CONVENTION ON INTERNATIONAL TRADE IN ENDANGERED SPECIES
OF WILD FAUNA AND FLORA

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SUPPLEMENTARY INFORMATION ON CAPE MOUNTAIN ZEBRA – CMZ OFF-TAKE SIMULATOR TOOL

1. This document has been submitted by South Africa in relation to amendment proposal CoP17 Prop. 6 on Cape mountain zebra (*Equus zebra zebra*)*.

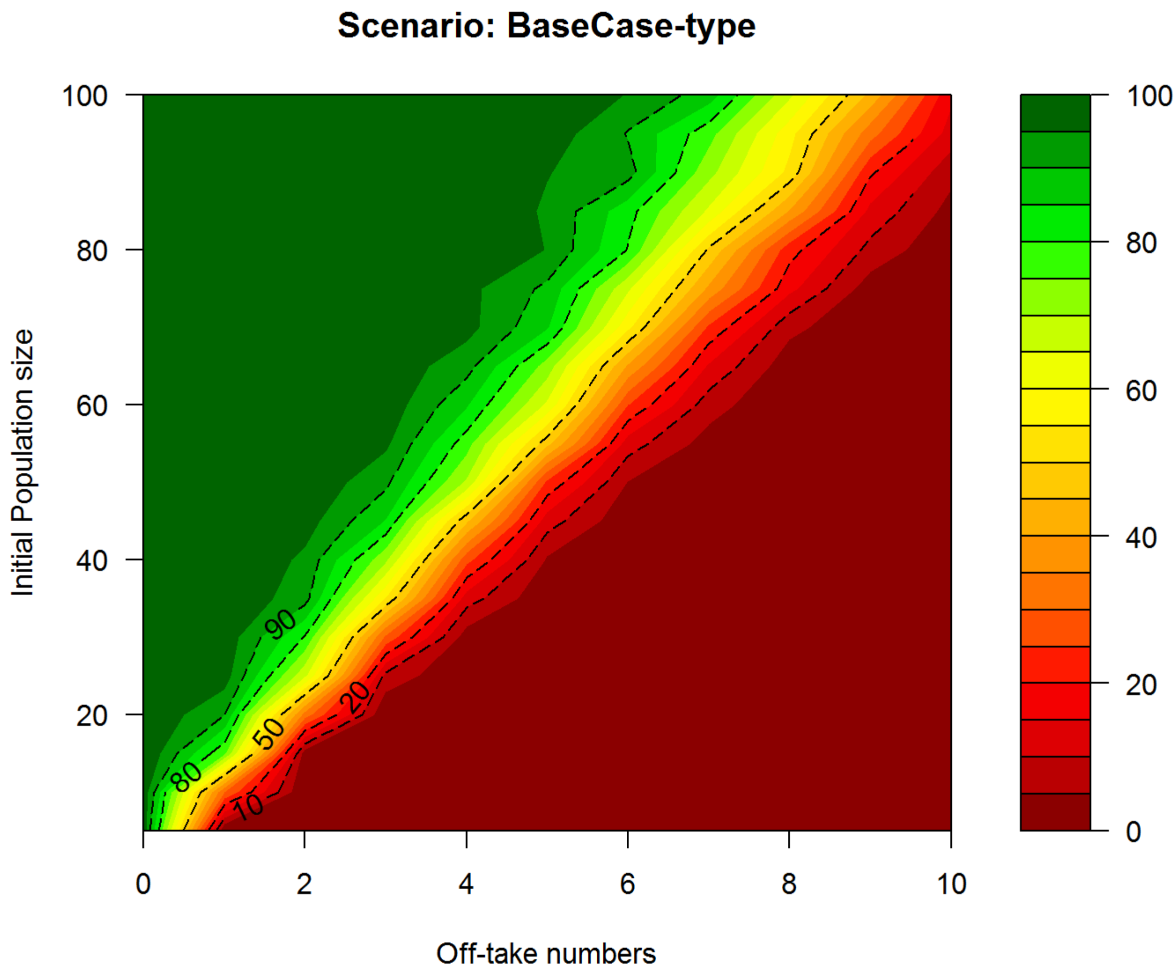
2. South Africa proposes the transfer of the Cape mountain zebra, *Equus zebra zebra*, from Appendix I to Appendix II in accordance with a precautionary measure specified in Annex 4 of Resolution Conf. 9.24 (Rev. CoP16).

3. The measure proposed for implementation is A. 2. a) iii) of Annex 4, namely: "an integral part of the amendment proposal is an export quota or other special measure approved by the Conference of the Parties, based on management measures described in the supporting statement of the amendment proposal, provided that effective enforcement controls are in place". Thus, conditional to the transfer of Cape mountain zebra from Appendix I to Appendix II, South Africa will implement a combination of active adaptive harvest management and management strategy evaluation to set a hunting quota for Cape mountain zebra, subject to the provisions of paragraph B of Annex 4.

4. The CMZ off-take simulator tool was developed through a collaboration between the South African National Biodiversity Institute, the University of Cape Town, Nelson Mandela Metropolitan University, and CapeNature. The tool allows forecasting of stochastic population trajectories under different selective off-take options for any specified initial population size under different environmental conditions. Three alternative scenarios based on different sets of survival and fecundity input parameters were devised: (1) Base-Case (average), (2) De Hoop-type and (3) MZNP-type. As an example, sustainable levels of off-take under the Base-Case scenario are illustrated in the Figure below, where dashed isopleth lines denote the population size to annual off-take combinations that would result in 10%, 20%, 50%, 80% and 90% probabilities of population increase over a 15 year simulation period.

5. The full technical report describing the development and testing of the CMZ off-take simulator tool is presented in Annex I.

* *The geographical designations employed in this document do not imply the expression of any opinion whatsoever on the part of the CITES Secretariat (or the United Nations Environment Programme) concerning the legal status of any country, territory, or area, or concerning the delimitation of its frontiers or boundaries. The responsibility for the contents of the document rests exclusively with its author.*


Scenario: BaseCase-type
Initial Population size
Off-take numbers
0
2
4
6
8
10
20
40
60
80
100
90
80
50
20
10
0

South African National Biodiversity Institute

Report

Population trends and management strategy tools for Cape Mountain Zebra

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Executive Summary

Equus zebra zebra (Cape mountain zebra) is currently listed under Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Because of the currently perceived low economic value of Cape mountain zebra (CMZ) for the private sector, there have been several requests for the establishment of hunting and export quotas for hunting trophies to increase incentives for landowners to invest in CMZ (NDF 2014), as allowed for Appendix I species in accordance with CITES Resolution Conf. 2.11 (Rev.). In terms of Article III of the Convention, an export permit shall only be granted for an Appendix I species when a Scientific Authority of the State of export has advised that such export will not be detrimental to the survival of that species. A report "Non-Detriment Finding" (NDF) for CMZ, issued in 2014 by the Scientific Authority of South Africa, identified that local and international trade in live animals and the export of hunting trophies poses a moderate to high risk for maintaining CMZ unless there is a comprehensive management plan and the risks of hunting and export can be evaluated against conservation and rebuilding targets based on a quantitative resource assessment. A draft Biodiversity Management Plan (Birss *et al*. 2016) has been completed and will soon be published for public comment. There is therefore a need to develop appropriate tools for evaluating the effect of the hunting quota.

This report introduces the CMZ off-take simulator tool, which allows forecasting of stochastic population trajectories under different selective off-take options for any specified initial population size. Comparison of model predictions with actual population performance showed overall good agreements, but point towards differences in key life history parameters among different habitat types. In addition, long-term trends, future growth potential and appropriate Red-List categories for CMZ are discussed in the light of the results from a trend analysis of count data (1985-2015) from nine formally protected and well established (> 30 years) Cape Mountain Zebra (CMZ) subpopulations, which were considered by an expert task-team as key source populations for future CMZ introductions. The model provides a tool to identify levels of offtake that would be sustainable under different conditions. The report highlights how the Management Strategy Evaluation can provide an adaptive management approach to assess the impact of hunting quotas in collaboration with stakeholders.

Introduction

Natural resource management presents the challenge of linking the interactive processes of population dynamics, management targets, decision-making, strategy implementation and stakeholder behavior (Bunnefeld *et al.* 2011), where each process is associated with uncertainties that translate into risks. Because of the inevitable uncertainty the science supporting wildlife management may be open to legal challenges from divergent stakeholder interests. The form of scientific advice is changing; decision rules for resource management cannot be based on expert judgment alone but also requires stakeholder involvement (Smith *et al.* 1999). Instead, there is a need to base management decisions and corresponding strategies on scientific evidence from quantitative resource assessments (Butterworth *et al.* 2010; Bunnefeld *et al.* 2011; Punt *et al.* 2014). The ideal situation for such assessments would be if annual long-term data of accurate, spatially disaggregated population numbers, off-take and introductions were available and supplemented by regular data on the population structure (e.g. sex-specific numbers of offspring, juveniles and mature animals from mark-recaptures). From this information robust quantitative analysis can be conducted to provide advice on selective hunting quota and introduction strategies or relocations schemes to achieve the targets considered for optimal resource use. However, this ideal is seldom met due to general lack of capacity, funding and skills to implement the necessary monitoring framework, data capture and analysis.

The situation is not different in South Africa, which can be readily illustrated using the example of the Cape Mountain Zebra (CMZ) *Equus zebra zebra* (Linnaeus 1758). Endemic to South Africa, CMZ were once widespread in the mountains of what is today the Western- and Eastern Cape Provinces, extending into the southern Northern Cape Province. However, this situation had dramatically changed by the 1930s, when the species had been driven towards extinction as a result of excessive hunting and an increasing demand for land-use for livestock (Novellie *et al.* 1996, 2002; Smith *et al.* 2008). Only a few groups had persisted, which were confined to the Cradock, Gamka, Kamanassie and Kouga mountains. In 1937, the MZNational Park (MZNP), west of Cradock, was proclaimed in an effort to provide special protection for the CMZ. However, the initial protected population of only five stallions and one mare died out, and only by 1950 had additional individuals been moved into the park. By then the world population had been reduced to less than 80 individuals, persisting in fragmented subpopulations. Apart from the MZNP population, only two other relict populations survived to the present day in the Gamka and Kammanassie mountains (Moodley and Harley 2005). The survivor numbers were small, with 19 in MZNP, and only five Gamka and six Kammanassie. Since the 1980s, species recovery efforts proved increasingly successful with CMZ having steadily increased in numbers (Novellie *et al.* 2002). As a result, the IUCN Red List status for CMZ was changed from Endangered (EN) to Vulnerable (VU) in 2008, and by 2011 the world population had been recovered to at least 2790 individuals distributed across 52 subpopulations, of which 17 are formally protected and 35 occur on privately owned properties (Hrabar and Kerley 2013). This provided first evidence that the target of the 2002 IUCN's Action Plan to recover the CMZ world population to > 2500 animals had been met. At the end of 2015, the global population was estimated at 4,872 in 76 subpopulations of which 56 were on privately owned properties (Hrabar and Kerley 2015; Birss *et al* 2016)

With the numbers increasing, several protected areas are predicted to soon reach their carrying capacity, which would likely halt further population growth unless new founder populations could be established on private land (Novellie *et al.* 2002; Hraber and Kerley 2015). Because of the perceived low economic value of CMZ for the private sector, there have been several requests for the establishment of hunting and export quotas for hunting trophies to increase incentives for landowners to invest in CMZ (NDF 2014). Recently, there has been limited hunting of CMZ permitted on some private properties, but there are currently no CITES quotas in place for CMZ export. A report on "Non-Detriment Finding" (NDF) for CMZ, issued in 2014 by the Scientific Authority of South Africa, identified that local and international trade in live animals and the export of hunting trophies poses a moderate to high risk for maintaining CMZ unless there is a management plan for meta-population management (NDF 2014) and that incentives based on hunting of Cape mountain zebra are based on scientifically based population models. The recently completed Biodiversity Management Plan addresses the first issue and this report focuses on tools to assess the impact of offtake on conservation and rebuilding targets based on a quantitative resource assessment.

A formal quantitative resource assessment of CMZ is heavily constrained by the lack of detailed information on population dynamics. Due to the absence of a unified monitoring framework, most available abundance data comprise count estimates from protected areas, which are aggregated by sex and life stages and vary in quality, methodology, consistency and frequency. Some records on introductions and removal exist, but these appear to be inconsistently reported, and in some cases biological implausibly when compared to corresponding count estimates. Estimates for the private sector rely entirely on the information volunteered by land-owners in response to questionnaires (Hrabar and Kerley 2013). Most of the available population parameters have been summarized in Novellie *et al*. (1996), but these parameters, derived from a combination of field observations of the MZNP population and expert knowledge, have never been formally re-assessed over the past 20 years. More recently, Smith *et al*. (2008) conducted an analysis of the CMZ population in the De Hoop Nature Reserve, which indicated considerably lower foaling and foal survival rates when compared to those inferred from the MZNP. There is a need to find a robust approach to meet the required management objectives that can account for considerable uncertainties in such data-limited situation.

