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POPULATION STATUS, THREATS AND CONSERVATION APPROACHES FOR A HIGHLY THREATENED ENDEMIC PLANT, *CENTAUREA TCHIHATCHEFFII* FISCH. & MEY

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POPULATION STATUS, THREATS AND CONSERVATION APPROACHES FOR A HIGHLY THREATENED ENDEMIC PLANT, *CENTAUREA TCHIHATCHEFFII* FISCH. & MEY.

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ABSTRACT

POPULATION STATUS, THREATS AND CONSERVATION APPROACHES FOR A HIGHLY THREATENED ENDEMIC PLANT, *CENTAUREA TCHIHATCHEFFII* FISCH. & MEY.

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Centaurea tchihatcheffii Fisch. & Mey. is a critically endangered annual endemic plant found only in Ankara. This study aimed to determine its distributional range, metapopulation status, the effects of agricultural activities, and assess conservation options.

Occurrences and population size estimates were carried out by ground surveys. Two adjacent subpopulations were intensively studied during 2004-2008. Plant and seed demographic data were collected in the field and by laboratory tests. Field experiments simulated the effects of agricultural practices. Risks of extinction and possible impacts of different management actions were investigated through a population viability analysis (PVA) by constructing a two-stage stochastic model. Six scenarios involving different management actions were run with 10,000 replications each using RAMAS Metapop.

A total of 14 patchily distributed subpopulations were found to have an extent of occurrence of >700 km^2. Herbicide applications caused extreme mortality and reduced germination success, and were shown to be the major anthropogenic threat against long-term survival of C. tchihatcheffii. Tillage led to an increase in density and reproductive success in the following year. PVA simulations for most scenarios predicted extinction of both subpopulations within 4 to 95 years, but a conservation management scenario involving delayed tillage ensured viable populations with a combined size of 21 million individuals.

PVA results demonstrated that timing and frequency of tillage is crucial. Therefore, we propose tillage to be carried out after seed set every other year for protected subpopulations to ensure their long term persistence. Alternatively, unprotected subpopulations elsewhere can benefit from organic or nature-friendly farming.

Keywords: Centaurea, critically endangered, population viability analysis-modeling, population biology, conservation strategy

ÖZ

CİDDİ TEHDİT ALTINDAKI BİR ENDEMİK BİTKİNİN, *CENTAUREA TCHIHATCHEFFII* (FISCH. & MEY.) POPULASYON DURUMU, TEHDİTLER VE KORUMA YAKLAŞIMLARI

Ergüner Baytok, Yasemin

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Tek yıllık endemik bir bitki türü olan Centaurea tchihatcheffii (Fisch. & Mey.), kritik yok olma tehdidi altında olup yalnızca Ankara'da bulunmaktadır. Bu çalışma ile, türün yayılış alanı, metapopulasyon durumu, tarımsal aktivitelerin türe etkilerinin araştırılması ve koruma olanaklarının değerlendirilmesi hedeflenmiştir.

Populasyon yayılış ve büyüklük tahminleri arazi taramalarıyla gerçekleştirilmiştir. Birbirine yakın iki altpopulasyon 2004-2008 yılları boyunca yoğun olarak çalışılmıştır. Bitki ve tohum demografisi verileri arazi ve laboratuvar çalışmalarıyla elde edilmiştir. Tarımsal aktivitelerin etkileri arazi deneyleriyle simule edilmiştir.
Yok olma riski ve farklı yönetim uygulamalarının olası sonuçları, populasyon yaşayabilme analizi (PYA) yoluyla, iki kademeli stokastik bir model oluşturularak

araştırılmıştır. Altı senaryolu farklı yönetim uygulamalarının herbiri 10,000 tekrarlı olarak RAMAS Metapop programında çalıştırılmıştır.

700 km^2 den geniş bir alanda varlık gösteren, parçalı bir şekilde yayılmış 14 altpopulasyon bulunmuştur. Herbisit kullanımının, yüksek ölüm oranlarına neden olup, çimlenme başarısını azaltarak C. tchihatcheff'nin uzun dönemde varlığını sürdürebilmesi için temel antropojenik tehdit olduğu gösterilmiştir. Sürülmenin uygulama sonrasındaki yılda populasyon yoğunluğunu ve üreme başarısını arttırdığı gözlenmiştir. PYA simulasyon senaryolarının çoğunluğu, her iki altpopulasyonun yokolma risklerini 4-95 yılları arasında olarak tahmin ederken, ertelenmiş sürülmeyi içeren koruma yönetimi senaryosu, toplam 21 milyon bireylik sağlıklı populasyonlar bir biçimde varlıklarını sürdürebileceklerini öngörmektedir.

PYA sonuçları sürülme uygulamasında zamanlama ve sıklığının önemini ortaya çıkarmıştır. Bu nedenle, koruma altına alınmış altpopulasyonların uzun dönemde varlıklarını devam ettirebilmeleri için her iki yılda bir tohum oluşturduktan sonra uygulanacak sürülmeyi koruma yönetim seçeneği olarak önermekteyiz. Buna ek olarak, koruma altında olmayan diğer yerlerdeki alt populasyonların organik ve doğa dostu tarım uygulamalarından fayda sağlamaları mümkündür.

Anahtar kelimeler: Centaurea, kritik tehlikede, populasyon yaşayabilme analizi-modelleme, populasyon biyolojisi, koruma stratejisi

to suns of my life, son and husband

The great book of nature can be read only by those who know the language in which it was written. And this language is mathematics. **Galileo Galilei**

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INTRODUCTION

1.1 Modeling as a Tool in Population Ecology and Conservation

Population ecology is a qualitative discipline to understand the underlying patterns in the distribution and abundance of living things through application of mathematics. It is concerned with understanding how populations change over time, and from one place to another, and how these populations interact with their environment.

Population sizes are under constant fluctuation and possible reasons for this are well known to ecologists as natural variation and population regulation. Sooner or later, all populations will run to extinction under natural circumstances. As stated by IUCN (2006 IUCN Red List of Threatened Species), the current species extinction rate is estimated to exceed the natural or 'background' rate by 100 to a 1,000 times due to human activities, mainly habitat destruction and fragmentation, overexploitation and global climate change.

The conservation biologist is faced with the task of evaluating the causes of endangerment of a species and ensuring its continued survival in nature. Models in population ecology are increasingly important tools in conservation biology. They are useful for assessing extinction risk, identifying which life stages are most important to population growth, guiding future data collection, and modeling effects of management plans on a population (Boyce, 1992; Menges, 2000; Doak et al., 2002). Indeed, demographic analyses are widely used in conservation biology to evaluate population performance and to suggest management actions for endangered and rare species. These analyses are often based on matrix population models in which individuals are classified into discrete stages according to their stage, size, or age (Caswell 2001). To perform a matrix population model, demographic data of individuals are required for estimating matrix elements, i.e. transition probabilities among stages.

A model is a mathematical description of the world. A model may be as simple as an equation with just one variable, or as complex as a computer algorithm with thousands of lines. One of the more difficult decisions in building models (and one of the most frequent mistakes) concerns the complexity of the model appropriate for a given situation, i.e., how much detail about the ecology of the species to add to the model (Akçakaya, et al. 1999). The purpose of writing a population model is to abstract our knowledge of the dynamics of a population. It serves to enhance our understanding of a problem, to explicitly state our assumptions, and to identify what data are missing and what data are most important. If the data required for building the model are plentiful, and if our understanding of the dynamics of a population is sound, we may use the model to make forecasts of a population's size or behavior.

The prediction of long-term consequences of management actions relies increasingly on population and community dynamics modelling (Kalisz 1992, Beissinger & Westphal 1998, Menges 2000, Buckley et al. 2003, Emlen et al. 2003). Population models often form the basis of population management decisions regarding threatened or endangered species in nature conservation (Beissinger & Westphal 1998, Lindenmayer et al. 1993, Menges 2000, Schwartz & Brigham 2003).

1.1.1 Population Viability Analysis

Demographic modeling and Population Viability Analyses (PVAs) are widely used to address both deterministic and stochastic threats to natural populations of species of concern. PVA is a systematic examination of interacting factors that put a population or species at risk of extinction (Gilpin and Soule 1986; Shaffer 1990; Beissinger and Westphal, 1998; Brook et al., 2000). The factors that PVA examines may be both natural and anthropogenic in origin, and their analysis often involves mathematical or computer models that predict the future changes in the abundance and distribution of the species in question, given information about its ecology and demography (Burgman et al. 1993).

Population viability analysis (PVA) is a process of identifying the threats faced by a species and evaluating the likelihood that the species will persist for a given time into the future (Shafer 1981, 1987, 1990; Gilpin and Soule 1986; Boyce 1992). It provides to estimate the probability of extinction, time to extinction, or future population size or structure at certain time (Akçakaya, et al. 1999; Menges, 2000).

Population viability analysis is often oriented towards the conservation and management of rare and threatened species, with the goal of applying the principles of population ecology to improve their chances of survival. Species conservation management has two broad objectives. The short term objective is to minimize the risk of extinction. The longer term objective is to promote conditions in which species retain their potential for evolutionary change without intensive management. Within this context, PVA may be used to address the following aspects of threatened species management (Akçakaya and Sjögren-Gulve, 2000):

Planning research and data collection. PVA may reveal that population viability is insensitive to particular parameters. Research may be guided by targeting factors that may have an important impact on extinction probabilities.

Assessing vulnerability. Together with cultural priorities, economic imperatives and taxonomic uniqueness, PVA may be used to set policy and priorities for allocating scarce conservation resources.

Impact assessment. PVA may be used to assess the impact of human activities (exploitation of natural resources, development, pollution) by comparing results of models with and without the population-level consequences of the human activity.

Ranking management options. PVA may be used to predict the likely response of species to reintroduction, captive breeding, prescribed burning, weed control, habitat rehabilitation, or different designs for nature reserves or corridor networks.

For more than 20 years PVA has been used as a risk analysis tool by conservationists and biologists to predict the relative probability of extinction for a wildlife population under various management scenarios, in order to aid in decision-making for population management (Shaffer 1991, Boyce 1993, McCarthy et al. 2001, Reed et al. 2002). Based on field-collected demographic data, the viability of a population is usually assessed by means of computer modeling tools, including a variety of packaged modeling programs (e.g. Vortex; RAMAS Metapop; Alex; PATCH), and/or custom modeling tools like MATLAB relying on modeler's code development.

In most cases, PVA uses available population information to develop a model- a simplified representation of a real system- that simulates how the population functions. The viability of a population at a particular time directly depends on the existing population size (N) and average vital rates (Caswell, 2001). The model can then be used to project various future scenarios and predict resulting outcomes for the population. The model may incorporate many factors that affect the status of a population, such as environmental stochasticity (e.g., climate, food supply), demographic stochasticity (e.g., reproductive success, survival), catastrophes (e.g., drought, disease), genetic stochasticity (e.g., inbreeding, genetic drift), and interaction among these factors (Gilpin & Soulé 1986, Shaffer 1991). These factors enter the life of an individual as events that occur with particular probabilities, rather than with absolute certainty, at any given time. Computer simulations are regularly used in PVA to allow for complex models that are explicitly stated and can be tested.

PVA is particularly effective in making "relative" predictions, such as how a population or species may be affected by various alternative management strategies, or the relative risk to different populations, allowing managers to prioritize conservation efforts among the populations (Beissinger and Westphal 1998, Boyce 2001, Ellner et al. 2002, McCarthy et al. 2003). Another strength of PVA is the complexity that it can accommodate; multiple factors and their interactions can be integrated into the process of evaluating a population's relative extinction risk (Shaffer 1991, McCarthy et al. 2003). In addition, "*sensitivity analysis*" can identify the parameters in the model that have the largest impacts on the modeled population. PVA results can be used to identify future research needs by exposing the parameters for which data are weakest or lacking (Reed et al. 2002), which is particularly important if sensitivity analysis shows those parameters are key to the population's persistence. "Absolute" predictions, such as a precise probability of population extinction, are not realistic, but relative predictions are more reliable (Beissinger and Westphal 1998, Ellner et al. 2002, McCarthy et al. 2003). Because a PVA uses a model, it will not present a complete picture of the system of interest, but an approximation of it, and results must be used with this in mind (Reed et al. 2002, McCarthy et al. 2003). PVA will likely be based in part on inadequate data (Beissinger and Westphal 1998, Boyce 2001), especially because data for populations at risk may be limited (Shaffer 1991, Boyce 1993) and the populations may be difficult to study. However, if the limitations are recognized, a PVA can offer an opportunity to direct future research towards obtaining more reliable data, more precise estimates of population parameters, to modify the model to improve its performance, and to frame testable hypotheses about how the population/system functions (Boyce 1993, Beissinger and Westphal 1998, Reed et al. 1998, McCarthy et al. 2003). McCarthy et al. (2003:987) concluded that, "The process of parameter estimation, model construction, prediction, and assessment should be viewed as a cycle rather than a one-way street."

The fundamental step in a population viability analysis (PVA) is to determine whether population size is decreasing or not, and which life stages contribute most to population growth rate (Schemske et al. 1994, Caswell 2001). Therefore, reliable estimates of population parameters, such as the long-term population growth rate (λ), and the sensitivity and elasticity of λ, are desirable. Sensitivity measures the effect of a change in any matrix element on λ, holding all other elements constant, whereas elasticity measures the impact of a proportional change in any matrix element on λ (Caswell 2001). Elasticities are often used to determine the most critical life stages for (λ) and to assess different management actions for a population (Benton and Grant 1999).

Sensitivity analysis can indicate the relative contribution of a suite of demographic and environmental parameters to the population's persistence. In PVAs, this involves determining their relative impact on the probability of extinction. This may be used in a retrospective context or a prospective context (Caswell, 2001; Cross and Beissinger, 2001). For example, predicting the effects of changes in future demographic parameters may be use to assess management strategies and guide management effort (Caswell, 2001; McCarthy et al, 1995; Possingham et al, 1993). Conversely, using empirical data from several field studies might also provide a retrospective and quantitative assessment of the effects of past changes (Caswell, 2001).

The demographic parameters for which the model is most sensitive will also be responsible for the most error propagation. These parameters are also likely to require more sampling and monitoring effort (Caswell, 2001). This is particularly useful when the parameters are derived from limited data (Goldingay and Possingham, 1995) as sensitivity analysis can direct the researcher to the parameters that with more precise measurement will improve the model's precision. Sensitivity analysis also draws our attention to the important system dynamics that lead to extinction, shifting the emphasis away from predicting absolute extinction times (Cross and Beissinger, 2001).

In Monte Carlo simulation models, sensitivity analysis involves explicitly varying model input parameters in order to ascertain their relative influence on the results (Jørgensen, 2001; McCarthy et al, 1995; Turchin, 1998; Cross, 2001). This is distinct from analytical models or matrix models where differential calculus and Eigen analysis are used to derive parameter elasticities or sensitivities (Caswell, 2001).

Conventional sensitivity analysis is exhaustive and usually involves running a number of simulations for a given parameter set and then varying only one parameter at a time by a set percentage and rerunning the simulations (Cross and Beissinger, 2001). Varying the parameter by a percentage of its range is considered to be a relative approach. However, exhaustive sensitivity analysis necessitates a very large number of fixed parameter combinations to assess each parameter independently and an unwieldy number of combinations to assess possible interactive effects between fixed levels of each parameter (McCarthy et al, 1995).

1.1.1.1 Population Viability Analysis for Plant Populations

PVAs have a long history of use for management of endangered animals, but have only recently also been applied to plant species (reviewed in Menges 2000, Schwartz & Brigham 2003). At first, PVA modeling approaches (Miller & Botkin

1974) comprised simple, equation-based deterministic matrix-based models, but subsequent development led to complex, spatial explicit individual-based population- and metapopulation models (Gonzalez-Andujar & Perry 1995, Valverde & Silvertown 1997, Brigham & Thomson 2003). Presently, stage- or size-classified matrix-models are the main used method in plant PVAs (Menges 2000).

