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Innovations in cryoconservation of animal genetic resources

Practical guide

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SECTION 4
The economics of gene banking

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4.1 INTRODUCTION

The costs of gene bank programmes and facilities are an important consideration for any institution managing gene bank collections. FAO (2012) reviewed the basic functional requirements for typical small, medium and large facilities and the corresponding costs for operation and maintenance. Basic requirements regarding infrastructure and physical design of gene-banking facilities have not changed substantially since the previous guidelines. This section draws attention to the economics of genetic collections in which the cost element is one variable in a broader objective of designing efficient collections. Other elements to be considered are the benefits derived from the eventual future use of stored material, and minimizing overlaps and redundancy in genetic resources that may be held elsewhere, either nationally or globally. This rationalization process involves careful planning of material collection to minimize cost for maximum benefit. Methods for formal economic evaluation and mathematical optimization are presented, and the institutional needs and barriers that can facilitate or hinder rationalization efforts are discussed.

4.2 REVISITING THE COSTS OF GENE BANKING

The costs of gene bank operations and facilities are country and context specific, and depend upon the strategy and the objectives of the gene bank and of the general management of animal genetic diversity within the country. Several preservation parameters need to be determined, for example, how many species and breeds need to be preserved, which type of germplasm and which preservation protocols are to be used for each species, and the number of doses per animal to be stored in liquid nitrogen. Answers to these questions will help to determine the long-term investments and the annual operational costs. The purpose of this section is to provide a summary of relevant cost categories or items to be considered when planning a budget to implement an animal preservation programme. Specific cost categories may require *long-term investment* and can be considered as *fixed* or *variable* costs (see Table 4.1). As a general principle, maintaining infrastructure and staff can be considered *fixed* costs, while costs directly implied when collecting new doses or when upgrading equipment are *variable* costs.

4.2.1 Long-term investments

Long-term investments are the foundation of an animal preservation programme, which should target at least twenty years of operation. The physical plant location needs to be carefully chosen in relation to the animal genetic diversity in the vicinity, the environment, the biosecurity, potential hazard risks, and the proximity of public services (e.g. liquid nitrogen supplier, fast courier companies, airport, etc.). Cryopreservation laboratory and long-term storage rooms are the most critical infrastructure for an animal gene bank. A cryopreservation laboratory must be designed to facilitate the different steps of the preservation of germplasm. It must include areas to prepare, evaluate and freeze germplasm. Also, a computer workstation is needed to record the different information on the preserved genetic material. Long-term storage rooms require enough space for the cryotanks and liquid nitrogen dispensers. To ensure safety of personnel and prevent loss of the collection, the environment of these rooms should be carefully monitored with specialized equipment to detect liquid nitrogen spills, humidity and oxygen levels, and smoke.

Key staff to operate an animal gene bank will determine the success of an animal preservation programme. A curator or gene bank manager will supervise the strategy and different operations of the gene bank, including material acquisition, material processing, storage and distribution. This person will be the primary contact for stakeholders interested in providing or having access to animal gene bank material. Skilled technicians should be available for collecting the genetic material from animals in the field or in-house. A lab technician will be in charge of cryopreservation processes. Finally, a database manager will ensure that all information on the donor animal (such as species, breed, line, registration number, pedigree information, phenotypic and genomic information) and germplasm (such as viability, number of doses, location in the cryotank) are correctly digitally recorded (see Section 8). These human resources should be a minimum to operate an animal gene bank adequately, and to efficiently provide services to stakeholders. Flexibility in the availability of the human resources and their responsibilities would help gene banks to anticipate variability in workload during the year.

Basic equipment to collect and process germplasm is essential in a cryopreservation lab (see Table 4.1). These instruments would allow the handling of germplasm and produce doses for storage in liquid nitrogen. However, it is strongly recommended to invest in specialized processing equipment, if the preservation program's mission and objectives are growing in terms of number of donor animals and doses. For instance, a computer-assisted sperm analyser can rapidly evaluate the motility and viability of sperm cells collected from several animals in a day. Another example is a straw filler and sealer capable of handling an extensive collection of germplasm. For the storage of the doses in liquid nitrogen, the number of tanks is proportional to the number of species to be preserved; preferably one tank for one species. These tanks should be equipped with an alarm system to monitor the level of liquid nitrogen. Quality of equipment should not be compromised to respect the investment target of twenty years.