A potentially suitable framework to address these challenges is known as 'Management Strategy Evaluation' (MSE; Smith *et al.* 1999) or 'Operating Management Procedures' (OMP; Butterworth and Punt 1999). This framework essentially uses simulation-testing to evaluate alternative management strategies in terms of risk to both the population under assessment and stakeholder interests (Smith *et al.* 1999; Punt *et al.* 2014). MSE originates from the management procedure approach of the Scientific Committee of the International Whaling Commission, which aimed to apply scientific principles in support of the moratorium on commercial whaling in 1982 (Butterworth *et al.* 2010). To date, MSE is widely considered to be 'best practice' in fisheries management (Punt *et al.* 2014), but its scope for applications in terrestrial systems has not remained unnoticed. Bunnefeld *et al.* (2011) pointed out that MSE has enormous potential to revolutionise wildlife management that requires decision-making on hunting quota, translocation and supplementations. As such, MSE provides powerful tools to evaluate the trade-offs among management strategies and to assess the consequences of uncertainty for achieving management objectives (Punt *et al.* 2014).

The basics steps are illustrated in Fig. 1 and can be summarised as follows:

1. Identification and specification of the management objectives. A key aspect is to then translate the objectives into quantifiable management targets against which the management strategy can be evaluated.

2. Identification of major sources of uncertainty (e.g. population parameters, environmental variation, observation and reporting error and compliance) to which the management strategy should be robust to
3. Development of simulation models, referred to as 'Operating Models' (OMs), that provide a mathematical representation of the population dynamics based on the best ecological knowledge and the key processes of management strategy, including monitoring, stake holder behavior and data accuracy, precision and availability. The OM simulates the response of the population to a management strategy and tracks the desired metrics of 'true' populations (e.g. numbers, age-structured, sex-ratio etc.). It also generates the 'observation data' that represent the information available from monitoring and reporting, including observation and process noise.
4. The observation data are then passed on to the management model, which can be implemented as a full assessment model or as a simple mathematical algorithm, e.g. based abundance indicators. The output of the management model is translated into control rules that are used to determine the management action (e.g. setting of a quota) for the next time step.
5. The last step involved the performance evaluation of management strategy simulations against the management targets. This process can assist to identify a range of suitable management strategies for a particular species, refine existing strategies and identify management strategies that will not work a priori (Butterworth *et al.* 2010; Punt *et al.* 2014).

In this work, we will mainly focus on the key aspects of points (2), (3) and (5) as a first step towards a full MSE framework and to provide a way forward for implementing adaptive management of CMZ. The management objectives under point (1) follow from the draft Biodiversity Management Plan (Birss et al. 2016) and NDF (2014).

The overall aim of this work was to provide a robust adaptive management tool to test the effect of off-takes through the implementation of hunting quota on CMZ populations. To build on the best available information of the current population status, we first present the results of a Bayesian state-space trend analysis of count data (1985-2015) from nine formally protected and well established (> 30 years) CMZ subpopulations, which were considered by the expert task-team as key source populations for future CMZ introductions. The aims of this analysis were to (1) predict and forecast the absolute numbers of long-term protected subpopulations, (2) to determine the average rate of increase across populations and (3) to provide robust population trend estimates, and associated uncertainties, with implications for the IUCN Red List status of CMZ.

To provide a conceptual framework for the development of the CMZ simulation-evaluation tool, we adapted the basic principles of the Management Strategy Evaluation (MSE) framework as a robust approach for addressing the challenges of CMZ management in particular, and wildlife management in general. Briefly, the thrust of MSE is to use the most plausible population simulation model specifications within an adaptive framework that enable the comparison of alternative strategies in a virtual world against multiple pre-agreed management targets. As a first step towards a potential MSE implementation, we then present an age- and sex-structured simulation population model, specifically developed for CMZ. The population model simulates the impact of selective or unselective off-take of different age and sex classes on population trajectories. The input parameters were derived from available literature and agreed upon by an expert task-team during a series of three dedicated workshops. To assess the plausibility of the simulation scenarios, we compare the simulated population trajectories against available count data for eight protected populations.

Materials and Methods

Trend analysis

Data

Time series of CMZ count data from protected subpopulations were provided by Halszka Hrabar and Peter Novellie (NMMU). The annual counts varied highly in regularity, quality and estimation approaches among subpopulations. Count estimates were often not available for sequential years. Several more recently founded subpopulations, such as those in Anysberg, Hottentots Holland or Tankwa-Karoo, had only two to four count estimates available, which often did not overlap in years with the sequence of introduction events, or it was unclear if the introduction occurred before or after the census. Due to these difficulties, we only included long-term time series, which we refer to as "established" hereafter. We defined established subpopulations as 31 years or older, which approximately equates to three generation times. This resulted in an initial inclusion of count data from ten protected subpopulations from De Hoop Nature Reserve (NR), MZNP, Gamkaberg NR, Kammanassie NR, Karoo National Park (NP), Gariep Nature Reserve (NR), Camdeboo NP, Commando Drift NR, Tsolwane NR and Addo Elephant NP (Fig. 2). Subsequently, it was agreed by the expert task-team that this meta-population analysis should only focus on subpopulations that have potential to act as a source population in the foreseeable future. On this basis it was decided to exclude Addo Elephant NP from the analysis as potential source population. This decision was based on available evidence that suggested very poor population growth potential due to suboptimal habitat conditions for CMZ.

IUCN Red List support tool

The IUCN Red List guidelines (2001) provide specific rationales for using quantitative criteria for assessing the risk of extinction. For listing as Critically Endangered (CR), Endangered (EN) or Vulnerable (VU), there are three major criteria, each with several sub-criteria. These three major criteria are: **(A)** population reduction, **(B)** current geographic range and **(C)** number of mature individuals. If a population is in a severely decimated state, with only a few survivors persisting in a small number (< 10) of fragmented locations, criteria **B** and **C** might be directly applicable. However, the specifications outlined under **B** and **C** for less severe situations typically apply only if there is additional evidence for a continuing population decline. In the presence of long-term time series that contain quantitative information on the population trend, criterion **A** is therefore probably the most robust stand-alone criterion for assigning a Red List status in most situations.

To limit complexity, we only focused on the most cautious population reduction thresholds, which are based on the assumption that the cause for the potentially observed population reduction "may not have ceased or may not be understood or may not be reversible". It follows that the thresholds of ≥ 30%, ≥ 50% and ≥ 80% population reduction over three generations (if > 10 years) would lead to VU, EN and CR listings respectively. IUCN (2001) notes the importance of accounting for uncertainties associated with the available information that can arise from natural variability and measurement error. However, there are currently no specific guidelines for dealing with uncertainty in the Red Listing process. This means that perception towards the uncertainty of individual assessors can result in inconsistent, subjective assessments (Akçakaya and Ferson 2000).

Here, we propose a Bayesian state-space (BSM) framework to objectively incorporate uncertainty into the Red Listing evaluation process. The BSM is considered a powerful tool for time series analysis (de Valpine 2002), as it allows accounting for both process error (environmental year to year variation) and observation (or reporting) error simultaneously (Thorson *et al.* 2014). In a Bayesian analysis all quantities of interest can be extracted from the fitted model in the form of posterior distributions, which describe the likely range of the values conditioned on the data (and prior distributions). The posterior for the estimated population reduction provides a natural way to assign probabilities of the size reduction falling within each of the Red Listing categories. We present an easy to interpret graph, in which the posterior of the reduction estimates is plotted against the IUCN Red List criteria.

Bayesian state-space model

A Bayesian state-space model (BSPM) framework (Meyer and Millar 1999) was implemented to estimate the abundance trends and associated uncertainty for the nine established CMZ source populations within formal protected areas . The BSPM was fitted to the count data. The change in the number of animals N follows a Markovian process, which means that, for example, N_{t+1} in the following year t + 1 will depend on N_t in the current year t (Kery and Schaub 2012). For the number of animals $N_{i,t}$ in subpopulation i in year t, a conventional exponential growth model was assumed, such that:

$$N_{i,t+1} = N_i \lambda_{i,t}$$

where $\lambda_{i,t}$ is the growth rate in year t. Growth rate $\lambda_{i,j,t}$ was allowed to vary to accommodate fluctuations in reproductive success and survival as a result of environmental conditions or other latent (unobserved) effects. State-space models are hierarchical models that explicitly decompose an observed time-series of the observed responses into a process variation and an observation error component (Simmons *et al.* 2015). On the log scale, the process equation becomes:

$$\mu_{i,t+1} = \mu_{i,t} + r_{i,t} \qquad \beta_i \sim N(0, \sigma^2)$$

where $\mu_i = \log(N_{i,t})$ and $r_{i,t} = \log(\lambda_{i,t})$, with variations in log-growth rates realised as a random normal walk given the estimable process error variance σ^2. The observation process equation was then

$$\log(y_{i,t}) = \mu_{i,t} + \varepsilon_{i,t} \qquad \varepsilon_{i,t} \sim N(0, \tau_i^2)$$

where $y_{i,t}$ denotes the reported counts for subpopulation *i* in year *t*, and τ_i^2 is the observation variance for subpopulation *i*. The observation variance was estimated for each subpopulation separately to account for the variation in accuracy of the counts.

Projections

As a result of the CMZ expert workshop held in June 2016, it was agreed that most plausible forward projections of population numbers within the nine source population could be produced by incorporating the maximum population limits as management targets to reflect the carrying capacity of the currently available habitat. The upper limits for subpopulation numbers (see Table 2) were implemented by conditioning the posterior of the forward projections of each subpopulation. For this purpose, it was assumed that the upper source limit for each source population *i*, K_i, will act as a management target that can be actively controlled by the respective conservation authorities through off-take (translocations or hunting). The conditioning becomes effective, if any number predicted $N_{i,t}$ for subpopulation *i* at time *t* (post 2015) within the retained posterior would exceed K_i. In this case, the expected $N_{i,t}$ is replaced by a random $N_{i,t}$ that is drawn from a lognormal distribution with a mean of $\log(K_i)$ and a CV of 10% to implement a 'soft' upper limit. A 'soft' rather than a static upper bound was considered here because animal numbers will likely fluctuate around K_i as a result of active population control, but won't be exact.

Total annual numbers, summed over all subpopulations, was then modeled as a function of:

$$TN_t = \sum_k \hat{N}_{i,t}$$

where $\hat{N}_{i,t}$ is the estimated number in subpopulation *i* and year *t*. BSPM fits were then used to forecast the trend in total numbers TN_t over the next ten years until 2025.

Finally, population reduction R, was taken as the ratio of the three years' average of *TN* after a period equal to three generation times, to the three year average of *TN* at the start of the time series, such that

$$R(\%) = \frac{\sum_{t=G-3}^{t=G} TN_t}{\sum_{t-1}^{t=3} TN_t} \times 100$$

where *G* denotes the three generation times. We chose a three year average over single values at t = *G* and t = 1, respectively to reduce the influence of short-term fluctuation.

Bayesian Modelling framework

As for every Bayesian analysis, all estimable hyper-parameters had to be first assigned to a prior distribution. We exclusively used vague and non-informative prior distributions, so that all inference was drawn from the information in the data. For both process error σ and observation errors τ_i, we assumed non-informative uniform priors with bounds at zero and one, *U*(0,1). The initial numbers in the first year $N_{i,t=1}$ were drawn in log-space from a flat normal distributions with the means set equal to the log of first available counts $y_{i,t=1}$ and a standard deviation of 1000. The estimation of mean logarithm of growth rates for each source population $i, \bar{r}_i = \log(\bar{\lambda}_i)$, was implemented through hierarchical priors (Jiao *et al.* 2009), where $\bar{r}_i$ is informed by the global mean estimate across all source populations $\bar{r} = \log(\bar{\lambda})$ and annual growth rate deviates $r_{i,t}$ are informed by $\bar{r}_i$. A normal flat prior distribution with a mean of zero and standard deviation of 1000 was assumed for the global $\bar{r}$. For the source population estimates of $\bar{r}_i$, we then assumed a normal distribution with a mean of $\bar{r}$ and variance estimated using a non-informative inverse-gamma prior with both scale and shape parameter set to 0.001 (Chaloupka and Balazs 2007). Finally, the log of the rate of annual subpopulation increase $r_{i,t} = \log(\lambda_{i,t})$ was formulated as a hierarchical normal prior as a function of $\bar{r}_i$ and the process error variance σ^2, where the process error σ was estimated using a non-informative uniform prior with bounds at zero and one, $U(0,1)$.

