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Decision making in livestock conservation

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Abstract

In this article, theory and practical implementations of decision making in livestock conservation are reviewed. It is argued that the objective of livestock conservation is a composite of maintaining between and within breed diversity and single breeds of recognised value. Assuming that this goal can be reflected in an objective function, decision making requires maximisation of this objective function with or without restrictions. Different strategies have been proposed in the literature to achieve this goal. While the diversity measure suggested by Weitzman (1992) [Weitzman, M.L., 1992. On diversity. Quart. J. Economics, CVII: 363-405.] is not fully appropriate to be applied to breed conservation within livestock species, the approach of maximising expected diversity Weitzman (1993) [Weitzman, M.L., 1993. What to preserve? An application of diversity theory to crane conservation. Quart. J. Economics, CVII: 157-183.] is seen as a fundamental concept in this area. Although highly elaborate methods of decision making are discussed in the scientific literature, the concepts presently used by national or international authorities or non-government organisations are rather simplistic, mainly risk-related and based on simple functions of population size. It is argued that decision making has to account for the global diversity of a species and therefore decisions and conservation activities should be coordinated on an international level. The use of more appropriate decision rules will strongly increase the cost efficiency of conservation investments. Livestock conservation should be based on an extended objective function reflecting the expected future value of the conserved set of breeds, which encompasses within and between breed diversity as well as specific traits and cultural or scientific value of the main breeds. A critical issue is the derivation of the required parameters like the breed value or the risk status of a breed. Since it will generally be difficult to obtain exact values, decision making under uncertainty will be the usual challenge and Bayesian decision theory might be an option. The optimum allocation pattern and implementation of conservation activities can be derived based on Weitzman's expected diversity concept. Approximate decision rules for breed prioritisation based on the extinction probability of a breed and its marginal objective function are given. Even if the respective parameters are not perfectly known, the use of the suggested approaches has the potential to double the cost efficiency, in terms of maintained diversity per conservation dollar spent, compared to the simplistic approaches that are used today.

Keywords: Diversity; Livestock; Conservation; Decision making

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1. Introduction

Of the 6400 documented farm animal breeds, about one third is threatened by extinction (Scherf, 2000). It is estimated that 1–2% of the described farm animal breeds go extinct per year, this is equivalent to the vanishing of one or two breeds per week. However, erosion of diversity in the farm animal area is mainly a process that happens within species, none of the approximately 30 mammalian and avian farm animal species is endangered as such.

The Convention on Biological Diversity (CBD, 1992) has put the need to conserve farm animal genetic diversity on the agenda. The Food and Agricultural Organisation of the United Nations (FAO) was given the global mandate to take the initiative, and a global network has been established for this purpose. However, this network is mainly working descriptively on an inventory of breeds and does not have the mandate (nor the resources) to impose conservation activities on the national or regional level. Practical conservation decisions are made by governments or non-government organisations, often on the national level, and actual conservation activities are often rather arbitrary, both with respect to the breeds included and to the measures taken.

This contribution tries to consider the process of decision making in livestock conservation from a systematic and theoretical point of view, asking the main questions:

- what is the objective?
- what is the decision space?
- how can we decide?

These three key questions are discussed and theoretical arguments are given. This theoretical concept then is compared to the actual situation of decision making in this field, and more elaborate concepts, which are in the scientific discussion, are introduced. Finally some suggestions for a more efficient and goal-oriented decision making process are made.

2. What is the objective?

Farm animal breeds are adapted to specific challenges, which might encompass specific environmental conditions, infection pressures or market needs. Some breeds are more adapted to the actual profile of requirements than others and therefore are, locally or globally, more successful than other breeds. Looking at the economically most important farm animal species cattle, pig, and chicken, about half a dozen breeds or commercial strains within each species are globally competitive. This concentration process has been pushed forward by biotechnological innovations, like the use of artificial insemination and kryoconservation of sperms and embryos, which allow a global exchange and trade of breeding animals (Clark, 1998). As a consequence, globally active breeding companies concentrate their breeding work on few strains to be sold to global markets, which is necessary to finance the increasingly expensive breeding work. This strategy continuously widens the gap between highly productive, global breeds, like Holstein cattle, Large White pigs or Leghorn chicken, and less productive local breeds which eventually are better adapted to specific production conditions or local market requirements. Tisdell (2003) argued that emerging markets and economic development also favour a shift from multi-purpose local to specialised global breeds. With improved access to global markets, production systems in developing countries tend to become standardised and uniform allowing the production with global breeds, while local production for local markets is more diverse both with respect to production systems and breeds used.

Since economic performance is of increasing importance and, as a consequence of WTO regulations, global trade of animal products is steadily increasing, local, well adapted breeds are continuously replaced by global, more productive breeds. This development is accompanied by the use of standardised animal husbandry systems (with respect to feeding, air-conditioning and hygienic regime) to compensate for the higher and more specific environmental requirements of the high performance breeds. Although the use of locally adapted breeds might be more rewarding and sustainable in a macro-economic sense, these decisions are often made on a micro-economic scale with a short to medium term perspective.