Particularly for plants, the definition and application of PVA is relatively opaque. This may be the reason why recent reviews of PVAs have included few plant studies (Boyce 1992; Beissinger & Westphal 1998; Menges 2000) and animal PVAs are apparently more common.

The first published PVA for plants was for Furbish's lousewort (*Pedicularis furbishiae*), an endandered riparian herb of the northeastern U.S. published in 1990, this paper by Eric Menges marked the beginning of the application of PVA to plants (Brigham and Schwartz, 2003). In the following years several plant PVA studies (e.g. Doak et al.; Harrison; Thomas et al.) were conducted and discussed in the "Population Viability Analysis Conference: Assessing Models for Recovering Endangered Species" (1999).

Plant PVAs are principally different from animal PVAs as animal PVAs are often based on age-classified matrices, most plant PVAs are stage or size-classified -so called "Lefkovitch" matrix models. In stage or size-classified matrix models each plant individual is subject to a stage or size class with a certain transition probability of reaching the next class. For plant matrices this applies to life-history stages such as dormant seeds, seedlings and flowering plants. In other words, in the PVA model plant individuals have a certain probability to emerge from a seed bank, become adults and, eventually, reach the reproductive stage, i.e. produce seeds for the next generation. Particularly for plants, the process of deriving these probabilistic values from empirical data and generating quantitative predictions has revealed many challenges to both plant ecologists and modelers.

Despite a relatively large body of population viability studies and PVA program packages, there are no plant population specific PVA simulation tools. Generally, most of the currently available PVA computer programs have been developed for animal conservation purposes and reveal difficulties when applied to plants. This is particularly true for plant-specific life history traits. The reason for this lack of specific software may be due to the fact that, until now, plant PVAs (compared to animal PVAs) are relatively scarce.

1.1.1.2 Challenges of Plant Population Viability Analyses

To highlight the reasons why plant PVAs are limited, which typical features of plants brings challenges and which approaches for population viability analysis in plants, a selected literature reviewed based on 15 recent plant PVA studies which summarize the current knowledge and assess plant PVA as a tool in conservation biology. As pointed out by Menges (2000) the answer, of course, depends on the definition of a PVA. In his review Menges found 95 plant PVA studies when the term PVA was broadly defined. However, here, 15 recent case studies were selected for the last decade to emphasize particular challenges in plant PVAs (Table 1-1).

Review of these selected studies highlights that the particular aspects of plant life history in plant PVA are crucial for model precision. Particularly, seed and plant dormancy, periodic recruitment and clonal growth can present obstacles when obtaining empirical data and generating population projections. Only seed dormancy traits among them are selected to be explained with the following examples, to illustrate challenges of annual plant PVAs.

Table 1-1 Overview of selected plant PVA studies for the last decade

Reference	**Species**	**Management/ threat**	**Variable of risk analysis**
Nantel et al. (1996)	*Panax quincefolium, Alium tricoccum*	Harvest	Finite rate of increase (λ), minimum viable population size
Damman & Cain (1998)	*Asarum canadense*	Forestry	Extinction risk, mean time to extinction
Menges & Dolan (1998)	*Silene regia*	Fire	Finite rate of increase (λ), extinction probability
Enright et al. (1998)	*Banksiana hookeriana*	Fire	Finite rate of increase (λ)
Gross et al. (1998)	*Hudsonia Montana*	Burning, trampling	Finite rate of increase (λ)
Hof et al. (1999)	*Platanthera praeclara*	Drought, flood	Population density
Shimada & Ishihama(2000)	*Aster kantoensis*	Flood	Extinction frequency
Kaye et al. (2001)	*Lomatium bradshawii*	Fire	Stochastic growth rate (λs), extinction probability
Lennartson & Oostermeijer (2001)	*Gentianella campestris*	Grazing, mowing, environmental stochasticity	Extinction probability, Finite rate of increase (λ)
Dinnétz & Nilsson (2002)	*Saxifraga cotyledon*	Environmental/ demographic stochasticity	Finite rate of increase (λ), extinction risk
Lennartsson (2002)	*Gentianella campestris*	Fragmentation	Extinction risk, Mean time to extinction
Quintana-Ascencio et al. (2003)	*Hypericum cummulicola*	Fire	Mean time to extinction, extinction probability
Adams et al. (2005)	*Helenium virginicum*	importance of seed banks dynamics	Finite rate of increase (λ),Elasticity and perturbation analysis
Thomson (2005)	*Oenothera deltoids*	invasive grasses	Finite rate of increase (λ) Sensitivity Analysis
Satterthwaitea et al. (2007)	*Holocarpha macradenia*	alternative managements	deterministic and stochastic model comparison

Seed banks are characteristic for many, mostly annual, plant species. They are a reserve of viable seeds in the soil that hold seeds dormant until a later germination season. As seed banks buffer environmental variation and therefore reduce extinction risk they have to be considered explicitly in population viability analysis. However, data on seed dormancy are often fragmentary, even for plant species with longer time series of empirical data. For example, Kalisz & McPeek (1991; 1992) created experimental seed banks to obtain two years of data on the annual *Collinsia verna*. Subsequently, they then used simulations to examine what proportion of the demographically-favorable year would be required for long-term population viability. Quintana-Ascencio et al. (2003) studied *Hypericum cummulicola*, a fire-dependent plant with a persistent seed bank endemic, and stated that 50% reduction of *H. cummulicola* seed survival significantly increased projected extinction risk. In most cases, however, data on seed dormancy are lacking, and simulation scenarios have to be based on theoretical assumptions. For example, Gross et al. (1998) assumed that seeds of *Hudsonia montana*, a threatened shrub, may be viable for up to 10 years. They computed an annual seed survival rate (0.512) that produced a small probability (0.001) of a seed surviving 10 years in the soil. Although this is a reasonable approach, the authors failed to include the variability in seed survival. The latter critique seems to apply to many other studies of plant population viability analysis where seed dormancy is an important life history trait.

For annual plants, which do not have the ability to regenerate vegetatively, the existence of an extensive seed bank makes it possible to persist over periods long enough to bridge unfavorable phases in succession. This ability to buffer environmentally unfavorable phases with the aid of seed banks has been demonstrated for e.g. desert annuals (Pake & Venable 1996).

A fundamental difference between quantitative population models for vertebrates and those for plants is the need to consider seed demographic rates. Because the seed bank is largely invisible and difficult to measure, plant population models that include explicit consideration of seed bank dynamics are relatively rare (Menges, 2000). This is particularly true for species with persistent seed banks, for which the field experiments needed to obtain age-specific vital rates for seed viability loss and seed germination must necessarily be long term (Doak et al., 2002).

Seed banks have only recently begun to be incorporated in demographic models of plant populations. This is probably because seed bank data (e.g. seed survival and germination rates) are often more difficult to collect than data for adult plants (Vanessa et al. 2005). However, this may limit the effectiveness of demographic models. For example, models can provide inaccurate assessments if they fail to include important life stages such as seed banks (Doak et al., 2002). In addition, most studies that include quantitative analysis of seed demographic rates are for weedy species. Very few such studies have been carried out for nonweedy species, and almost none have been carried out for plants of conservation concern. Doak et al. (2002) showed that, in the absence of good information on seed demographic rates, model predictions based on assumptions about a persistent seed bank can vary widely depending on the amount of variation in vital rates for the reproductive phases of the plant life cycle. This points to the need for realistic assessment of environmental variation and its impact at all life history stages.

As shown above, plant life history characteristics create some difficult challenges which should be conformed in order to improve the precision of plant PVA models. Moreover, particular methodological issues and modeling approaches are of major importance for the outcome of plant PVAs. For example, the type of density dependence that is modeled is crucial since this will affect population projections and potential management decisions: if a local population is able to overshoot the long-term average of the habitat carrying capacity this will have positive effects for population persistence. The same principle accounts for the consideration of buffer mechanisms that limit the environmental variation of demographic parameters. For example, availability of safe Sites in the habitat (McLaughlin et al. 2002; Greene 2003), dormant seeds, i.e. seeds will germinate when environmental conditions enable successful emergence. Buffer effects are also the reason why the way density dependence is modeled is so important (Chapman et al. 2000; Henle et al. 2003).

Furthermore, many authors have stressed the need for plant population models to be able to reflect the biology of the species in question and to provide an insight into the environmental perturbations that cause much of variability observed in nature (Cousens 1995, Buckley et al. 2003). Like simulation models, based on empirical demographic parameters, should be used to determine the effects of natural disturbances on plant population dynamics, man-made disturbances, and their frequencies.

To conclude, population dynamics of plants represents challenges in plant population viability analysis. Aspects of plant life history such as seed bank dynamics are strongly linked to disturbance and buffer mechanisms. In addition, the implementation of plant genetics and consideration of density dependence particular is crucial. Both may also alter the outcome and modify management suggestions.

1.1.2 Decision–Making for Conservation Strategies and Criticism on PVA

As the human-caused activities accelerate the extinction rates, conservation biology arises as a crisis discipline. To communicate about the risks faced by different species, universally accepted terminology for conservation status has been developed by agencies for conservation and environmental impact assessment principally the International Union for the Conservation of Nature (IUCN).

Determination of threatened species and the classification of the threat levels form the basis of nature conservation. Since 1994, IUCN has been developed criteria for the conservation status of a species. According to IUCN risk-based criteria, there are four threat categories (IUCN 2001, Ver. 3.1) defined in terms of probability of extinction:

CRITICALLY ENDANGERED (CR)**:** the probability of extinction in the wild is at least 50% within 10 years or three generations, whichever is the longer (up to a maximum of 100 years).

ENDANGERED (EN): the probability of extinction in the wild is at least 20% within 20 years or five generations, whichever is the longer (up to a maximum of 100 years).

VULNERABLE (VU): the probability of extinction in the wild is at least 10% within 100 years.

Therefore, when quantitative information about species is available, PVA may act as a reliable tool based on those risk-based criteria.

Determination of the factors that narrows the plant distribution area or decrease the population size and their scaling are quite important for the conservation and restoration of the threatened plants (Pavlik et al.,1993; 1995). These can be the intrinsic factors like habitat preferences, limited dispersal and insufficient seed production (Primack and Miao, 1992; Pantone et al.,1995; Wolf et. al, 1999), or can be the extrinsic factors such as weed management and habitat destruction (Cully, 1996;Guerrant, 1996; Johnson, 1996). Extrinsic factors, especially the anthropogenic ones, play more important roles for the limitations of rare plant distributions (Pavlik and Barbour, 1988; Pavlik et al., 1993;1995), and mostly these species have the conservation priorities. Habitat destruction and fragmentation are possibly the biggest causes of extinction. As habitat is eroded, species reliant upon that habitat reduce in number. Fragmentation isolates proportionally small populations, reducing genetic variability over time. Such populations are vulnerable to extinction.

Conservation strategies can be applied in two ways: *in-situ* conservation and *ex-situ* conservation. *In-situ* conservation involves the maintaining of populations in natural habitat where they occur such as, national parks, gene management zones. *Ex-situ* conservation maintains the populations outside their natural habitat in artificial conditions under human supervision like botanical gardens, game farms, and gene banks (Primack, 1999). If the conditions are available, *in-situ* conservation will always be the best choice as providing the evolutionary adaptations. But, it generally requires large areas and natural threats still exist. *Ex-situ* conservation has the advantage of providing new habitats free of natural treats but it involve risks for the many considerations like sampling type and size, low genetic diversity, genetic drift, preservation conditions, germination requirements. As *ex-situ* conservation actions, translocation and reintroduction programs are common for threatened plants (Sainz-Ollero and Hernandez-Bermejo, 1979; Gordon, 1996; Jusaitis, M. et al., 2003). According to Pavlik (1996), a successful translocation program should be reached characteristics like quantity, distribution, elasticity and stability. The first two of them can be achieved in 10 years while the others two require more time. Thus, it requires long term monitoring of the population.

Success of plant conservation program relies on the knowledge of population biology like most critical life stages, plant demographic parameters such as death rates in these stages and possible reasons, natural area of distribution, changes in population sizes and area and factors affecting these- major threats on population, seed demography, dispersal. And the quantitative results of population biology constitute the base of population viability analysis which provides to evaluate future trends in population.

PVAs are most useful when they address a specific question involving a focal (e.g., threatened, indicator, sensitive, or umbrella) species, when their level of detail is consistent with the available data, and when they focus on relative (i.e., comparative) rather than absolute results, and risks of decline rather than extinction (Akçakaya and and Sjögren-Gulve, 2000).

PVA has been criticized because it demands a lot of demographic data and field effort (Schemske et al. 1994, Beissinger and Westphal 1998), which may limit its use for some species (Boyce 1992, Reed et al. 2002). Especially, for rare and endangered species few populations are available and populations tend to be small (Ouborg 1993). Sample sizes are thus often inadequate to perform a PVA successfully (Beissinger and Westphal 1998). Due to high variation in vital rates (birth, growth, and death), too little data may lead to erroneous estimates of transition probabilities (Morris and Doak 2002).

Due to the extensive use of PVA in managing species and the potential for misuse of models and their output (Beissinger & Westphal 1998), there is an ongoing debate about the usefulness of PVA. Beissinger & Westphal (1998) concluded that poor data cause difficulties in parameter estimation, which in turn lead to unreliable estimates of extinction risk. However, as pointed out by Brook et al. (2002), even if data are sparse or of low quality (commonly the case for threatened species), no alternative methods may be superior to PVA other than some vaguely defined hypothesis. This is of particular importance in conservation biology where decisions have to be made quickly, even in the face of incomplete data.

Even if empirical data are scarce, population viability analysis presents a useful tool in species management, as it allows us to identify, through e.g. sensitivity analysis, which ecological processes matter and which further data should be collected. It is suggested that, particularly for plants, care should be taken in terms of the absolute values derived from PVA (e.g. mean time to extinction). It is the relative assessment of different management or environmental scenarios which is important in plant species risk assessment.

While not enough for a full demographic analysis, even two or three years of demographic data collection can greatly inform later, less intensive monitoring effort. Such demographic data collection will help one to pick the most informative variables for later monitoring. For instance, a small set of demographic data may show that it is easier, faster and more informative to monitor, say, the relative numbers of adults to subadults than it is to estimate the absolute numbers of either, making for more efficient long-term monitoring. Finally, intensive initial data collection provides what is essentially mechanistic information with which to understand future population patterns. For example, if later monitoring shows very high correlations in fluctuations between some populations, demographic knowledge can often lend insight into what life stages are being affected to create these correlations (Morris et al, 1999)

1.2 Study Species

1.2.1 Taxonomy

Turkey is one of the richest countries in terms of plant biodiversity. Of more than 11300 taxa of flowering plants it has, almost 3700 are endemic plants. *Compositae*

(Asteraceae) is the largest flowering plant family of the world including 20.000-25.000 species (Bhattacharryya, 1998). Of this family, *Centaurea* is also the one of the largest genus. Turkey is one of the main centers of diversity for the genus *Centaurea* (Wagenitz, 1986). It is also the third largest genus, in terms of species numbers in Turkey, where 187 taxa in 34 sections occur mainly in the Mediterranean and Irano-Turanian regions (Wagenitz, 1975; Davis, Milli & Tan, 1988; Guner, 2000; Duran & Duman, 2002) there are 112 endemic taxa of *Centaurea* and the endemism value is about 60% in Turkey (Turkoglu et al., 2003). According to the Red Data Book of Turkish Plants, there are 181 critically endangered (CR) plants and *Centaurea tchihatcheffii* Fisch. & Mey. is one of the 12 critically endangered (CR) *Centaurea* species of Turkey (Ekim,2000). *Centaurea tchihatcheffii* Fisch. & Mey. also belongs to strictly protected plant species according to Bern Convention (1998).