The full BSM model projected over n years requires a joint probability distribution over all unobservable hyper-parameters $\boldsymbol{\theta} = \{r_{i,t}, \bar{r}, \sigma^2_{,} \tau_i^2\}$ and the n process errors relating to the vector of unobserved states $\boldsymbol{\eta} = \{\eta_{i,1}, \eta_{i.2}, \ldots \eta_{i,t})$, together with all observable data in the form of the abundance indices $\mathbf{I} = \{I_{i,1}, I_{i,2}, .I_{i.t}\}$ (Meyer and Millar, 1999). According to Bayes' theorem, it follows that the joint posterior distribution over all unobservable parameters, given the data and unknown states, can be formulated as:

$$p(\boldsymbol{\theta} \,|\, \boldsymbol{\eta}, \mathbf{I}) = p(N_{i,t=1})\, p(r_{i,t})\, p(\bar{r}_i)\, p(\bar{r})\, p(\sigma^2)\, p(\tau_i^2) \times$$
$$p(N_{i,1} \,|\, \sigma^2) \prod_{y=2}^{n} p(N_{i,y} \,|\, N_{i,t-1}, r_{i,y}, \sigma^2, \bar{r}) \times \prod_{y=1}^{n} p(y_{i,t} \,|\, N_{i,t}, \tau_i^2)$$

Joint posterior probability distributions of model parameters were estimated using the Metropolis-Hastings Markov Chain Monte-Carlo (MCMC) algorithm implemented in JAGS, called from R using the library 'jagsUI'. The expected values of the model's parameters and predictions were taken as the mean of the posterior, and the 95% Bayesian credibility intervals (95% CIs; equivalent to parametric confidence intervals) were taken as the 2.5th and 97.5th quantiles of the posterior probability distributions.Convergence of the MCMC chains was diagnosed using the 'coda' package (Plummer *et al.* 2006), adopting minimal thresholds of $p = 0.05$ for Geweke's diagnostic (Geweke 1992) called from R.

Simulation model for CMZ

MSE provides a platform to simulation test a variety of management options for animal populations with the aim that biological and economic goals are met in the long run. As a first step towards a potential MSE implementation, we present an age- and sex-structured population simulation model, specifically developed for CMZ. The population model allows projecting the numbers and off-take of juveniles, bachelors, mares and stallions under various management strategies.

Accompanying this report, we provide the CMZ off-take simulator as an adaptive management tool for rapid risk evaluation of proposed hunting off-takes by the private sector. The CMZ off-take simulator software version ‘mzps_v3’ has been designed for routine use by conservation authorities and scientist. The software consist of two source code files (Tool_mzps.v3.R and Model.mzps_v3), which can be executed within the statistical platform R. The Tool_mzps.v3.R file is used to specify the basic simulation settings, such as the number of simulation runs, the number of years of the projection period, the scenario type (BaseCase, DeHoop-type, MZNP-type) or off-take frequencies. Based on the population parameter inputs, stochastic population dynamics are projected under different selective off-take options for any specified initial population size. The user has the options to either provide the initial total population size as a single number or to specify the numbers of stallions, mares, bachelors and juveniles if reliable information were to be available. Additional simulation outputs include the estimated generation time, the probability of population decline and predicted percentage change over the evaluation period. More details on the CMZ off-take simulator software are provided in the form of a simple user guide in **Appendix A**, including descriptions of the input files and output files.

The basic model parameters for the initial CMZ population scenarios were largely sourced from the primary work by Penzhorn (1988) and the population studies by Novellie *et al.* (1996) and Smith *et al*. (2008). Whereas most parameters describing the basic population dynamics were generally in good agreement, there were notable differences in the estimates of fecundity and first year survival rates. More specifically, Novellie *et al*. (1996) inferred higher foaling and first year survival rates from MZNP population than those observed by Smith *et al*. (2008) for the De Hoop CMZ. To address this discrepancy, we devised the following three alternative scenarios based on different sets of survival and fecundity input parameters: (1) Base-Case (average), (2) De Hoop-type and (3) MZNP-type (Table 1).

Table 1. Summary of demographic input parameters used in the CMZ simulation model

Parameter	Scenario	Mean	Description
Btm	All	3	Age-at-Bachelor
Ftm	All	5	Age-at-Mare
Mtm	All	8	Age-at-Stallion

Ft.max	All	20	Maximum female age
Mt.max	All	25	Maximum male age
F	Base-Case	0.41	Fecundity
	De Hoop	0.35	
	MZNP	0.46	
S1	Base-Case	0.88	Foal survival
	De Hoop	0.8	
	MZNP	0.95	
S2	All	0.95	Juvenile survival
S3	All	0.98	Adult survival

Age- and sex-structure

The population simulation model is sex- and age-structured, with a total of five life stages assigned to specific age-classes of each sex. Foals are born at age 0 with an equal sex ratio of males and females. They become juveniles age 1. At age 3, both female and male juveniles were assumed to join the non-breeding "bachelor" groups. Females are assumed to mature at age 5 and join breeding groups as mares. Males remain longer in the bachelor groups and are assumed to join the adult population breeding stallions at the age of 8. Maximum age for females and males was taken to be 25 and 20 years, respectively.

Survival

Mean survival rates were set to 0.95 for juveniles and 0.98 for adults of both sexes for all scenarios but survival rates were allowed to vary by year by randomly drawing from beta distributions with CV's of 2% for juveniles and adults. Mean survival rates of foals were set to 0.88, 0.8 and 0.95 for Base-Case, De Hoop-type and MZNP-type scenarios, respectively, where the Base-Case value of 0.88 represents the average of the two alternative scenarios. A CV of 5% was assumed to account for annual variation in foal survival, with random annual deviates drawn from a beta distribution. In the absence of any off-take or introductions (see below), the numbers of survivors in an age class are randomly drawn from a multinomial distribution as a function of the survival at age and the numbers at age of the previous age class and previous year.

Reproduction

Breeding was assumed to be dependent on mares and the ratio of stallions to mares. Females were assumed to have a mean fecundity of 0.41 foals per year for the Base-Case, and 0.35 and 0.46 for the De Hoop-type and MZNP-type, respectively. To account for uncertainty of variations among subpopulations, mean fecundity was allowed to vary between simulations by assuming a CV of 10%, drawn from a beta distribution. In addition, inter-annual variation in fecundity was introduced in the same way by assuming a CV of 10%. To explicitly incorporate the role for reproduction of stallions, we introduced a 'hockey-stick' function, which allows setting a threshold for the stallion to mare ratio at which mating success attains 100%. The reproductive rate is then given as a product of mating success (dependent on the stallion to mare ratio) and mare fecundity. For all three scenarios, we assumed that there is 100% mating success as long as the stallion to mare ratio does not drop below 0.25 (i.e. 1:4). If the ratio drops below 0.25, the mating success decreases linearly until there is zero mating success in the absence of any stallions.

Initialisation

The first step is to specify the number of animals for the first year of the simulation. The initial numbers at age and sex can be set manually or randomly initialised by random numbers at age that are generated from a multinomial distribution as a function of the numbers of each sex and the proportion of animals within each selected age class as would be expected from a stable age-structure (given the survival rate at age).

Off-take and introductions

Off-take (or hunting) is implemented by manually setting quotas (in numbers). The simulator explicitly accommodates age- and sex-selective strategies, which is realised by specifying the age-range, the desired proportion of the target population and the off-take frequency (see below). The numbers at age that are removed from the population are then drawn from a multinomial distribution as a function of the off-take by sex and the relative proportion of animals in each target age-class within each sex. Introduction events are simulated in the same way as population initializations (see above). Finally, off-take and introductions in numbers at age for each sex are sequentially deducted and added, respectively, from the survivors (starting with off-take).

The off-take in numbers can be specified by the following options:

- OT_Random (Individuals of all ages and sex are selected randomly based on relative proportions in the population at each time step)
- OT_Adult (Same as Random, but excluding juveniles of ages 0-3)
- OT_Mares (Only breeding mares are randomly selected, Females age 5-25)
- OT_Stallions (Only stallions are randomly selected, Males age 8-20)
- OT_Bachelors (Only bachelors are randomly selected from Females of the ages 3-4 and Males of the ages 3-7)
- OT_Juveniles (Only juveniles are randomly selected ages 0-3)

In addition, an option is provided to specify the frequency of offtake events. Currently, these options include ‘Once-off’, ‘Annually’, ‘Biennial’, ‘Triennial’, ’Quadrennial’ and ‘Quinquennial’ (i.e. every second, third, fourth and fifth year).

Simulation-evaluation against observed count data

Records for CMZ population counts, numbers introduced and numbers of off-take were compiled for eight subpopulations that had fairly reliable census data. The aim of this simulation analysis was to assess the plausibility of the model specifications used for the simulation scenarios against the observed population trajectories. The assessed subpopulations comprised five subpopulations located in the Western Cape (De Hoop Nature Reserve, Kammanassie, Gamkaberg, West Coast NP and Karoo NP) and three subpopulations in the Eastern Cape and Free State Province (MZNP, Camdeboo NP and Gariep NR). De Hoop NR, Kammanassie NR, Gamkaberg NR and West Coast NP are associated with the Fynbos Biome, Karoo NP with the Nama Karoo biome and MZNP, Camdeboo NP and Gariep NR are located at the interface the interface between the Nama Karoo and Grassland Biomes (Fig. 2).

The numbers of introduced and removed animals were passed on to simulations and the observed counts were then compared with the resultant population trajectories from 1000 simulations. All subpopulation scenarios were initialized based on the first available count estimate and then randomly drawn from a sex- and age-structure at equilibrium.

The relative error (RE) and the median absolute relative error (MARE) were calculated to evaluate the bias and ‘goodness-of-fit’ between the simulated population trajectories and the observed counts from population surveys, such that:

$$\mathrm{RE}_{y,k} = \left(\frac{N_y - \tilde{N}_{y,k}}{\frac{1}{2}\sum \tilde{N}_{y,k} + N_y} \right) \quad \text{and} \quad \mathrm{RE}_k = \frac{1}{Y}\sum_y RE_{y,k}$$

$$\mathrm{MARE}(\%) = median\left(\frac{1}{Y}\sum_y \left| RE_{y,k} \right| \right) \times 100$$

where $\tilde{N}_{y,k}$ denotes the simulated population size for year *y* and simulation run *k*, N_y is the observed population, *Y* is the total number of years with observations and $\left|RE_{y,k}\right|$ denotes the absolute value of the relative error for *year y* and simulation run *k*.

Off-take quota cross-evaluation

To determine relationship between initial population sizes (*N0*) and sustainable annual off-take (O_a), we conducted a cross-simulation experiment using the hunting simulator tool for all three scenarios. To do this, we increased N_0 from 5 to 100 in steps of 5 and calculated for each N_0 the probability of a population decrease (*PD*) for off-take numbers between 0 and 10 over a 15 years evaluation period based on 250 simulation runs per evaluation. All initial N_0 values were randomly drawn from a stable population structure at equilibrium and the random 'Adult' off-take setting was considered the most appropriate for generalization of the results.

We modelled the relationship between the harvest rate *H* ($H = O_a/N_0$) and the probability of a population increase (*PD*) using a logistic model of the form:

$$PD = \frac{1}{1 + \exp\left(-(H_i - H_{50})/\delta\right)} \ ,$$

where H_i is the annual harvest rate defined by the ratio O_a/N_0, and H_{50} and δ are the estimable parameters that determine the off-take ratios that result in a 50% probability of decrease and the slope of the ogive, respectively. The regression parameters H_{50} and δ were estimated by minimising the negated binomial log-likelihood function of the form:

$$-LL = -\sum_i \left[m_i \ln\left(PI_i\right) + (n_i - m_i)\ln(1 - PI_i) \right],$$

where n_i is the number of simulation runs and m_i represents the number of times a population decline was noted.

Results

Trend analysis

The estimated mean annual growth rates showed considerable variations among the nine source populations (Table 2). Highest growth rates were estimated for reserves located at the eastern edge of the known natural range at Commando Drift NR and Gariep NR (Fig 2). Of concern was the very low population growth estimate of 3.53% for the relict population at Gamkaberg NR, when compared to the (weighed) mean estimate across the nine populations of 6.73% (Table 2). However, the high estimate for Commando Drift NR should be treated with caution as the initial population increase appeared biologically implausible with rapid population doubling within less than three years.