Technological and practical advances since 2012 have, on one hand, increased options to cryopreserve reproductive material for a range of species, which also may result in higher total operational costs for a gene bank. For example, cryopreservation of embryo or ovarian tissue is generally more expensive compared to semen. On the other hand, technology development may contribute to enhanced effectiveness or efficiency of gene bank operations, thus increasing the value of potential benefits or decreasing the cost per unit of genetic variation conserved. For example, better cryopreservation protocols may allow the gene banking of new species or improve the viability of material from certain breeds. Genomic information can be used to optimize the genetic variability in collections (see Section 5), and thus reduce costs associated with duplication.

4.2.2 Annual operational budget

When planning an operational budget, categories/items should be classified as fixed or variable costs.

Fixed costs could be defined as a fixed expense required every year, regardless of the collection and cryopreservation activities in that year. It is important to have long-term commitments of relevant stakeholders to cover the fixed costs and to avoid compromise of the investments done in the previous years. Major categories/items classified as fixed costs are annual costs of cryopreservation lab facilities and cryostorage rooms, salary and overhead of the staff, basic equipment, database, and long-term storage tanks. Gene bank infrastructure requires preventive or corrective maintenance every year. Annual collection and preservation activities hardly influence the salary and overhead of human resources. Basic equipment needs to be replaced or fixed regularly regardless of the amount of genetic material handled in a year. Regular maintenance and security of the informatics system ensure the protection of the data and the continuity of the services to stakeholders. Cryogenic tanks require a constant supply of liquid nitrogen. Usually, the number of tanks in storage rooms is set for several years following long-term investment in acquiring these cryocontainers. Thus, the annual amount of liquid nitrogen should not vary substantially over the years, facilitating the estimation of this cost when preparing a multiyear budget.

Variable costs in the operational budget are influenced by the quantity of genetic materials to be collected and processed in a year. Frozen germplasm needs to be shipped to the animal gene bank, and the cost will depend on the size of the required (dry) shipper. When the genetic material needs to be collected from an animal, the cost of preserving the material depends on the preservation strategy. For instance, a producer can transport his animal to a specific handling facility, and an independent veterinarian/technician would perform the harvesting of the genetic material.

Another instance is field collection trips organized by gene banks themselves. Staff will need to travel to the collection area, requiring a budget to cover different costs such as transport, accommodation, meals, consumables, storage liquid nitrogen tank, etc. In general, a field trip duration could extend to several days if many farms need to be visited in a larger country. So, it is essential to have clear objectives for the preservation programme when planning a budget associated with variable costs.

A basic framework for evaluating full costs of gene bank operations is presented in Table 4.1. Examples of how to budget gene bank costs in the context of national programmes and objectives are provided from Canada (Box 4.1) and the Netherlands (Box 4.2).

TABLE 4.1
Cost structure and evaluation framework for gene bank operations

Cost category / item	**Fixed (annual costs, 20-year horizon)**	**Variable (per donor animal or per dose)**
Key staff – labour costs (salary and overheads) • gene bank manager/curator • field technician/animal housing/collecting • lab technician • database manager	X	
Wet lab (costs/m^2) • receipt of material • preparation and evaluation • processing • packaging • freezing • computer workstation	X	
Equipment • maintenance and repair • processing equipment (microscope, centrifuge, spectrophotometer, counter chamber, haemocytometer, pH meter, osmometer, water bath, straw filling equipment, straw printer, styrofoam box, programmable freezer, quarantine tank)	X	
Database • maintenance • security	X	
Staff (additional or temporary) • animal facilities • collecting (in field, on farm, on station) • processing (in lab)	X	
Genotyping		X
Animal collecting facilities • quarantine period • collecting period		X
Veterinary costs and diagnostic tests		X
Transport • animal • genetic material • shipping tanks		X
Collecting material •consumables and disposables • reagents • portable equipment		X
Processing material • consumables and disposables • reagents		X
Long-term storage • tanks • liquid nitrogen		X

Source: Authors' own elaboration.

