Optimum allocation of conservation funds and choice of conservation programs for a set of African cattle breeds

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Abstract – Although funds for livestock conservation are limited there is little known about the optimal allocation of conservation funds. A new algorithm was used to allocate Mio US$ 1, 2, 3, 5 or unlimited funds, discounted over 50 years, on 23 African cattle breeds conserved with four different possible conservation programs. Additionally, Mio US$ 1 was preferably allocated to breeds with special traits. The conceptional in situ conservation programs strongly involve breeders and give them part of the responsibility for the conservation of the breed. Therefore, the pure in situ conservation was more efficient than cryoconservation or combined in situ and cryoconservation. The average annual discounted conservation cost for a breed can be as low as US$ 1000 to US$ 4400 depending on the design of the conservation program and the economic situation of the country of conservation. The choice of the breeds and the optimal conservation program and the amount of money allocated to each breed depend on many factors such as the amount of funds available, the conservation potential of each breed, the effects of the conservation program as well as its cost. With Mio US$ 1, 64\% of the present diversity could be maintained over 50 years, which is 13\% more than would be maintained if no conservation measures were implemented. Special traits could be conserved with a rather small amount of the total funds. Diversity can not be conserved completely, not even with unlimited funds. A maximum of 92\% of the present diversity could be conserved with Mio US$ 10, leaving 8\% of the diversity to unpredictable happenings. The suggested algorithm proved to be useful for optimal allocation of conservation funds. It allocated the funds optimally among breeds by identifying the most suited conservation program for each breed, also accounting for differences in currency exchange rates between the different countries.

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optimal allocation / conservation program / African cattle / conservation funds / choice of program
1. INTRODUCTION

About 30% of all farm animal breeds worldwide are at a risk of extinction. Funds for conservation of breed diversity are limited and not sufficient to conserve all breeds.

Several authors have examined the choice of breeds according to their endangerment (e.g. [8, 21]) or their endangerment and contribution to diversity [15, 18, 27–30]. In other studies the cost of different conservation programs and their effects [1, 13, 14, 17, 24–26] have been analyzed.

Yet, research on how to use the limited funds on the breeds most efficiently, i.e. with the highest conserved diversity possible is scarce. Such allocation of funds must include the choice of breeds, conservation programs and shares of the total budget spent on each breed.

Simianer [22] and Simianer et al. [23] proposed a new algorithm for the optimal allocation of conservation funds. Simianer [22] compared the algorithm with giving equal shares to all breeds, or giving 1/3 of the funds to the three most endangered breeds, respectively, and found in an application to 23 African cattle breeds that the cost efficiency of conservation is increased by about 60% when funds are optimally allocated. In those analyses, it was assumed that the same functions linking conservation cost to conservation effects apply for all breeds. Reist-Marti et al. [19] analyzed designs, cost and benefits of possible conservation schemes and suggested, based on empirical results, more specific functions for a set of 23 African cattle breeds.

The general decision making and allocation problem therefore needs to be extended. Given that a defined amount of funds is available for this purpose, it is necessary to specify:

(a) which breeds should be chosen for active conservation measures;
(b) which conservation strategy will be applied to any one of the chosen breeds; and
(c) what is the optimal size of the chosen conservation scheme (e.g. number of individuals included in an in vivo or in vitro scheme).

The primary objective of this study is to present a methodology that will provide answers to these three questions. The algorithm will be illustrated with the same set of 23 African cattle breeds used in the studies mentioned before. In addition, it will be shown how the relative value of special traits can be quantified, i.e. how much conserved diversity needs to be sacrificed to conserve a certain proportion of one or multiple special traits present in the set of breeds considered.
2. METHODS

2.1. Functional relationship between conservation cost and returns

The suggested methodology is an extension of the method described in detail by Simianer et al. [23]. In this study, the change in extinction probability, $\Delta z_i$, of breed $i$ is considered to be a continuous function of the actual extinction probability, $z_i$, and the amount of funds spent for conservation in this breed, $m_i$, i.e.

$$\Delta z_i = f(z_i, m_i),$$

where $\Delta z_i = z_i^* - z_i$ and $z_i^*$ is the extinction probability after the conservation activity has taken place. Note that $\Delta z_i < 0$ since $z_i^* < z_i$. Simianer et al. [23] suggested three mathematically continuous and steady functions reflecting different conservation schemes. However, neither discontinuities nor economic realities like fixed cost of a conservation program are taken into account by these functions.

We suggest using an alternative function $z_i^* = f(z_i, m_i)$, which overcomes these problems. This function is based on the approach suggested by Reist-Marti et al. [18] using a scoring system to derive extinction probabilities, with

$$z_i = a + b \sum_{j=1}^{N} s_{ij}$$

where $s_{ij}$ is a score indicating whether effect $j$ affecting the degree of endangerment of breed $i$ is present or not, and $a, b$ are appropriately chosen constants to scale $0 < z_i < 1$.

Note, that following [18] $a$ and $b$ should be chosen such that the breed is neither entirely safe ($z_i = 0$) nor guaranteed to become extinct ($z_i = 1$) in the time horizon considered. The effects affecting the degree of endangerment can be population size, sociocultural importance, or geographic distribution of the breed, where always the unfavourable condition is indicated by a higher score. The assumed mechanism of a conservation scheme is that it removes or reduces some of the factors affecting the degree of endangerment. If, for example, a breed is originally geographically concentrated in a region threatened by natural disasters like droughts, and conservation funds are used to re-locate a part of the population to a less endangered area, the score for ‘geographic distribution’ will be reduced.
Mathematically this means that for some $j$ the score after implementation of the conservation scheme $s_{ij}^* < s_{ij}$ and

$$z_i^* = a + b \sum_{j=1}^{N} s_{ij}^* < z_i.$$

Different conservation programs will affect different components of the degree of endangerment. This is obvious, when \textit{in situ} live conservation and \textit{in vitro} cryoconservation are compared. Different programs will also have different costs, which are a combination of fixed cost (necessary to establish the program) and variable cost (depending on the number of animals conserved). At the same time, the reduction in the degree of endangerment will be proportional to the number of animals included in the scheme.

This will be illustrated with an example. Consider a hypothetic breed with a given set of variables indicating the actual level of endangerment (Tab. I). The ten variables are taken from Reist-Marti \textit{et al.} [18]. Using the constants $a = 0.1$ and $b = 0.66$, the resulting actual extinction probability is $z_i = 0.63$.

Now consider a conservation program $P$, which has positive effects on a number of variables. This conservation program can be conducted on various levels. The lowest level $P_L$ has the cost $C_{PL} = \text{Mio } $0.037 and reduces the factors total population size, degree or risk of indiscriminate crossing, established conservation scheme and reliability of information, so that the resulting extinction probability is $z_{i}^{PL} = 0.37$. The highest level $P_H$ has the cost $C_{PH} = \text{Mio } $0.078 and reduces the factors total population size, distribution of the breed, degree or risk of indiscriminate crossing, established conservation scheme and reliability of information, so that the resulting extinction probability is $z_{i}^{PH} = 0.33$. We assume, that intermediate levels can be generated by a linear extrapolation. It should be clear, that $C_{PL} = \text{Mio } $0.037 is the minimum sum that has to be spent in this conservation scenario, mainly reflecting fixed cost. It should also be noted that there will be no additional effect by spending more than $C_{PH} = \text{Mio } $0.078.

An alternative conservation scheme $Q$ is considered, again with two levels $Q_L$ and $Q_H$, with cost $C_{Q_L} = \text{Mio } $0.058 and $C_{Q_H} = \text{Mio } $0.100 and resulting extinction probabilities $z_{i}^{Q_L} = 0.27$ and $z_{i}^{Q_H} = 0.23$.