This remarkable flower was described in the *Flora of Turkey and The East Aegean Islands*, "as annual, up to 20 cm, branched from near base. Involucre, broadly campanulate. Appendage a narrow brown border with white cilia. Marginal flowers with purple, radiant, funnel-shaped with crenate margine; central rose-purple, anther tube straight" (Davis, 1975). Its shiny pinkish red flowers are unique in the genus so it is called "yanardöner" by the general public. It has potential economical value as an ornamental plant. Flowering time is late April and May. Its natural distribution is limited to Ankara steppes. Until 2006, it was thought that the species was first collected by Tchihatcheff from Afyon in 1848 and described by Fish.& Mey. in 1854, even there was no other records from that province later; also, in 1956, the Turkish botanist Karamanoğlu collected a specimen from Gölbaşı, Ankara. Apparently, the type locality as published is erroneous and the correct provenance is provided by Tan and Vural (2006). They clarified that it had never been found in the province of Afyon where the type locality was stated to be. The old geographical name ''Lycaoniae'' as mentioned by Tchihatcheff, comprises the provinces of Konya, Nigde and part of Ankara. It does not include Afyon so it is strange that the type locality should be ascribed to this province. No one has ever found the plant nor the locality "Mehmet-koi" in Afyon. The correct type locality should be Type: Turkey B4 Ankara: ''Galatia, inter pagos OElbek et Yaurdjik, alt. c. 1000 m, reg. plana'', Tschihatcheff (holo. LE; iso. G-BOIS [fragm.], P).

1.2.2 Life History Characteristics

The life cycle of *C. tchihatcheffii* begins with germination of seeds through fall (September-October), slows down at winter, speeds up in spring with the raising temperature (March) and flowers (April), seed disperses (May-June) finally completes the life cycle by senescence in the mid summer (July). *C. tchihatcheffii* can be considered as a winter annual growing in disturbed lands, showing poor dispersal ability but high seed production.

With natural distribution mainly on arable lands, *C. tchihatcheffii* demonstrates traits of annual weeds, specifically the seed bank persistence as a buffer against local extinction in unfavorable years (Fenner and Thompson 2005).

Weed characteristics such as the ability to germinate and grow rapidly and produce numerous seeds maintain recruitment of populations and are the principal source of its invasive ability in cereal crops.

Although considered as a "Weed" over many decades, this endemic species is also under extremely high risk of extinction as "Critically Endangered". This paradox of *C. tchihatcheffii* brings up a difficult challenge for those who want to propose applicable conservation strategies.

1.2.3 Study Area and Past Geographical Distribution

As stated by several studies, in the past, the species has a large distribution around the farmlands of Gölbaşı. However, due to herbicide applications and collection for ornamental purposes, it is under the risk of extinction (Ekim, 1994; Ekim ve ark 2000; Vural, Adıgüzel, 2001). *C. tchihatcheffii* is regarded to have a narrow distribution with in a few km^2 especially around farmlands represented by only few populations at Gölbaşı, Ankara. (e g. Çakaroğulları, 2005; Tan and Vural, 2006).

Centaurea tchihatcheffii exists in a number of populations that are isolated from each other and such a collection of populations of the same species is called a "*metapopulation*". Each distinct population in a metapopulation can be referred as a subpopulation or a local population (Akcakaya et al. 1999).

1.2.4 Past and the Current Threats

The species is represented as a metapopulation since habitat fragmentation has led to widely separated groups. It seems that major threats on *C. tchihatcheffii* are anthropogenic factors like intensive agriculture and land development. Both are the examples of man-made disturbances.

Plants response in different ways to different forms of disturbance. This explains that some plant populations will profit and expand, while others will suffer and decrease (Box 3, White & Jentsch 2001). Species are successful either due to disturbance resistance adaptation or, in case of extinction, due to the ability to recolonize the disturbed Sites before disturbance happens again (Eriksson 1996). However, after extinction on the patch level recolonization by long-distance dispersal is less likely with increasing distance from a source population (Menges 1990, Fahrig & Merriam 1994). For species without the ability to disperse over long distances it is therefore essential to persist on the local level. Species which have no apparent mechanism for storing reproductive potential between generations, as an extreme example annual plants without a persistent seed bank, would not be able to persist over periods long enough to bridge unfavorable phases of recruitment (Higgins et al. 2000).

Plant species with a short life cycle and transient or a short-term persistent seed bank are expected to be more vulnerable to less frequent cyclic disturbances, especially when compared to species with storage ability, e.g. perennials, clonal plants or species with a long-term persistent seed bank (Harper 1977, Warner & Chesson 1985, Stöcklin & Fischer 1999, Higgins et al. 2000). This is in accordance with the C-S-R strategy theory of Grime (1977) and other theories regarding about disturbance level and plant persistence, in that only high disturbance levels select for short-lived species with a high population growth rate e.g. McArthur (1962) and McArthur & Wilson (1967) extended by Venable & Lawlor(1980), Levin et al. (1984) and Klinkhamer et al. (1987). Schippers et al. (2001) found a clear segregation of perennial and annual species due to disturbance. At low disturbance levels annuals were replaced by competitive, long-lived plant species.

However, it has to be taken into account that small-scale natural disturbances (e.g. summer drought), allow the coexistence of species with contrasting life histories within closed grassland communities that are more or less free from a major human impact (Grubb 1986). Summer drought reduces biomass of perennial matrix species, and annuals may germinate within these gaps. However, only below-ground disturbances stimulate the germination of seeds from the soil seed bank and thus ensure the survival of annual species in such cases when the above-ground populations are extinct.

Fritzsch (2004) show that rototilling has a massive impact on both above-ground and below-ground components. This sort of management is similar to plowing-tillage- (after senescence) and the subsequent effects can impact at depths of up to 20 cm, depending on soil conditions. In general, rototilling is applied via a track-laying tractor that is especially constructed to cultivate steep slopes such as vineyards. Such management can have direct and indirect effects on plant population. Direct effects of rototilling are the destruction of vegetation cover, disturbance of plant modules, and even death of individuals and changes in population structure. Rototilling thus may cause changes in population structure of plant species. Indirect effects can be observed through subsequent succession due to increasing biomass and through competition until the treatment is repeated.

Furthermore, many studies have shown that intervention down to the root horizon and destruction and breakdown of biomass activate germination from the soil seed bank (Leck et al. 1989, Bakker et al. 1991, Bazzaz 1996, Kalamees & Zobel 2002,Jentsch 2004) and provide new germination sites by creating gaps (Aguilera & Lauenroth 1995, Krenova & Leps 1996, Jutila & Grace 2002). These facts have led to the hypothesis that mechanical cultivation by rototilling could be an alternative management (Kleyer 1998).

Re-establishment and recolonization of disturbed sites depends on seed availability for annuals. Seeds either originate from the soil seed bank or arrive via immigration through dispersal. A persistent seed bank -dispersal in time- is especially important in highly fragmented landscapes and in cases where long-distance dispersal ability is poor (Bonn & Poschlod 1998).

Thus, the seed bank is an important feature for vegetation dynamics, especially after soil disturbance. For example, it is still lack of knowledge on seed bank longevity of species, which is important for estimation of the role of the soil seed bank in regeneration after disturbance events.

In this study effects of herbicide application, tillage practices and stubble burn will be investigated as the threats of agricultural practices. Previous knowledge on Yıldırım (2001) and Vural (pers. comm.) states that the known habitats of the species are under intensive agricultural activities, mainly wheat cultivation with herbicide (2,4-D Ester) application. Also, one subpopulation experienced prescribed burning and clearing of vegetation prior to tree plantation for afforestation purposes (Vural and Adgüzel, 2001; Ekim, 1994; Ekim *et al.*, 2000). In addition to these, collection of flowers for ornamental purposes is known to be common practice (Ekim, 1994) even if it is forbidden.

The herbicide 2,4-D (2,4-dichlorophenoxyacetic acid) is the most widely used herbicide in the world and its working mechanism is well-known. 2,4-D is a selective herbicide, a member of the phenoxy family with highest toxicity to broadleaf plants. 2,4-D mimics plant hormones called auxins which control "a multitude of plant growth and development processes." Concentrations of auxins normally fluctuate in order to properly direct growth. In cells exposed to 2,4-D, however, levels of this auxin mimic remain high because 2,4-D is more stable and persistent than auxins. As a result, 2,4-D stimulates the synthesis of nucleic acids and proteins and causes abnormal growth. Death occurs when the plant's transport system (xylem and phloem) is crushed and plugged by this growth. Other physiological processes are also disrupted by 2,4-D, including the activity of certain enzymes, energy production, and cell division.

As a potent herbicide, 2,4-D's impacts on endangered plant species should not be surprising. US Environmental Protection Agency (EPA) believes that "certain uses of 2,4-D may jeopardize the continued existence of endangered species....”According to the agency, 2,4-D use jeopardizes 13 endangered species of plants. One such experiment has been conducted with 2,4-D at a natural community of winter annuals in Oregon and found that treatment with the isooctyl ester of 2,4-D reduced the total weight of plants in the community (Pfleeger&Zobel, 1995). The study with the Yellow Starthistle (*Centaurea solstitialis*) showed that bud stage was the phenological limit for effective reduction of viable seed by picloram, which caused both bud abortion and lower seed germination (Vanelle et al., 2004).

Stubble burns are not the current threat for the species since it is not allowed and applied in the farmlands as weed controlling and clearing mechanism, by the government. But, it was a common practice in the past and there is no doubt that this species as many of others has experienced the effects of stubble burns for many years. Therefore, it needs to be investigated to understand the current population status which was also being shaped partly due to by this practice. Because failure of regeneration is a major factor limiting the ecological and geographical range of short-lived species (Grime et al., 1988), traits related to seed germination and seedling establishment under major disturbance events deserve particular attention. Pieterse & Cairns stated that (1986) the position of seeds within the soil profile is critical for seed survival following the passage of fire, and only seeds at a depth greater than a few cm may survive for the Mediterranean *Centaurea* taxa (Riba et al., 2003). On the other hand, fire might be an effective tool for maintaining viable populations as in the case of the rare endangered plant, *Lomatium bradshawii* which were frequently burned many years, and the study showed that fire has a positive effect on population viability for this species (Thomas et. al, 1999).

Unfortunately, in the study area land development activities like road and building constructions are still accelerating the habitat fragmentation and making subpopulations smaller and far from each other. Understanding the consequences of habitat fragmentation for plant and animal populations is a central area of research in ecology (Harrison and Bruna 1999, Debinski and Holt 2000). While changes in population size have been widely documented for animal taxa found in fragmented landscapes, most ecological studies investigating how fragmentation influences plants have focused on describing communitywide rather than population-level trends (Scariot 1999, Tabarelli et al. 1999). These studies have found that certain plant species are less likely to be found in fragments (Dzwonko and Loster 1988, Norton et al. 1995, Scariot 1999), often as a result of local extinctions (Turner et al. 1995). However, the precise mechanisms responsible for these extinctions are usually unknown, as are the consequences of habitat fragmentation long term plant population dynamics (Bierregaard et al. 1997) (Bruna, 2003).

1.2.5 Previous Studies on the Species

In vitro propagation of *C. tchihatcheffii* was studied and successful results were achieved (Özel, 2002). Gömürgen and Adıgüzel (2001) conducted a study on chromosome numbers and karyotype analysis of the species. In addition to these, pollen morphology of the species was also studied by Pehlivan (1995) as part of a study on certain endemic *Centaurea* species of Turkey. Another study on anatomy and palynology of species was presented by Kaya and Genç (2002).

Recently a book titled '*Centaurea tchihatcheffii*', aiming to raise the public awareness, also containing results of some scientific research, has been edited by Boşgelmez (2005).

Latest research on germination ecology and seed bank studies were investigated by A. Yıldırım as a part of completed TUBITAK project (no 103T171), which provided a framework for this dissertation. A more recent study on population biology of species was carried out by Çakaroğulları (2005).

1.3 Aim of the Study

In this study, the population growth and long-term viability of a threatened annual plant were aimed to be studied with the help of RAMAS/Metapop software (Applied Biomathematics, New York). A stage-structured, stochastic and density dependent model was based on demographic parameters like survival rates, fecundities and density dependence. Through evaluating the outcomes of different possible scenarios that may include effects of fire, tillage and other human-based activities, options for successful conservation action were explored. In order to investigate impact of known threats such as herbicide application, tillage and stubble burn, experiments were carried out both in the field and in the laboratory.

The specific objectives of this study were:

- To determine species distribution range and estimated population sizes of all subpopulations of the species
- To investigate the effects of threats due to established agricultural activities (herbicide application, tillage and stubble burn)
- To construct a population model based on the knowledge of the species' population biology and germination ecology,
- To propose conservation strategies as suggested by Population Viability Analysis (PVA) results based on RAMAS.

CHAPTER 2

MATERIALS AND METHODS

2.1 Study Sites

There were two known populations at the beginning of the study, namely, the population in Süleyman Demirel Forest will be referred as "Site 1" and the other population located to the south west of Site 1 will be referred as "Site 2" from now on.

Site 1 is located parallel to the South West side of Mogan Lake (Lat 39.760°, Lon 32.790, altitude: 972 m) which has been recently transformed into a recreational area with plantation of trees. Site 2 is owned by State Opera and Ballet Directorate and is located about 970 m south west of the Site 1. (Figure 2-1 **Location Map of Study Sites**)

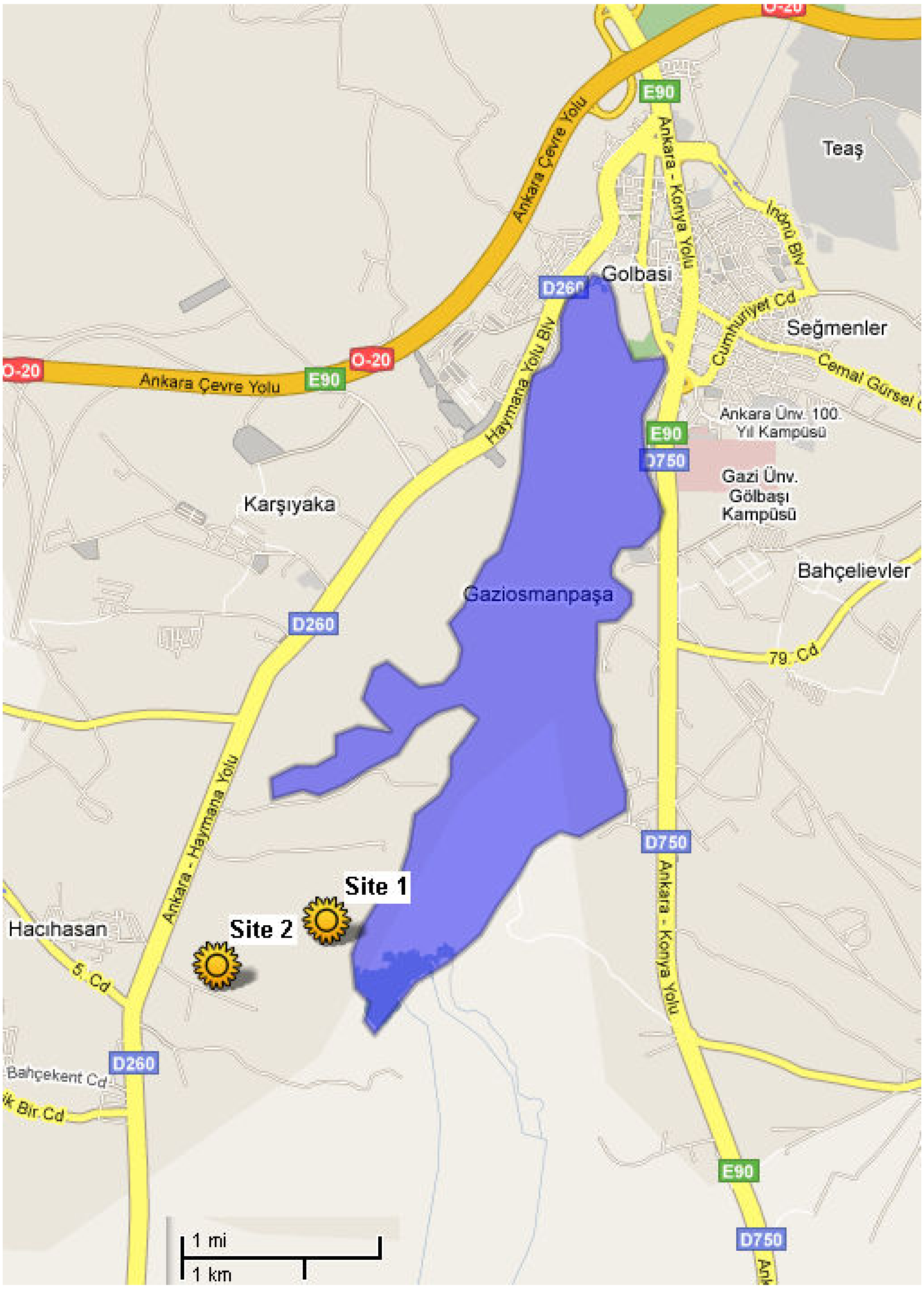


Figure 2-1 Location Map of Study Sites

2.1.1 Edaphic Factors of the Area

The soil properties and nutrient content of soils of the study area was analyzed by Özcan *et al.* (2005). The soil of Mogan Lake was grouped as "semi-arid" which is a typical soil property for the region. Özcan *et al.* (2005) found that the soil of the study area has high clay content (43-70 %), high lime content and low organic matter. Sodium is the dominant cation lowering water permeability and causing high water table. The water saturation and farmland capacity are also high. Soil pH changes between 8.03-8.88. It seems there are no soil characteristics that would limit the species growth or distribution.