BOX 4.1

Investments of Canada to preserve its animal resources

Carl Lessard

Canada launched the Animal Genetic Resources of Canada (AnGRC) in 2006 (previously called Canadian Animal Genetic Resources). The industry principally owns Canadian livestock, and AnGRC is a preservation programme to sustain Canadian animal production development. Its mission is to ensure the genetic diversity of the Canadian livestock by acquiring, evaluating and cryopreserving germplasm. A genetic representation of each animal breed used for food and agriculture should be stored in the Canadian national gene bank located in Saskatoon, Saskatchewan, Canada.

The objectives:

1. Collect sperm or embryos from donations from producers or industries. These donations can be frozen germplasm, or field collections can be organized to capture Canada's animal resources.
2. Determine the genetic diversity of each Canadian breed.
3. Develop a database to record the animals' information, doses and location in the gene bank. Information contained in the database should be accessible to the public.

Long-term investment:

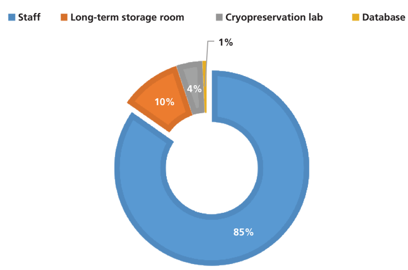
- **Infrastructure:** The animal national gene bank is located in a refurbished room at an existing federal centre in Saskatoon (Saskatchewan, Canada). This room has all the monitoring equipment to detect liquid nitrogen spills or a low level of oxygen. In addition, an industrial dehumidifier ensures that a proper level of humidity and temperature is maintained, which improves the environmental conditions to handle and store germplasm in this room. The cryopreservation laboratory is located at the Western College of Veterinary Medicine (University of Saskatchewan), located near the animal national gene bank. Having a physical presence at the Veterinary College allows the AnGRC group to train future veterinarians in the field of animal genetic diversity. Thus, Canada did not build new infrastructures for its animal preservation programme, but used existing facilities to accommodate the needs of AnGRC.
- **Equipment:** AnGRC acquired computer-assisted sperm analysis (CASA), a flow cytometer, a genetic sequencer, a straw filler and sealer, a straw printer, a programmable freezer, and several cryotanks for the adequate preservation and quality analyses of the donated germplasm.
- **Database:** AnGRC joined an international group (Brazil, United States of America and Canada) to build a shared database to record the different information. Investment on informatics system and security programs were made to ensure the protection of the data (see Section 8 for more information).
- **Staff:** AnGRC group comprises a curator, a field specialist, a genetic advisor and a programmer. Graduate and summer students help to complete the different AnGRC's preservation activities.

(Cont.)

Operational budget: In general, fixed costs represent around 80 percent of the operational budget, while the variable costs are 20 percent.

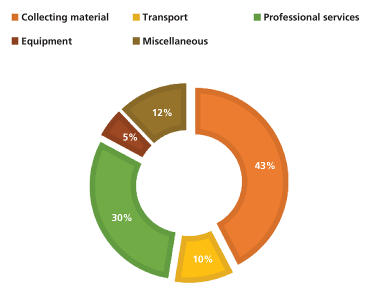
- **Fixed costs:** Staff salaries account for around 85 percent of the fixed costs (see Figure 4.1). A significant amount of liquid nitrogen is required to fill all the cryotanks located in the storage room, which requires 10 percent of the fixed costs budget every year, because the number of cryotanks to fill does not vary significantly. The remaining fixed costs budget covers the renting of space at the University of Saskatchewan for the cryopreservation labs, and the security program updates or upgrade of the informatics system.
- **Variable costs:** Each year, several livestock producers and industries donate frozen germplasm to the AnGRC programme, which shipping to AnGRC's facilities is free of charge. Animals can also be brought to the Veterinary College for collection. So, transport can represent 10 percent of the variable costs (see Figure 4.2). Field collections are a major activity for the Canadian preservation programme, and they can represent around 43 percent of the variable costs. Canada is a vast country, and the production of animals is geographically dispersed. AnGRC staff must travel long distances to reach important animal resources produced in Canada. The number of trips in a year depends on the interest of producers or the working capacity of the AnGRC group. Analysis of genetic diversity can be done in-house or by a third party. Veterinarian services can also be solicited to collect genetic material from animals when the AnGRC group cannot attend. These services can represent 30 percent of the variable costs every year. Finally, a small portion of the operational budget is kept to cover replacement or repair of equipment and unexpected contingencies.