For both scenarios, the functions between conservation expenditure and extinction probability are depicted in Figure 1. From this function, the choices depending on the available conservation budget for this breed are clear:

(a) if the budget is $< \text{Mio } $0.037: do not invest in this breed, because there will be no conservation effect;

(b) if the budget is between $\text{Mio } $0.037 and $\text{Mio } $0.058: use program $P$,
Table I. The effects of the low (L) and high (H) cost scenarios of two conservation programs P and Q on the extinction probability of a breed (zi).

| Variable                                           | Breed not conserved | Breed conserved with |
|----------------------------------------------------|---------------------|----------------------|
| Total population size                              | 0.30                | 0.20                 |
| Change of total population size 0.10 over the last 10 years | 0.10                | 0.10                 |
| Distribution of the breed                          | 0.10                | 0.10                 |
| Degree or risk of indiscriminate crossing           | 0.10                | 0                      |
| Organization of farmers                            | 0                   | 0                     |
| Established conservation scheme                    | 0.10                | 0                     |
| Political situation of the country/ies (average over all countries) | 0                   | 0                     |
| Special traits                                     | 0                   | 0                     |
| Sociocultural importance                           | 0                   | 0                     |
| Reliability of the information                     | 0.10                | 0                     |
| Total                                              | 0.80                | 0.40                 |
| Extinction probability zi^a                        | 0.63                | 0.37                 |
| Maximum cost C(in Mio US$)                         | 0.037               | 0.078                |

\[ zi^a = ((\text{Total}) \times (0.8/1.2)) + 0.1 \text{.} \] For details see [19].

because this is the only feasible program with that budget;
(c) if the budget is between Mio $ 0.058 and Mio $ 0.100: use program Q, because it gives you a better return than program P;
(d) if the budget is > Mio $ 0.100: use Mio $ 0.100 to implement QH and use the rest in another breed, because you will not get any additional effect by spending more than C_{QH}.

As is demonstrated with the dotted line in Figure 1, the two curves (or in general as many curves as different conservation schemes are considered) can be combined in one function linking conservation expense in this breed both to a choice of conservation scheme and a quantification of returns in terms of reduced extinction probability. In the remaining presentation this function will be denoted as \( F(m_i) \).

If e.g. Mio $ 0.080 should be allocated to this breed, the function \( F(m_i) \) both specifies that the optimal conservation scheme is scheme Q and the resulting extinction probability is 0.25.
Figure 1. The cost efficiency of the conservation programs $P$ and $Q$ and the optimal allocation function (dotted line) for a breed. The optimal allocation function indicates which conservation program is most efficient subject to the funds allocated to the breed.

2.2. Optimum allocation of funds

Consider a situation where a total budget $B$ should be optimally allocated to a set of $N$ breeds. Let $M$ be a vector of length $N$ where element $m_i \geq 0$ reflects the amount of money spent on conservation of breed $i$ and $\sum m_i = B$. Let $Z$ be a vector of size $N$ containing extinction probabilities of the $N$ breeds, with $z_i$ being the extinction probability of breed $i$ in a given time period $t$ without any conservation measures. By a given allocation pattern defined through $M$, $Z$ is modified to $Z|\cdot$ with element $z_i^* < z_i$ for at least some $i$. Note, that for a given $m_i$ both the reduced extinction probability and the optimum choice of conservation program is determined through the function $F(m_i)$ for that breed. Hence, a certain $M$ specifies both the allocation pattern and the choice of conservation program in every single breed. Adopting the method suggested by Simianer et al. [23], it is straightforward to calculate the expected Weitzman diversity $E(D|M)$ conditional on the allocation pattern.

Let $J$ be a vector of size $N$ containing the indicator variables $j_i$, $i = 1, \ldots, N$, where $j_i = 1$ if breed $i$ is still existing and $j_i = 0$ if it is extinct at a given point of time. Hence, $J$ reflects a situation where a subset of the total breeds is still existing and the complementary subset is extinct.

The probability that a specific situation, characterized through a specific vector $J$, arises under the allocation pattern $M$ can be computed as

$$P(J|M) = \prod_i (j_i + (-1)^{j_i} z_i^*).$$
From the above, $2^N$ different combinations of present and extinct breeds are possible, for which the respective probabilities can be computed as described.

Let $D_J$ be the Weitzman diversity [28] of the set of breeds not extinct, i.e., with $j_i = 1$ in vector $J$. Then, the expected diversity at the end of the assumed time period can be computed as

$$E(D|M) = \sum_{i \in J} P(J|M)D_J.$$

The objective thus is to find the vector $M$ with $\sum m_i = B$ which leads to the maximum value of $E(D|M)$.

Simianer et al. [23] propose a stepwise algorithm using marginal diversities to find the optimum allocation. This approach is not feasible with the suggested function $F(m_i)$, because this function is no longer steady and monotonically decreasing. If e.g. the allocated shares are less than the fixed cost of any conservation design in any breed, the algorithm will not be able to allocate the first share to any breed.

As an alternative, a two-step algorithm is suggested. In the first step, the optimum number of conserved breeds is derived under the assumption that the total budget is allocated in equal shares to all selected breeds. If the budget is divided in $K \ll N$ equal shares, the conservation budget for each selected breed will cover fixed and variable cost to a sufficient extent. As was shown above, the budget allocated to any one breed automatically determines the conservation scheme to be conducted in this breed being the scheme with optimum cost efficiency at the defined investment level. In the second step, the optimum unbalanced allocation is derived in the subset of breeds chosen to be conserved in the first step.

In step one of the suggested method, we use the following algorithm:

1. We start assuming that all breeds will be conserved by dividing the total budget $B$ in $N$ equal shares. Technically, this is done by setting $m_i = B/N$ for all breeds $i$, the resulting vector is called $M_N$. Using this allocation vector, we compute $E(D|M_N)$.

2. We calculate all values $E(D|M_{N-1})$, where $B$ is divided in $N-1$ equal shares and allocated to all but one breeds. Since one out of $N$ breeds can be left out at a time, we get $N$ different results of $E(D|M_{N-1})$, of which we store the maximum value and the corresponding allocation vector.

3. Of the remaining $N-1$ breeds, we again leave out one at a time and generate all possible allocation vectors $M_{N-2}$ having $N-2$ elements $m_i = B/(N-2)$ and two zero elements. Again, the maximum value for $E(D|M_{N-2})$ and the corresponding allocation vector is stored.
This algorithm is continued, until the value $E(D|M_K)$ exceeds $E(D|M_{K-1})$, showing that a uniform allocation to $K$ breeds gives a higher expected Weitzman diversity than a uniform allocation to $K-1$ breeds. $K$ then is identified as the optimum number of breeds, $N_{opt}$ under a balanced allocation.

In most cases, $N_{opt}$ will take an intermediate value. If many breeds are chosen, all of them will receive little funding and a large proportion of the funds will be used to cover the fixed cost of many conservation programs. If on the other side all the conservation budget is allocated to just one breed, this breed will be made as safe as possible, but the endangerment of all other breeds remains unchanged. Since both extreme scenarios appear to be suboptimal, the optimum balanced allocation will be for an intermediate number of breeds, i.e. $1 < N_{opt} < N$.

In step two, the optimum unbalanced allocation among the breeds selected in step one is found by the following algorithm:

We start with any vector $M_K$ reflecting allocation of the total funds to a subset of $N_{opt}$ breeds. Among these we chose at random two breeds $i$ and $j$. We then take a small share $b$ from the conservation budget of breed $i$, changing $m_i \rightarrow m_i - b$, and reallocate this share to breed $j$, changing $m_j \rightarrow m_j + b$. With the modified allocation vector $M'_K$ we compute $E(D|M'_K)$. If this value is larger than the expected diversity $E(D|M_K)$ with the original vector, we accept this reallocation, if $E(D|M'_K) < E(D|M_K)$, we undo the reallocation. This step is repeated until no increase in $E(D|M_K)$ occurs any more.