Other causes that might contribute to the risk that a breed might go extinct are genetic erosion, due to small population size and inbreeding, which is known to reduce fitness and reproductive performance. Also external factors like war, civil strives, infectious diseases, or natural disasters like drought or flooding can threaten the existence of breeds.

In ecology, species richness in an ecosystem is seen as a barrier against ecological invasion of alien species (Kennedy et al., 2002). In extensive livestock production systems simultaneous use of diverse species (like chicken, sheep, goat and cattle) and eventually different breeds or crosses within species guarantees the most efficient usage of the available resources (see e.g. Ayalew et al., 2003). Introducing animals with increased productivity through import or crossbreeding with exotic breeds requires that the necessary production factors, access to market for animal products and adequate animal husbandry knowledge are provided simultaneously. If this is not the case, the risk of failure is immense with the consequence that the original breeds are replaced through imported breeds which are not sustainably viable in the respective production environment. Hence, diversity is a factor of economic stability in extensive livestock production systems, while introduction of exotic breeds or strains potentially corrupts the balance of these production schemes, and ultimately threatens the existence of the local breeds in the system (Wollny, 2003).

Conservation of farm animal genetic resources should be designed with a long term perspective, using a planning horizon of at least 50 years. Note that this figure corresponds to quite different numbers of generations in different species, because the generation interval of farm animals ranges between about two years (e.g. chicken) and 8–10 years (e.g. cattle), so that the required genetic management to maintain diversity over a given time horizon differs between species.

There are two main arguments for conservation of farm animal biodiversity.

(a) The cultural argument

Animal breeds are a result of a cultural process. Man has used selection and designated mating to develop breeds according to a breeding goal, which has been explicitly defined or not. This often has happened in a defined environment, leading to breeds that are specifically adapted to certain, sometimes very specific environmental conditions. Examples are the trypanotolerant N′dama cattle breed in West Africa (Mattioli et al., 1998), Kuri cattle of the lake Chad bassin being highly adapted to an aquatic environment (Tawah et al., 1997), or the North Ronaldsday sheep with high salt tolerance and efficient copper absorption due to almost exclusive feeding on seaweed (Ponzoni, 1997). Other breeds play a central role in social, political or religious ceremonies, an example is the king's privilege to keep a herd of white N′guni cattle in South African zulu tribes (Felius, 1995). A methodological approach to the analysis of the cultural value of livestock breeds recently was suggested by Gandini and Villa (2003). Farm animal breeds must be seen as a man-made good with a long history, often parallel with the cultural development of human populations (see e.g. Hanotte et al., 2002) and therefore similar arguments for conservation apply as for other cultural assets like, say, old buildings or artwork.

(b) The insurance argument

Genetic diversity can be seen as an insurance against future changes (Smith, 1984). The objective might be defined as to maintain sufficient genetic diversity to be able to adapt to the challenges that are ahead. Those challenges might be

- a change of market requirements (e.g. other composition of the fatty acids in animal products);
- a change of production conditions (e.g. as a consequence of global warming);
- resistance or immunity against new diseases (comparable to the relatively recent advent of BSE or new variants of avian influenza).

The environment for animal production has changed enormously in the past 50 years, and there is no reason to believe that it will not change significantly in the forthcoming 50 years as well. The same is true for market requirements, with e.g. a demand for very fat pigs in the 1950s and high value of lean meat in today's European pig industry.

The two arguments result in different targets for conservation. The first, cultural argument clearly favours the conservation of specific breeds in their present state, especially of those breeds which have a recognised cultural or ecological value. Therefore it is necessary to quantify the cultural or ecological values of certain breeds and to identify specific traits like resistance to certain diseases or capability to cope with specific environmental conditions.

The second argument, however, is not focusing on single breeds, but on the diversity within species. Assuming that it will never be possible to maintain the complete diversity, priority will be given to those breeds with the highest contribution to the present or expected future diversity. Since we need to maintain the genetic capacity to cope with challenges that are not even known today, this can be best accomplished by maintaining neutral genetic diversity within a species.

Genetic diversity can be defined as the variability of alleles in a population. Since the genes which will be relevant in the future are unknown, it is consensus that diversity at a set of neutral, representative marker loci is an appropriate approximation. Different measures of marker-based diversity have been suggested, e.g. by Weitzman (1992), Eding and Meuwissen (2001), Piyasatian and Kinghorn (2003), and Simianer (2005). The latter argued that it is important to keep alleles segregating in the population, even at low frequency, since selection will efficiently increase allele frequency in case an allele has a selective advantage under changed conditions (Falconer and Mackay, 1996).