2.1.2 Meteorological Data

The climate of the area is the typical Central Anatolian with hot and dry summer months and cold winter months (Figure 2-2 and Figure 2-3). Meteorological data of the study area recorded on İkizce Station of Turkish State of Meteorological Service is obtained by Boşgelmez (2005). Ikizce station (Ikizca Haymana at 925 mt. elevation), its location falls to the 10 km west of the Karagedikli site. The annual average temperature over 20 years is 10 C and average precipitation is 408, 5 kg/m^2 and detailed annual meteorological factors can be seen in Boşgelmez (2005).

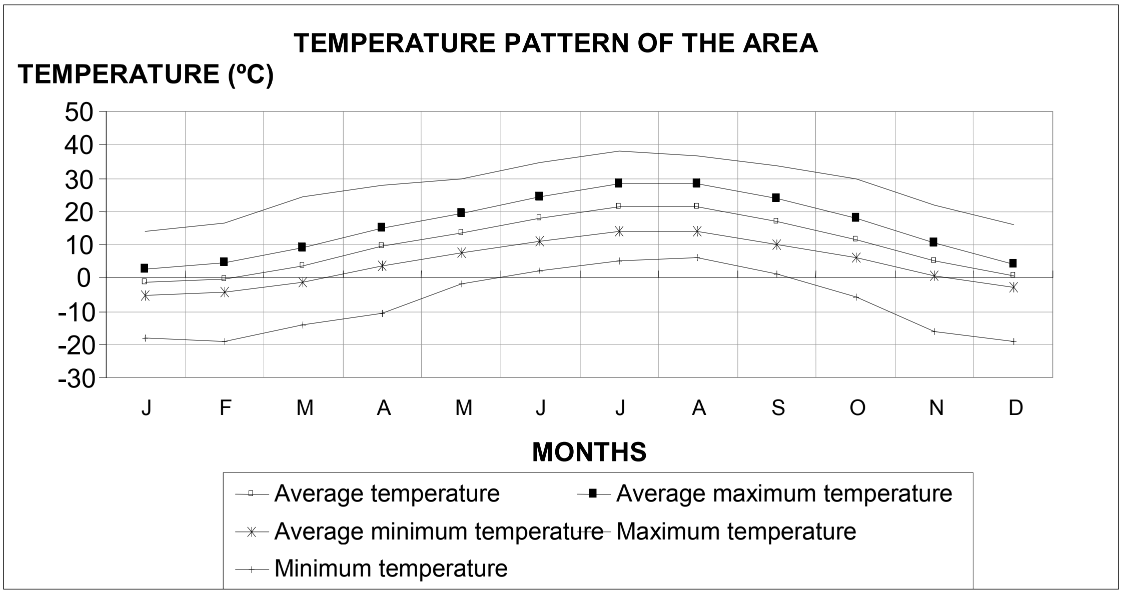


Figure 2-2 Temperature pattern of the area given as monthly means (Boşgelmez, 2005)

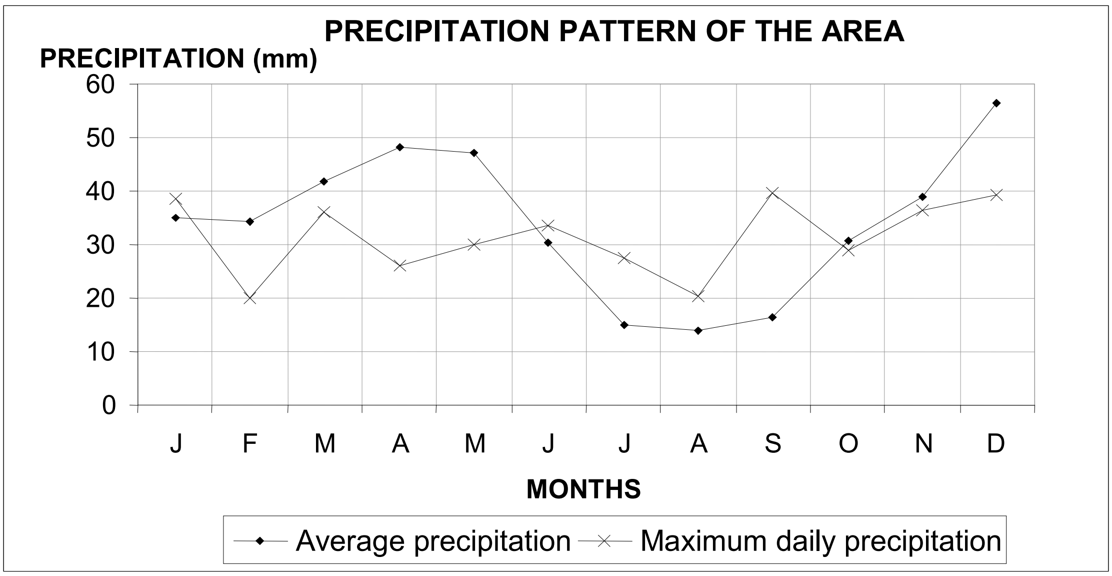


Figure 2-3 Precipitation pattern of the area given as monthly means (Boşgelmez, 2005)

2.2 Population Status

To project future trends in the population, its current status along with the past population status should be studied. Understanding of population status entails studies of population structure; how population sizes, geographical extent and habitat quality differs and is shaped throughout the years and by which mechanisms; studies of threats and natural catastrophes.

2.2.1 Population Structure

C. tchihatcheffii's metapopulation, its distribution area, abundances and extent of each subpopulation are estimated by following methods.

2.2.1.1 Distribution Area

The sketch of the search area that has been studied during 2003-2007 and layout of the observed subpopulations of *C. tchihatcheffii* is given in Figure 2-4.

2.2.1.2 Geographical Distribution Survey

Projection of future trends in the population rely on understanding of its current status along with the past population status. Geographic Information System (GIS) provides predictions about past and present habitat distribution of the research species.

Geographic Information Systems are an information technology with the capacity to store, analyze, and display both spatial and nonspatial data (Parker 1988). Storing, managing, and integrating spatially referenced data; conducting spatial queries (e.g., searching for areas in which a particular species occurs); displaying data in the form of high-quality maps are some major utilities of GIS (Scholten and de Lepper 1991).

GIS becomes an invaluable tool in ecology, conservation planning, and large-scale biodiversity assessment. GIS offers great applications in ecological studies like storage, management, and spatial analysis of species inventories, plant community dynamics, long-term habitat monitoring, GAP analysis, spatial modeling of vegetation patterns, GIS-based population viability analysis and reintroduction of the endangered species and rare plant conservation (Wu and Smeins 2000; Akçakaya et al; Shuster et al. 2005; Powell et al. 2007).

In this study, by using GIS spatial data is organized to identify the population structure; in other words, to calculate the number, location, size and shape of habitat patches. Therefore, the species distribution area was predicted with ground surveys by using GPS every year during flowering times (May- June) between 2003 and 2007. Moreover, changes in the population sizes were censused by random quadrat sampling.

At the beginning of the research there were two known populations which were about 500 m away from each other and about 200 m of Lake Mogan.

In the first year of the study (2003) field work was conducted to determine whether those two known populations are somehow connected or separated. Therefore, the area in between these two populations was traced with about 50 m distant transections. Each year the survey area was extended along with the newly discovered subpopulations, and the ones that had been found in previous years were revisited.

To achieve more practical and efficient plant survey method for detection of subpopulations, some combination of random and roadside surveys similar to Shuster et al. (2005) was conducted. The methodology of this survey can be summarized as follows:

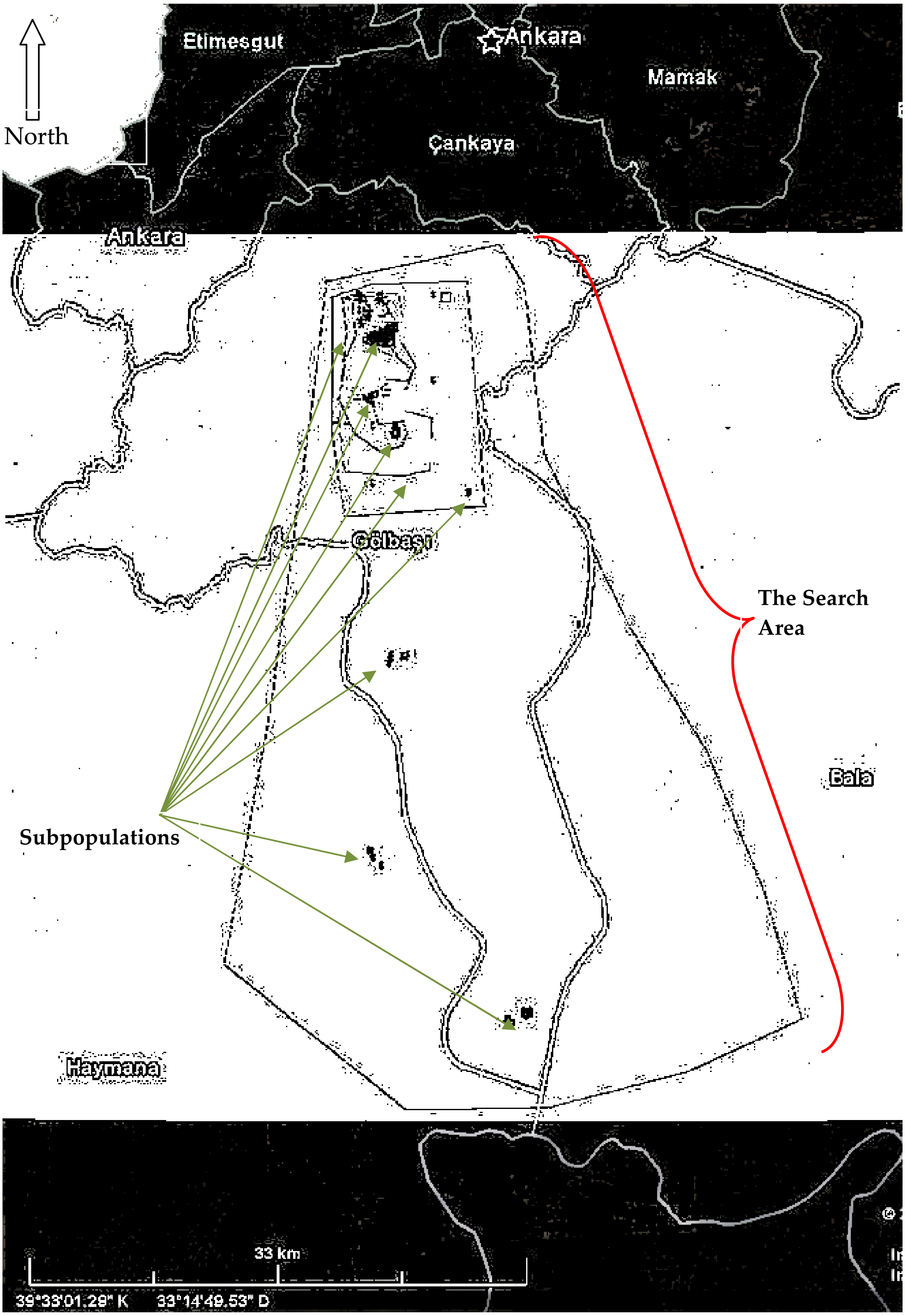


Figure 2-4 The search area and layout of *C. tchihatcheffii* subpopulations

The survey area was considerably sectioned with dirt roads passing by the sides of agriculture fields. And following each dirt road around 500 -1000 m. distances a larger truck road next to the dirt roads exists. These roads are used to reach small agriculture fields by trucks. A sample view of the field can be seen at Figure 2-5. The survey has been conducted by the road sides of the dirt and larger roads next to fields allowing eye side view of the ground. Whenever the fields were either too steep or too rocky for species to grow, the survey has been extended to next adjacent area. Due to the off road characteristics of the roads, a cross motorcycle has been widely used.

Since the above mentioned dirt roads do not depicted in available road maps, it was hard to perform a systematic survey on the ground. Although the entry to the field and passing to the next adjacent dirt road was a fairly good method, a GIS supported easy mapping which helped us in deciding when to leave the field and from where to enter to next adjacent field, has been applied after the first year's surveys.

Since the area was close to Ankara, detailed satellite images allowing us to distinguish the fields, dirt roads, fertile and steep rocky places were available on Google Earth (see Figure 2-5).

Once the area has been spotted on Google Earth, an entry point from the main road to the field has been defined on Google Earth software. And several waypoints through the dirt road allowing us to keep the dirt road track have been defined (see Figure 2.5). This helped us, to pass by the most likely areas (away from rocky, steep and close by the water) and not to choose a wrong direction. It also tracked us back to the main road and allowed to pass to the next adjacent field.

Figure 2-5 The sample view of the field search area

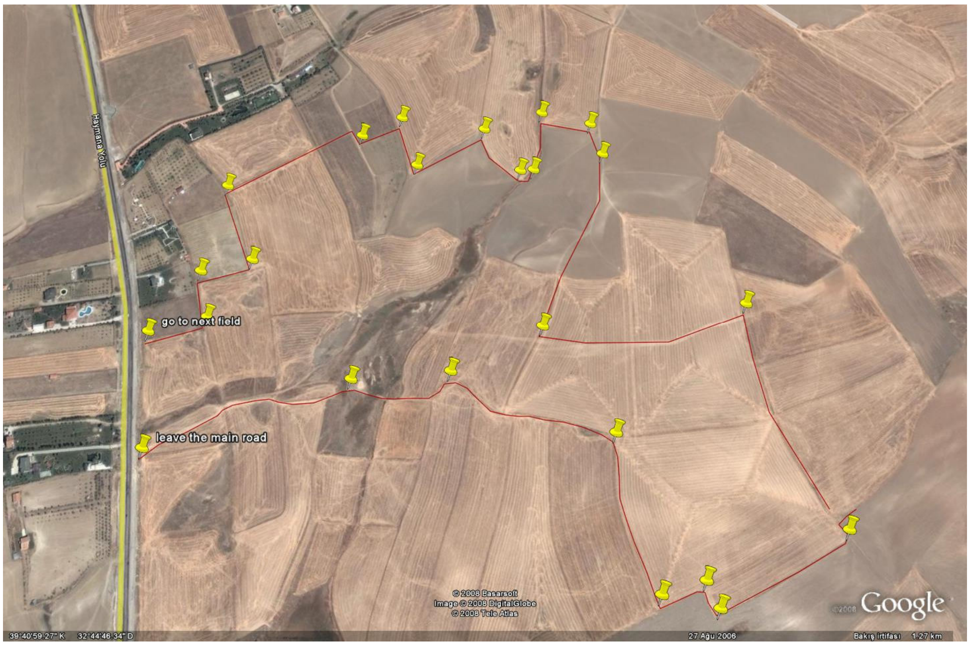


Figure 2-6 A sample search track passing by dirt roads

Once the waypoints has been defined on Google Earth, the points has been exported to a GPS mapping software (several mapping software has been used which were compliant with the GPS units that we had) and with that to the GPS devices (see Figure 2-7).