This algorithm is not necessarily finding the global optimum. Therefore it is useful to restart it repeatedly with different random number seeds. It also may result in an optimum allocation which does not include all breeds that were in the optimal balanced subset with equal shares, so it may end up with a subset of size $< N_{opt}$, while it technically never can add new breeds. Therefore it is recommended to start this algorithm also with the suboptimal balanced allocation vectors of size $N_{opt} + 1$ and $N_{opt} - 1$.

### 2.3. Consideration of special traits

The objective of livestock conservation is not only to conserve diversity, but also to conserve special traits which may be present in one or several breeds. In the most general case, one may wish to conserve several special traits, present in different breeds, simultaneously.

The basic assumption here is that a special trait is a characteristic of entire breeds. This means, that the trait is conserved if at the end of the planning
horizon at least one breed has survived that carries this trait, and that the trait is lost if all breeds carrying this trait have disappeared.

The indicator variable $x_{it} = 1$ if breed $i$ carries trait $t$ and $x_{it} = 0$ if not. We suggest two different summary statistics to quantify the amount of special traits in a given set of breeds which is specified through the vector $J$ as described earlier.

(a) The variable $T_1$ reflects the number of breeds showing special traits, summed over all traits, and is defined as $T_1 |J = \sum_t \sum_i j_i x_{it}$.

(b) The variable $T_2$ indicates how many special traits are present in at least one of the breeds present in subset $J$. For this, we have to define a variable $\tau_t$ which is

$$\tau_t = \begin{cases} 1 & \text{if } \sum_i j_i x_{it} > 0 \\ 0 & \text{if } \sum_i j_i x_{it} = 0 \end{cases}$$

Then, $T_2 |J = \sum_t \tau_t$.

If, for example, special trait one is present in breed A, B, and C, special trait two is present in breed C and D, and special trait three is present in breed D, then $T_1 = 6$ and $T_2 = 3$ in the total set of all breeds. If the subset $J = [1, 1, 1, 0]$ is considered, $T_1 |J = 4$, because the traits two and three expressed in breed D are disregarded, and $T_2 |J = 2$, because trait three, which is only expressed in breed D, is not present in this subset.

Diversity and either of the two special trait statistics can be combined in one objective function by a weighted summation. As suggested in Simianer [22], we call this a utility function defined as

$$U_J = w_1 D_J + w_2 T_1 |J$$

where $l = 1$ or $2$ and $w_1$ and $w_2$ are appropriately defined relative weights of diversity and special trait statistics, respectively. Conditional on an allocation vector $M$, the expected utility can be computed as

$$E(U |M) = \sum_{\forall J} P(J |M)U_J$$

and the algorithm suggested to find allocation vector $M$ maximizing the expected diversity can be used straightforwardly to maximize the expected utility.
2.4. Computational aspects

In the proposed methodology it is necessary to repeatedly calculate the expected diversity of the total set of $N$ breeds. The following arguments are equally valid for the calculation of an expected utility, but will be shown for the case of expected diversity only.

When using the algorithm suggested by Simianer et al. [23] the computing time for one calculation of $E(D|M)$ is proportional to $2^N$, which may be prohibitive for large sets of breeds.

In the second step of the allocation algorithm suggested above, only a subset of $N_{opt}$ extinction probabilities is variable, while extinction probabilities for the $N - N_{opt}$ breeds not getting any financial support for conservation are fixed.

In the following, it is shown how the expected diversity in this case can be calculated much more efficiently and rapidly.

Let us assume that the first $N_v$ breeds have variable extinction probabilities $z_i^*$ conditional on $M$ while the extinction probability of the remaining $N_f$ breeds is fixed as $z_i$.

Let $V$ be a vector of size $N_v$ containing the indicator variables $v_i, i = 1, \ldots N_v$, where $v_i = 1$ if breed $i$ is still existing and $v_i = 0$ if it is extinct at a given point in time. Correspondingly, $F$ is a vector of size $N_f$ describing the presence or absence of those breeds with fixed extinction probabilities, containing the indicator variables $f_i, i = 1, \ldots N_f$, where $f_i = 1$ if breed $i$ still exists and $f_i = 0$ if it is extinct. Hence, $\{V, F\}$ reflects a situation where a subset of the total breeds still exists and the complementary subset is extinct. Note that the vector $J$ defined earlier is equivalent to $\{V, F\}$.

The probability that a specific situation, characterized through a specific vector $\{V, F\}$, arises with allocation vector $M$ can be computed as:

$$P(V, F|M) = \prod_{i=1}^{N_v} \left( v_i + (-1)^{v_i} z_i^* \right) \prod_{i=1}^{N_f} \left( f_i + (-1)^{f_i} z_{N_v+i} \right)$$

$$= P(V|M) \times P(F).$$

Let $D_{V,F}$ be the diversity of the set of breeds not extinct in a specific scenario described through $\{V, F\}$. 
Then, the expected diversity at the end of the assumed time period can be computed as

\[
E(D | M) = \sum_{V,F} P(V,F) D_{V,F}
\]

\[
= \sum_{V,F} P(V | M) \times P(F) \times D_{V,F}
\]

\[
= \sum_{V} P(V | M) \times \left[ \sum_{F} P(F) D_{V,F} \right].
\]

Since \( P(F) \) is invariant over the possible allocation alternatives leading to changes in \( Z \), the term \( \sum_{F} P(F) D_{V,F} \) has to be computed for each possible vector \( V \) only once. Different allocation patterns are reflected in different values of the elements in \( P(V | M) \), so that summations still have to be done over the \( 2^{N_v} \) different vectors \( V \).

This reduces computing time substantially: with \( N = 23 \) breeds and a subset of \( N_v = 8 \) breeds receiving conservation funds, the necessary computing time to calculate \( E(D) \) for one allocation pattern is reduced by the factor \( 2^{-(N-N_v)} = 3.05 \times 10^{-5} \).

### 2.5. DATA

#### 2.5.1. Breeds

The genotypes of 23 African cattle breeds are used for illustration, which all are of zebu (\textit{Bos indicus}) and zenga (\textit{Bos indicus} \times \textit{Bos taurus}) type. They are further described in Table II and [4, 9, 10, 18, 23]. To avoid confusion and mingling of breeds or strains having the same name, it is assumed that the country of conservation is equal to the origin of the blood sample (Tab. II). For further detail see [9] and [18]. For Arashie (Beja), Sudan was chosen as the country of conservation in accordance with information on the origin of the breed given by [6].

Most of the breeds are reported to have one or several of the following special traits (Tab. II): trypanotolerance, tick/disease resistance, hardiness, adaptation to the local environment, docile/calm temperament, high fertility, good mothering ability and high product quality.