Diversity in farm animal species can be subdivided in between and within breed diversity using Wright's (1969) F_{ST}-statistic. An often cited reference (Hammond, 1994) states that over all farm animal species about 50% of genetic diversity are within and 50% are between breeds. Specific studies on geographically restricted sets of breeds, like African cattle breeds or European pig breeds, usually reveal a higher proportion of within breed diversity and a lower proportion of between breed diversity, though (see e.g. Saitbekova et al., 1999; Jordana et al., 2003; Piyasatian and Kinghorn, 2003; Simianer, 2005).

In a formal decision making process, it is necessary to define an objective function, whose maximisation, with or without restrictions, leads to the optimum outcome. In most cases the objective function is a mixture of continuous (e.g. conserved amount of diversity) and discrete (e.g. survival or extinction of a breed, maintenance or loss of a specific trait) components. One of the major challenges in practical application will be to identify the components of the objective function and to attach appropriate relative weights. A formal model for this process was suggested by Simianer et al. (2003).

3. What is the decision space?

Decision making means allocation of resources. This implies in the first place that there are resources to be allocated. Resources are not only defined in the monetary sense, but may also include goods and services, training, etc. Since all of these resources in principle can be valued on an economic scale, decision making is reduced for simplicity to an allocation of proportional shares of a total budget to different conservation activities. The entire set of different options on how resources can be allocated to a variety of conservation activities is called the decision space.

Before analysing different conservation options in the farm animal area, the question has to be addressed, how much resources should be put in conservation of farm animal resources as compared e.g. to plant genetic resources, or to the conservation of cultural goods, like buildings or artwork. As conservation programs are often considered within species, it even is necessary to decide which proportion of the (hypothetical) over-all budget for livestock conservation is assigned to, say, cattle vs. pigs or sheep.

The appropriate total budget for livestock conservation cannot be derived from a scientific point of view, since this is rather a political decision. Some imbalances may affect the outcome of such a general decision:

- An imbalance with respect to the stakeholders: With respect to the maintenance of diversity as a safeguard for future changes, the expected benefit clearly will be on a global level, while conservation activities have to be done on a local, national or regional level.
- An imbalance with respect to cost and profit: While the expected profit realised at some point in the future likely will not be in the form of a predictable monetary return, conservation investments have to be made now and require a specified budget.

Both factors likely will lead to a situation that less funding is provided for livestock conservation than would be assigned if the cost and benefits were easy to quantify and would relate to the same stakeholder.

Decisions have to be made under substantial uncertainty. For this reason it is hardly possible to consider decision making in a purely economic framework, e.g. by finding the optimum investment level by considering the expected discounted returns.

There are two ways to define the decision problem in a tractable form:

1. Actually, resources are invested in the conservation of farm animal diversity, although it is not trivial to get an overview over the actual amount spent. For the case of African cattle breeds, this was attempted by Reist-Marti et al. (2005). Given the information on the budget spent for conservation in one species or breed group is available, one can derive the optimum allocation of the same amount of resources, in the sense of optimising the objective function. This optimum outcome can be compared with the actual outcome and allows statements on the relative efficiency of the actual policy compared to an optimum one.
2. A hypothetical conservation budget can be assumed, and the optimum allocation and the respective effect on the objective function can be quantified. By assuming different levels of the available budget, the return can be displayed as a function of the conservation budget. We will see diminishing marginal returns, which may help decision makers to get an idea how much resources should be put in this area and how these resources should be allocated.

If this latter approach is used in different conservation fields (e.g. pig vs. cattle conservation, plant vs. animal conservation), the marginal cost efficiency in the different fields may even serve as a guideline to find the optimum allocation proportions between these fields.

Livestock conservation activities can be implemented in very different forms:

- Keepers of an economically inferior breed can be awarded a premium to balance the loss of income compared to keepers of other more competitive but less well adapted breeds.
- Training courses can be offered to improve the genetic management within the breed, aiming at a reduction of inbreeding and genetic drift.
- Marketing activities can be supported, like development of special products and brands of 'geographical origin', adding value to the products and thus giving a higher income to the keepers of the endangered breed.
- A kryoconserve of embryos or semen can be implemented.
- An exchange of male animals between herds can be organised to impose the basic concept of a circular mating scheme (Kimura and Crow, 1963) to reduce the increase of inbreeding.
- It might even be an option to invest in AIDS research, because in many African countries this disease is about to destroy the social structures first which may put a high risk on the breeds kept in those countries as well.

In addition to those activities oriented towards single breeds or breed groups, there are non-negligible fixed cost associated with the design and coordination of a conservation program, setting up an inventory of breeds, estimation of distances and diversity based on molecular information, etc.

The design of a conservation is not a decision between few well defined alternatives but rather a matter of prioritisation and a 'fuzzy' allocation of resources. In practical decision making problems, this multitude of different options has to be boiled down to a limited number of possible conservation schemes, each of which can be modelled with sufficient accuracy, both with respect to costs and to expected effects on the objective function. Then it will be possible to identify the setting with the most promising cost/benefit ratio.