Table 2. Assumed upper limits of population numbers (*K*) of Cape Mountain Zebra for nine potential source populations, and annual mean growth rate estimates (%) summarised as means and 95% credibility intervals. MZNP: Mountain Zebra Nation Park

Source Population	Limit (*K*)	Growth rate (%)	95% Cis
De Hoop NR	170	5.98	1.81 - 10.13
MZNP	1200	6.83	2.91 - 10.90
Gamkaberg NR	40	3.53	-0.71 - 7.59
Kammanassie NR	140	6.62	2.67 - 10.66
Karoo NP	1000	7.75	3.69 - 12.06
Gariep NR	100	8.09	4.09 - 12.38
Camdeboo NP	300	6.65	2.66 - 10.75

Commando Drift NR	140	9.32	5.21 - 14.03
Tsolwane NR	150	6.06	1.77 - 10.39
Total	3240	mean = 6.73	3.84 - 9.79

Predictions of initial and current population sizes for each subpopulation are summarized in Table 3. Although all subpopulations were predicted to have increased between 1985 and 2015 (Fig. 3), the rate of increase varied markedly, ranging from 54.7% in Gamkaberg (N_{1985} = 19, N_{2015} = 29) to 1817.8% in Commando Drift (N_{1985} = 7, N_{2015} = 137). All subpopulations had attained the highest population estimates in 2015 compared to all previous years. The only exception was the Gamkaberg NR subpopulation, for which the current population estimate (N_{2015} = 29) was estimated at 60% of its maximum size attained in 2009 (N_{2009} = 47). The two largest subpopulations, in MZNP and Karoo NP, together, were responsible for a net increase of 1685 animals (Fig. 3), which represents 70% of the total net increase in numbers for all nine protected source populations combined. For 2015, the total population numbers summed over all nine subpopulations were predicted to fall between 2488 and 3000 animals at a 95% confidence level with a mean of 2748 (Fig. 4; Table 3).

Table 3. Estimated population numbers of Cape Mountain Zebra for nine potential source populations, summarized as means and 95% credibility intervals for 1985 and 2015. MZNP: Mountain Zebra Nation Park

Subpopulation	1985		2015	
	Mean	95% Cis	Mean	95% Cis
De Hoop NR	25.0	17.6 - 34.1	121.4	88.8 - 167.2
MZNP	144.9	132.1 - 149.9	1070.7	940.9 - 1186.0
Gamkaberg NR	18.9	17.3 - 20.1	29.2	27.5 - 31.8
Kammanassie NR	12.1	10.5 - 14.4	80.4	68.5 - 94.7
Karoo NP	75.2	48.7 - 97.3	835.0	610.0 - 1036.2
Gariep NR	7.6	6.5 - 10.0	97.1	82.0 - 116.8
Camdeboo NP	34.1	28.5 - 42.0	233.1	191.7 - 276.5
Commando Drift NR	7.2	6.3 - 8.7	137.8	110.2 - 168.4
Tsolwane NR	34.4	22.1 - 51.4	143.8	100.8 - 179.8
Total	359.4	326.7 - 390.7	2748.7	2488.5 - 2999.7

The forward projections of individual source population numbers indicated that the two largest subpopulations in MZNP and Karoo NP are likely to attain their upper population limits within the next five years (Fig. 4). The detailed source population predictions for 2020 and 2025 are presented in Table 4. It can be readily inferred that the implementation of upper source population size limits is predicted to heavily constraint future growth potential (Fig. 4), with no further increases total numbers for the nine source populations predicted for the 2020 to 2025. To maintain current rates of increase in source population numbers will either require extending the available land or founding new source populations in areas where suitable land is available

Red List implications

The total percentage change over the 31 years was + 572% for the nine subpopulations combined (Fig. 5). As the timespan of 31 years roughly approximates to three generation times of CMZ reported as reported for the MZNP (Novellie *et al.* 1996), this estimate qualifies as a population reduction estimate according the IUCN Red List criteria **A.** The corresponding posterior distribution of the percentage change resulted in a 0% probability to support a population size reduction of more than 30%, and, *vice versa*, provided 100% support for CMZ to be listed in the Least Concern (LC) category based on the population reduction criterion alone (Fig. 5). Because a population reduction of any extent over the last 31 years can be excluded after accounting for process and observation error, this results in IUCN criterion **A** having a direct impact on criteria **B** and **C.** More specifically, according to criterion **B,** the threshold of the extent of occurrence covering less than 20.000 km^2, would only qualify for the current Vulnerable (VU) threat category if, either, there is risk of an ongoing population decline, or, if mature individuals were to exist in less than ten known locations. Similarly, criterion **C**’s threshold of less than 10.000 mature individuals, would only qualify for VU if any continuing trend can be inferred.

Table 4. Predicted population numbers of Cape Mountain Zebra for nine long-term protected source populations, summarized as means and 95% credibility intervals for 2020 and 2025.

Subpopulation	2020		2025	
	Mean	95% Cis	Mean	95% CIs
De Hoop NR	147.1	80.8 - 199.3	157.1	81.6 - 203.1

MZNP	1158.6	812.1	-	1442.3	1180.9	848.5	-	1451.3
Gamkaberg NR	33.3	19.0	-	46.1	34.9	16.7	-	47.2
Kammanassie NR	109.5	59.7	-	158.4	124.6	61.2	-	165.8
Karoo NP	955.2	621.4	-	1202.3	981.0	682.8	-	1207.2
Gariep NR	99.0	77.6	-	121.3	99.7	79.1	-	121.3
Camdeboo NP	277.0	172.9	-	357.2	288.8	179.5	-	361.8
Commando Drift NR	139.6	111.8	-	169.7	140.3	113.5	-	170.2
Tsolwane NR	146.1	99.3	-	181.3	147.4	100.7	-	181.6
Total	3065.4	2593.6	-	3466.5	3065.4	2692.7	-	3529.9

Simulation analysis

Simulation-evaluation against observed counts

We assessed the plausibility of simulation projections for eight subpopulations against observed count data based on three scenarios pertaining to the life history input parameters. The results showed substantial differences among the three scenarios as a result varying fecundity and foal survival rate input parameters (Figs. 6-9).

The simulation runs for the Base-Case scenario were positively biased for the De Hoop NR, Kammanasie NR, Gamkaberg NR and West Coast NP subpopulations, which are all located within the Fynbos Biome (Figs. 6-7). The largest discrepancy in terms of the Median Absolute Relative Error (MARE) was evident for Gamkaberg NR and West Coast NP. By contrast, the Base-Case simulation runs for the four subpopulations MZNP, Karoo NP, Cambdeboo NR and Gariep NR, associated with the Nama Karoo and Grassland Biomes, were slightly underestimated relative to the observed count data (Figs. 6-7), and the MARE values were generally lower than for the four Fynbos subpopulations.

This pattern changed drastically for the De Hoop-type scenario (Figs. 6 & 8), which resulted in very good agreement between the observed and simulation population size for De Hoop NR and Kammanasie NR. Although Gamkaberg NR and West Coast NP still remained below the simulation expectations, the observed counts now fell within the 90% simulation intervals of the projections (Fig. 8). However, the De Hoop-type scenario resulted in poor agreement between the observed and simulated population sizes for the four Nama Karoo/Grassland Biome subpopulations. In particular, the MZNP and Gariep NR population indicated that their fairly high regular off-take numbers due to translocations and culling could not have been sustained given the input parameters for the De Hoop-type scenario. Unsurprisingly, the MZNP-type scenario resulted in the poorest agreement between observed and simulated population size for De Hoop NR and Kammanasie NR. Although Gamkaberg NR and West Coast NP, but in very good agreement for MZNP, Karoo NP, Cambdeboo NR and Gariep NR (Figs. 6 & 9).

These results are in general agreement with the variations in the estimated population growth rates (Table 2) and point towards differences in key life history parameters among different habitat types with strong implications for the resilience to off-take.

Hunting quota cross-evaluation

Graphical illustrations of the results from the adult off-take cross-validation runs are provided in the form of isopleth plots for the three considered scenarios in Figs. 10-12. The isopleths plot the calculated probabilities of population increase (*PI*) against the combination initial population sizes and the annual adult off-take numbers based on 250 simulation runs for each of evaluation step. Dashed isopleth lines are provided to highlight the population size to off-take combinations that would results in 10%, 20%, 50%, 80% and 90% probabilities of population increase (note that PI = 1-PD).

The relationships between the adult harvest rate ($H = O_a/N_0$) and the probability of population decline (*PD*) are illustrated in Fig. 13. The annual adult off-take ratios that would lead a 50% *PD* (i.e. an on average stable population) were 6.3% for the De Hoop-type, 8.8% for the Base-Case and 10% for the MZNP-type. A rapid empirical approximation of the probability of population decline for any given off-take ratios for any of the three considered scenario types can be obtained from the three following logistic model equations:

$$PD = \frac{1}{1+\exp(-(H-0.088)/0.011)} \qquad \textbf{(Base-case)}$$

$$PD = \frac{1}{1+\exp(-(H-0.064)/0.011)} \qquad \textbf{(De Hoop-type)}$$

$$PD = \frac{1}{1+\exp(-(H-0.101)/0.011)} \qquad \textbf{(MZNP-type)}$$

where *H* can be calculated from the proposed annual off-take quota divided by number of animals in the population under assessment.

Discussion

This report highlights the potential of Management Strategy Evaluation as an adaptive management approach to assess the impact of hunting quotas in collaboration with stakeholders. To provide decision support, we presented the CMZ off-take simulator as a promising tool to assess the risks of off-take for CMZ populations on a case by case basis. In addition to supporting sustainable off-takes by the private sector, the CMZ off-take simulator has potential applications for the implementation of the meta-population management plan envisaged in the draft Biodiversity Management Plan (Birss *et al*. 2016), particularly where it relates to the establishment of new subpopulations through off-takes from source populations and reinforcement of existing populations through translocations.

Comparisons of model predictions with actual population performance showed good agreements for either the MZNP-type or De Hoop-type scenario, which points towards important differences in key life history parameters among different habitat types. In general, the results indicate that population growth performance is better in the Nama Karoo Biome and the interface between the Nama Karoo and Grassland Biomes than in the Fynbos Biome. However, the validity of application of the protected area scenarios for assessing the risks of off-take for populations belonging to private sector applicants remains associated with uncertainty. A potential challenge is that the life history parameters for these diverse and mostly small populations may differ from the protected area populations for which some demographical data is available (De Hoop NR and MZNP). Good quality monitoring data for such populations under assessment would help to reduce uncertainty, and should be a consideration in assessing applications for quotas. In particular, improved estimates of foaling rates (fecundity) and foal and juvenile survival present critical demographic parameters that would substantially contribute to reduce the forecasting uncertainty of the CMZ off-take simulator. This further highlights the need for close engagement and collaboration with applicants, and the importance of encouraging them to monitor outcomes to improve the simulation model precision.

Future growth potential and appropriate Red-List categories for CMZ were inferred from long-trend trends count data (1985-2015) from nine formally protected and well established (> 30 years) Cape

Mountain Zebra (CMZ) source populations. For 2015, the total population numbers summed over all nine source populations were predicted to fall between 2488 and 3000 animals at a 95% confidence level with a mean of 2748 animals. The forward projections of individual source population numbers indicated that the two largest in MZNP and Karoo NP are likely to attain their upper population limits within the next five years. Incorporating carrying capacity limits into forward projections suggest a heavily constrained future growth potential of the nine identified source populations. To maintain rates of increase in source population numbers, the expansion of available land or the founding of new source populations on suitable land will be required.

CMZ is currently listed as Vulnerable based on criteria D1, which would only apply if the total population number is estimated to comprise fewer than 1000 mature individuals. Therefore, the total population estimates of 2488 and 3000 animals for the nine long-term protected source populations, alone, support a revision of the current Red List status for CMZ. The population reduction estimate according the IUCN Red List criteria **A** resulted in a total percentage change + 572% over the last 31 year for the nine source populations combined and the corresponding posterior distribution provided 100% support for CMZ to be listed in the Least Concern (LC) category based on the population reduction criterion alone.

Some risks to the CMZ population remain. There appears to be a strong dependency on the two large source populations in MZNP and Karoo NP in terms of contribution to total population numbers and surplus production of CMZ as a source for new founder populations. The recent evidence for cases of hybridisation with plain zebras poses a risk to the genetic integrity of both source populations and, therefore, the world population as whole. Another current threat to CMZ is the ongoing loss of genetic diversity (Moodley and Harley 2005). The national population is fragmented into 52 subpopulations (Hrabar and Kerley 2013). The largest relict population in the MZNP has been the source population for establishing more than 30 subpopulations (Novellie *et al*., 2002) and, consequently, more than 95% of the current meta-population derives from the MZNP population (Moodley and Harley, 2005). Despite evidence from genetic population structure analysis suggesting that mixing of the three relict populations could halt further loss of genetic diversity (Moodley and Harley, 2005), there is currently no meta-population management in place. These risks have been explicitly considered in the draft Biodiversity Management Plan for CMZ (Birss *et al*. 2016).