In this application, the relative weight for special traits was defined in such a way, that the utility of a set of breeds was increased by a quarter of a standard deviation of expected diversity for each special trait shown by a breed represented in the set. This weight was chosen arbitrarily, but allowed to quantify the relative equivalence of conservation of special traits compared to the conservation of neutral diversity.
Table II. The name and its abbreviation of African cattle breeds, their country of conservation and its exchange ratio from international $ to US$ (PPP/OER) and the breeds’ special traits.

| Breed                  | Abbreviation | Country of conservation | PPP/OER<sup>a</sup> | Trait<sup>b</sup> |
|------------------------|--------------|-------------------------|----------------------|------------------|
|                        |              |                         |                      | 1  2  3  4  5  6  7  8 |
| Angoni                 | ANGONI       | Zambia                  | 0.46                 | X X X            |
| Arado                  | ARADO        | Eritrea                 | 0.29<sup>c</sup>     | X                |
| Arashie (Beja)         | ARASHIE      | Sudan                   | 0.20                 | X                |
| Arsí                   | ARSI         | Ethiopia                | 0.12                 |                 |
| Bale                   | BALE         | Ethiopia                | 0.12                 |                 |
| Ethiopian Boran        | ETHBORAN     | Ethiopia                | 0.12                 | X X X            |
| Butana                 | BUTANA       | Sudan                   | 0.20                 |                 |
| Fogera                 | FOGERA       | Ethiopia                | 0.12                 | X                |
| Gobra                  | GOBRA        | Senegal                 | 0.31                 | X                |
| Highland Zebu          | highZEBU     | Kenya                   | 0.38                 |                 |
| Horro                  | HORRO        | Ethiopia                | 0.12                 | X                |
| Iringa Red             | IRINGARED    | Tanzania                | 0.52                 | X X X            |
| Kavirondo              | KAVIRONDO    | Kenya                   | 0.38                 |                 |
| Kenyan Boran           | KENYBORAN    | Kenya                   | 0.38                 | X X X            |
| Kilimanjaro Zebu       | KILIMANJA    | Tanzania                | 0.52                 |                 |
| Malawi Zebu            | MALAZEBU     | Malawi                  | 0.29                 | X X X            |
| Maure                  | MAURE        | Mauritania              | 0.18                 | X                |
| Mbororo                | MBORORO      | Nigeria                 | 0.37                 | X                |
| Nuba Mountain          | NUBA         | Sudan                   | 0.20                 | X                |
| Ogaden                 | OGADEN       | Ethiopia                | 0.12                 |                 |
| Orma Boran             | ORMABORAN    | Kenya                   | 0.38                 | X X X            |
| Sokoto Gudali          | SOKOTO       | Nigeria                 | 0.37                 |                 |
| Madagascar Zebu        | MADAZEBU     | Madagascar              | 0.35                 | X X X            |

<sup>a</sup> **PPP**: Purchasing Power Parity conversion factor to the international $ and **OER**: Official Exchange Rate to the US$ of the local currency in year 2001 [33].

<sup>b</sup> 1: trypanotolerance; 2: tick/disease resistance; 3: hardiness; 4: adapted to local environment; 5: docile/calm temperament; 6: fertile; 7: good mothering ability; 8: good product quality. Source: [6, 7, 11].

<sup>c</sup> No **PPP** conversion factor available for Eritrea in 2001. Assumption: average ratio of **PPP/OER** over all breeds (= 0.29).

### 2.5.2. Design of the conservation programs

*In situ, ex situ* and combined (*in/ex situ*) conservation programs running over 50 years were modeled. For each conservation program a low and a high input (cost) scenario was calculated. Low input scenario means that only a minimum
is invested to have a certain conservation effect. Hence, cost is mainly a fixed cost. High input scenario results in a substantial conservation effect at the price of a higher variable cost. Reist-Marti et al. [19] describe the modeled conservation programs in detail; a summary is given below (low/high input scenarios are separated by “/”):

- **HB** For the *in situ* conservation program HB, a herdbook is installed and events (e.g. sales, competitions or courses) are organized to promote the breed and motivate breeders to keep this breed. It is assumed that 168/252 animals are registered in the first year with an annual increase in registered animals of 10%. Two/four events are organized per year and the effective population size is assumed to remain constant over the 50 years.

- **IS** The *in situ* conservation program IS consists of a circular mating scheme, where sires rotate between 10/30 cow groups. Each group consists of five cows and one sire. The cows are owned by farmers and the sires belong to the program. The sires and cows are replaced by one of their offspring every fifth year when the rotation of sires takes place.

- **CC** For the *ex situ* conservation program CC semen from 25/75 unrelated sires is cryoconserved. The breed is reactivated by backcrossing from another breed with artificial insemination over six generations (27 years) resulting in 58 cows having 98% of the genes from the cryoconserved breed. It is assumed that time to first calving is four years [31], the calving interval is two years [2, 20, 32] and the survival rate of the offspring is 70% [2, 20, 32].

- **IC** The combined *in situ* and cryoconservation program starts with a base population of 320 unrelated animals (300 cows, 20 sires) of the breed. Additionally 25/75 sires not related to this founder generation of the base population are cryoconserved and used for artificial insemination on half of the cows every fifth year, *i.e.* once per generation. The other half of the cows of the base population are mated with the sires from the base population. Cows and sires are replaced by their offspring.

### 2.5.3. Cost of Conservation Programs

The basic assumption underlying this study is that a transnational budget of a fixed size is available and should be allocated to the populations in the different countries such that the expected conserved diversity or utility is maximized. To overcome biases due to different market structures and economic levels in the countries of conservation, Reist-Marti et al. [19] suggested using the international dollar (IS) to calculate and compare cost of conservation programs. The international dollar is not a real currency but a measure for the
purchasing power (standardized to the US market) necessary to buy a certain
good,

\[ I$ = \frac{LC}{PPP}, \]

with \( PPP = 1 \) for the US$; \( LC \) = local currency.

Hence, Reist-Marti et al. [19] compared the purchasing power of the money
needed to setup and run different conservation programs. To illustrate we as-
sume that in Zambia a conservation program \( P \) cost Mio Kwacha (K) 3 290.
In the US the same program \( P \) cost Mio US$ 2. Hence, the Mio K 3 290
on the Zambian market are equivalent to Mio US$ 2 on the US market as
the same good, i.e. the conservation program \( P \), was bought. This relation of
the purchasing power of a local currency on a local market with the US$ on
the US market is given by the purchasing power parity conversion factor \( PPP \). The
\( PPP \) issued by the World Bank [33] is derived by comparing prices in different
countries and the US for a certain basket of goods.

Different to Reist-Marti et al. [19], biases in cost for different countries due
to their market structure and economic level should be considered in this study.
Therefore, the cost of the different conservation programs given by Reist-Marti
et al. [19] is converted from I$ to the local currency of the country of conserva-
tion using the \( PPP \) of the year 2002 given by the World Bank [33]. It is further
assumed that funding is paid in US$. Hence, it must be calculated how much
the program would cost in US$. Therefore, the conservation cost (in local cur-
rency) is converted to US$ using the official exchange rate (\( OER = \frac{LC}{US$} \)) of
the country of conservation [33] and rounded to Mio US$ 0.001. The \( OER \) for
Zambia is 3610.94. Hence, the conservation program \( P \) costing Mio K 3 290
would need Mio US$ 0.091112 (rounded to Mio US$ 0.091) for funding.

The translation from I$ to US$ getting the currency translation effect reflecting
the economic situation of the country of conservation can be done directly
with the ratio \( PPP/OER \) given in Table II. The missing \( PPP/OER \) ratio for Er-
itrea was assumed to be 0.29, which is the average ratio of \( PPP/OER \) for all
breeds (Tab. II).

In the remainder of this paper we will refer to the US$ as $.

2.5.4. Effects of conservation programs

The effects of a conservation program are measured as reduced endan-
germent, i.e. lowered extinction probability as defined by Reist-Marti et al. [18].
Reist-Marti et al. [19] estimated the effects of the conservation programs on a
hypothetical breed having a maximum extinction probability of 90%. In this
study, the expected effects on the extinction probability of the low and high cost scenarios of the four conservation programs HB, IS, CC and IC are estimated for each of the 23 African cattle breeds individually. Consider, as an example, breed $i$ with an extinction probability $z_i = 0.63$. In Table I, column one gives the value for each variable if the breed is not conserved. Column two shows the maximum values of the ten variables and the resulting extinction probability $z_{i}^{PL}$ when the low cost scenario of the conservation program $P$ is applied to breed $i$.