It should be clear that with a limited budget it is neither possible nor desirable to impose conservation schemes in all breeds. Many breeds are members of breed groups (like Merino sheep or Landrace pigs) and can easily be replaced through other breeds. Other highly endangered breeds with just few animals left may be genetically impoverished (through inbreeding and genetic drift) so that the effort to maintain the breed is in no relation to its genetic contribution to the within species diversity (Ruane, 2000). In his 'crowned-crane paradox', Weitzman (1993) showed that, if conservation decisions are made with the objective of maximising the expected diversity in the future, the rational–but counter-intuitive–decision may be to sacrifice a highly endangered breed and to make a rather safe breed even safer.

4. How can we decide?

With a given objective function, decision space, and a defined amount of resources to allocate, the optimum allocation of resources will yield the highest (expected) value of the objective function. Maximisation can be done by applying numerical maximisation procedures, like the simplex or moment-based approaches like the Newton-Raphson or conjugate gradient methods (Press et al., 1992).

In many cases, there will be competing objectives which cannot be maximised at the same time or combined in a single optimisation criterion. The best example for this is the trade-off between expected return and risk. Risk adverse strategies, like the minimax principle, aim at the reduction of the risk of total loss, at the expense of a reduction of the expected value of the objective function.

Thus, decision making in this context in many cases is a maximisation problem with restrictions.

Restrictions may be implemented in such a form that certain subspaces of the decision space are not eligible. This is the case, if, say, possible conservation activities are restricted to a subset of breeds, which might be the case if the infrastructure for conservation is limited.

Another way of imposing restrictions is to put a penalty on certain outcomes so that the search algorithm will try to avoid allocation patterns which favour highly penalised results. This approach is more flexible than the former one, but requires to quantify penalties that reflect the degree of acceptance or non-acceptance of different outcomes.

A further approach is to look not only at the first moment of the objective function (the expected value), but to include higher moments, first of all the variance of the expected outcome. This allows assignment of asymmetric weights to expected values. Assigning low (or negative) weight to the lower part of the distribution about the expected outcome will gradually favour allocations which lead to a reduced variance (risk) of the result.

Decision making requires specification of the model parameters, like diversities, breed values or extinction probabilities. This can be done in a deterministic approach, assigning a single value to each of the required parameters. This leads to a clear, probabilistic solution of the optimisation problem (see e.g. Reist-Marti et al., 2003) and provides the posterior distribution function of the expected value of the optimisation criterion.

As an alternative, Bayesian decision rules (Berger, 1997) can be applied, requiring the definition of a priori distributions of the required parameters, which reflect the degree of uncertainty included in the parameter specification. Given that some parameters, like the probability that a breed will go extinct within the next 50 years, are almost impossible to quantify exactly, the Bayesian option of assigning moderately informative priors reflecting the degree of belief is appealing. Empirical approaches like contingent valuation methods can be used to obtain estimates and variances of such values from expert panels.

5. Review of implemented or suggested concepts for decision making in livestock conservation

Compared to the complex theoretical concepts, practically implemented rules for decision making in livestock conservation are rather simplistic. They mostly rely on a single or a combination of few simple criteria, which may be the number of breeding males and females, the inbreeding rate estimated from the actual or effective number of animals (for the concept of effective population size see e.g. Falconer and Mackay, 1996), or population dynamics like increasing or decreasing population size. Certain conservation activities are started if population size falls below a defined threshold. Such a scheme may have different steps, putting a breed on a 'watch' status at threshold 1, and triggering specific, a priori defined activities if the chosen parameter falls below further thresholds.

Three examples for simple schemes to define risk categories will be given:

Table 1 reports the set of risk categories used by FAO (Scherf, 2000). This mainly relies on actual numbers of male and female breeding animals and

Table 1
Risk categories used by FAO (Scherf, 2000)

Risk category	Number of				Additional criteria
	Females		Males	Total breeding animals	
Extinct	0	or	0		Impossible to recreate breed population
Critical	≤100	or	≤5	or ≤120 and decreasing and <80% pure breeding	
Critical-maintained					Critical +conservation or commercial breeding program in place
Endangered	≤1000	or	≤20	or between 81 and 99 and increasing and >80% pure breeding or between 1001 and 1200 and decreasing and <80% pure breeding	
Endangered-maintained					Endangered +conservation or commercial breeding program in place
Not at risk	>1000	and	>20	or >1200 and increasing	Other categories don't apply

adds criteria of population dynamics. Also, existence of conservation programs or inclusion of endangered breeds in breeding programs is accounted for.

