, and reproductive technology use (semen, embryos, somatic cells, primordial germ cells) for both in situ and ex situ approaches.

Policy options. Documents from FAO, ERFP/EUGENA, AU-IBAR, and national regulatory examples (e.g., Dutch endangered breed registry, relaxation of laws governing use of Spanish endangered breeds) were examined to derive policy frameworks enabling genetic safeguarding before and after disasters.

Results & Discussion

While rare or minor breeds get a lot of attention in national conservation strategies for AnGR there is a need to focus to a portfolio of more widely used breeds that potentially contribute the most to the national livestock economies. For example, in OECD countries breed types might consist of specialized dairy (e. g., Holstein, Jersey) or beef breeds (e.g., Angus); while non-OECD countries may decide to focus upon *Bos indicus* breeds or robust breed types that can contribute most across a spectrum of production environments.

Pre-disaster - In situ conservation. Maintaining genetic variation is central to increasing population resilience. High genetic diversity reduces vulnerability to epidemics and environmental stresses. For example, Guaymí and Guabalá cattle in Panama (Villalobos-Cortés 2025) illustrate the importance of conserving locally adapted breeds, which possess heat tolerance, disease resistance, and efficient grazing behavior. Mapping of nationally important breeds, key herds or ill-defined breed types emerged as a critical preparedness tool. First, important breeds serve as reservoirs for genetic recovery but require clear selection criteria, periodic updates, and strong collaboration among breeders, veterinary authorities, and research institutions. Second, mapping breed locations can be used to understand population protection when steps are being taken to control (e.g., quarantined areas or areas identified for euthanizing animals) the spread of an epidemic. EWS and ERS are widely available for animal health, but seldom incorporate genetic risk. Integrating genetic conservation elements, for example, geospatial distribution of key herds, breed census data, and risk mapping—is essential for timely intervention. Databases such as DAD-IS and GLEWS+ can be leveraged to strengthen these systems. Genomic tools further enhance characterization and preparedness. Studies show heritable resistance to diseases like bovine tuberculosis and strong genetic signals for heat or parasite tolerance.

Pre-disaster – Gene bank-Ex situ conservation. Globally there are more than 100 national gene banks that have collected germplasm on breeds/populations of interest within their respective countries. While continued efforts are needed to secure populations through sufficient quantities of germplasm for reconstitution, there is a need for gene banks to broaden their scope. Specifically, for key breeds/populations, banks must increase the amount of germplasm collected so that sufficient numbers of animals can be reconstituted to have a national impact, if needed. For example, in swine, the targeted quantity of semen (0.5 ml straws) held by a gene bank will have to increase from approximately 9,000 straws needed to

reconstitute a breed (FAO 2012) to 38,000 straws to build a population of ~1,000 recovery sows which can then be rapidly scaled up to 100,000 sows. Embryos allow rapid reconstitution but require specialized infrastructure and offer less genetic flexibility compared to semen. However, somatic tissues (e.g., ear notches) offer low-cost harvesting but entail higher downstream costs for cloning, but can be used in conjunction with semen stores to reduce recovery times and speed the amplification of animal numbers. Primordial Germ Cells are particularly promising for poultry, enabling rapid recovery compared with multigenerational backcrossing.

Post-disaster. Unaffected subpopulations provide a vital genetic reservoir for reconstitution. Recovery depends on the proportion of populations impacted and their geographic distribution. Evidence shows substantial genetic differentiation within breeds across regions (e.g., Hereford cattle under different heat-stress ecoregions, Blackburn *et al.* 2017; Duroc pigs across Australia, Canada, and the U.S., Wen *et al.* 2026), suggesting strategic selection among surviving subpopulations can preserve locally adapted traits. Reconstitution may combine in situ herds with ex situ germplasm, in which case the full range of biotechnological options should be considered and brought to bear. For example, combining IVF, synchronization, embryo transfer, and cloning.

The total or partial loss of key populations or breeds during a disaster suggests that gene bank collections will be used for reconstitution. As with post disaster in situ recovery, speed will be important to minimize economic loss. It is now becoming evident that germplasm samples from one to 10 generations prior to the day of use can produce productive progeny (Dechow *et al.*, 2020; Eynard *et al.* 2018). These works demonstrate that while progeny of older bulls generally have lower breeding values, the phenotypic performance of progeny can be competitive with contemporary genetics. Therefore, if reconstitution is taking place in a subpopulation of an effected breed, rebuilding could be relatively rapid, especially if cryopreserved semen is used with super ovulation and IVF, in the case of ruminants. If an entire breed is lost, combining cryopreserved semen with somatic cell/cloning can also speed reconstitution for mammalian species. Advances in using primordial germ cells with gene editing (Ballantyne et al., 2021) suggest reconstitution of an entire chicken breed or population can occur in ~400 days vs 1,400 days if cryopreserved semen is used in a backcrossing scheme.