For certain breeds it occurred that the low and high cost scenarios of a conservation program resulted in the same extinction probability ($z_{i}^{PL} = z_{i}^{PH}$). Since the algorithm needs a difference between $z_{i}^{PL}$ and $z_{i}^{PH}$, $z_{i}^{PH}$ was reduced by 0.1 after rescaling (not shown in Tab. I). This slight overestimation of the cost efficiency of the conservation programs will not have a substantial impact on the results since it is equally effected for all conservation programs and breeds.

2.5.5. Funds for conservation

It is assumed that either unlimited funds or a hypothetical amount of Mio $1, 2, 3$ or $5$ is provided for conservation. For modeling the conservation of special traits, conservation funds of Mio $1$ are assumed. The total amount is split up in 200 equal shares ($b$) for allocation.

Conservation programs vary in the time the money is spent. To account for this, all expenses were discounted with an interest rate of 3%. The aforementioned total amounts therefore reflect the present discounted value. Assuming an equal distribution over the planning horizon of 50 years, an annual investment of Mio $0.037733$, and summing up to Mio $1.886650$ over 50 years, would be equivalent to Mio $1$ discounted. All sums in the remaining text refer to the present discounted values.

3. RESULTS

3.1. Cost of conservation programs

Table III shows the conservation cost of each breed with different programs. The lowest conservation cost was Mio $0.048$ for in situ conservation (IS) in Ethiopia of the Arsi, Bale, Ethiopian Boran, Fogera, Horro and Ogaden breed. The highest cost caused combined in situ/ex situ conservation (IC) of the Iringa Red and Kilimanjaro Zebu in Tanzania (Mio $1.683$). The cost ranged from Mio $0.062$ to Mio $0.781$ for the herdbook conservation program HB, from
Table III. Conservation cost for African cattle breeds with different conservation programs (in US$ 1000).

| Breed          | HB low | HB high | IS low | IS high | CC low | CC high | IC low | IC high |
|----------------|--------|---------|--------|---------|--------|---------|--------|---------|
| ANGONI         | 237    | 687     | 187    | 708     | 259    | 585     | 855    | 1,480   |
| ARADO          | 152    | 438     | 119    | 257     | 165    | 374     | 546    | 945     |
| ARASHIE        | 105    | 304     | 83     | 313     | 114    | 259     | 379    | 656     |
| ARSI           | 62     | 178     | 48     | 184     | 67     | 152     | 222    | 384     |
| BALE           | 62     | 178     | 48     | 184     | 67     | 152     | 222    | 384     |
| ETHBORAN       | 62     | 178     | 48     | 184     | 67     | 152     | 222    | 384     |
| BUTANA         | 105    | 304     | 83     | 313     | 114    | 259     | 379    | 656     |
| FOGERA         | 62     | 178     | 48     | 184     | 67     | 152     | 222    | 384     |
| GOBRA          | 164    | 474     | 129    | 489     | 179    | 404     | 591    | 1,023   |
| HIGHZEBU       | 197    | 570     | 155    | 587     | 215    | 486     | 710    | 1,228   |
| HORRO          | 62     | 178     | 48     | 184     | 67     | 152     | 222    | 384     |
| IRINGARE         | 270   | 781    | 212    | 805     | 294    | 665     | 973    | 1,683   |
| KAVIRONS       | 197    | 570     | 155    | 587     | 215    | 486     | 710    | 1,228   |
| KENYBORAN      | 197    | 570     | 155    | 587     | 215    | 486     | 710    | 1,228   |
| KILIMANJAR     | 270    | 781    | 212    | 805     | 294    | 665     | 973    | 1,683   |
| MALAZEBU       | 152    | 438     | 119    | 452     | 165    | 374     | 546    | 945     |
| MAURE          | 96     | 278     | 76     | 287     | 105    | 237     | 347    | 600     |
| MBORORO       | 195    | 564     | 153    | 581     | 212    | 480     | 702    | 1,215   |
| NUBA           | 105    | 304     | 83     | 313     | 114    | 259     | 379    | 656     |
| OGADEN         | 62     | 178     | 48     | 184     | 67     | 152     | 222    | 384     |
| ORMABORAN      | 197    | 570     | 155    | 587     | 215    | 486     | 710    | 1,228   |
| SOKOTO         | 195    | 564     | 153    | 581     | 212    | 480     | 702    | 1,215   |
| MADAZEBU       | 180    | 520     | 141    | 537     | 196    | 444     | 648    | 1,122   |

a For further description of the conservation programs see text.

Mio $ 0.048 to Mio $ 0.805 for in situ conservation with sire rotation (IS), from Mio $ 0.067 to Mio $ 0.665 for cryoconservation (CC) and from Mio $ 0.222 to Mio $ 1.683 for the combined conservation program (IC).

The highest average conservation cost due to the economic and political situation of the country (high ratio PPP/OER) resulted for Tanzania (PPP/OER = 0.52), followed by Zambia (0.46) and Kenya (0.38); the lowest average cost resulted for Ethiopia (0.12), Mauritania (0.18) and Sudan (0.20).
Table IV. Effects of different conservation programs applied to African cattle breeds given as reduced extinction probability ($z$).

| Breed        | Extinction probability | Conservation program | HB low | HB high | IS low | IS high | CC low | CC high | IC low | IC high |
|--------------|------------------------|----------------------|--------|---------|--------|---------|--------|---------|--------|---------|
| ANGONI       | 0.40                   |                      | 0.13   | 0.03    | 0.20   | 0.10    | 0.33   | 0.23    | 0.27   | 0.17    |
| ARADO        | 0.50                   |                      | 0.17   | 0.07    | 0.23   | 0.13    | 0.30   | 0.20    | 0.30   | 0.20    |
| ARASHIE      | 0.53                   |                      | 0.27   | 0.17    | 0.40   | 0.30    | 0.33   | 0.23    | 0.33   | 0.23    |
| ARSI         | 0.53                   |                      | 0.17   | 0.07    | 0.30   | 0.20    | 0.37   | 0.27    | 0.37   | 0.27    |
| BALE         | 0.57                   |                      | 0.17   | 0.07    | 0.30   | 0.20    | 0.37   | 0.27    | 0.37   | 0.27    |
| ETHBORAN     | 0.48                   |                      | 0.18   | 0.08    | 0.25   | 0.15    | 0.38   | 0.28    | 0.31   | 0.21    |
| BUTANA       | 0.43                   |                      | 0.17   | 0.07    | 0.27   | 0.17    | 0.30   | 0.20    | 0.33   | 0.23    |
| FOGERA       | 0.43                   |                      | 0.17   | 0.07    | 0.20   | 0.10    | 0.30   | 0.20    | 0.27   | 0.17    |
| GOBRA        | 0.37                   |                      | 0.17   | 0.07    | 0.17   | 0.07    | 0.23   | 0.13    | 0.17   | 0.07    |
| HIGHZEBU     | 0.70                   |                      | 0.30   | 0.20    | 0.43   | 0.33    | 0.50   | 0.40    | 0.43   | 0.33    |
| HORRO        | 0.43                   |                      | 0.17   | 0.07    | 0.20   | 0.10    | 0.30   | 0.20    | 0.27   | 0.17    |
| IRINGARED    | 0.60                   |                      | 0.20   | 0.10    | 0.33   | 0.23    | 0.40   | 0.30    | 0.33   | 0.23    |
| KAVIRONDO    | 0.47                   |                      | 0.17   | 0.07    | 0.27   | 0.17    | 0.30   | 0.20    | 0.27   | 0.17    |
| KENYBORAN    | 0.35                   |                      | 0.18   | 0.08    | 0.25   | 0.15    | 0.31   | 0.21    | 0.25   | 0.15    |
| KILIMANJA    | 0.63                   |                      | 0.27   | 0.17    | 0.37   | 0.27    | 0.47   | 0.37    | 0.37   | 0.27    |
| MALAZEBU     | 0.50                   |                      | 0.13   | 0.03    | 0.23   | 0.13    | 0.33   | 0.23    | 0.30   | 0.20    |
| MAURE        | 0.40                   |                      | 0.13   | 0.03    | 0.20   | 0.10    | 0.27   | 0.17    | 0.27   | 0.17    |
| MBORORO      | 0.37                   |                      | 0.13   | 0.03    | 0.17   | 0.07    | 0.20   | 0.10    | 0.17   | 0.07    |
| NUBA         | 0.57                   |                      | 0.23   | 0.13    | 0.37   | 0.27    | 0.37   | 0.27    | 0.37   | 0.27    |
| OGADEN       | 0.60                   |                      | 0.30   | 0.20    | 0.37   | 0.27    | 0.43   | 0.33    | 0.37   | 0.27    |
| ORMABORAN    | 0.40                   |                      | 0.17   | 0.07    | 0.23   | 0.13    | 0.23   | 0.13    | 0.30   | 0.20    |
| SOKOTO       | 0.53                   |                      | 0.17   | 0.07    | 0.27   | 0.17    | 0.37   | 0.27    | 0.33   | 0.23    |
| MADAZEBU     | 0.50                   |                      | 0.13   | 0.03    | 0.23   | 0.13    | 0.33   | 0.23    | 0.30   | 0.20    |