The European Association of Animal Production (EAAP, 1998) suggests the use of the expected increase of the inbreeding level over 50 years, which basically is estimated from the effective population size derived from the number of male and female breeding animals and the generation interval (Table 2). Note that for species with long generation intervals (like cattle) a larger increase of inbreeding per generation is accepted in this scheme.

The risk status suggested by American Livestock Breeds Conservancy (Bixby, 1994) is based on the number of annually registered breeding animals in North America and world wide (Table 3). Other than FAO, which is a UN organisation and therefore has to define criteria on the level of member countries, the ALBC criterion takes into account that a breed may be rare on the national level, but still can be part of a sufficiently large global population, so that it should not be considered as endangered.

Table 2
Risk categories based on inbreeding rate (ΔF) over 50 years used by the European association of animal production (EAAP, 1998)

Risk category	ΔF over 50 years
Critically endangered	>40%
Endangered	26–40%
Minimally endangered	16–25%
Possibly endangered	5–15%
Not endangered	<5%

In all cases conservation activities are linked to the risk status, with increasing intensity of activities with increasing degree of endangerment. However, decisions on actual conservation activities are made in a subsidiary form, often through regional government or non-government organisations, and often are conditional on the availability of funds.

Although being simple and pragmatic, such schemes lack almost all criteria that characterise a rational and cost effective decision making process from a systematic viewpoint. The main criticism is that the objective of the conservation strategy is not well defined. Implicitly, the objective is to maintain all presently existing breeds. Whether the breeds as such are of any specific value or to what amount they contribute to the intra-specific diversity is by no means accounted for. Also, by pre-defining a series of actions to be taken when certain population size thresholds are passed, decisions are

Table 3
Risk categories of the American Livestock Breeds Conservancy (Bixby, 1994)

Risk category	Annual registrations		Additional criteria
	North America	World wide	
Critical	<200	<2000	
Rare	<1000	<5000	
Watch	<2500	<10,000	Or genetic concerns/ limited distribution
Recovering	>2500	>10,000	Was in higher risk categories and needs monitoring

restricted to a minimal subset of the entire decision space.

Ruane (2000) suggested a framework for prioritising domestic animal breeds on the national level. For the case of Norway he classified 45 breeds from 17 animal species (including exotic farm animal species like mink and salmon) and scored them for the following criteria:

- degree of endangerment, determined primarily by its current population size and additional factors (level of inbreeding, existence of conservation scheme etc.);
- traits of current economic value;
- special landscape value;
- traits of current scientific value;
- cultural and historical value;
- genetic uniqueness.

Scores for all these criteria were listed for each breed, however this list is just used as a structured information basis for an informal decision on conservation priorities. Ruane (2000) argues that the degree of endangerment should be used as the most important criterion because if a breed is not at risk to go extinct within the next years, high priority for conservation activities are not justified.

Eding et al. (2002) have considered the special situation of selecting a 'core set' which can be thought of as a sample of individuals from different breeds that are stored permanently, e.g. as a kryoconserve. They suggest to identify breeds to be represented in the core set based on the average kinship (Malécot, 1948) which can be estimated from marker information. While their approach guarantees the conservation of a maximum proportion of founder alleles, non-genetic criteria like any sort of specific breed value or degree of endangerment are not taken into account. It should also be noted that selection of a 'core set' is a very specific case of decision making, and it is not obvious, how this concept can be generalised to choose between different technical conservation options to be implemented in different breeds.

A widely used formal approach to rational decision making in livestock conservation is based on Weitzman's (1992) diversity concept, which, however, is a diversity of elements which are homogeneous and pair-wise clearly distinct. In a biological sense this applies to diversity of species (like the crane species considered by Weitzman, 1993), but not immediately to livestock breeds within species, which lack both homogeneity and clear distinctiveness. Therefore, applications of Weitzman's theory to farm animals as first suggested by Thaon d'Arnoldi et al. (1998) and later by Laval et al. (2000), Cañon et al. (2001), Simianer (2002), Grigaliunaite et al. (2002), Garcia et al. (2002), Reist-Marti et al. (2003), and Simianer et al. (2003) account for between breed diversity only, which is known to capture only 50% of the total diversity (Hammond, 1994) or less.

Weitzman's diversity $D(X)$ of a set of elements X is a diversity in the strict mathematical sense. It can be calculated from a distance matrix, which can be estimated from allele frequencies or DNA sequence comparisons (Weir, 1996). The objective function is the expected diversity, $E(D)$, which is a projection of the diversity into the future and reflects the probability that breeds go extinct over the considered time horizon. For each breed, this is quantified in an extinction probability $0 \leq z_i \leq 1$ The marginal diversity $m_i = \partial E(D)/\partial z_i$ reflects the change of expected diversity of the total set of breeds if the extinction probability of breed i is modified (e.g. through conservation measures). Simianer et al. (2003) showed that the marginal diversity of a breed is functionally independent of the breed's extinction probability. Conservation decisions based on marginal diversity therefore will not reflect the degree of endangerment of a breed.