FIGURE 4.1
Distribution of fixed costs (Canada)



Source: Authors' own elaboration.

FIGURE 4.2
Distribution of variable costs (Canada)



Source: Authors' own elaboration.

BOX 4.2

The Dutch farm animal gene bank

Sipke Joost Hiemstra

The Dutch gene bank for farm animals is managed by the Centre for Genetic Resources, the Netherlands (CGN), of Wageningen University and Research. Development and maintenance of the gene bank collections for farm animals is part of the Statutory Research Tasks programme of CGN, funded by the Ministry of Agriculture and supported by the Dutch livestock breeding sector.

The main objectives of the Dutch gene bank are:

1. To establish and to maintain gene bank collections of all native Dutch rare livestock breeds;
2. To facilitate regular backup gene bank collections of all breeding programs; and
3. To stimulate the use of gene bank collections in breeding and research.

Long-term investment:

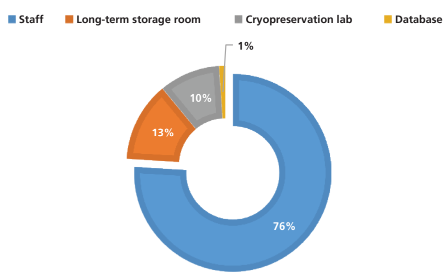
- **Infrastructure:** The national Dutch gene bank for farm animals is located at the Campus of Wageningen University and Research, and a duplicate collection is maintained at the Veterinary Faculty of Utrecht University. The gene bank consists of a cryopreservation laboratory facility and two storage rooms. The facility has monitoring equipment to detect liquid nitrogen spills or a low level of oxygen in the liquid nitrogen containers. The facilities are rented from Wageningen University and Research.
- **Equipment:** All relevant equipment for quality analysis and freezing genetic material is available to carry out cryopreservation for different species.
- **Database:** CGN is using the gene bank database CryoWeb that was developed by a European consortium, funded by the European Commission. Genomic data is stored in a separate database.
- **Staff:** CGN staff involved with the gene banking activities include the following (part time) positions: (i) gene bank/project manager; (ii) database specialist and programmer; (iii) lab technician; (iv) field technician; (v) cryobiology specialist; and (vi) a genetic advisor.

Operational budget: In general, fixed costs represent around 90 percent of the operational budget, while the variable costs are 10 percent.

- **Fixed costs:** Staff salaries account for around 75 percent of the fixed costs (see Figure 4.3). Around 10 percent of the fixed costs is related to the rental costs of the cryopreservation lab, and more than 10 percent of the fixed costs is associated with storage (main storage and duplicate storage).
- **Variable costs:** The major part of the variable costs is associated with collecting material and adding material to the gene bank collections (see Figure 4.4). Around 10 percent of the costs are transport and travel costs, around 20 percent are costs of specialized services (in particular, veterinary costs), and around 15 percent is associated with maintenance or replacement of lab equipment.

FIGURE 4.3

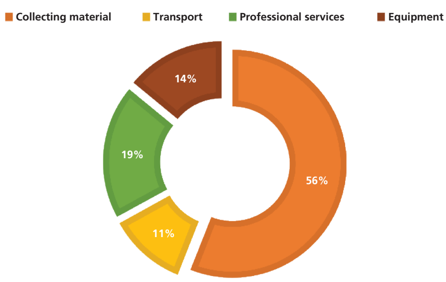
Distribution of fixed costs (Netherlands)



Source: Authors' own elaboration.