a For further description of the conservation programs see text.
b Taken from [19].

3.2. Effects of conservation programs

Initially, the Kenyan Boran had the lowest ($z = 0.35$) and the Highland Zebu the highest ($z = 0.70$) extinction probability (Tab. IV). After conservation, the lowest expected extinction probability of a breed was 0.03 for Angoni, Malawi Zebu, Maure, Mbororo and Madagascar Zebu (conserved with HB high) and the highest expected extinction probability was 0.50 for the Highland Zebu conserved with CC low. The conservation program with the lowest impact ($\Delta z = -0.04$) on the extinction probability was CC low for the Kenyan Boran ($z^* = 0.31$). The highest ($\Delta z = -0.50$) impact on the extinction probability had HB high for Bale ($z^* = 0.07$), Iringa Red ($z^* = 0.10$) and Highland Zebu
Figure 2. Conserved diversity subject to the total amount of conservation funds.

\( z^* = 0.20 \). Each conservation program had a different effect on breeds with an equal initial extinction probability.

3.3. Conserved diversity

Figure 2 shows that investing Mio \$ 0, 1, 2, 3 or 5 resulted in an expected diversity (percentage of present diversity in brackets) of 0.6223 (51.3\%), 0.7717 (63.6\%), 0.8664 (71.4\%), 0.9325 (76.8\%) and 1.0516 (86.6\%), respectively. To conserve a maximum of diversity, \textit{i.e.} 1.1151 or 91.9\% of the present diversity, Mio \$ 9.785 would be needed. The remaining 8.1\% of the diversity can not be conserved with the four conservation programs.

When a bonus was given to breeds with special traits, 63.2\% (0.7673) of the present diversity was conserved with Mio \$ 1. This is about 0.5\% less as when diversity is conserved disregarding special traits. The total number of traits conserved in the set (variable \( T_1 \)) was augmented from 15.953 to 17.404 (+ 9.1\%) by the bonus scenario and the probability of conservation of a special trait (variable \( T_2 \)) was increased by 2.1\% (Tab. V).
Table V. Conservation of special traits in African cattle breeds with Mio US$ 1 giving preference to breeds with special traits.

| Trait                      | Presence in the set of breeds without preference | Probability of conservation without preference | Presence in the set of breeds with preference | Probability of conservation with preference |
|----------------------------|-------------------------------------------------|-----------------------------------------------|---------------------------------------------|---------------------------------------------|
| Trypanotolerance           | 1.373                                           | 0.909                                         | 1.373                                       | 0.909                                       |
| Tick/disease resistance    | 0.650                                           | 0.650                                         | 0.650                                       | 0.650                                       |
| Hardiness                  | 2.746                                           | 0.996                                         | 2.743                                       | 0.996                                       |
| Adapted to local environment| 4.828                                           | 1.000                                         | 5.485                                       | 1.000                                       |
| Docile/calm temperament    | 3.033                                           | 0.994                                         | 3.433                                       | 0.999                                       |
| Fertile                    | 0.650                                           | 0.650                                         | 0.650                                       | 0.650                                       |
| Good mothering ability     | 1.170                                           | 0.832                                         | 1.570                                       | 0.972                                       |
| Good product quality       | 1.503                                           | 0.953                                         | 1.500                                       | 0.952                                       |
| Total/average              | 15.953                                          | 0.873                                         | 17.404                                      | 0.891                                       |

3.4. Amount of funds allocated to each breed

Figure 3 displays the funds allocated to each breed for the different scenarios. With Mio $1 the Madagascar Zebu, Arashie, Malawi Zebu, Nuba Mountain Zebu, Sokoto and Arsi get funds. Mio $2 are most efficiently allocated to the same breeds as for the Mio $1 scenario and the Bale, Ogaden, Gobra, Butana and Maure. Total funds of Mio $3 were allocated to the same breeds as for Mio $2 except Sokoto, plus the Highland Zebu, Mbororo, Kavirondo, Arado, Ethiopian Boran, Fogera and Horro. Mio $5 and Mio $9.785 were allocated to all breeds, though not with equal shares (results not shown).

Within the bonus scenario Madagascar Zebu, Arashie, Malawi Zebu, Nuba Mountain Zebu, Ethiopian Boran and Maure got money for conservation. The Kenyan Boran with most (four) special traits got no money.

Figure 4 shows the optimal allocation function for the breeds chosen for conservation with total funds of Mio $1. The amount of money allocated to each breed by the algorithm coincides with the edges of the optimal allocation function.

3.5. Optimal conservation programs

The conservation programs HB and IS were generally selected as optimal by the algorithm (Fig. 4, other results not shown).
Figure 3. Amount of money allocated to each breed with total funds of Mio US$ 1, 2 and 3, respectively (for details on the bonus scenario see text). Breeds are ranged top down according to their conservation potential.
4. DISCUSSION

4.1. Cost of conservation programs

Reist-Marti et al. [19] showed for a hypothetical breed the wide range of conservation cost with different conservation programs. In this study, conservation cost for breeds did not only depend on the program, but also on the purchasing power parity of the local currency of the country of conservation as well as its official exchange rate to the US$. The ratio PPP/OER varied substantially among the countries of conservation. Cryoconservation programs were more expensive than the other programs due to high fixed cost arising from the facilities needed to collect semen. Some of the countries may already have such facilities in place which could be used. However, checking the availability of facilities in each country was beyond the scope of this study. Annual average discounted conservation cost over 50 years could be as low as $1000 for IS, $1200 for HB, and $1300 for CC for breeds conserved in Ethiopia (Arsi, Bale, Ethiopian Boran, Fogera, Horro, Ogaden). These costs are reasonable compared with an average annual cost of $4400 for IC. However,
depending on the country of conservation, the cost can be fourfold or more for the same conservation program. The choice of the country of conservation may depend on many factors such as infrastructure or political aspects. Yet, the countries’ economic situation must not be neglected.