Weitzman (1993) suggested the 'elasticity' or 'conservation potential', which is proportional to $\partial E(D) \times z_i / \partial z_i$, as the 'single most useful species alert indicator'. This value reflects the amount of expected diversity that could be conserved if breed i was made completely safe, however ignoring specific conservation cost trade-offs. Although the conservation potential is only approximate in that the marginal diversity is linearly extrapolated, Simianer et al. (2003) found it to be a good predictor of breed prioritisation in much more elaborate optimum allocation schemes. In this study, the breeds with highest conservation potential were also chosen to obtain conservation funds in a complex optimum allocation scheme, while in this subset of selected breeds the conservation potential was a poor predictor of the relative share of the total conservation budget allocated to any one breed.

While Weitzman's (1993) objective function to maximise the expected diversity of a defined set is a very strong concept, decision making is reduced to setting up a priority list for conservation activities in the original papers. Later Weitzman (1998) argued that the resulting conservation scheme with a limited budget will make a subset of species completely safe and leave the remaining subset of species in their actual state of endangerment. This, however, was refuted by Simianer et al. (2003) who showed that species will never be made completely safe if conservation investments have diminishing returns.

Based on Weitzman's (1993) expected diversity concept, Simianer (2002) and Simianer et al. (2003) proposed an algorithm to find the optimum allocation of a given quantity of resources in such a way that the expected diversity is maximised. This method assumes that marginal costs and marginal returns (in terms of conserved diversity) of conservation activities can be specified for each breed. In an application with 26 African taurine and sanga cattle breeds, Simianer (2002) showed that with optimum allocation only about 50% of the resources are required for the same conservation effect that can be achieved when conservation funds either are spread equally over all breeds or are concentrated on the most endangered breeds only.

Piyasatian and Kinghorn (2003) suggest to combine diversity with other quantities, like expected genetic merit towards a breeding goal, and breed viability, in a weighted objective function. A similar suggestion was made by Simianer et al. (2003) proposing a composite objective function containing diversity, specific features (like disease resistance), and specific breed values. Econometric approaches like hedonic pricing and contingent valuation can be used to derive appropriate economic weights (see e.g. Kristjanson et al., 1999; Scarpa et al. 2003; Tano et al., 2003).

Simianer (2002) suggested a slightly different strategy in that he gave a penalty to those breed combinations in which defined special traits (e.g. trypanotolerance) were lost. This led to a moderate re-allocation of resources to those breeds showing the desired specific traits, and through this imposed a combined objective of conserving diversity and increasing the probability of maintaining special traits.

Eding et al. (2002) and Caballero and Toro (2002), among others, criticised that Weitzman's (1992, 1993) diversity metric considers only between breed diversity, while within breed diversity is known to be a major source of genetic variability in farm animal populations.

Some studies (García et al., 2002; Eding et al., 2002) focus on the inclusion of within breed diversity. Caballero and Toro (2002) argue that conservation priorities based on Weitzman's (1992) diversity favour phylogenetically distant breeds which might, however, be highly inbred and therefore may not contribute substantially to the gene pool of the species. Those studies suggest different methodological options to combine between and within breed variability, but do not include other, non-genetic criteria in the objective function.

6. A generalisation of Weitzman's concept of conservation potential

Relatively simple concepts like Weitzman's (1993) conservation potential could be modified to account not only for the between breed diversity, but to be used with an objective function encompassing both within and between breed diversity as well as other non-genetic factors.

Consider a continuous objective function G for which the value $G(X)$ can be specified for any possible subset of breeds X in such a way that $G(X)>G(Y)$ if subset X is of higher total value than subset Y. Using extinction probability z_i for breed i, we can derive the expected value $E(G)$ and its posterior distribution. Using very similar arguments as in Weitzman (1993), the conservation potential $-\partial E(G)\times z_i/\partial z_i$ can be computed and used for identifying breeds for conservation purposes.

The basic concept is illustrated in Fig. 1. The expected objective quantity is displayed as a function of the extinction probability of two (out of many) breeds, $E(G)=f(z_1)$ and $E(G)=f(z_2)$, respectively. For breed 1 and breed 2, the actual extinction probabilities are $z_1=0.22$ and $z_1=0.27$, and with the present set of extinction probabilities $E(G)$ is assumed to be 100. Reducing the extinction probabilities leads to an increase of $E(G)$ that is why the marginals $m_i=\partial E(G)/\partial z_i$, the slopes of the curves in A and B