FIGURE 4.4

Distribution of variable costs (Netherlands)



Source: Authors' own elaboration.

4.3 CONSIDERING THE BENEFITS DERIVED FROM GENE BANKING

Establishment or operation of a gene bank can be regarded as an investment. Funds are spent now with the expectation of obtaining benefits (or avoiding losses) in the future. With this in mind, the conventional economic approach to evaluating alternative options for establishing new or modified genetic collections is to treat them in the same way as any other investment decision (FAO, 2020), that is, to consider the private and public economic rates of return (the benefits) to the investment (the costs) over the expected period of the investment (the period during which the materials are stored and eventually used).

This approach requires clarity in the initial "investment objective(s)" (i.e. the gene banking goals), so that the expected costs and anticipated benefits can be identified and quantified as part of the analysis. A complement to the analysis is a consideration of who is incurring investment costs and who will receive benefits. This second consideration extends to the governance of the gene banking process, and the related institutional decisions around ownership and control of the genetic resources and the sharing of costs and benefits. While these questions will be clearly relevant to the ultimate configuration and management of *ex situ* collections, the purpose of this section is not to directly address or resolve these governance questions. Section 9 addresses these matters in more detail.

The assumed rationale for genetic collections is that the stored material will be used in future breeding, research, or *in situ* species conservation or restoration activities. The variety of potential scenarios for use of stored materials is almost infinite, and the range of possible uses is usually summarized in terms of future option or insurance values (see Box 4.3). That is, genetic resources are usually cryoconserved to the possibility of presently uncertain future uses. These values may or may not be quantified explicitly, but public and/or private stakeholders implicitly express their perceived value of the stored material by their willingness to support collection and storage costs in anticipation of unknown future need.

Being specific about use scenarios for stored genetic resources can help to identify multiple benefits and values that can be important as justifications of investment funding. Some scenarios are common to many gene banks, such as helping to maintain sufficient genetic variation to adjust to changes in market needs and avoiding extinction. Estimating the value of these benefits may be relatively straightforward, achieved by considering the economic consequences of losing current market share or by loss of a breed in its entirety. Determining the value of other uses is more uncertain and may depend on other variables. For example, quantification of value for scenarios involving improved breeding and productivity is potentially feasible, but speculative.

One important question is how gene bank stakeholders might adopt and implement new breeding innovations related to the use of *ex situ* stored material. Economic justifications can also be derived from less tangible categories of non-use-values that can entail elements of existence and bequest value – the value accruing to us through knowing something exists irrespective of location, and in securing a legacy to future generations (see Box 4.3). The maintenance of cultural (including environmental) heritage and the vitality of rural areas and communities that depend on a livestock economy is important to many countries. Gene bank material has value through supporting the maintenance of the *in situ* population. Such scenarios involve not only future use values to the breeders in

BOX 4.3
Types of "values" for cryoconserved genetic material

Current use value – the value derived from immediate exploitation of the stored resources now or in future. Future value may be contingent on the emergence of new information about stored resources. The value of the information gained from that delay is the quasi-option value (see below).

Option value – the value of a potential benefit associated simply with the opportunity or need to use that resource in the future (even if the probability of its use is low). This is also known as insurance value, and is of particular relevance when the objective of gene banking is to protect against breed extinction or loss of genetic variation.

Bequest value – the value of potential future benefits to be obtained by future users that are different from the current investors or gene bank stakeholders. This type of value is of particular importance for public rather than private stakeholders.

Existence value – the value associated with simply knowing that a resource exists. This type of value is usually associated with natural or cultural treasures, such as an endangered wildlife species or livestock breeds that have a typical historical or cultural value. For livestock gene banks, it may be relevant if stored material helps to ensure the continued existence of a culturally significant breed.

Opportunity costs – the potential benefits a decision-maker misses out when choosing one alternative over another.