4.2. Effects of conservation programs

In the literature, the effects of conservation programs are often measured as reduced inbreeding or increased (effective) population size (e.g. [13]). Therefore, cryoconservation is proposed as one of the best conservation actions to reach this aim. In this study, the effects of the conservation programs were measured as a reduction in extinction probability ($\Delta z$). The (effective) population size is only one among ten factors affecting $z$, though the one with the highest weight. For most breeds, the effects for HB and IS were higher than for CC and IC. Even for the most and least endangered breeds, CC was less effective than HB. While cryoconservation mainly focuses on the effective population size, in situ conservation programs such as HB and IS do have a more holistic approach. They affect many factors of the extinction probability, involve breeders and give them part of the responsibility for the conservation of the breed. Thus, they do not only increase the effective population size of the breed, but also reduce the risk of failure of conservation through promotion of the special traits and cultural embedding of the breed. The risk of failure of conservation is an important factor for the choice of a conservation program. Further research on this topic is highly needed.

4.3. Conserved diversity and special traits

Figure 2 shows the diminishing marginal utility of the invested funds, reaching the maximum conserved diversity at around Mio $ 10 of funds. Therefore, doubling funding does not guarantee double conserved (or expected) diversity. There are about 8% of today’s diversity, which can not be conserved by the conservation programs used in this study. Better conservation programs or combinations of the conservation programs considered may conserve more diversity. If the risk of failure is considered, there will always be a certain amount of diversity, which can not be conserved by any means.

It should be mentioned that this study is entirely based on the Weitzman [28] diversity measure, which recently was criticized by some authors [3, 5, 16] to disregard the within breed diversity. This criticism is fully justified, however including within breed diversity leads to a massive conceptual complication: if within breed diversity is taken into account, we also have to model the
change in this quantity over the assumed time horizon. Furthermore, within
and between breed diversity are not independent, if within breed diversity is
reduced, through a small effective population size, say, between breed diver-
sity is increased. It will not be trivial, to derive an appropriate model reflecting
this, and to implement it computationally for large breed groups. Unless such
a model is operational, we feel that using Weitzman diversity is an acceptable
compromise, as long as its shortcomings are kept in mind.

When giving a bonus to breeds with special traits, the expected diversity
decreases by 0.0043 or 0.56% to 0.7673. This loss of about half a percent of
diversity is highly compensated by an additional 9% of special traits and a
gain of 2% in the average probability of conservation of a special trait.

Investing Mio $ 1.05 of funds results in an expected diversity of 0.7734
(results not shown). This means that on this level of investment, 0.0018 units
of expected diversity correspond to about Mio $ 0.05. Hence, the special traits
conserved with the bonus scenario – i.e. –0.0043 units of expected diversity –
do have a value of about Mio $ 0.12 or 12% of the invested funds. Instead of
investing these 12% of funds into 0.56% additional expected diversity, it may
be worth to conserve an additional 9% of special traits. Given that the value
of such special traits is known, as is the case for e.g. trypanotolerance [12]
the suggested approach can be used to better assess the economic trade-off
between conserving (neutral) diversity and conserving special traits of known
value.

4.4. Amount of funds allocated to each breed

Figure 3 shows that the lower the total funds were the smaller was the num-
ber of breeds for which conservation schemes were established. Low total
funds were allocated to breeds with a high conservation potential (results not
shown). The conservation potential \(CP\) is calculated as

\[ CP = m \ast z, \]

where \(m\) is the marginal diversity of a breed. The marginal diversity reflects
the change of diversity when the extinction probability of the breed is changed
by one unit [18, 23].

Sokoto and Mbororo are closely related breeds, which are to be conserved in
countries with an equal \(PPP/OER\) ratio. With total funds of Mio $ 2, Sokoto is
chosen for funding due to its higher conservation potential. If more money is
available (Mio $ 3), however, Mbororo is conserved instead of Sokoto since
it has a very high marginal diversity [17]. Although conservation of Mbororo
is more costly compared to Sokoto, lowering Mbororo’s extinction probability
even slightly will highly increase the expected diversity of the set.

A high impact of a conservation program on the extinction probability of a
breed – e.g. HB high reduces the extinction probability of Bale, Iringa Red and
Highland Zebu High strongly ($\Delta z = -0.50$) – does not guarantee for allocation
of money to that breed by the algorithm.

Although Iringa Red had a high conservation potential due to its marginal
diversity and high extinction probability, and showed a substantial effect of the
conservation program HB, it was not chosen for conservation with total funds
of Mio $3 or less due to the disadvantageous PPP/OER ratio. Hence, not only
the conservation potential and the effects of the optimal conservation program
are crucial for the choice of a breed, but also the program’s cost, which depends
on the design of the program and the economics of the country of conservation.

Breeds with low conservation cost due to a favourable economic situation of
the country of conservation had a high chance of getting funds although they
had a low conservation potential (e.g. Arsi).

Reist-Marti [17] showed that allocating Mio $2 to one breed only or giving
equal shares to all 23 breeds does not lead to a maximum of expected diversity.
This result could be verified in this study. The optimal number of breeds and
the optimal amount of money allocated to each breed depended on the diversity
of the set of breeds, the extinction probability and conservation cost of each
breed as well as the number of breeds and the amount of funds available.

Within the bonus scenario, the algorithm allocated money to the same breeds
with low conservation cost and high conservation potential and many special
traits as when allocating Mio $1 without bonus for special traits. Furthermore,
the Ethiopian Boran (three traits) and Maure (one trait) got money for conser-
vation, both breeds representing genetically different branches from the other
conserved breeds [18]. No money was allocated to the breed with the highest
number of special traits, i.e. the Kenyan Boran (four traits). The conservation
potential of this breed was one of the lowest and its conservation cost were
high compared to the other breeds.

The new algorithm split the funds optimally among the breeds since shares
were allocated to each breed only as long as a high reduction in extinction
probability resulted, i.e. a steeply sloping optimal allocation function (Fig. 4).

The risk linked to the investment and changing circumstances was not con-
sidered in this study. It may happen that a cryoconserved breed never goes
extinct and, hence, never has to be re-established by backcrossing. The money
for backcrossing could then be spent on another breed. A conservation program
may also fail due to internal (e.g. bad management) or external (e.g. civil unrest) reasons and the money invested is lost. Further research on investment risk of diversity conservation is needed to be able to optimally allocate funds.

4.5. Optimal conservation programs

The in situ conservation programs HB and IS were often more efficient due to the various reasons mentioned above with regards to cost per reduction in extinction probability. Therefore, they were preferred as optimal conservation programs over often suggested cryoconservation programs. This result, however, pertains very specifically to the case studied and might be very different in countries where the cryoconservation infrastructure is established and can be used with little extra cost.

5. CONCLUSIONS

Although assumptions can always be discussed, it was shown that under realistic scenarios pure in situ conservation was more efficient than cryoconservation or combined in situ and cryoconservation. These findings for a broad application on 23 African cattle breeds are in line with the results of Reist-Marti et al. [19] for the general case of a hypothetical breed.

The choice of the country of conservation may depend on many factors such as infrastructure or political aspects, but its economic situation should also be taken into account. Average annual conservation cost for a breed could be as low as $1000 to $4400 for in situ and cryoconservation programs.

While the cryoconservation programs CC and IC mainly focus on high effective population sizes, the in situ conservation programs HB and IS strongly involve breeders and give them part of the responsibility for the conservation of the breed. Therefore, those programs were more efficient in lowering the extinction probability and reducing the risk of failure of conservation.