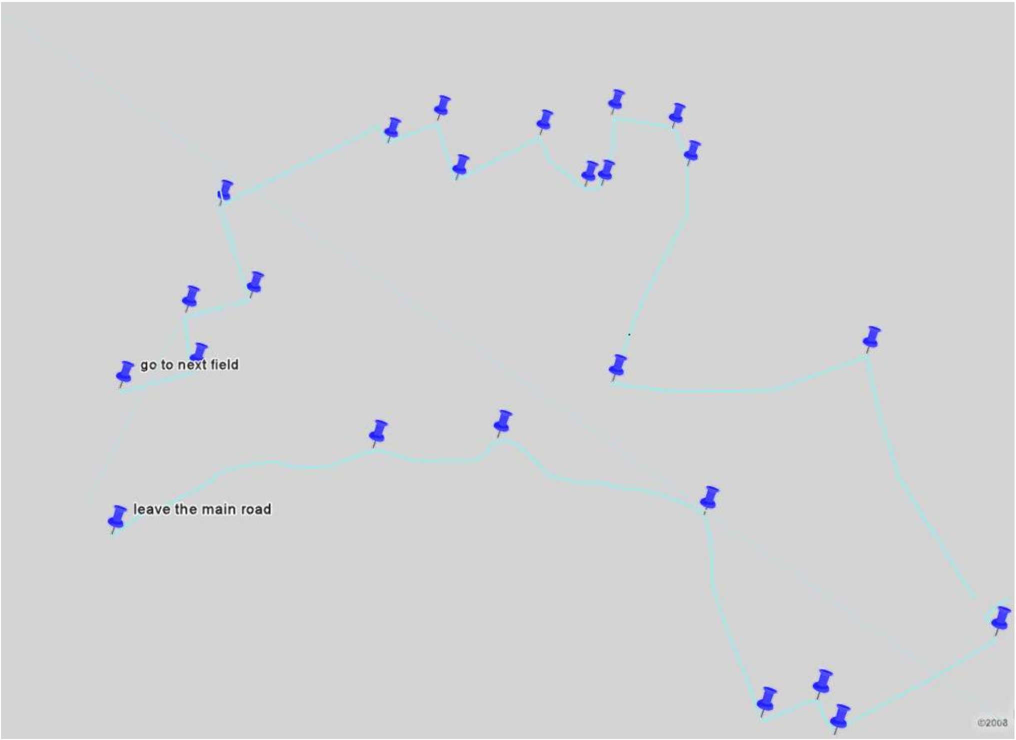


Figure 2-7 A sample search track passing by dirt roads

The GPS devices were used with the pre-loaded waypoints of the fields that was going to be surveyed. That allowed us systematically perform a roadside survey on an area which we did not have detailed dirt road maps.

Once a species was seen during roadside survey, stopped and defined the distribution area for that subpopulation.

In order to define the distribution area, first spot points were marked on GPS and walking was started into a randomly chosen direction towards the other specimens that could be seen in the field (usually once spotted there were more than one cluster of specimens). A walk in a single direction was made until the last species were spotted. At each spot, a GPS waypoint was recorded.

In order to form a vertex to define a population area, the walk continued to the next right to the last seen species, on a clockwise manner GPS waypoint collection continued. Once reached to the starting point, the subpopulation's boundaries drawn.

After completing the area digitization, abundance estimations were done. This estimation was later used to calculate the subpopulation size in that specific field by multiplying the area calculated in GIS layer with the number of species per square meter.

In order not to miss the species out of the drawn distribution area of the population, once the area was closed with the above defined method, at least 50 m single direction walks in all possible directions – except for evident non-occurrence (like lake, road, etc.) – far from the nearest drawn area border has been made. Once the occurrence was spotted, the area was extended and the whole procedure was started again.

The area was scanned during 2003-2007 and the maps of the yearly surveyed areas and their approximate extents are given in Table 3-2.

By the year 2007 it was decided not only to cover and enlarge gradually the area that was previously visited, but also to cover as big as an area, due to discover of new subpopulations up to 40 km away from the known ones in 2006.

In order to search such a big area effectively and efficiently, searches were extended into south where the new populations were found. Google Earth satellite pictures were used in planning prior to the 2007 survey. Since most of the populations found so far was either in or near the watershed lying at South to North direction and containing Lake Mogan, it was decided to cross the watershed at least once with 1-3 km distances and trace the area from West to East and moving further South each time. In order not to be lost in the field and to be sure that area has been searched effectively, the designated routes that should be followed by the survey teams were uploaded to the GPS units. The routes were drawn in the light of satellite images which show agricultural fields, hills, roads (paved, dirt and even temporary farming roads which can change easily).

2.2.2 Spatial Analyses and Instrumentation

The GPS marked species locations and distribution area boundaries has been exported to GPS software. When there were more than one visit or different GPS units were used in survey, all the marked waypoints have been merged into waypoint file constituting whole year's results.

The marked points were than imported into the Mapinfo GIS software point data were used to construct polygons that represent the borders of subpopulations which later constituted the vectoral map layers of different years (Figure 2-8).

The areas of the regions have been calculated in Mapinfo (see Figure 2-9).

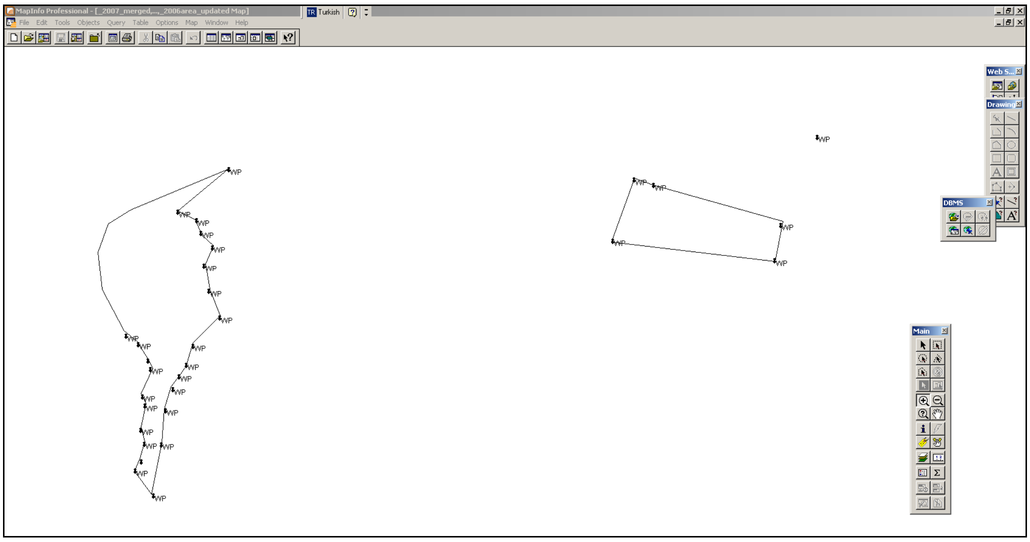


Figure 2-8 Vectoral map of a subpopulation

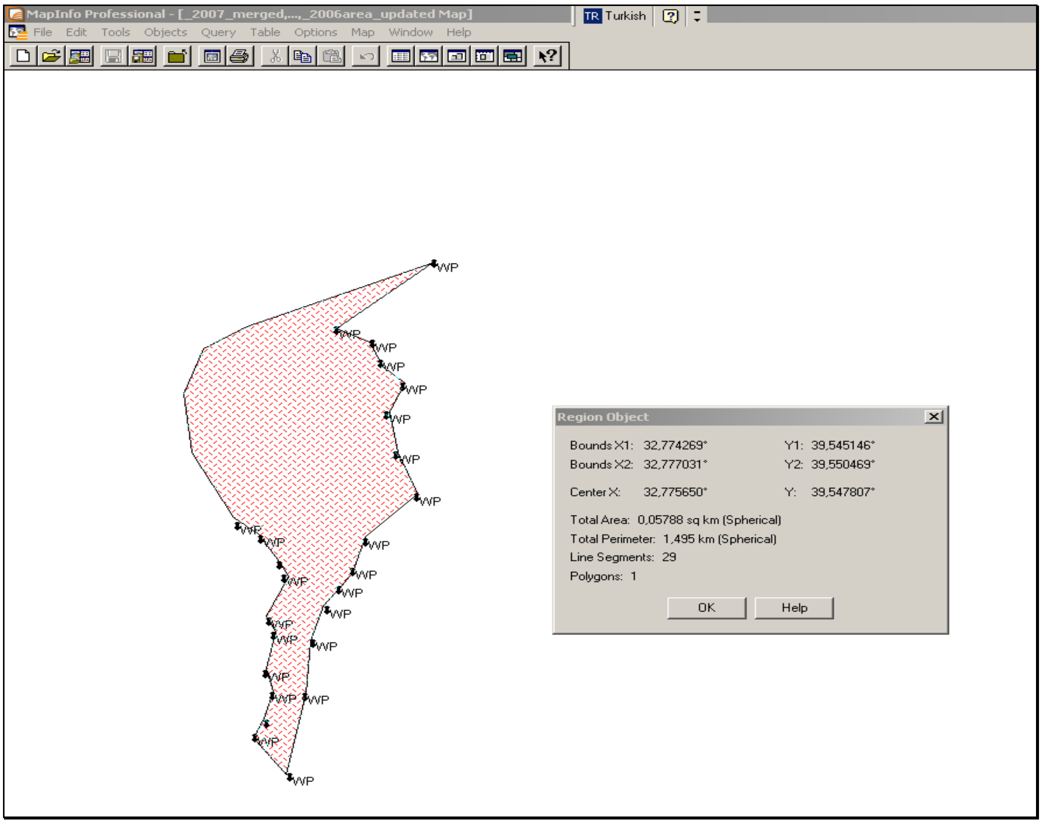


Figure 2-9 The surface area calculation of a subpopulation from a vectoral map

The datum in the GPS units was set to WGS84 and waypoint precisions were always less than 4 meters.

The measurements are based on spherical distances rather than Cartesian distances. The Google Earth images which were saved separately were merged in Photoshop software to have the detailed satellite image of a wider area. This satellite image was registered with the geographical coordinates and then constituted the raster layer of the distribution maps. By that way instead of acquiring a satellite image with a cost of about 5.000 €, even though it is patchy, a free and yet satisfactory raster map was created.

2.2.3 Abundance Estimates

Semi-random quadrat sampling with 5 to 30 replications was performed for the estimation of each subpopulation's abundances, according to their geographical extent. Details of quadrat sampling and design are given in the plant demography part below. For point subpopulations and those on private lands where access is restricted, qualitative estimates were done within ranges.

The yearly estimates of subpopulations were done by multiplying the extent of areas that has been calculated by using the GIS with corresponding densities.

2.3 Studies of Population Demography

Plant population demography studies entail both the *plant demography* (aboveground parts) and the *seed demography* (seed bank analysis) to reveal a complete picture about population dynamics, especially for the plants having persistent seeds in the seed banks like annuals. In this study, both plant and seed demographics were investigated by the following methodology and experimentations.

2.3.1 Plant Demography

Plant demography studies were conducted to estimate population sizes and some vital rates (e.g. reproductive values), and also to provide information about causes of deaths and abnormal growth, conspecific interactions and interactions with other plant species.

2.3.1.1 Design of Study Plots and Quadrats

Systematic-random quadrat sampling design, which combines a random and systematic sampling system is a common method for plant density estimations, was used. Rectangular quadrats of 50 cm x 100 cm were placed in a systematic-random plan, for both study sites. At first, starting points for transects of 6 to 10 were chosen randomly; then along these transects, quadrats were sampled at every 10 steps at 5 times systematically from left and right in alternation. Flowering individuals whose roots were inside the quadrat were counted. Between the years 2004 and 2008, these temporary quadrats were sampled during the flowering period (from the mid flowering to late) to estimate densities more precisely.

Plant demography studies were conducted on large rectangular plots (~100 m^2) that were set up in the center of the both study Sites. In these demography plots 21 permanent microframes (20 cm x 20 cm) were placed with a systematic plan of a 7 by 3 grid. Placement of microframes and weekly monitoring of individuals were started at fall when first emergence starts until the mid of summer when senescence ends, during 2004-2007, except for years 2004 and 2005 for Site 1.

Timing of plant demography monitoring should overlap with life cycle of a species under study. Since the germination of *C. tchihatcheffii* begins at fall, the quadrats were set up and monitoring started then; monitoring was delayed in winter until the spring when growth speeds up and finished in mid summer when senescence sets in.

2.3.1.2 Estimation of Plant Density and Population Size

Plant density estimates for the subpopulations at Site 1 and Site 2 were performed by systematic-random quadrat sampling (explained above) and direct counting methodology for the period of 2003 – 2008. Density estimates were based on flowering individuals to indicate reproductive success and contribution to the next generation.

To estimate population size, areas of study sites were estimated by using GPS waypoints and creating polygons using MapInfo to calculate the extent of the areas in m^2. Then, yearly population sizes for both sites were estimated by multiplying that extent with corresponding densities.

2.3.1.3 Estimation of Reproduction and Survival Rates

Plant demography parcels were studied by individual marking and tracking methods, through fall (September-October when emergence starts), spring (March) till the mid of summer (July when senescence ends), between years 2004 and 2008. Marked individuals from every parcel were followed through emergence, rosette, budding and flowering-seed dispersing stage (TD) to death (Figure I 1,2,3,4). Individuals that died before the flowering stage were abbreviated as TD0- meaning dead at rosette or budding stage, the ones flowered or dispersed seed were classified accordingly with the number of flowers that produced seed i.e. as capitula classes and denoted as TDi, where (i) goes (1) to (n).

For estimation of the number of seeds per flowerhead, different ranges of capitula (3-30) were collected for each capitula class. With all this data, distribution of capitula classes and the number of capitula in each class (i^{th} flowerhead) and their distributions (probability) in the total number of individuals were estimated. For example, TD7 represents an individual that died after its 7^{th} capitulum had flowered and dispersed, so it also possesses TD1, TD2 …TD6. Thus, the total number seeds that "this individual (TD7)" can give is calculated by the summation of average number of seeds in each capitulum, i.e. [$TD_7 = AV_1 + AV_2 + \ldots + AV_6 + AV_7$].

Reproductive values of the species such as distribution of capitula classes, the number of seeds per flowerhead (capitula), and the number of seeds per individual i.e. *fecundity* rates (F) were calculated by developing specific equations:

[1]

$$p_i = \frac{k_i}{T}$$

Where: **p_i** : probability of having i^{th} flowerhead individual

k_i : number of individuals having i^{th} flowerhead

T : total number of individuals

[2]:

$$\text{number of seeds/ flowerhead} = \frac{\sum_{i=1}^{n} AV_i * X_i}{N}$$

[3]:

$$\textit{fecundity}\ \text{(F): number of seeds/ individual} = \sum_{i=1}^{n} T * i * p_i * \frac{\sum_{i=1}^{n} AV_i * X_i}{N}$$

Where: **AV_i** : average number of seeds in the i^{th} flowerhead

X_i : total number of i^{th} flowerhead

n : maximum number of flowerheads that an individual would have

N : total number of flowerheads

Besides reproductive values, through individual tracking methods plant demography studies provide estimates of survival success of the plants i.e. *survival rate* (S) from emergence to flowering. Percent survival (S) was calculated by simply dividing the total number of flowering plants to the total number of emerging individuals followed in the parcels.

2.3.2 Seed Demography

To understand seed bank dynamics such as germination rate, emergence success, persistence, mortality rates or seed density, several experiments were carried out.