Source: Modified from **OECD.** 2018. Cost–Benefit Analysis and the Environment: Further Developments and Policy Use, OECD Publishing. Paris. Cited 18 October 2020. https://doi.org/10.1787/9789264085169-en

these communities, but also bequest and existence values for other members of society. For example, iconic long-haired Highland cattle may be valued by many people beyond Scotland, even if they have never seen live animals. Benefit valuation in monetary terms for such non-market situations is challenging, but some approaches have been developed (Bishop *et al.*, 1997; Bockstael *et al*., 2000).

While obtaining an estimate of such benefits may facilitate a cost-benefit appraisal of gene bank investment options, such estimates may not always be necessary in the rationalization process. Simple awareness that gene banking can provide such types of benefits may be sufficient justification for gene bank managers, policymakers and other stakeholders to support a given cryoconservation programme or activity.

4.4 COST ANALYSIS CHALLENGES

Financial tools such as cost-benefit analysis (CBA) and cost-effectiveness analysis (CEA, see Section 4.5) are useful for evaluating public and private investment decisions (Riegg Cellini and Kee, 2015), and can be applied to investments in *ex situ* conservation programs. A CEA relates the costs of a programme to clearly defined outcomes or benefits. In the conservation context, the costs of achieving identical breed or species survival outcomes by using different *ex situ* facilities can be compared. Alternatively, the *ex situ* and *in situ* costs can be compared, provided both can guarantee the same outcome. The outcome does not have to be expressed in monetary terms.

In contrast, CBA goes a step further and converts multiple outcomes (that is, the value of the benefits achieved) into monetary values for comparison with costs. CBA has advantages of using a common metric to compare outcomes that are sometimes not strictly identical. For example, a CBA applied to decide which livestock breed (materials) to collect might determine the monetary value of several potential benefits of each breed (e.g. cultural value, genetic gain that could deliver increased performance and productivity, climate change adaptability, etc.), and then compare the benefit-cost ratios to see which breed generates the highest ratio. Ultimately, this valuation exercise is far from straightforward when moving beyond productivity benefits.

Guidance on CBA (see EIB, 2013) defines investments as being either private or public decisions. This difference in perspectives describes who is incurring the cost of the investment, and defines which costs and benefits are included for comparison. In most gene banking situations, it can usually be assumed that the relevant perspective involves a public resource allocation decision. Looking from a governmental perspective, the (hypothetical) investment considers how to minimize overall (public and private) costs and maximize total (or social) benefits related to the eventual configuration of *ex situ* collections. This decision can be conceptualized as being taken in a single region or country, or as a collaborative decision between several authorities. Configuration in this case refers to storage of which materials from which breeds and species, in which locations. In the CBA, the net-benefits (or benefit-cost ratio) of the current collection configuration are compared with alternative scenarios where collections are consolidated to save costs or to maximize benefits through use.

This type of economic CBA is routine for trained economists, but is challenging when cost data are incomplete and when there are non-market benefits deriving from an activity such as gene banking. Appraisal is also complicated when costs and benefits are uncertain, and this uncertainty increases over longer time horizons as is often the case with gene banking.

This document will not address in detail the principles of non-market valuation challenge (see Bockstael *et al*., 2000, for further information). Even without benefit valuation, gene bank managers, governments and other stakeholders can seek other ways to maximize the efficiency of their investment spending.

4.5 COST-EFFECTIVENESS ANALYSIS

As noted, CEA avoids the need for benefit scenarios and their monetary valuation by re-framing the economic problem as one where the aim is to maximize the diversity of genetic collections at minimum cost. Essentially this redefines the appraisal as an optimization problem requiring clear definition of the objective and selection of the least-cost investment option to deliver it. There may only be one technical option for conservation or several. The key point is that these cost alternatives relate to an identical outcome.

CEA thus defines an optimization problem that can be solved either by simple comparison of options, or through more detailed mathematical methods such as linear programming (LP) (Dantzig, 1998). The LP, also known as linear optimization, is a method to achieve the best possible outcome of a planning problem, such as maximum profit or least cost. The rationale behind LP is that, in real life problems, resources such as capital, labour, water and storage capacities are limited and therefore an "optimum for use" should be identified. So, for example, an LP could suggest ways to collect and store genetic materials, in terms of number of semen doses, collection regions and in which gene bank to store, so that the current costs of operating gene banks could be reduced by up to 20 percent (see Annex 4.1 and De Oliveira Silva *et al*., 2019).