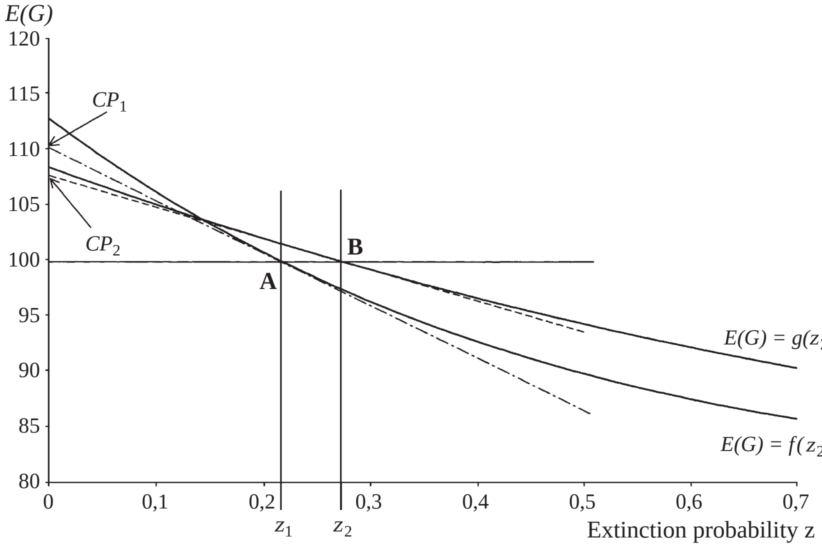

Fig. 1. Example for the derivation of the conservation potential for two breeds with different extinction probabilities (z_1, z_2) and different functional dependency of the expected objective function $E(G)$ on the extinction probabilities. CP_1 and CP_2 are the result of the linear extrapolation using the marginals in the intersections A (for breed 1) and B (for breed 2).

are negative. A simple approach to calculate the marginal diversity exactly was suggested by Simianer et al. (2003). Although it will be difficult to derive the exact value of m_i in more complex situations, it is possible to approximate this quantity with sufficient accuracy by considering a limited number of subsets of breeds and their respective value of the objective function and the joint probability. The estimated conservation potential for breed i is $CP_i = E(G) - \partial E(G) \times z_i / \partial z_i$, the intersection of the linear extrapolation with the y-axis. In the present example breed 2 is more endangered than breed 1, but reducing the extinction probability of breed 2 only has a small effect on $E(G)$, which may be due to the fact that a third breed is in the set, which is similar to breed 2, but hardly endangered. Then, the contribution of breed 2 to the set is limited and its marginal is small.

The linear extrapolation in this example reveals that the estimated conservation potential of breed 1 is higher than the one of breed 2, and hence in this case conservation activities in breed 1 should be prioritised. Note, however, that the linear extrapolation results in an estimation error, which may be substantial and misleading if the curves differ in the degree of non-linearity and/or if extinction probabilities are very different between breeds.

From this we propose as a simple rule for decision making when the alternative is to implement a conservation scheme in one of two breeds that breed 1 should be chosen if $m_1/m_2 > z_1/z_2$ and otherwise breed 2 should be preferred.

In the example of Fig. 1, $m_1 = -57$ and $m_2 = -28$, so that

$$\frac{-57}{-28} > \frac{0.22}{0.27}$$

and hence breed 1 should be chosen.

While this criterion may be very efficient to rank the breeds that should be included in a conservation program, it was not found to reflect the optimum allocation of limited resources to the chosen set of breeds (Simianer et al., 2003). Nevertheless this criterion clearly should outperform all the simple criteria in use which are only accounting for risk and ignore the contribution of breeds to diversity and their special values.

While the use of Weitzman's (1992) diversity metric as objective function is heavily disputed and clearly is not fully satisfactory for livestock breed conservation studies, Weitzman's (1993) concept of maximising the expected diversity and using marginals and the conservation potential to find the optimum allocation has a strong methodological appeal, especially if it is not restricted to Weitzman's diversity metric but used with generalised objective functions. The major challenge thus will be to define a proper objective function that captures both within and between genetic diversity as well as other non-genetic criteria which contribute to the long-term value of a breed. If this is available, Weitzman's (1993) optimisation approach fulfils the requirements of rational decision making, in that it maximises the objective function and allows a flexible definition or restriction of the decision space.

7. Practical aspects of decision making

In livestock conservation, decisions are made based on imperfect information. We usually have a good knowledge about the inventory of breeds and in the major farm animal species, phylogenetic structures have been analysed with the use of molecular markers. Information becomes more scarce when it comes to effective population sizes and the risk status of breeds. Reist-Marti et al. (2003) have suggested a number of criteria beyond population size which can be included in a semi-quantitative estimation of the extinction probability of a breed.

Very little is known on the economics of conservation, i.e. the cost and the cost-efficiency of different strategies (Brem et al., 1984; Cunningham, 1996; Lömker, 1993; Smith, 1984; Cicia et al., 2003). Simianer et al. (2003) have suggested three basic parametric functions linking different conservation strategies to conservation effects, which need to be further specified for a given situation. Economic valuation of farm animal genetic resources has only recently been put on the research agenda, though (Rege, 1999; Rege and Gibson, 2003).