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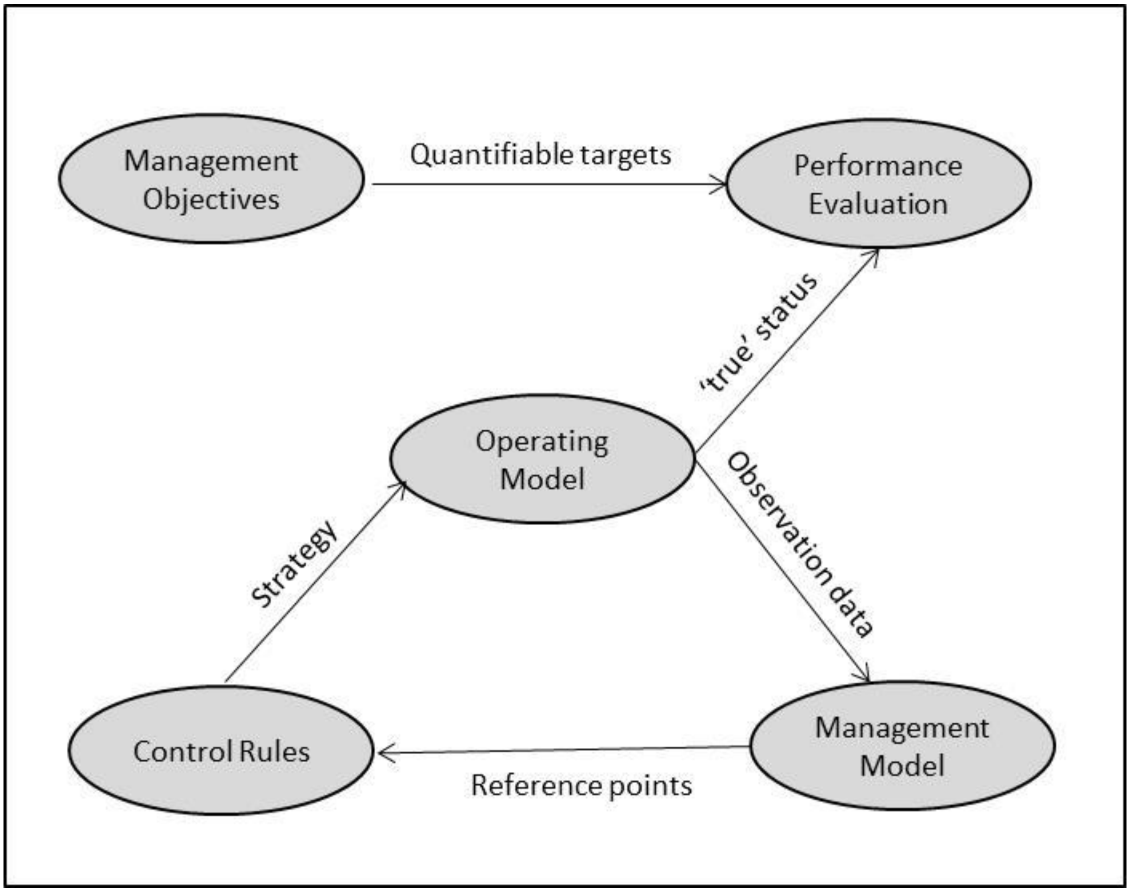

Figure 1. Schematic representation of the simulation testing framework for the Management Strategy Evaluation approach.

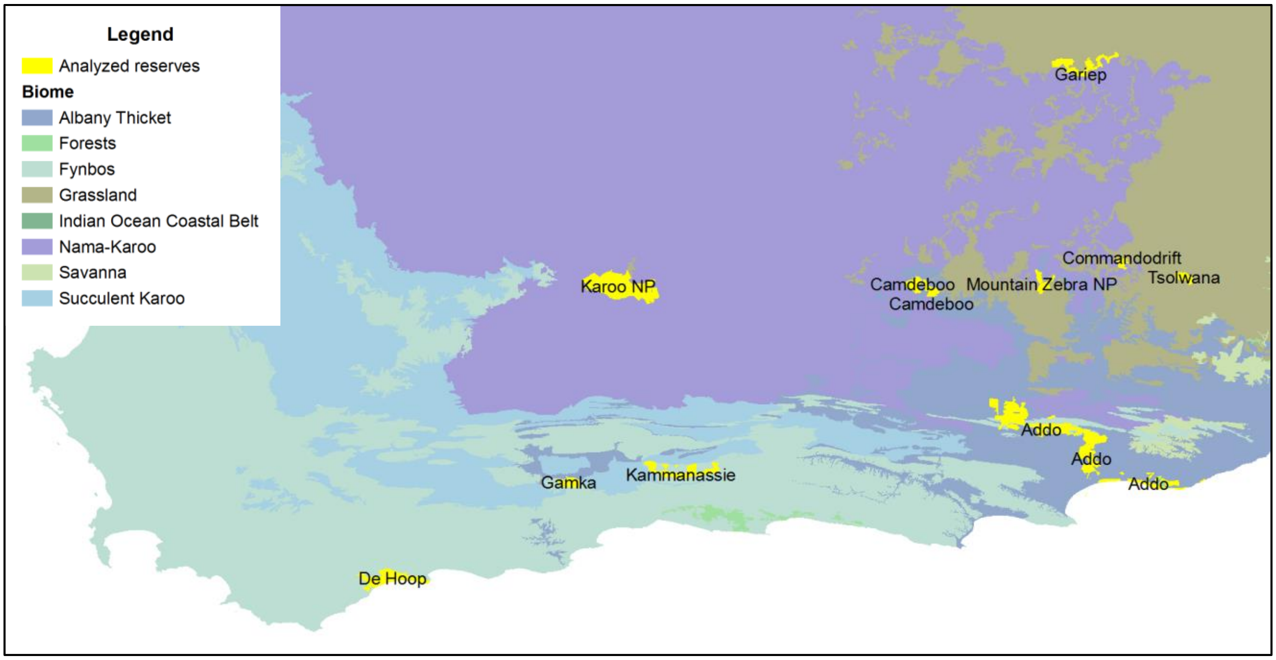

Figure 2. Illustrating the locations of the ten Cape mountain zebra subpopulations under assessment, with different biomes shown as a background layer.

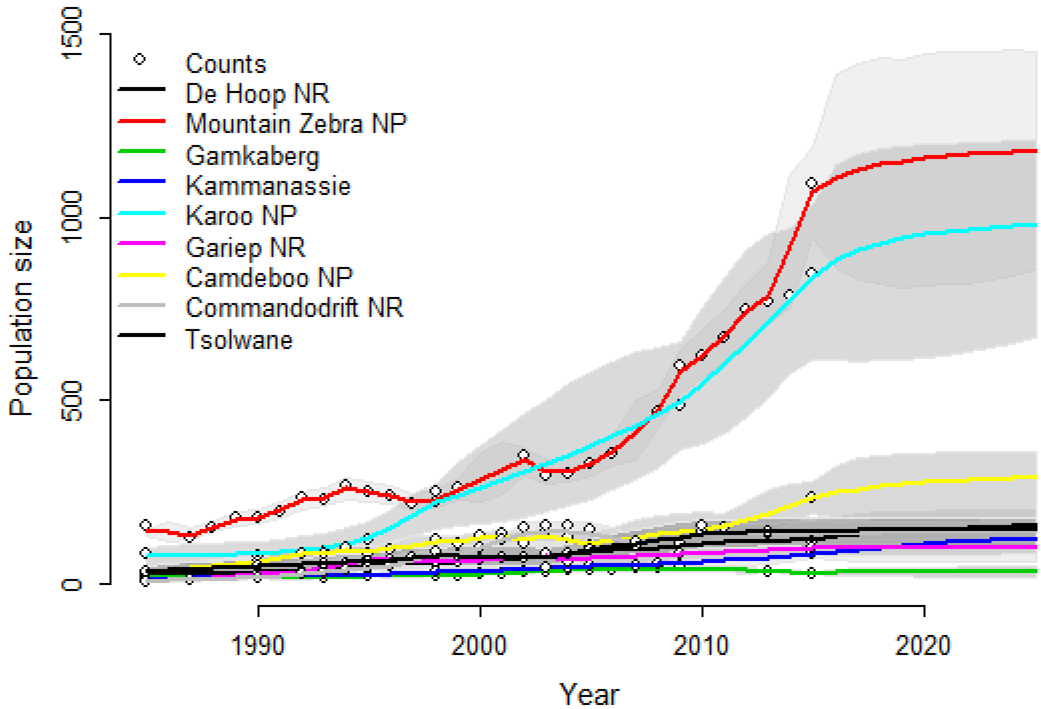

Figure 3. Reported and model predicted population numbers for nine long-term protected subpopulations over the period 1985-2015. Gray-shaded areas denote the estimated 95% Bayesian Credibility Intervals.

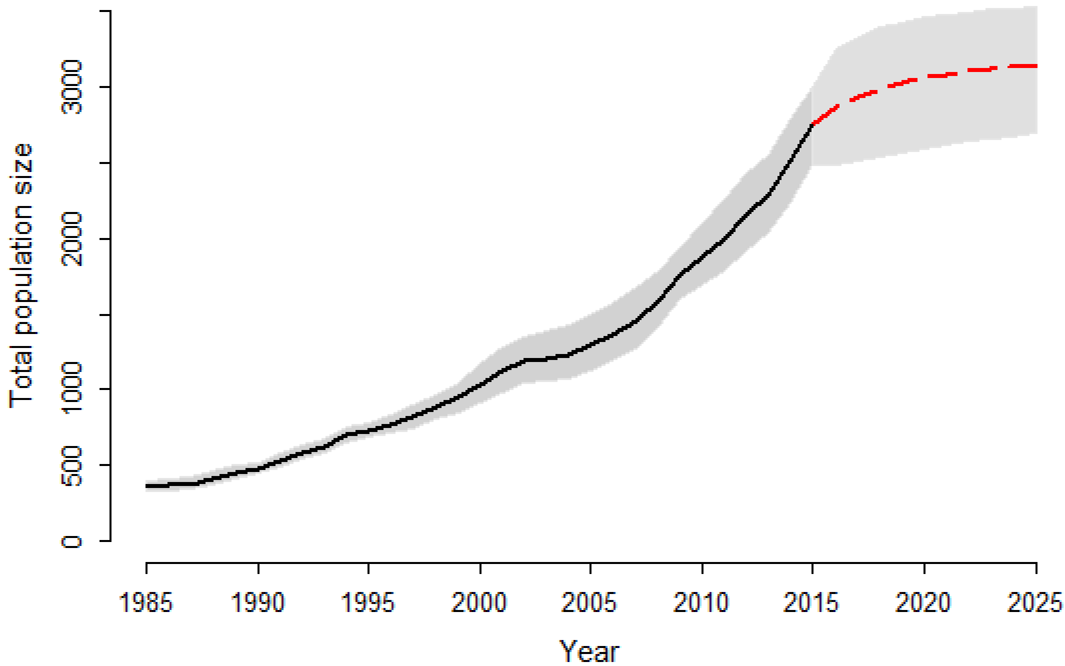

Figure 4. Estimated (black solid line) and forecasted (red dashed line) total populations numbers, summed over nine long-term protected subpopulations, with gray-shaded areas illustrating the estimated 95% Bayesian Credibility Intervals.

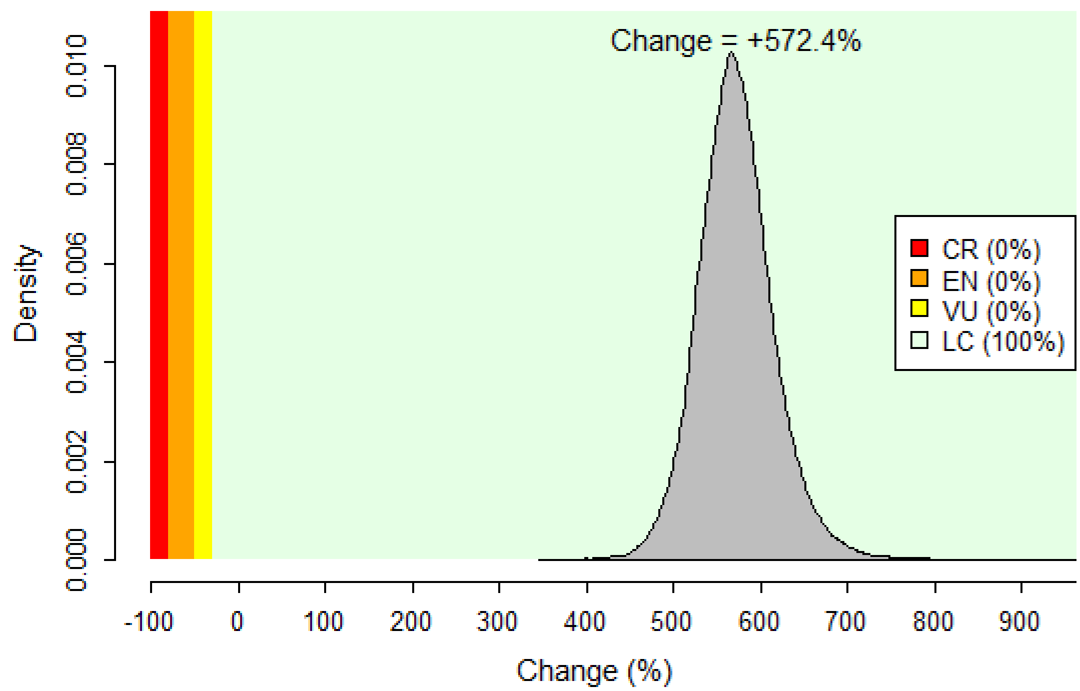

Figure 5. IUCN Red List support plot illustrating the posterior of the change (%) in populations numbers over three generations. Estimated (black solid line) and forecasted (red dashed line) total populations numbers summed over ten long-term protected subpopulations, with gray-shaded areas illustrating the estimated 95% Bayesian Credibility Intervals.