Policy options. Policies enabling coordination among breeding industry, veterinary services, and gene banks are essential. Sanitary requirements, guided by WOA standards, remain a bottleneck for preserving in situ or ex situ nationally important populations. Countries that successfully integrate key herds or breed types into biosecurity, early warning systems and eradication protocols can safeguard unique genetics during outbreaks. National laws should permit quarantine-based protection of key herds during outbreaks, avoiding unnecessary culling. For example, Spain and the Netherlands have introduced adapted health regulations allowing tailored collection for conservation purposes—highlighting the importance of flexible yet safe regulatory frameworks. In the Netherlands rare breed and herd locations are flagged in a national identification system, allowing for exceptional measures to avoid indiscriminate culling during disease outbreaks. In Poland, data on the number and location of animals covered by the genetic resources conservation program are updated annually and submitted to district veterinary officers in accordance with national legislation.

National breeding laws, breeding programs or corporate codes of good practices should include complementary in situ and ex situ elements, taking into account short- and long-term perspectives. For example, breeding laws and national strategies must explicitly incorporate ex situ roles for emergency recovery, not only conservation. Multilateral collaboration could be exercised to allow shared pools of germplasm at regional or global scale—such as within the

European Genebank Network (EUGENA) initiative or AU-IBAR initiatives in Africa. This strategy can support countries lacking robust gene bank infrastructure. In addition, public–private partnership agreements with breeding companies and breed associations can expand available germplasm and facilitate coordinated restocking.

Conclusions

Safeguarding AnGR against epidemics and other disasters requires coordinated in situ and ex situ strategies, strong policy frameworks, and proactive planning. Countries must identify key breeds and herds, strengthen biosecurity and early warning systems, expand and diversify gene bank collections, and establish clear procedures for post-disaster reconstitution as there are a wide range of options that can be used in the reconstitution process (Fig 1). Multilateral cooperation and public–private partnerships are critical to scaling rapid recovery and if possible should be preplanned. Ultimately, integrating genetics into disaster preparedness is essential for ensuring long-term sustainability, food security, and the adaptive capacity of livestock systems.

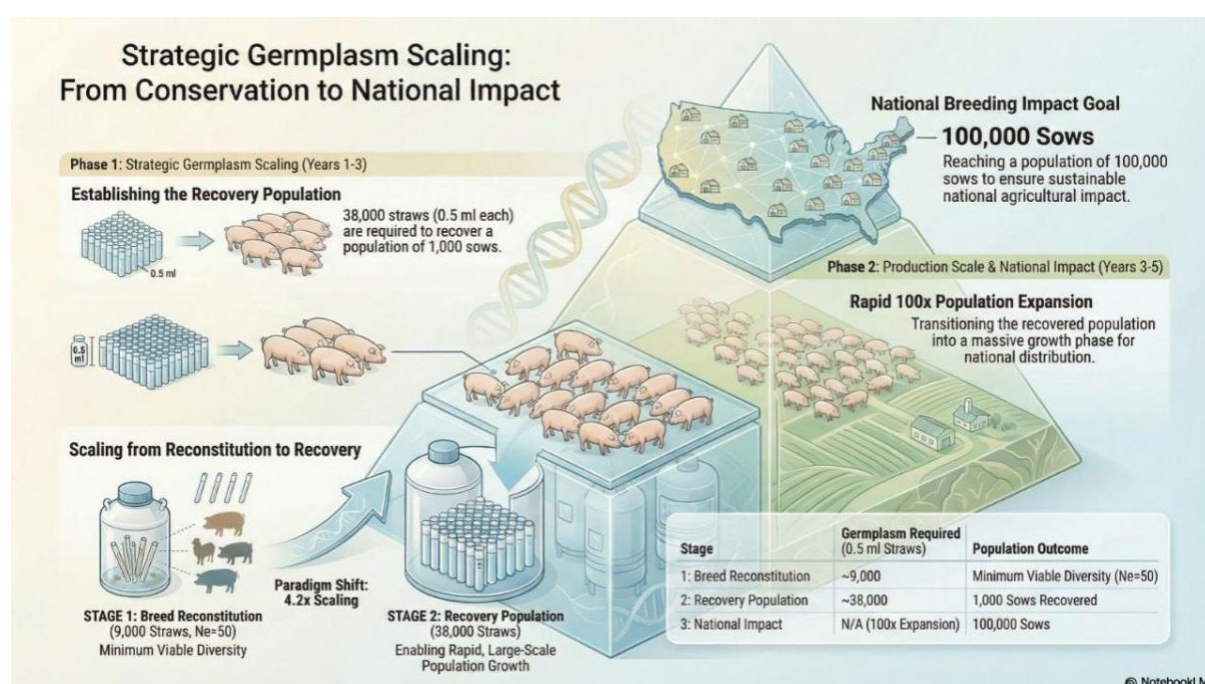


Figure 1. Scheme of proposed gene banking strategy for increasing collection size and use in reconstituting a population of pigs.

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