Diversity conservation has direct (e.g. for ex situ conservation programs) and indirect (e.g. acceptance of reduced productivity of endangered breeds) cost. It was demonstrated that people are only accepting these extra cost if they are sufficiently informed about the expected benefits. Otherwise a significant proportion of individuals refuses the trade-offs between biodiversity and other goods (Spash and Hanley, 1995). Therefore, information is the key for a general acceptance of complex conservation policies.

A very important aspect is that decisions are made on the appropriate scale. In most cases, decisions on the national level are inappropriate, because livestock species are spread across political borders. Therefore, decisions must be based on a global inventory of the species diversity, which is one of FAO's objectives, and conservation activities must be documented and coordinated on the international level.

Decision making must take into account the uncertainty about a number of basic parameter values. Even with a much better data base, subjective assessments and perceptions will always play an important role in conservation decisions. Bayesian decision theory appears appealing, since it has the built-in feature of accounting for uncertainty and subjective assessment, however to my knowledge it was not used for this purpose to date. Reist-Marti et al. (2003) showed that Weitzman's (1993) concept yields not only an estimate of expected diversity, but also the corresponding posterior distribution. This might be a starting point to use asymmetric penalty functions to favour robust and risk-adverse allocation patterns. In any case, sensitivity analyses to study the robustness of the result towards significant changes in the model parameters are strongly suggested.

There is a considerable discrepancy between highly complex decision making concepts discussed in the scientific literature, having many of the theoretically desired properties, and the simplistic and pragmatic decision rules used in practical applications. Results like the doubling of cost efficiency of conservation expenditure with optimum allocation strategies (Simianer, 2002) strongly suggest that implementation of more sophisticated decision rules in practical decision making processes should be of high priority.

Who are decision makers in livestock conservation? In developed countries, conservation decisions are often made by idealistic individuals or NGOs. A decision may be to keep one or few animals of an endangered breed on a private basis or to create a network of breeding enthusiast for this purpose. A second group of decision makers is in the political sphere, mainly on the level of national or regional administrations. Compulsory conservation decisions on the international level are a rare exception in this field, however international organisations like FAO or EU are engaged in supportive activities like research and policy development, coordination of national activities, creating an information base, training, etc.

It should not be overseen that also decisions not directly linked to conservation activities may substantially affect the conservation of livestock diversity. A decision of a donor organisation to improve animal production by replacing local adapted breeds through seemingly more efficient exotic breeds may be a larger threat for a country's diversity than all conservation activities together could possibly balance. Thus, awareness about the value of diversity and the mechanisms of diversity loss is not only essential for those people or organisations who are positively involved in conservation programs, but needs to be communicated as a general concept to all involved parties.

An important aspect to mention is the role of intellectual property rights in connection with breed conservation. While animal breeds as such generally can not be patented and–other than for plant varieties–no specific legal framework regulating ownership of and access to farm animal breeds exists, DNA-sequences and genes of livestock breeds can be and have been patented (Rothschild, 2002). This has raised considerable concern especially in developing countries to allow foreign partners access to the country's genetic resources for conservation purposes, and is one of the main factors hampering internationally coordinated conservation activities in livestock. Such initiatives, like a trans-national kryoconservation center or ex situ collections, can only be successful if ownership, access and use of the stored material is fully regulated in an appropriate and legally binding material transfer agreement of the involved parties.

8. Conclusions

It must be recognised that it is neither possible nor reasonable to conserve all described 6400 farm animal breeds. Under the given, mostly financial restrictions, the objective thus cannot be to maintain every single breed, but to maximise the conserved diversity within the species, which is a function of between and within breed diversity.

A sound conceptual framework for a formal decision making process is mainly based on Weitzman's (1992, 1993) diversity concept. In this contribution, Weitzman's approach is generalised and possible pragmatic criteria for decision making are suggested and discussed. The practical situation, however, is often characterised by fragmented and largely uncoordinated decision making processes based on simplistic criteria or even a complete lack of well-defined policies in this area.

Since the major species are globally distributed, conservation of farm animal diversity is a global task. In contrary to this, conservation decisions mostly are made on the national level. Therefore, creating an internationally coordinated conservation policy is of crucial importance. Beyond that, the value of farm animal biodiversity and the mechanisms possibly leading to a threat need to be communicated to all stakeholders making decisions which might possibly affect the populations.

Based on the suggested general framework the necessary steps towards a rational conservation policy are:

(a) the definition of the adequate scope of a decision making process, which usually will not follow political borders;
(b) a well defined operationalised objective function, including both within and between diversity as well as additional traits;
(c) a toolbox of possible conservation activities with quantified cost-efficiency;
(d) a good strategy to find the best policy and a mechanism to implement the policy which is found to be optimum.

These four criteria can be used to validate ongoing conservation programs and should be a guideline for the implementation of new policies.

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