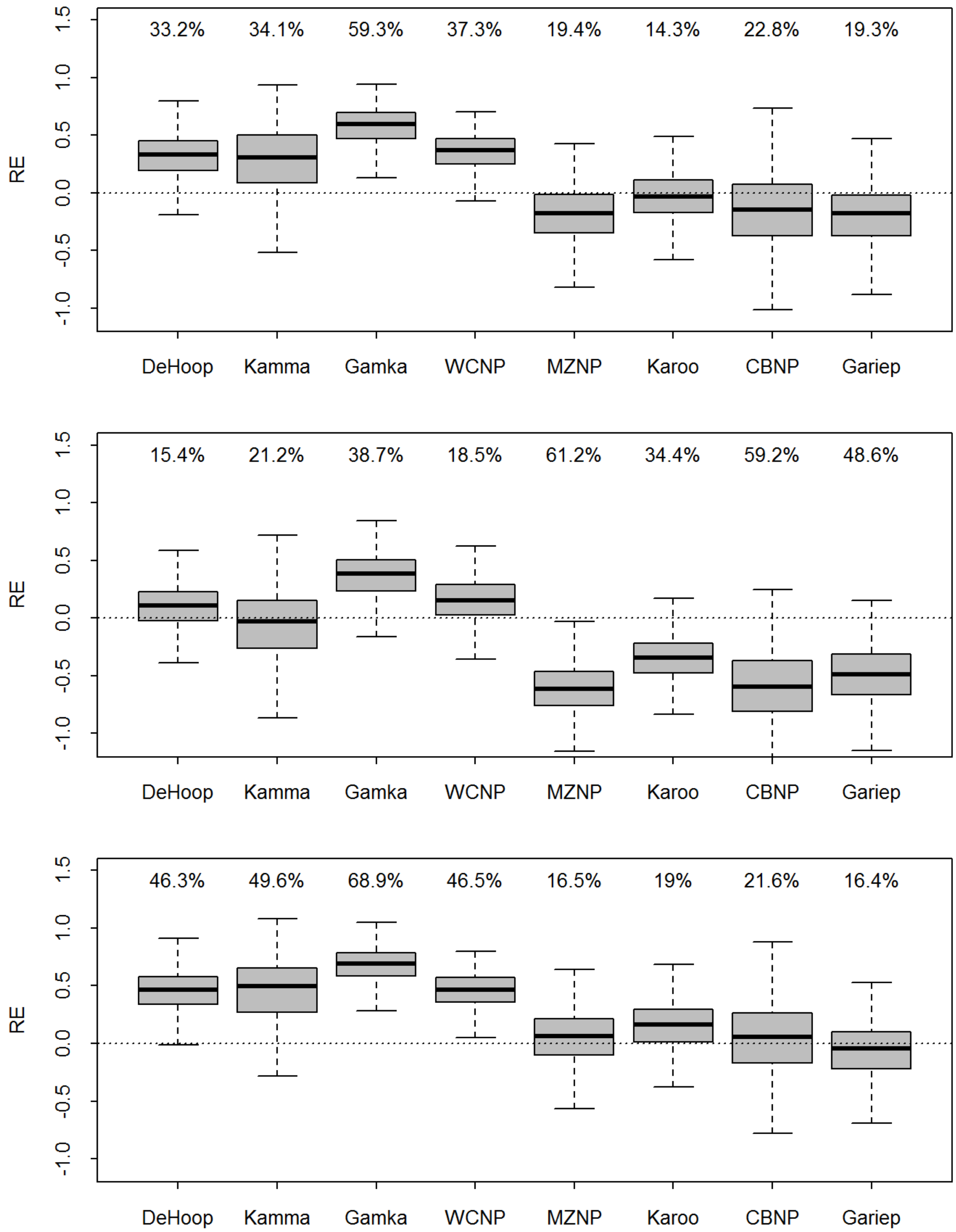

Figure 6. Statistical evaluation of the simulation trajectories against the observed counts for eight subpopulations of CMZ based on the “Base-Case” (Top Panel), “De Hoop-type” (Middele Panel) and “MZNP-type” (lower panel) scenarios. Values denote Median Absolute Error (MARE) expressed as percentage.

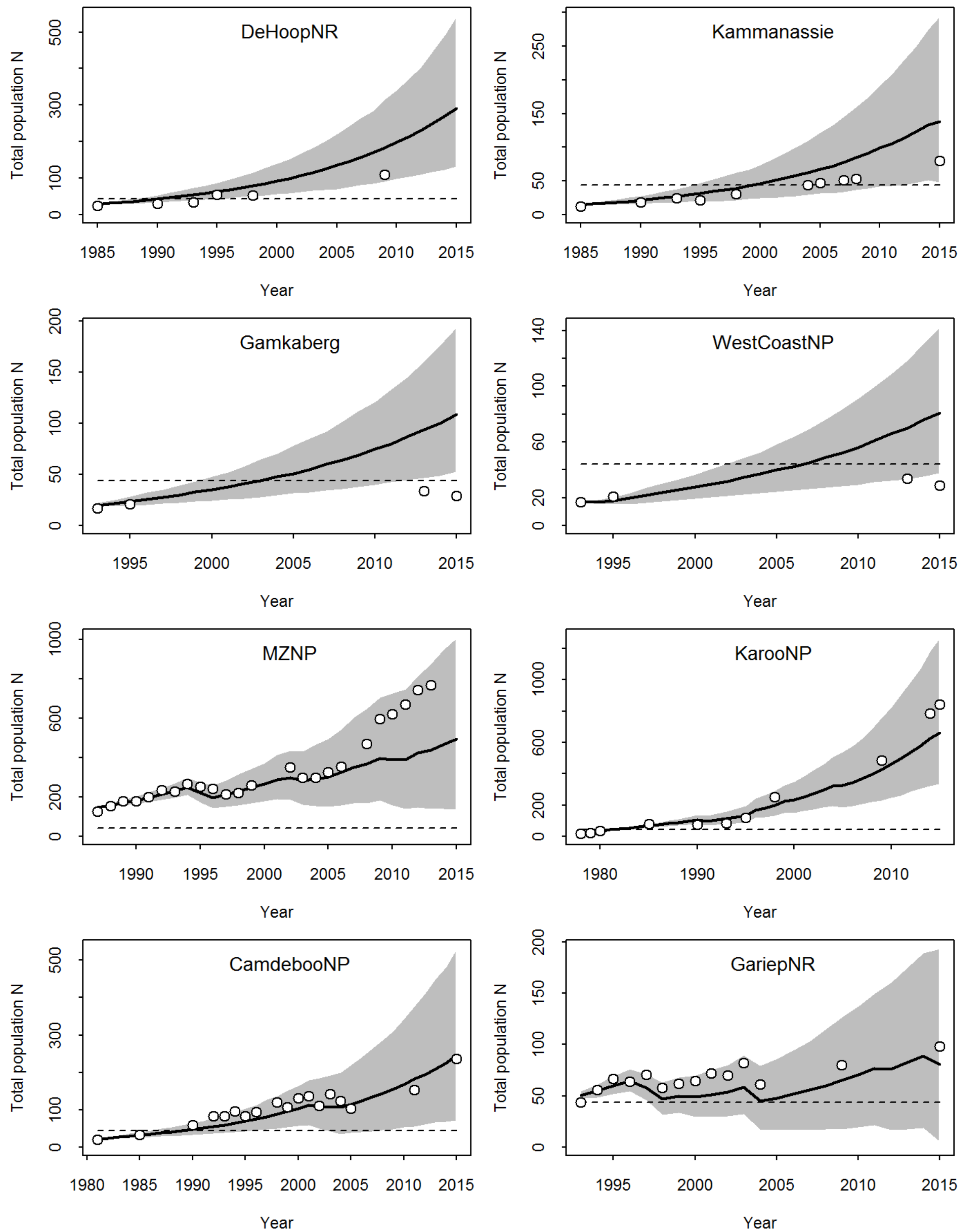

Figure 7. Graphical evaluation of the simulation trajectories against the observed counts for eight subpopulations of CMZ for the "Base-Case" scenarios, showing the observed counts, the means of simulation trajectories (solid line) and 90% simulation interval (grey-shaded area).

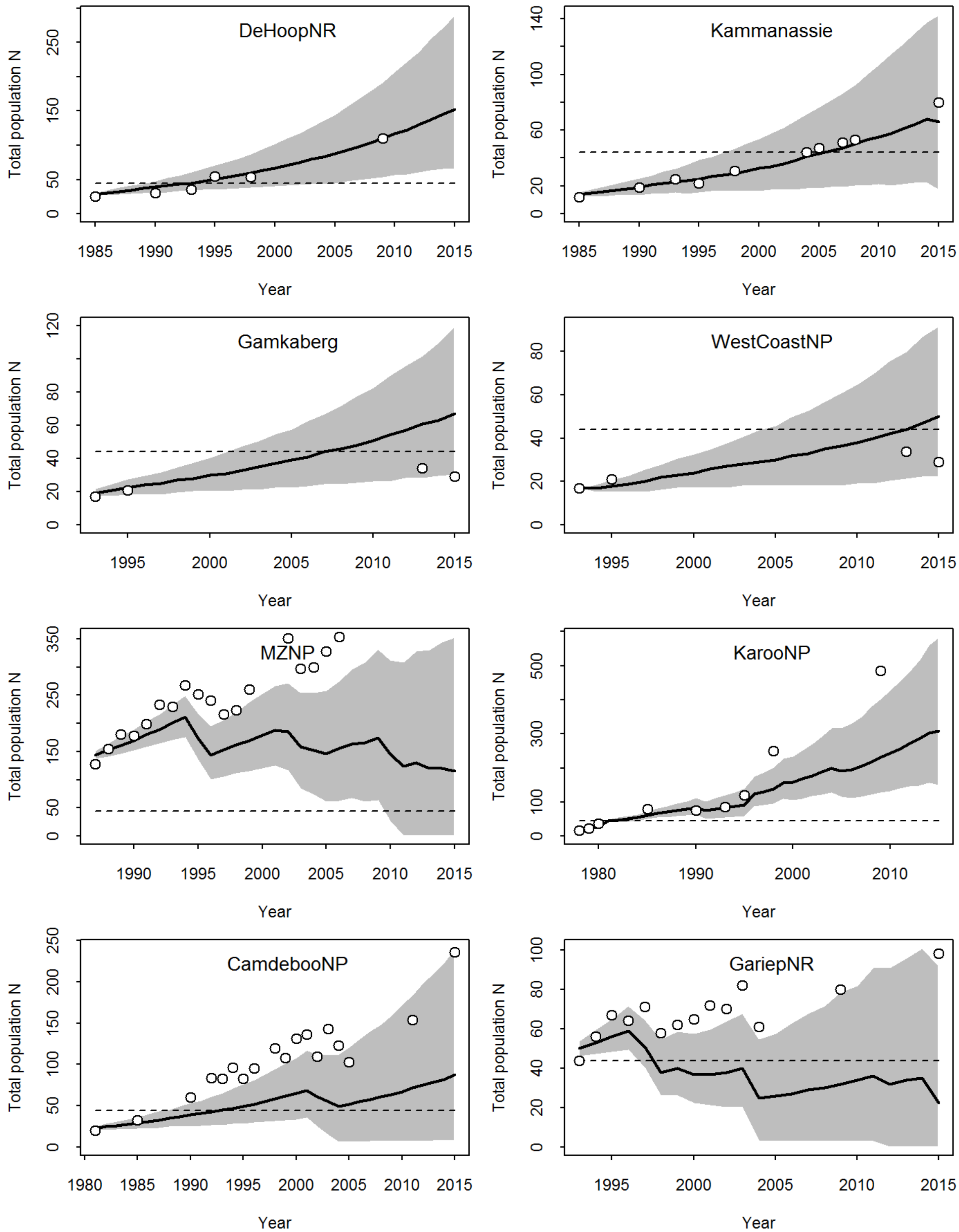

Figure 8. Graphical evaluation of the simulation trajectories against the observed counts for eight subpopulations of CMZ for the "De Hoop-type" scenario, showing the observed counts, the means of simulation trajectories (solid line) and 90% simulation interval (grey-shaded area).