It was verified that the allocation of money is optimal for a certain number of breeds. This number depends on the diversity of the set of breeds, the extinction probability and conservation cost of each breed as well as the number of breeds and the amount of funds available. Equal allocation of funds on the breeds chosen for conservation does not lead to a maximal expected diversity. The choice of the breeds and the amount of money allocated to each breed further depends on the breed’s conservation potential and the effects of the optimal conservation program as well as on the program’s cost.
It was shown that special traits can be conserved with a rather small amount of the total funds and thus, with a little waiving of expected diversity.

With a budget of Mio $ 1 discounted over 50 years, 64% of the present diversity can be maintained over 50 years, which is 13% more than would be maintained if no conservation measures were implemented. However, diversity can not be conserved completely by any conservation program, not even with unlimited funds. With the conservation programs used in this study, a maximum of 92% of the present diversity could be conserved with Mio $ 10, leaving 8% of the diversity to unpredictable happenings.

The suggested algorithm proved to be useful for the optimal allocation of conservation funds. It allocated the funds to diverse breeds considering the most suited conservation programs and splitting the funds optimally among breeds. However, further research in this area is needed to consider the risk of success or failure of conservation programs or changing circumstances when optimally allocating limited funds.

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REFERENCES

[1] Brem G., Graf F., Kräusslich H., Genetic and economic differences among methods of gene conservation in farm animals, Livest. Prod. Sci. 11 (1984) 65–68.
[2] Buck N., Light D., Lethola L., Rennie T., Mlambo M., Muke B., Beef-Cattle Breeding Systems in Botswana – the Use of Indigenous Breeds, World Anim. Rev. 43 (1982) 12–16.
[3] Caballero A., Torro M.A., Analysis of genetic diversity for the management of conserved subdivided populations, Cons. Genet. 3 (2002) 289–299.
[4] Eding H., Conservation of Genetic Diversity: Assessing Genetic Variation Using Marker Estimated Kinships, PhD thesis, Animal Breeding and Genetics Group, Department of Animal Sciences, Wageningen University, Wageningen, 2002.
[5] Eding H., Meuwissen T.H.E., Marker based estimates of between and within population kinships for the conservation of genetic diversity, J. Anim. Breed. Genet. 118 (2001) 141–159.
[6] Food and Agriculture Organization of the United Nations, DAD-IS Global Information System for Domestic Animal Diversity, version 2.0, Rome (2000) http://www.fao.org/dad-is [consulted: November 2003].
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[7] Felius M., Cattle Breeds: An Encyclopedia, 1st edn., Misset uitgeverij bv, Doetinchem, The Netherlands, 1995.

[8] Hall S.J.G., Ruane J., Livestock breeds and their conservation: A global overview, Conserv. Biol. 7 (1993) 815–825.

[9] Hanotte O., Tawah C.L., Bradley D.G., Okomo M., Verjee Y., Ochieng J., Rege J.E.O., Geographic distribution and frequency of a taurine Bos taurus and an indicine Bos indicus Y specific allele amongst sub-Saharan African cattle breeds, Mol. Ecol. 9 (2000) 387–396.

[10] Hanotte O., Bradley D.G., Ochieng J.W., Verjee Y., Hill E.W., Rege J.E.O., African pastoralism: genetic imprints of origins and migrations, Science 296 (2002) 336–339.

[11] International Livestock Research Institute, DAGRIS Domestic Animal Genetic Resources Information System, Animal Genetic Resources Programme, International Livestock Research Institute, Nairobi, 2001.

[12] Kristjanson P.M., Swallow B.M., Rowlands G.J., Kruska R.L., de Leeuw P.N., Measuring the costs of African trypanosomosis: the potential benefits of control and returns to research, Agric. Syst. (UK) 59 (1999) 79–98.

[13] Lömker R., Erhaltung genetischer Vielfalt in-situ, ex-situ und in Kombination unter genetischen und ökonomischen Gesichtspunkten, PhD thesis, Institut für Tierzucht und Vererbungsforschung, Tierärztliche Hochschule Hannover, Hannover, Germany, 1993.

[14] Lömker R., Simon D.L., Costs of and Inbreeding in Conservation Strategies for Endangered Breeds of Cattle, in: Proceedings of the 5th World Congress on Genetics Applied to Livestock Production, 7–12 August 1994, Vol. 21, University of Guelph, Guelph, pp. 393–396.

[15] Metrick A., Weitzman M.L., Conflicts and choices in biodiversity preservation, J. Econ. Persp. 12 (1998) 21–34.

[16] Ollivier L., Foulley J.L., Aggregate diversity: New approach combining within- and between-breed genetic diversity, Livest. Prod. Sci. 95 (2005) 247–254.

[17] Reist-Marti S.B., Analysis of methods for efficient biodiversity conservation with focus on African cattle breeds, PhD thesis, Swiss Federal Institute of Technology, Zurich, 2004.

[18] Reist-Marti S.B., Simianer H., Gibson J., Hanotte O., Rege J.E.O., Weitzman’s Approach and Conservation of Breed Diversity: an Application to African Cattle Breeds, Conserv. Biol. 17 (2003) 1299–1311.

[19] Reist-Marti S.B., Abdulai A., Simianer H., Conservation programs for African cattle: design, cost and benefits, J. Anim. Breed. Genet. 122 (2005) 95–109.

[20] Rennie T., Light D., Rutherford A., Miller M., Fisher I., Prachett D., Capper B., Buck N., Trail J., Beef-Cattle Productivity under Traditional and Improved Management in Botswana, Trop. Anim. Health Prod. 9 (1977) 1–6.

[21] Scherf B.D., World Watch List for Domestic Animal Diversity, 3rd edn., Food and Agriculture Organization of the United Nations, Rome, 2000.

[22] Simianer H., Noah’s Dilemma: Which Breeds to Take Aboard the Ark?, in: Proceedings of the 7th World Congress on Genetics Applied to Livestock Production, 19–23 August 2002, CD-ROM communication No. 26–02, Montpellier, France.
[23] Simianer H., Marti S.B., Gibson J., Hanotte O., Rege J.E.O., An approach to the optimal allocation of conservation funds to minimise loss of genetic diversity between livestock breeds, Ecol. Econ. 3 (2003) 377–392.
[24] Smith C., Economic benefits of conserving animal genetic resources, Anim. Genet. Res. Info. 3 (1984) 10–14.
[25] Smith C., Estimated costs of genetic conservation in farm livestock, Animal genetic resources conservation by management, data banks and training, FAO animal production and health paper 44 (1984) 21–30.
[26] Smith C., Genetic aspects of conservation in farm livestock, Livest. Prod. Sci. 11 (1984) 37–84.
[27] Thaon d’Arnoldi C., Foulley J.L., Ollivier L., An overview of the Weitzman approach to diversity, Genet. Sel. Evol. 30 (1998) 149–161.
[28] Weitzman M.L., On diversity, Quart. J. Econ. CVII (1992) 363–405.
[29] Weitzman M.L., What to preserve? An application of diversity theory to crane conservation, Quart. J. Econ. CVIII (1993) 157–183.
[30] Weitzman M.L., The Noah’s Ark Problem, Econometrica 66 (1998) 1279–1298.
[31] Wilson R.T., Central Mali – Cattle Husbandry in the Agropastoral System, World Anim. Rev. 58 (1986) 23–30.
[32] Wilson R.T., Clarke S.E., Studies on the Livestock of Southern Darfur, Sudan: II. Production Traits in Cattle, Trop. Anim. Health Prod. 8 (1976) 47–51.
[33] World Bank, World Development Indicators 2001: Relative prices and exchange rates, World Bank, Washington, 2003. http://www.worldbank.org/data/icp/documents/Table5_7.pdf [consulted: 6 November 2003].