2.3.2.1 Seed Basket Experiments

In 2005 October, at both study Sites, in their natural habitat "seed basket experiments" were conducted to estimate in-situ germination rate of seeds with respect to soil depth, and seed age. Specifically, four soil depths, surface (0-2 cm) 5 cm, 10 cm and 15 cm; two age groups of seeds, fresh seeds that are produced in the previous spring (*0-year old seeds*) and 1- year old seeds were investigated. For experimental setup, small sacks made of gause with 1 mm^2 pores, containing 25 seeds each were placed at corresponding soil depths with 4 replications for both study Sites. (Appendix F). This experimental set up keeps seeds in the sacks and allows environmental factors, except herbivory, to influence in a natural manner. Seed baskets were monitored consecutive two years through fall 2005 till fall 2007, by picking out and recording the number of germinating seeds, decayed ones and keeping and recording the number of remaining seeds that were assumed to be viable.

First year (2005 fall- 2006 spring) provided the germination success of 0-year old seeds while the following year (2006 fall- 2007 spring) provided germination success for 1- year old seeds.

2.3.2.2 Seed Cage Experiments

In 2006, "seed cage experiments" were conducted for two different age classes (fresh seeds-*0 year old* and *1 year old*) to estimate the emergence of seeds that were produced in the previous spring and two springs ago in their natural habitat (G_0, G_1), survival rate from emergence to flowering (S), probability of seeds entering and remaining in the seedbank as viable seeds (P1, P2) and by means of all these to deduce total death rate (m). For experimental design and methodology, a similar approach to Kalisz's (1991) methodology was used. For both study locations, seed cages (made of wire with 1 mm^2 mesh size) containing sieved Site soil (free of study species seeds) were set up at ground level with 8 replications. Then, 30 seeds for each age class were placed in each cage that allowed environmental factors occurring in a natural manner. Seed cages were monitored through fall 2006 (September-October when emergence starts) and spring 2007 (March) till the middle of summer 2007 (July when senescence ends) by individual marking and recording the number of emerging individuals and the number of that survive to flowering. And the same procedure is repeated for year 2008.

2.3.2.3 Estimation of Emergence, Persistence and Survival Rates

Percent emergences (G_0, G_1) were calculated by simply dividing the total number of emerging individuals by the total number of seeds that were placed in the cages.

In spring 2007, when emergence was complete, half of the cages were removed from the field to laboratory. Then, the soil inside was sieved to obtain remaining seeds that represent persistence of seeds that entering and remaining in the seed bank. The viability of these remaining seeds was determined primarily by a germination experiment in the laboratory.

Percent persistence (P1, P2) were calculated by simply dividing the number of viable seeds by the total number of seeds that placed in the cages.

The fates of seeds are either to germinate & emerge, persist or die. Thus, percent mortality of seeds (m), represents losses through herbivory and decay, was calculated by simply extracting percent emergence and percent persistence from "1". For example, percent mortality of *0 year old seeds* (m_0) was calculated as:

[1 - (G_0+P1)], i.e., sum of vital rates must be equal to 1, [G_0+ P1 + m_0 = 1]. All demographic parameters and assumptions for modeling *C. tchihatcheffii* population are listed in Table 2-1.

Table 2-1 Demographic parameters for modeling *C. tchihatcheffii* population

G_0 :	Emergence of seeds that were produced in the previous spring without entering a seedbank
P1 :	probability of seeds produced in the previous spring entering the seed bank as viable (persistence of seeds for 1 year)
G_1 :	Emergence of seeds after being in the seed bank for 1 year, and it is assumed to be equal to the emergence of seeds remaining in the seed bank for more than 1 year ($G_1 = G_2 = G_3$…)
P2 :	probability of seeds remaining in the seed bank from age 1 to age 2 as being viable, and it is assumed to equal to P_{22}; a carry-over loop, represents the seeds remaining in the seed bank for more than 2 years (persistence of seeds in the seedbank for 2 or more years, P2=P3…)
S :	survival rate from emergence to adult (flowering plant)
F :	fecundity (number seeds per adult)
m :	mortality rate of seeds (mortality of 1 year old seeds assumed to equal to the older ones, $m_1 = m_2 = m_3$…)
A_t :	number of adults at time (t)
B_t :	number of seeds in the seed bank at time (t)

2.3.2.4 Estimation of Seed Bank Density

Estimates of seed bank densities came from two groups of data: soil core samplings carried out in 2006 in the scope of this study and studies of Yıldırım (2004-2006, unpublished data).

2.3.2.4.1 Soil Core Sampling

In 2006, October, soil core samplings were performed to estimate seed bank density of *C. tchihatcheffii*. Eight random points were selected for sampling in each experimental parcel for two study areas. Soil cores were collected with a cylindrical metal soil corer of 8.5 cm diameter and 15 cm length (Appendix G). For every 5 cm depth, soil samples were extracted and collected separately to estimate the seed density in the seedbank at three different profiles (0-5, 5-10 and 10-15 cm). Samples were aerated for a few days at room temperature, then sieved through proper mesh sizes and, finally on a white background, seeds of study species were picked by direct observation. These seeds were examined with forceps, and firm and healthy ones were assumed as viable. The average numbers of seeds estimated by soil samples were converted to the area of 1 m^2 using the coefficient *k:*

$$\mathbf{k = 10000 / a} \qquad \textbf{[4]}$$

where: *a* is the area of the soil core that is $\prod r^2$ - in cm^2.

2.4 Effects of Agricultural Activities

Effects of agricultural activities were investigated in three groups (herbicide application, tillage practices and stubble burn application) by the establishment of large rectangular experimental plots (~100 m^2) at Site 2. The reason for performing these experiments at only Site 2 is because this Site has been used as agricultural land for many years, but to our knowledge Site 1 has experienced different practices but not for agricultural purposes at least for many years. Even stubble burn seems not a current practice; it is most probable that Site 2 has suffered from stubble burns to some degree in its history. All agricultural practices were applied by the help of a local farmer in accordance with the local farming calendar.

2.4.1 Herbicide Applications

Herbicide application experiments were conducted during 2004-2006 to investigate effects on the study species in two aspects, effects on survival and reproduction of plants and effects on germination success of seeds, namely.

2.4.1.1 Effects of Herbicide on Survival and Reproduction

In 2004, the first trial was applied in a small parcel (8 m^2) with the aid of AZMMAE (Ankara Ziraii Mücadele Merkez Araştırma Enstitüsü) researchers at a suggested dosage of 2,4 -D ester. The reason for using such a small parcel was not to harm the larger population, but it didn't provide reliable results which are discussed in Chapter 3. So the following year, the experiment was conducted at 12^{th} May, 2005, in the field with two 30 m^2 (3 X 10) parcels whose population sizes were estimated before application. 2,4 -D and Tamadol (TAMADA) mixture is the common local herbicide application so the experiment parcel was sprayed with this mixture extracted from the farmers tractor by backpack sprayer.

In 2006, the last herbicide application was conducted on larger parcel (100 m^2) to get more reliable results. Both control and the experiment parcels have been monitored through individual tracking and counting twice a week, similar to the methods of plant demography parcels that were explained in section 2.3.1.3.

2.4.1.2 Effects of Herbicide on Germination Success

Apart from the effects of herbicide directly on plant survival and growth, to investigate the effects on seed viability, germination success of few rescued flowers' seeds, were estimated under optimum conditions at laboratory. Optimum germination requirements for the species have been studied by A. Yıldırım of AZMMAE since 2003.

Effects of 2,4 -D ester and mixture of 2,4 -D ester with Tamadol on seed viability were estimated by germination experiments. Treated seeds not germinated were assumed unviable mainly due to herbicide effect but intrinsic factors may play roles. However, such are assumed to be minor effects and they are also valid for seeds in the control group.

2.4.2 Stubble Burn Applications

Effects of stubble burn was examined both in-situ and ex-situ environments. In order to understand the effects of stubble burn two different experiments were set, first to estimate the effects of stubble burns on plant demography, and second to estimate the effects on seed demography, specifically on the viability of seeds in the seed bank at different depths. The former experiment was conducted at the field on the cultivated parcel where stubble was burned on an experiment parcel (100 m^2) in August 2006 and the next year changes in plant demography were monitored. The latter experiment was carried out at Biology Department Garden, METU, in the same week when the field application was done, under controlled conditions with the following design: A soil pool with 15 cm depth was established and filled with seed-free soil to create a soil profile which was layered horizontally by placing seed plates at depths of 10 cm, 5 cm and 1 cm respectively (Figure 2-10 and Figure 2-11). The top soil was covered with dry cereal and grass stems to simulate field stubble. The temperature changes at the different layers of the soil during stubble burn were measured with a multi node thermometer provided by the RoketSan Company. Later, the viability of those burnt seeds was evaluated by the germination experiments.

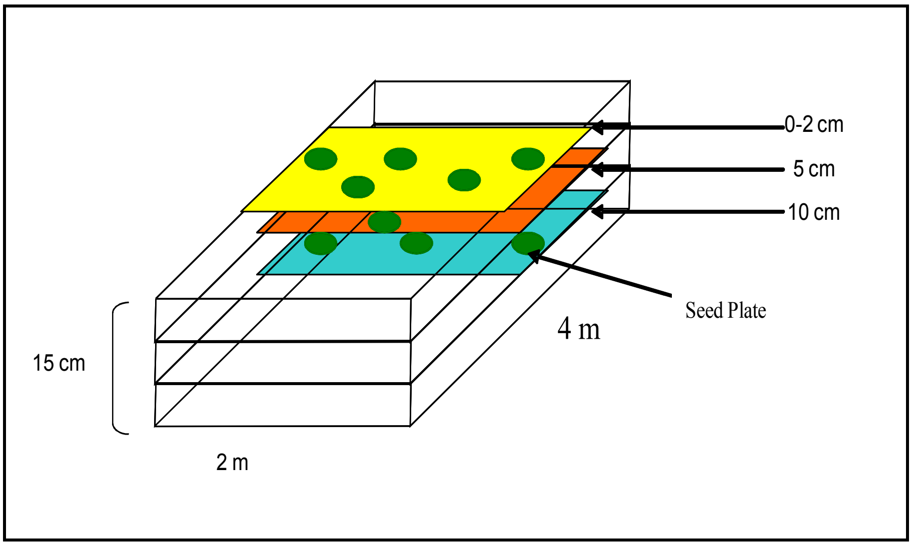


Figure 2-10 Soil pool scheme

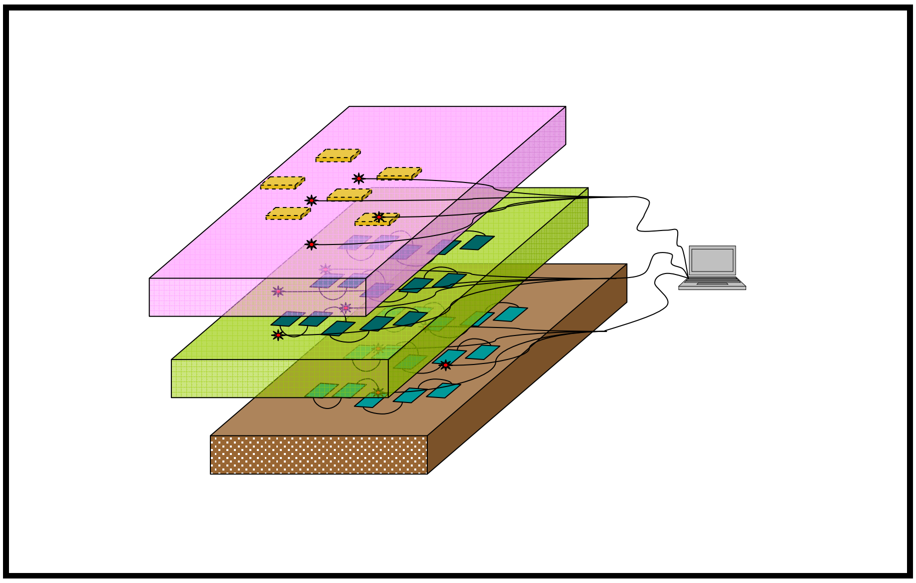


Figure 2-11 Stubble Burn Soil Pool Design

2.4.3 Tillage Applications at Cultivation and Fallow

To evaluate tillage effect, two groups of experiments have been performed in March 2005 on large experimental plots (100 m^2) in the field. The first experiment group was designed to investigate tillage effects at fallow when no crop is cultivated that year. The second experiment group was designed to evaluate tillage effects during a year with cultivation. Therefore, experiment parcels were sown with wheat in the previous fall. By this way real agricultural practices were simulated for both fallowing and cultivation.

In 2005, all parcels were plowed by tractor with proper instruments and at proper times, and the next year parcels were monitored by the plant demography monitoring method similar to individual tracking in microframes.

2.5 Modeling an Annual Plant Life Cycle and Annual Plant PVA

2.5.1 Life Cycle Graph for *Centaurea tchihatcheffii*

In their lifespan individuals go through stages, which differ in morphology, behavior, response to environmental factors, and resource availability. These stages are the components of a species' life cycle, are classified as age, stage or size, can be illustrated by life cycle graphs. "Life Cycle graph" is a graphical representation of the life stages and flow of individuals between them.

Since seed banks are characteristics for many, mostly annual, plant species, in this study, for the annual *Centaurea tchihatcheffii* population model, the life cycle graph is developed based on "seed bank" and "adults" (flowering plants) stages specifically. In the model, all estimates and simulations are based on that two-staged model. The life cycle graph for *C. tchihatcheffii* population model is given in Figure 2-12.

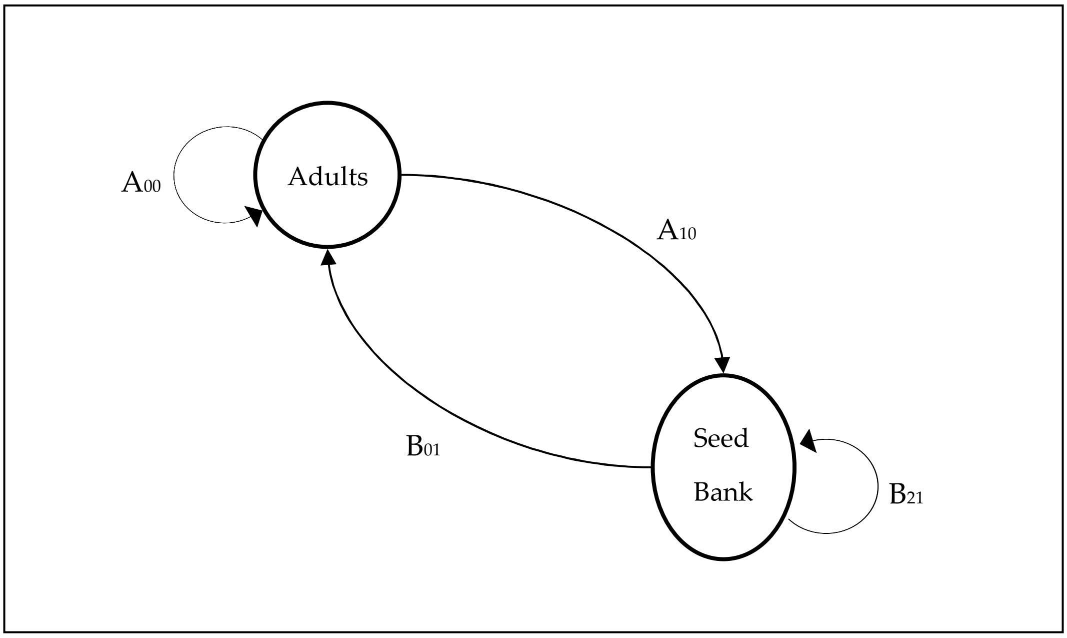


Figure 2-12 Life cycle graph for *C. tchihatcheffii* with two-staged model.

Each arrow represents an annual transition of which components defined below

A_{00} represents transition rate of previous year's (t) produced seeds to the next year (t+1) as adults (flowering plants). A_{10} represents transition rate of previous year's (t) produced seeds to the seed bank, in the next year (t+1), i.e. seeds that persist to become 1 year old. B_{01} denotes transition rate of seeds from seed bank at time (t) that germinated to adults in the next year (t+1) and finally B_{21} represents the proportion of seeds in the seed bank at time (t) that continue to remain viable in the seed bank in the next year (t+1). In the model considered, *Seed Bank* stage consists of at least 1 year old seeds (1 year old or older).