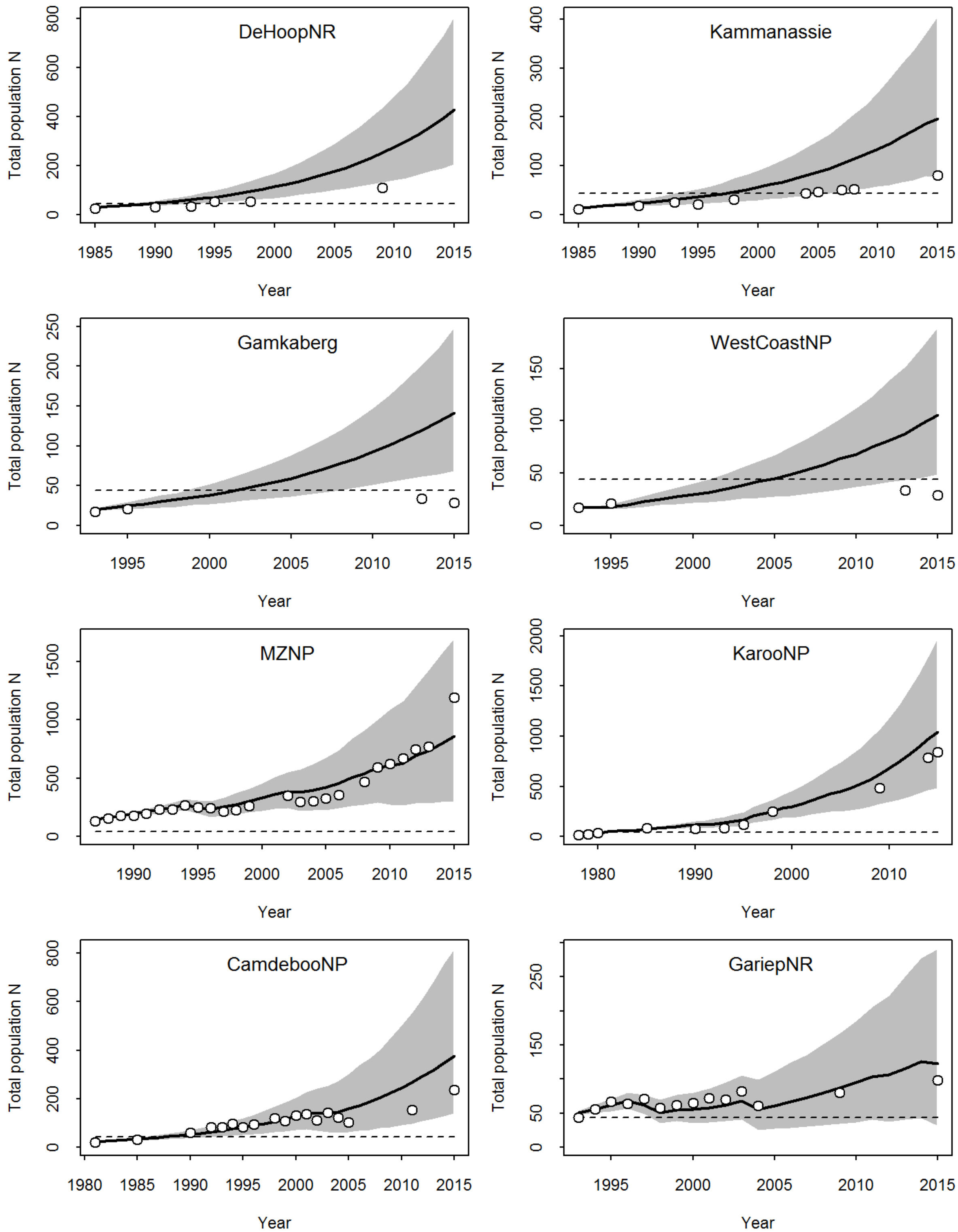

Figure 9. Graphical evaluation of the simulation trajectories against the observed counts for eight subpopulations of CMZ for the "MZNP-type" scenarios, showing the observed counts, the means of simulation trajectories (solid line) and 90% simulation interval (grey-shaded area).

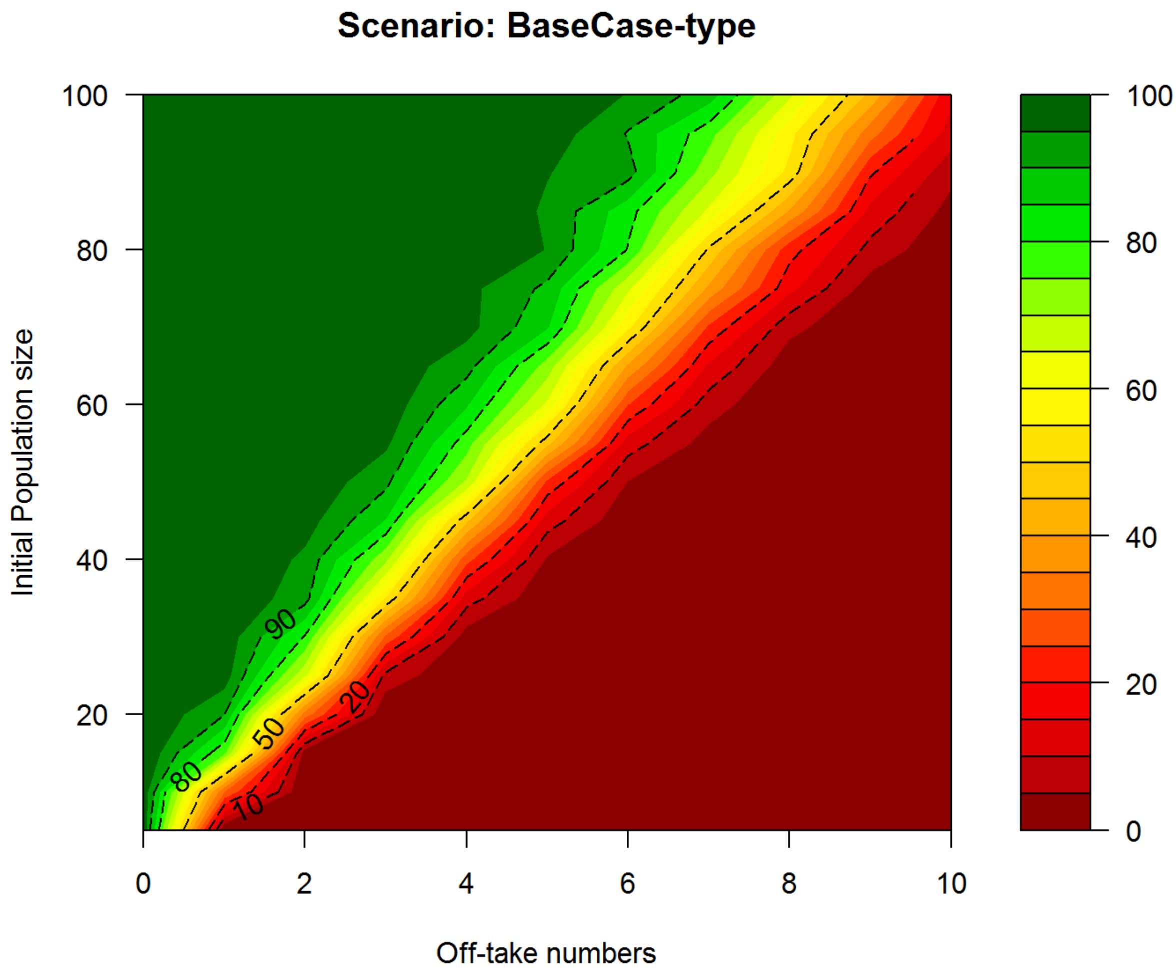

Figure 10. Isopleths plot the calculated probabilities of population increase (denoted by the gradient from dark red = 0 to dark green = 1) for the Base-Case scenario against the combination initial population sizes and the annual adult off-take numbers based on 250 simulation runs for each of evaluation step. Dashed isopleth lines denote the population size to off-take combinations that would results in 10%, 20%, 50%, 80% and 90% probabilities of population increase over a 15 years simulation period.

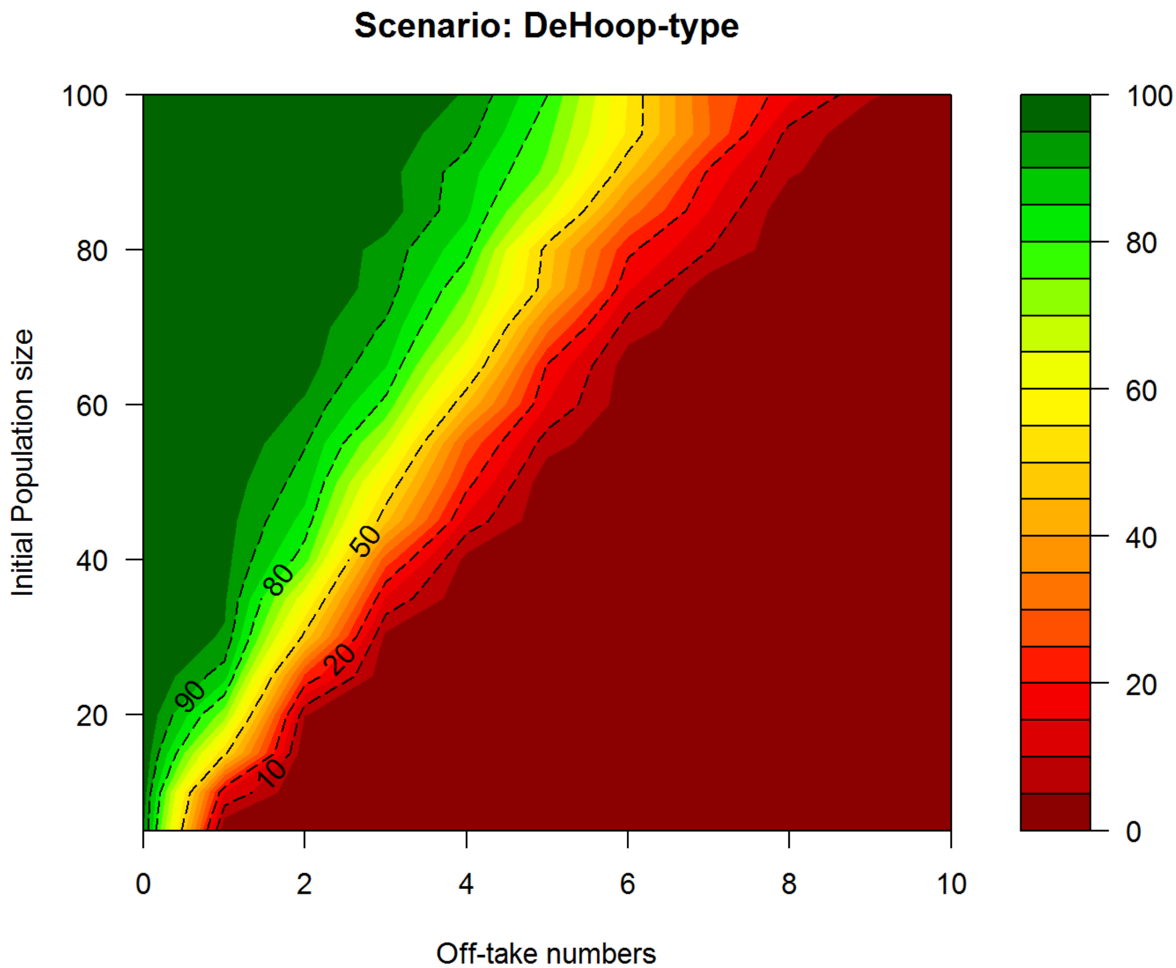

Figure 11. Isopleths plot the calculated probabilities of population increase (denoted by the gradient from dark red = 0 to dark green = 1) for the De Hoop-type scenario against the combination initial population sizes and the annual adult off-take numbers based on 250 simulation runs for each of evaluation step. Dashed isopleth lines denote the population size to off-take combinations that would results in 10%, 20%, 50%, 80% and 90% probabilities of population increase over a 15 years simulation period.