In a more complex modelling exercise, seeking to rationalize *ex situ* collections, LP models can be used to frame the problem in terms of minimizing collection costs and maximizing diversity. The latter can, for example, be defined as the maximum number of breeds that can have material in a gene bank network. The maximum number would be limited by several factors, such as collective budget, distance between gene banks and collection regions, gene bank fixed and variable costs, and cryotank capacity (De Oliveira Silva *et al*., 2019). Optimization can be used for efficient re-allocation of existing collections (De Oliveira Silva *et al*., 2019) or for planning future collections, for example, by considering projected extinction risks (De Oliveira Silva *et al*., 2021).

A focus on breeds is a simplification, as genetic diversity rather than the number of preserved breeds might be the more appropriate goal and can theoretically be addressed when genomic data are available. In the case of public conservation efforts, for example, in national policies incentivizing the conservation of local livestock breeds (MAPA, 2020), it is reasonable to consider a variable that relates to current and future status of the populations in terms of risk of extinction.

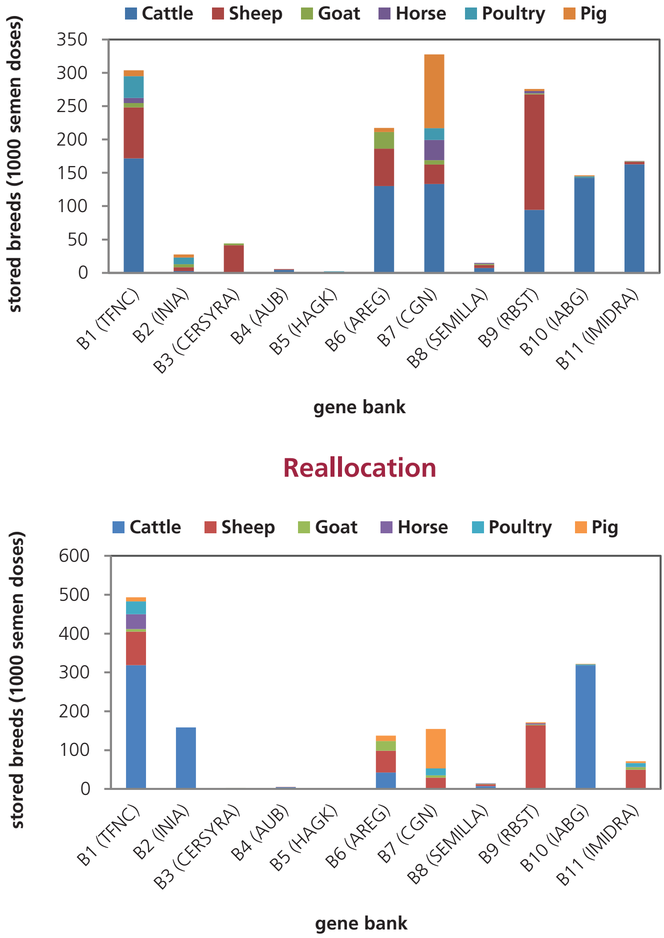
The probability of endangerment can be estimated using census data and regression methods (De Oliveira Silva *et al*., 2021). As resources are limited and *ex situ* conservation is a relatively expensive technology, it may be rational to prioritize breeds that are more likely to be at risk. In this case, CEA can be used to identify the trade-offs between costs (public or private) and extinction risks, genetic gain or other attributes.

Box 4.4 illustrates the steps in terms of defining variables, constraints, and data for a simple optimization model for cost-efficient collections. The final goal is to construct a model that is able to inform economically efficient *ex situ* collections across gene banks.

Figure 4.5 is an example of how information from LP can be used to inform strategic *ex situ* collections for a gene bank network with single objective. The example illustrates how reallocating existing collections across European gene banks can save costs, which in turn allows greater resources for conservation of endangered breeds.