For ease of plant monitoring during demography studies and estimation of vital rates, other developmental stages between seed bank and adults (flowering plants), namely, "rosette stage" and "budding stage" were also monitored. Former is defined as "a group of leaves making a circle or whorl around an axis on the ground, composed of true leaves emerging after two cotyledon leaves" by Baytop (1998); in this study the term was considered to correspond to the stage after five true leaves had emerged in order to prevent biased identification of plants with relatives. Latter is distinguished when the first and the central bud appears in the center of the rosette. A few weeks later, these budding individuals flower and set seed. The flowering stage is synchronized with the seed dispersing stage.

2.5.2 Life Cycle Model for *Centaurea tchihatcheffii*

Plant individuals have a certain probability to emerge from a seed bank, become adults and, eventually, reach the reproductive stage, i.e. produce seeds for the next generation. For long-lived plants, classification of life cycle into age structure may be appropriate when the age of the species is known. When the determination of age is not possible and or when the vital rates are driven by the morphological or developmental stages, "stage-structured models" are used for modeling and they are more practical for plants especially the annuals.

Life cycle of an annual plant can be investigated as stages: seed bank, germination, rosette, bud formation, flowering and seed-dispersing. This cycle continues with changing numbers and rates at every stage for every year. Therefore, vital rates for each stage and their ratios provide a PVA with input. (Akcakaya,1999, Caswell 2001).

Understanding the life cycle of the organisms under study is central to the "transition model approach" of population dynamics. Life cycle of an annual plant can be investigated as stages; seeds, seedlings, flowering, etc. This cycle continues with changing rates at every stage for every year. From these transition probabilities between stages (vital rates), transition matrices are derived, which allow calculation of *population growth rate* (λ), and various other useful aspects of demography and population dynamics.

For deterministic modeling, by using these transition rates, projection matrix can be derived as:

[5]:

$$\left[N_{t+1}\right] = \left[M\right] \times \left[N_t\right] = \lambda \left[N_t\right]$$

Where: M::Stage Matrix

N_{t+1} is population size at time t+1.

N_t is population size at time t.

Centaurea tchihatcheffii is an annual plant that completes its life cycle in one year. A life cycle graph for this annual plant is illustrated in Figure 2-12 and a flowchart for this two-staged model is illustrated in Figure 2-13 **Flowchart diagram for an annual plant life cycle.**. In this model, individuals are "born" only from seeds that are formed on the adults (flowering plants). There are also contributions to adults from the seed bank whose members are at least one year old but the values of fecundity incorporate only equations 1 and 3 (Eq1 and Eq3). Similarly, survival of plants to flowering incorporates with equations 1 and 2 (Eq1 and Eq2). In the same way, equation 4 includes only the probability of persistence of viable seeds in the seed bank i.e. survival of seeds that remain in the seed bank. Finally, equation 5 represents the rate of mortality at the seed bank stages.

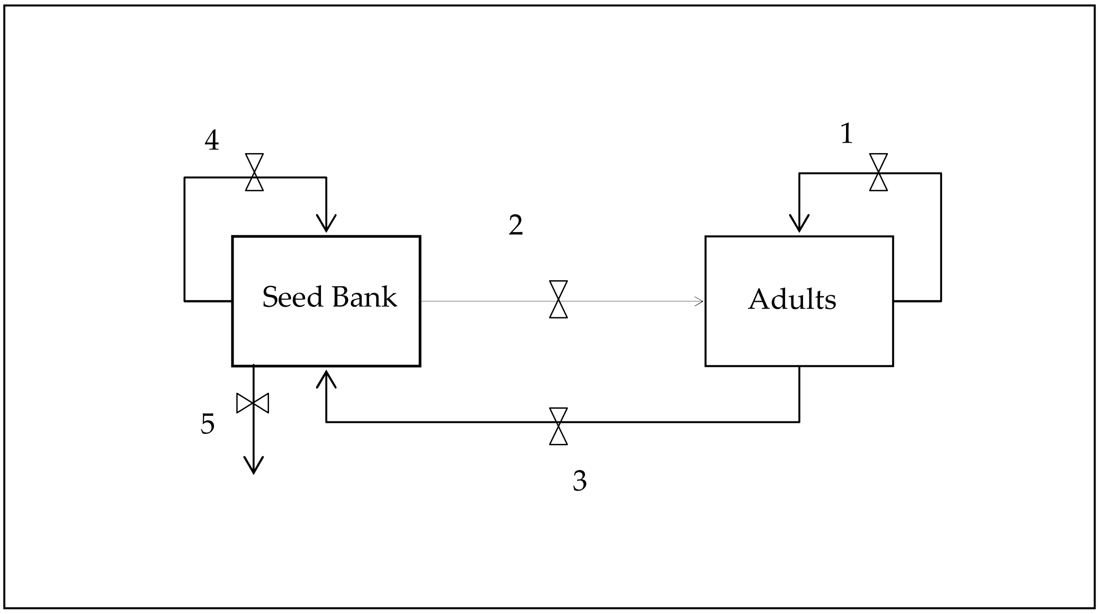


Figure 2-13 Flowchart diagram for an annual plant life cycle.

Each arrow represents an annual transition of which components defined below.

2.5.2.1 Equations and Transition Matrices

Each arrow in life cycle graphs and flowcharts indicates transition from one year to next, i.e. from time (t) to (t+1).

Eq 1: $F * G_0 * S * A_t$

Eq 2: $G_1 * S * B_t$

Eq 3: $F * P1 * A_t$

Eq 4: $P2 * B_t$

Eq 5: $B_t * m_1$

Where: the elements of the equations are defined at beginning part in Table 2-1 Demographic parameters for modeling ***C. tchihatcheffii*** population

Transition matrix is developed from life cycle graph and flowchart equations given below.

Table 2-2 Transition Matrix of the Model

Time (t)

Time (t +1)

	Seed bank	Adults
Seed bank	B_{21}	A_{10}
Adults	B_{01}	A_{00}

→

	Seed bank	Adults
Seed bank	P_2	$F * P_1$
Adults	$G_1 * S$	$F * G_0 * S$

For deterministic modeling, by using these transition rates, I generate the following Lefkovitch matrix model (Caswell, 2001):

$$\begin{bmatrix} B_{t+1} \\ A_{t+1} \end{bmatrix} = \begin{bmatrix} P2 & F\,P1 \\ G_1 S & F\,G_0 S \end{bmatrix} \times \begin{bmatrix} B_t \\ A_t \end{bmatrix} \qquad [6]$$

Where B_t denotes the number of seeds in the seed bank at time (t), and A_t denotes the number of adults (flowering plants).

2.6 Design of the Simulation Model

2.6.1 Modeling Tool

As stated earlier, despite a relatively large number of PVA sofware packages, most of the currently available such sofware have been developed with animal populations in mind. conservation purposes. In this study, RAMAS Metapop software (Applied Biomathematics, New York) is used as a simulation tool because it is complex enough to incorporate stochasticity and density dependence but clear and user-friendly at the same time. It also enables user-defined code writing. Moreover, most of the limted plant PVA literatures refere RAMAS.

2.6.2 Modeling Structure

Preparation of data for the Ramas Metapop involves estimations stage matrices and standard deviations of population demographic parameters came from both plant and seed demography studies throughout the study years. But available data only permits to estimate means and their standard deviations of fecundity and survival values, between years 2004-2008. Hence, emergence successes and persistence rates were measured only for 2 transition years (2006-2008). Standard deviations for emergence successes and persistence rates were estimated from between year's standard deviations for those values.

2.6.3 Density Dependence

Density dependence can be explained as the tendency of population growth rate that depending on the current population size. Scramble and Ceiling density dependencies alternatively has been used on PVA scenarios.

Scramble Density dependence type is assumed since individuals seems to share resources more or less equally but at higher densities, there won't be enough resources for all, so as population size increases, the amount of resources per individual decreases. Therefore, density dependence is selected to affect all stages and all vital rates.

In addition, to deal with the model uncertainties, *Ceiling* type density dependence has been used in several of the models as an alternative approach. Density dependence is selected to affect all stages and all vital rates for this type as well.

2.6.4 Product of Values with Standard Deviation

While calculating the Stage Matrix elements through multiplication the fractional standard deviations were squared, added, and then their square root taken to obtain the fractional total deviation.

2.7 Ramas Model Inputs

Density dependence parameters required by the dependence functions such as R_{max} (maximum growth rate) –only for Scramble type-, K (carrying capacity), local threshold are predicted as follows:

2.7.1 Maximum growth rate (Rmax)

The growth rate is defined as,

[7]

$$R(t) = N(t+1) / N(t)$$

Where: $R(t)$ is growth rate.

$N(t+1)$ is population size at time t+1.

$N(t)$ is population size at time t.

To estimate maximum growth rate (R_{max}), performed a regression of ln(R(t) on N(t), and used the y-intercept as the estimate of R_{max} assuming it is a declining function.

2.7.2 Carrying Capacity

The carrying capacities (K) of the populations were calculated from the averages of annual abundances while omitting the catastrophe year; they are 18,017,956 for Site 1 and 33,353,352 for Site 2. 10% coefficient of variation was used to estimate Standard deviations of K.

2.7.3 Local Threshold

The local threshold, which is the abundance under which this population will be considered unoccupied; for each population was taken as one tenth of the lowest value of abundance observed over the study period which are 22,865 for Site 1 and 45,726 for Site 2.

2.7.4 Initial Abundance

Initial abundance is the total number of individuals in the population at beginning of each replication. So, it is the summation of individuals in each stage. The Table 2-3 represent the year 2008 initial abundances for study Sites.

Table 2-3 Initial Abundances for Study Sites

	Seed Bank	Flowering
Site 1	15.967.896	418.191
Site 2	18.107.209	629.132

2.7.5 Assumptions

Seed bank is assumed to be composed of at least 1 year old viable seeds. All seeds sampled by the soil cores (densities) are assumed at least 1 year old. Even though this assumption creates some overestimation of seed bank densities, it has no effect on stage matrix and standard deviation matrix elements (vital rates) because vital rates are estimated by seed demography experiments that allows computation of *0 year seeds* and *1 year* or *older seeds* separately.

Dispersal is not included in the models and it is assumed that there is no dispersal between these two subpopulations since *C. tchihatcheffii* is considered a poor disperser (disperses its seeds within a few meters of mother plants based on qualitative observations in the field throughout the study years).

2.8 The Models Designed

Based on the modeling approach combinations of two types of density dependence (Scramble and Ceiling) and 3 levels of Survival 6 different models are designed (Table 2-4).

Table 2-4 Simulation Model Types

		Survival Rates		
		Low	Medium	High
Density Dependence	Scramble	Model S1	Model S2	Model S3
	Ceiling	Model C1	Model C2	Model C3

The simulations were run for six models for two study Sites, namely Site 1 and Site 2. Furthermore these models (with their associated inputs) were simulated for the below defined scenarios which cover catastrophes and management actions.

In order to define the stochasticity and different management actions separately, several scenarios were constructed evolving from a baseline scenario. The summary characteristics of the scenarios are as follows:

Scenario 0

Baseline scenario: This scenario only includes the predefined density dependency and stochasticity.

Scenario 1

Baseline Scenario includes the effect of habitat degradation as considering temporal trend in carrying capacity (K). This density dependent (scramble and/or ceiling), stochastic (environmental-demographic) model is developed just as a base to add other natural, anthropogenic factors and management options. The model also includes -0.05 (declining) temporal trend in carrying capacity (K) to demonstrate the effect of habitat degradation. No natural catastrophes are allowed.

Scenario 2

This scenario represents natural populations that are only subject to natural catastrophes like disease, drought so there is no anthropogenic factors are involved. Here after, this scenario grounds the rest of the scenarios to add those factors.

During the study period of six years drought and a disease were observed once at the study Sites. Only one catastrophe is included as a natural catastrophe, either disease or drought that decrease flowering plants 35 % with a 0.8 probability of occurrence at every 5 years. This scenario represents natural populations under natural catastrophes where no agricultural practices or any other threat effects are allowed but still there is no conservation management action is taken.

Scenario 3

This scenario includes catastrophe and agriculture without herbicide application. In this scenario, tillage effects with herbicide free agriculture are imitated. In an agricultural practice tillage takes place before flowering Tillage (bf) means, plowing is applied in spring before flowering. Tillage effect results showed that it diminishes majority of plants at application year in spring (t) and it increases the fecundity more than 3 times in the next year spring (t+1). Even though no herbicide is used; its extremely negative effect on the previous year's flowering plants (95% reduction) will cause a decline in the population under natural catastrophe. Therefore, tillage effect is included as a "harvest" event in addition to the Catastrophe 1. This is usually the case when rye is planted since it doesn't require using herbicide.

Scenario 4

This scenario illustrates today's agricultural practices to which the study species habitats are exposed due to farming with herbicides. Herbicide experiments showed that it destroys majority of the plants and it also decreases the germination success of seeds produced by surviving individuals at application year in spring (t).

Scenario 5

This scenario was designed to investigate past agricultural practice- stubble burn- that is known to be common at the natural distribution of study species. So it includes catastrophe with agriculture with herbicide application and stubble burn. This is the worst scenario that the population can be faced with.

Scenario 6

This is the base management scenario that can be proposed as an in-situ conservation approach where the tillage effect is used as a management. In an agricultural practice tillage takes place before flowering which kills plenty of above ground species and prevents offspring contributions to seed bank. As a management approach, tillage is proposed to be made after flowering, so that new contributions to the seed bank are secured.

These six scenarios have been tested on six different models (Table 2-4).

2.9 Metapopulation Models

Even tough detailed population demography was studied only for 2 subpopulations at the study sites, another 12 subpopulations were also classified according to those 2 subpopulations by considering similarities in population trends and disturbances that they experienced in recent history.

2.9.1 Model Assumptions

It is assumed that there is no dispersal between subpopulations. Subpopulations have been grouped into two types based on their similarity to Site 1 or Site 2. In order to estimate the initial abundances of subpopulations, the number of seeds in the subpopulations was estimated by a linear regression function between seed bank value and above ground flower numbers of the two study sites. The functions derived were used on the corresponding subpopulations.

.

The tillage effect has been incorporated into the model once every six years for sites similar to Site 1 and once for every two years for sites similar to Site 2, considering the likelihood of the frequency of an agricultural activity on two study sites.

CHAPTER 3

RESULTS

3.1 Species Distribution – New Explored Areas and Estimated Population Sizes

The distribution maps of the species were produced both on raster and vector layers according to the GPS surveys has been conducted during 2003- 2007. The maps representing yearly changes of population size and distribution area are shown in Appendix A. Figure 3-1 demonstrates the distribution area of the species as of year 2007.

Table 3-1 demonstrates approximate coordinates (edge points) and extent of the geographical distribution area of the species. The list of abbreviations for each subpopulation is given in Table 3-3.

Table 3-1 Approximate coordinates and the extent of the polygon representing distribution area

East	North	Total Area (approximate)
32° 44' 11.99	39° 46' 17.17	700 km^2
32° 49' 49.85	39° 46' 26.57	
32° 52' 59.73	39° 37' 41.20	
32° 56' 18.16	39° 24' 5.43	
32° 54' 56.32	39° 18' 41.79	
32° 50' 3.08	39° 18' 51.92	
32° 43' 35.34	39° 23' 3.15	

The area that has been scanned during 2003-2007 enlarged each year. The approximate extent and the maps of the yearly surveyed areas are shown in Table 3-2 and Figure 3-2.