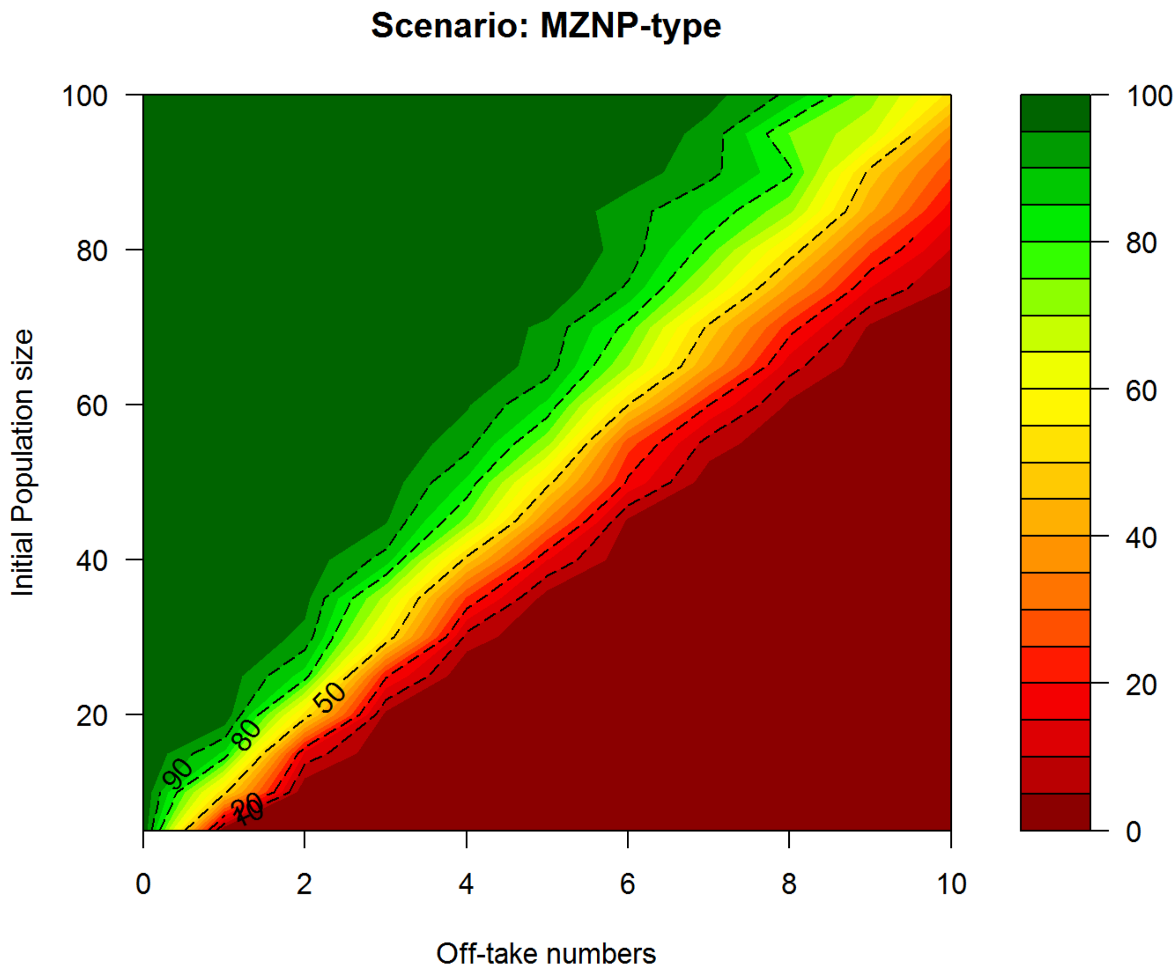

Figure 12. Isopleths plot the calculated probabilities of population increase (denoted by the gradient from dark red = 0 to dark green = 1) for the MZNP-type scenario against the combination initial population sizes and the annual adult off-take numbers based on 250 simulation runs for each of evaluation step. Dashed isopleth lines denote the population size to off-take combinations that would results in 10%, 20%, 50%, 80% and 90% probabilities of population increase over a 15 years simulation period.

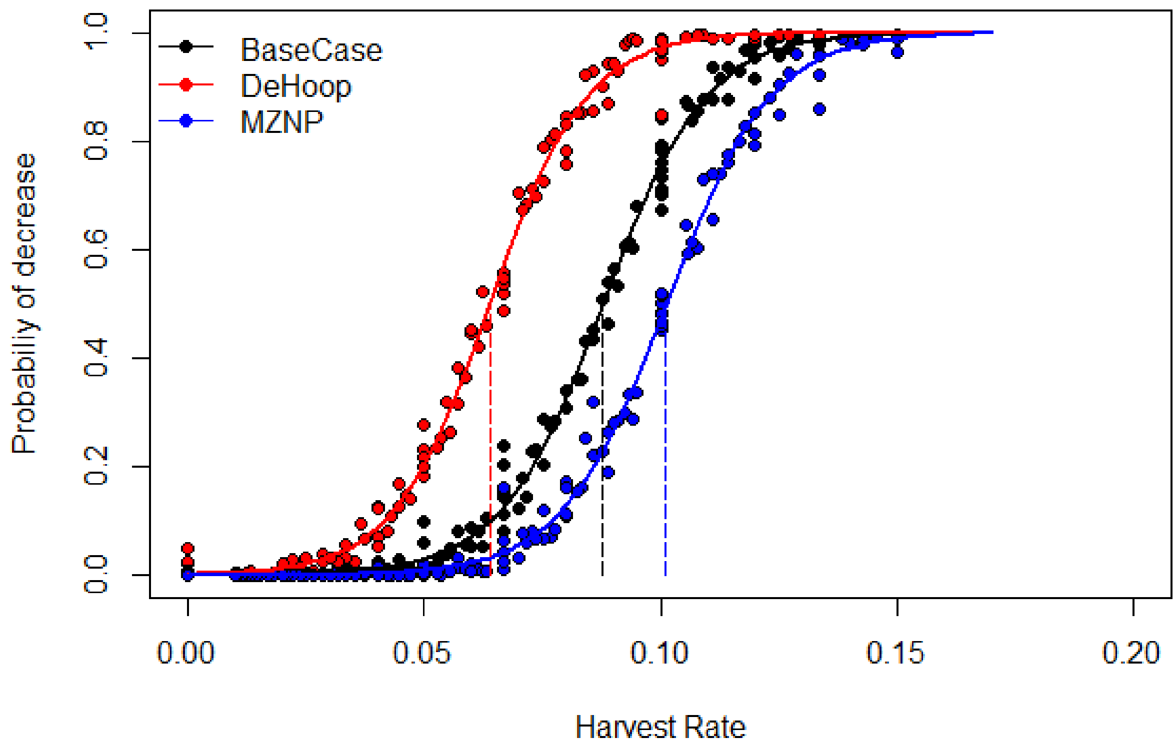

Figure 13. Logistic regression fits showing the relationships between the adult harvest rate ($H = O_a/N_0$) and the probability of population decrease over a simulated period of 20 years for the Base-Case, De Hoop-type and MZNP-type scenarios.

APPENDIX A

A User Guide for CMZ off-take simulator

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This is an accompanying guide the Cape Mountain Zebra (CMZ) off-take simulator tool presented in Winker *et al*. (2016) “Population trends and management strategy tool for Cape Mountain Zebra (SANBI, Final report prepared for the Scientific Authority of South Africa). The CMZ off-take simulator presents an adaptive management tool for rapid risk evaluation of proposed hunting off-takes by the private sector designed for routine use by conservation authorities and scientists.

The software version (cmzos.v3) referred to in this guide consists of two files (Tool_mzps.v3.R and Model.mzps_v3), which can be executed within the statistical platform R. The Tool_mzps.v3.R file is used to specify the basic simulation settings, including the number of simulation runs, the number of years of the projection period and the input population parameters, population numbers and the proposed off-take.

The required R-code and some example input files can be requested from the corresponding author (henning.winker@gmail.com)

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Installation instructions

1) Install a recent version of R on your computer. CMSY was tested under R version 3.2.3, available from http://www.r-project.org/, but newer versions should also work.

2) I suggest using RStudio as an R development environment. RStudio is a free software that is available for several Operating Systems (Windows, OS, Linux, ...) and can be downloaded at http://www.rstudio.com/products/rstudio/download/

3) Two different comma-delimited (.csv) files are required by the CMZ off-take simulator, which should be placed in the same directory as the Tool_mzps.v3.R and Model.mzps_v3.R files. The first csv file (e.g. LH_BaseCase.csv) includes the population parameter estimates. The file names for the currently three available scenarios can be specified under 'Scenario' in Tool_mzps.v3.R (lines 33-36). If you want to use your own parameter input values, you can just create a new scenario name (e.g. Scenario = 'Test') and save an existing input file as 'LH_Test.csv' in the same folder as the mzps.v3 files. The second file (CMZ.PopInfo.csv) entails information on current population numbers and the proposed off-take numbers, where every added row is representing a separate case-study. The listed scenarios can be activated by deleting the # in front of the line and deactivated by putting #, respectively.

4) Open R script Tool_mzps.v3.R in RStudio. Use the tab "Session" and select "Set Working Directory" -> "To Source File Location", so that the code will find the data files. Note that there is no need to open the Model.mzps_v3.R, as long as it is in the same directory as the Tool_mzps.v3.R file.

5) There are few simulation settings that need to be specified in Tool_mzps.v3.R . Basic settings include specifying the number of simulation runs (e.g. nsims = 1000) and the number if simulation years (e.g. n.years = 15). To specify the case to analyze just enter a unique case number identifier (e.g. Case.No = 1 or Case.No = "FarmA") as specified in the first column of the PopInfo.csv file.

The user has the options to either provide the initial total population size as a single number or to specify the numbers of stallions, mares, bachelors and juveniles in the CMZ.PopInfo.csv file. If only total populations size is provided, line 42 in Tool_mzps.v3.R must be specified as Pop_init = "random" or Pop_init = "specified" otherwise.

The off-take in numbers can be specified by the following options in the CMZ.PopInfo.csv:

- OT_Random (Individuals of all ages and sex are selected randomly based on relative proportions in the population at each time step)
- OT_Adult (Same as Random, but excluding juveniles of ages 0-3)
- OT_Mares (Only breeding mares are randomly selected, Females age 5-25)
- OT_Stallions (Only stallions are randomly selected, Males age 8-20)
- OT_Bachelors (Only bachelors are randomly selected from Females of the ages 3-4 and Males of the ages 3-7)
- OT_Juveniles (Only juveniles are randomly selected ages 0-3)

In addition, an 'offtake.frequency' option is provided to specify the frequency of off-take events. Currently, these options include 'Once-off', 'Annually', 'Biennial', 'Triennial', 'Quadrennial' and 'Quinquennial' (i.e. every second, third, fourth and fifth year).

6) In RStudio, click on "Source" (or press Ctrl+A followed by Ctrl+R) to execute the code.

7) When the simulation is complete an output subfolder will be created that is named after the unique identifier (having a "C" as prefix). This output subfolder will include results .txt file, an output figure (.png) and a .csv results file (see example below). The result file names include the unique identifier, the Scenario (i.e. parameter input type), the off-take frequency and simulation period. For example, "C1.BaseCase.Annual.15y" will entail results for Case.No = 1, Scenario = "BaseCase", with annual off-take over a period of 15 years.

Output .txt example

```
==================================
    Simulation output
==================================
Case: C1

Scenario: BaseCase

Projection period: 15 years

Initial Population size: N0 = 30 animals

Off-take frequecy: Annual

Off-take numbers:
Random = 0; Adults = 0; Mares = 0; Stallions = 0; Bachelors = 3; Juveniles = 0

*******************************************************
Estimated generation time (GT):

11.8  years

Predicted total population size after 15 years:

N =  31.2

Probability of decline:

64.6%

Predicted change over 15 years:

-11.13%

****************************************************************************
    Predicted mean population numbers
****************************************************************************
  Year Total.N Mare.N Stallion.N Bachelor.N Junile.N Foal.N Offtake
1    1  34.713 11.576     7.177     8.662   5.009  4.713   0.000
2    2  37.978 12.080     7.481     5.396   6.622  5.024   2.978
3    3  38.166 12.229     7.485     3.224   8.331  5.004   2.843
4    4  38.441 12.091     7.279     3.104   8.544  4.989   2.893
5    5  38.600 11.973     6.975     3.645   8.506  4.965   2.893
6    6  38.760 12.032     6.634     4.290   8.536  4.936   2.886
7    7  38.973 12.195     6.246     4.750   8.556  4.961   2.893
8    8  38.805 12.338     5.662     5.125   8.524  4.913   2.894
9    9  38.391 12.545     5.111     5.456   8.434  4.783   2.888
10  10  37.987 12.745     4.623     5.552   8.303  4.761   2.895
11  11  37.500 12.957     4.127     5.582   8.181  4.680   2.871
12  12  36.573 13.096     3.581     5.547   8.105  4.320   2.836
13  13  35.208 13.123     2.996     5.546   7.773  3.929   2.797
14  14  33.222 13.085     2.360     5.536   7.088  3.371   2.730
15  15  31.223 13.027     1.981     5.293   6.299  2.886   2.638
```

Figure output (.png file) example