Applying the concepts illustrated in Box 4.4, De Oliveira Silva *et al*. (2019) derived a CEA analysis of optimized collections, and found that current costs across European cryogenic banks could be reduced by around 25 percent by reallocating genetic material to more efficient banks, allowing for collective budget sharing and avoiding overlapping collections.

FIGURE 4.5
Distributions of semen doses per breed before and after cost-effectiveness analysis



Notes: An example of a CEA in which the reallocation of semen doses of livestock breeds in 11 European gene banks could reduce collection and storage costs by around 20 percent. S_o represents the current (2018) collections, while S_{UC} is the optmized (or least cost) collection strategies. Note how number of doses increases in some gene banks (e.g. B1, B2 and B10), but are reduced in others (B3, B6 and B11). The difference in collection costs is explained by a more cost-effective collection strategy that considers the relative breed costs (fixed and varible costs) across different gene banks.

Source: **De Oliveira Silva, R., Vosough Ahmadi, B., Hiemstra, S.J. & Moran, D.** 2019. Optimizing ex situ genetic resource collections for European livestock conservation. *Journal of Animal Breeding and Genetics*, 136(1): 63–73. https://doi.org/10.1111/jbg.12368

4.6 RECOMMENDATIONS FOR COST ANALYSIS

From the work by De Oliveira Silva *et al*. (2019, 2021) carried out as part of the Horizon 2020 European Union project Innovative Management of Animal Genetic Resources (IMAGE, 2020), the following basic recommendations for performing a full cost analysis of collection enrichment, maintenance and future regeneration steps can be given:

BOX 4.4

Cost-effective analysis (CEA) with optimization

1. **Define objective functions (OF).** A single or multiple OF should be determined, e.g. least cost OF, consisting of fixed and variable collections costs. Multiple OF may be used to balance conflicting objectives (e.g. genetic gains vs genetic diversity).
2. **Decision variables (DV).** DV relates to collection and allocation of genetic materials across a set of gene banks. For example, let $X_{t,gb,b,r}$ represent the number of semen doses of livestock breed *b* (in straws of 0.25 mL) collected in year *t* by gene bank *gb* in region *r*.
3. **Collection constraints (CC).** CC are presented by budget limitations (local or collective budget for gene banks network), geographic distribution of endangered animals, technological limitations (success rate, degradation), capacity (volume of cryotanks), labour availability, restoration targets and expected economic returns.
4. **Parameter uncertainty (PU).** Considering PU is recommended for parameters with significant uncertainty within the timeframe of the analysis, for example, future extinction risks should be added as stochastic parameters in the model.
5. **Model outputs (MO).** MO are generated to produce efficient (cost-effective) collection and allocation strategies of genetic resources (see Figure 4.5). MO allow for deriving cost-curves of diversity vs expected costs, or extinction risks vs costs, for example.

Collect cost estimates that are as accurate as possible. When undertaking an analysis that involves optimizing collections across multiple banks, cost collection should be standardized across banks and countries, where possible. The data collection list provided in Annex 4.2 may be used. This helps prevent inconsistent cost data across gene banks, as gene bank managers tend to consider different components when estimating costs, and some costs such as labour, electricity, documentation are not exclusive for managing the collections.

Use mathematical modelling to estimate costs in specific scenarios, but determine first whether modelling is required/beneficial and for what purpose. Mathematical modelling offers a flexible tool for rationalizing *ex situ* collections avoiding redundancy, at the same time, providing a systematic approach to cost data collection and in relation to formulating conservation objectives including acceptable *in situ* extinction risks.

Requirements for accurate modelling include the following: (i) consistent gene bank data; (ii) information on the quantity and nature of germplasm (e.g. number and volume of semen doses or goblets); (iii) real or potential cryotank capacity; (iv) breed census data (to link collection decisions with *in situ* populations and policy scenarios); (v) limits on the available or projected conservation budget; and (vi) conservation priorities for the formulation of conservation scenarios.

Ex situ collections are generally costly, and resources are limited. Rationalizing collections through cost-efficiency analysis can prevent suboptimal collection strategies.

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