Table 3-2 The Area Surveyed during 2003-2007 (note that the values are not cumulative)

Year	The Surveyed Area (km^2)
2003	2
2004	29
2005	62
2006	158
2007	1374

Figure 3-1 Distribution area indicated as (x) mark as of year 2007 (including all subpopulations)

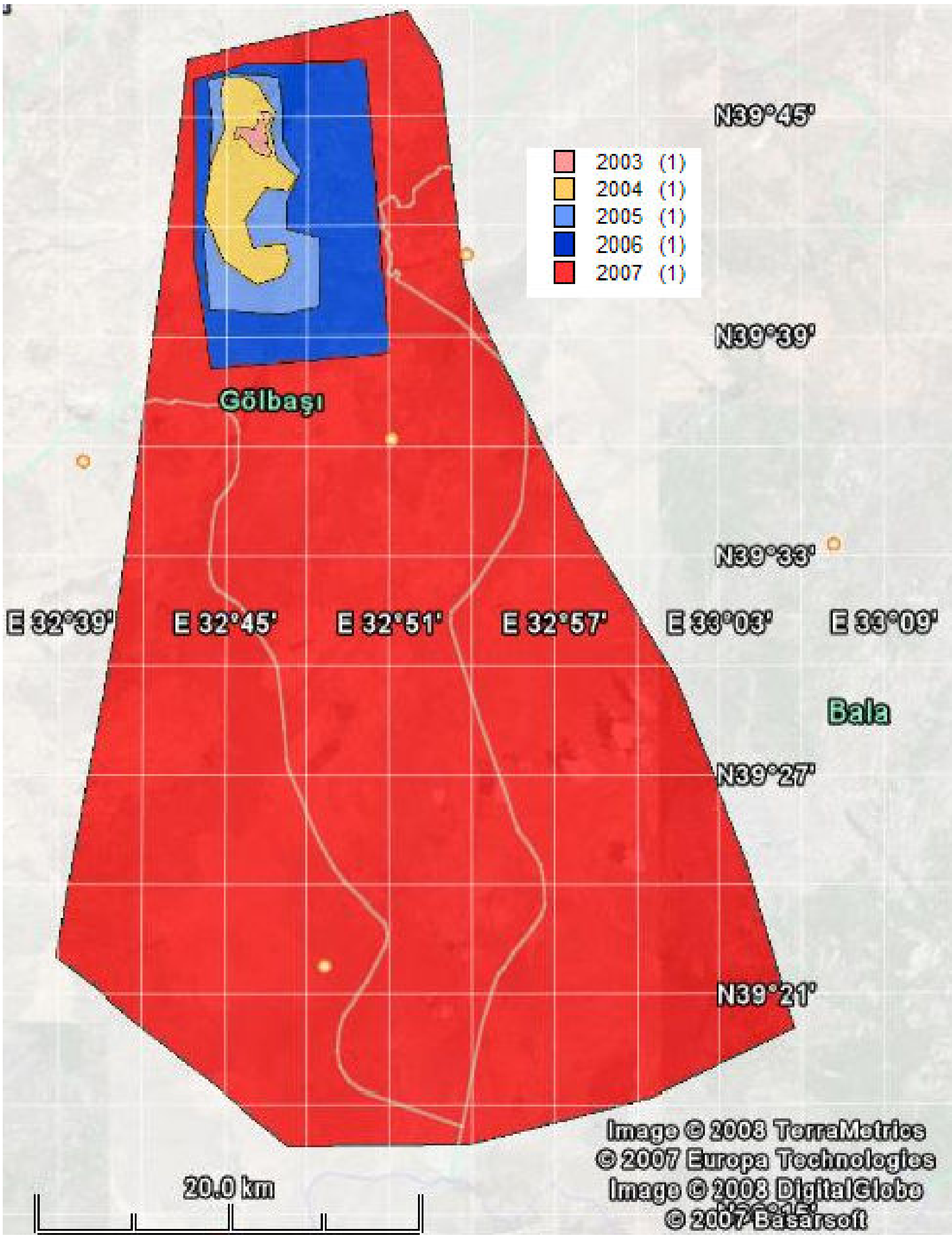


Figure 3-2 The survey areas between 2003 and 2007

The subpopulations explored throughout the study are compared in terms of population sizes and distribution areas are shown in the Table 3-4,5,6,7.

Table 3-3. The list of abbreviations for each subpopulation

Site 1	SDO
Site 2	DOB
Site 3	Hacılar
Site 4	Y.İhtisas arkası
Site 5	Y.İhtisas karşısı
Site 6	Örencik
Site 7	Inta space
Site 8	Yavrucuk
Site 9	Parapent
Site 10	Mahmatlı
Site 11	Karagedik
Site 12	Çalış-Bezirhane
Site 13	Gölbek
Site 14	Çeltek-Gökler

The known distribution area was slightly enlarged towards the South East direction due to a newly found small population in 2006. In 2007, new big healthy subpopulation has been found 60 km south of the Mogan Lake, at the same time, another big healthy subpopulation has been found by the Ministry of Environment Twining Project and by Vural et al. (2007), respectively; with these additions, as of 2007 the species has a distribution area of about 700 km^2 with 14 subpopulations.

Table 3-4 The subpopulations where the population sizes are larger than 20,000 individuals

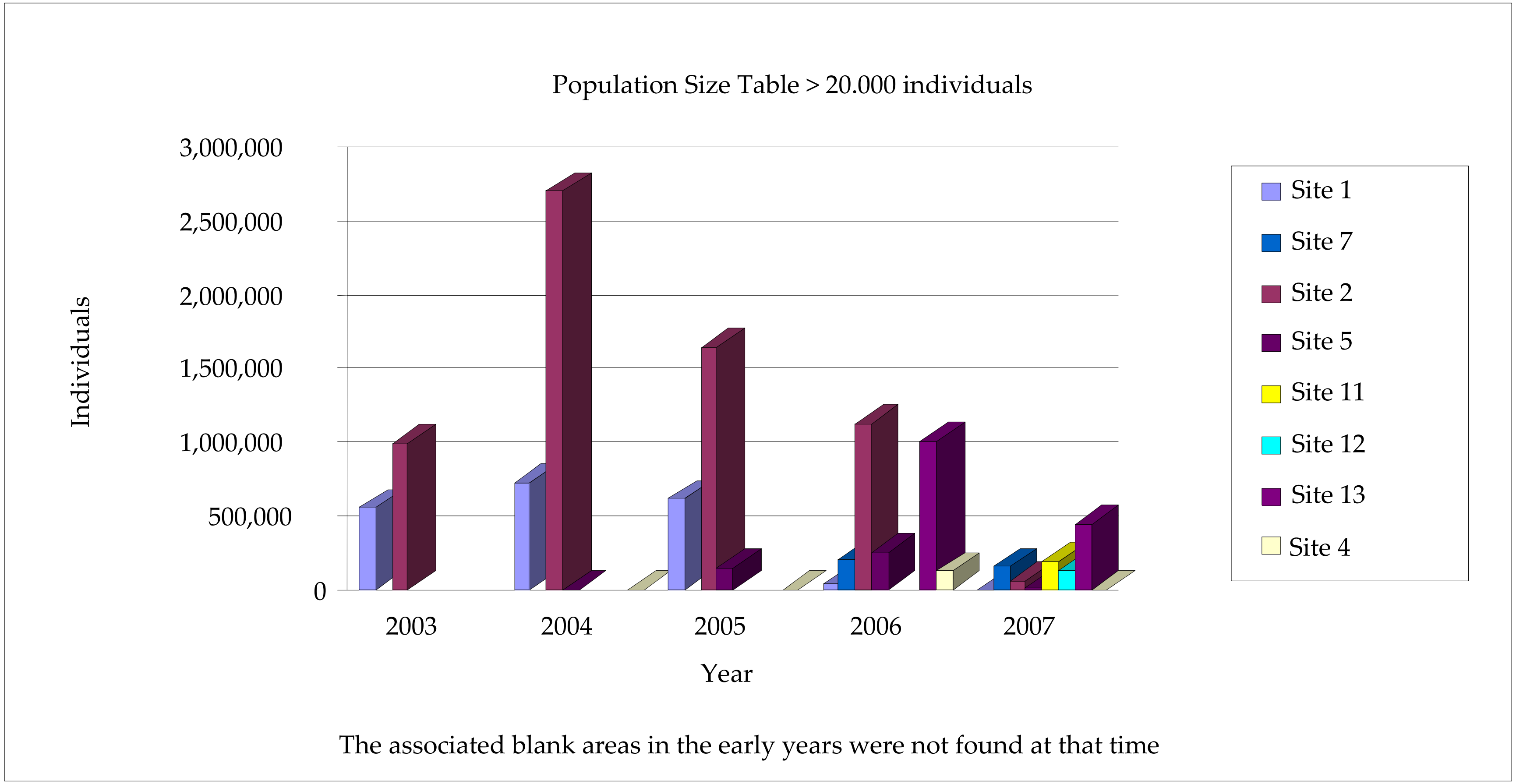


Table 3-5 The subpopulations where the population sizes are smaller than 20,000 individuals

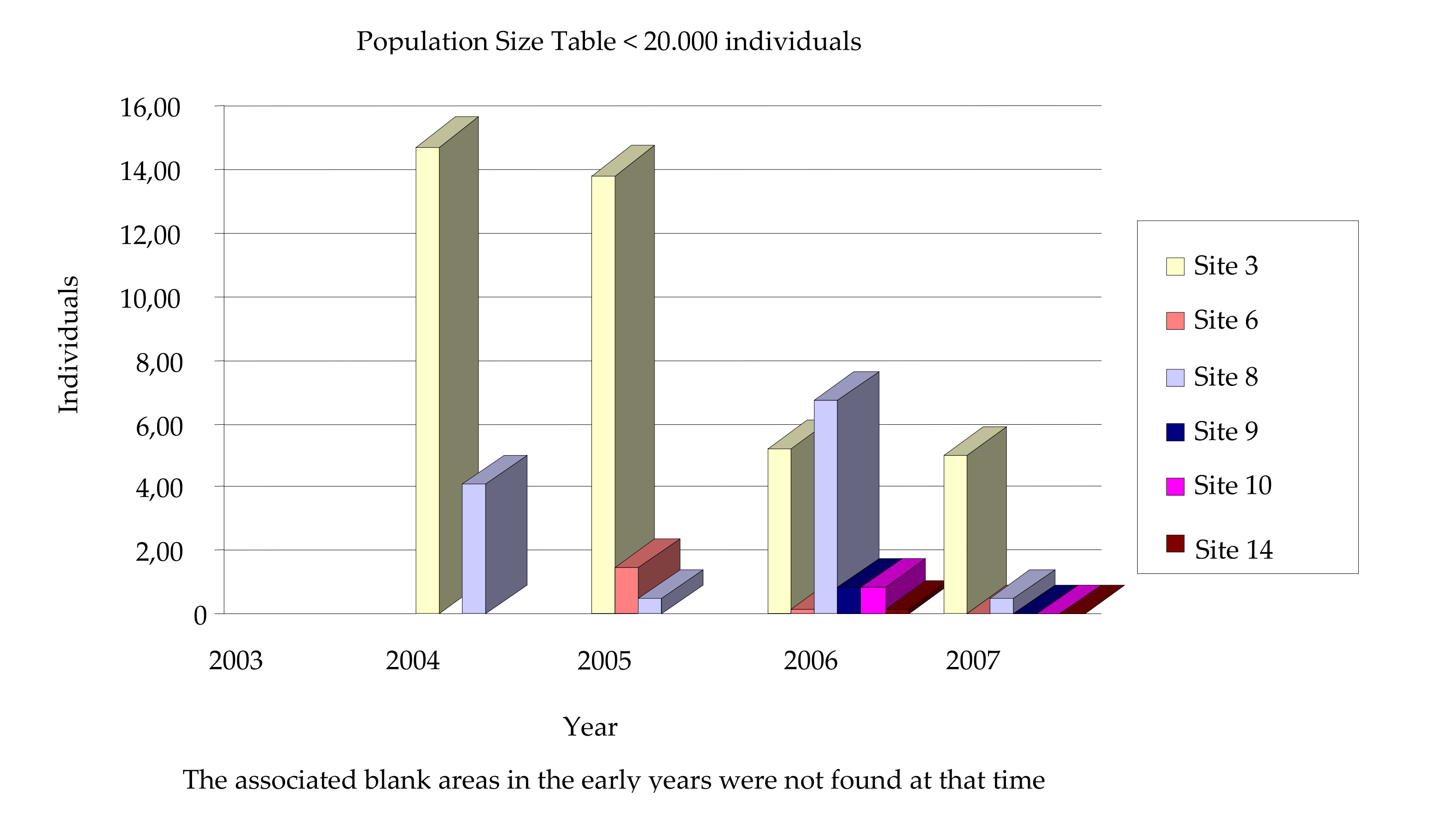


Table 3-6 The distribution area where the size is less than 70.000 m²

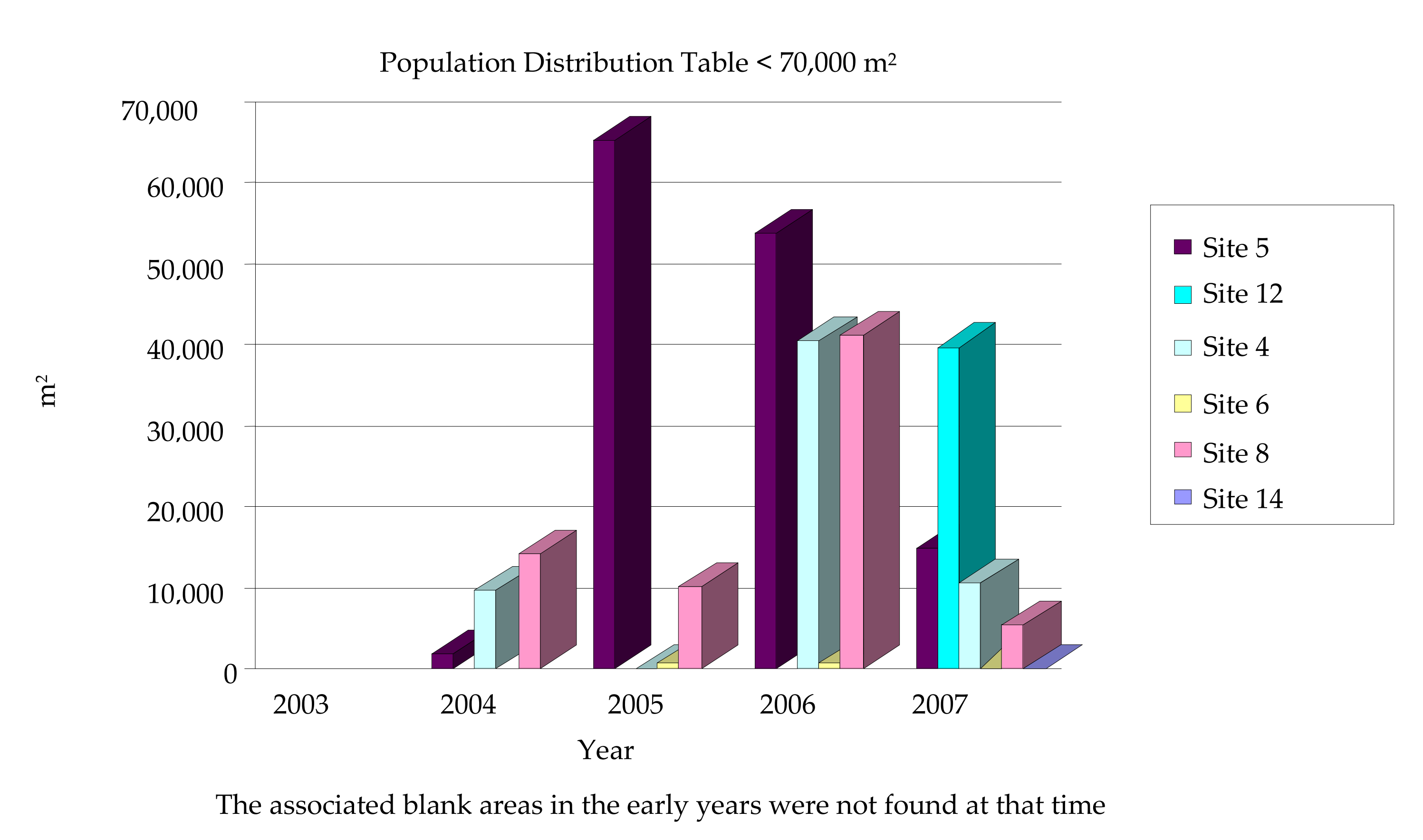
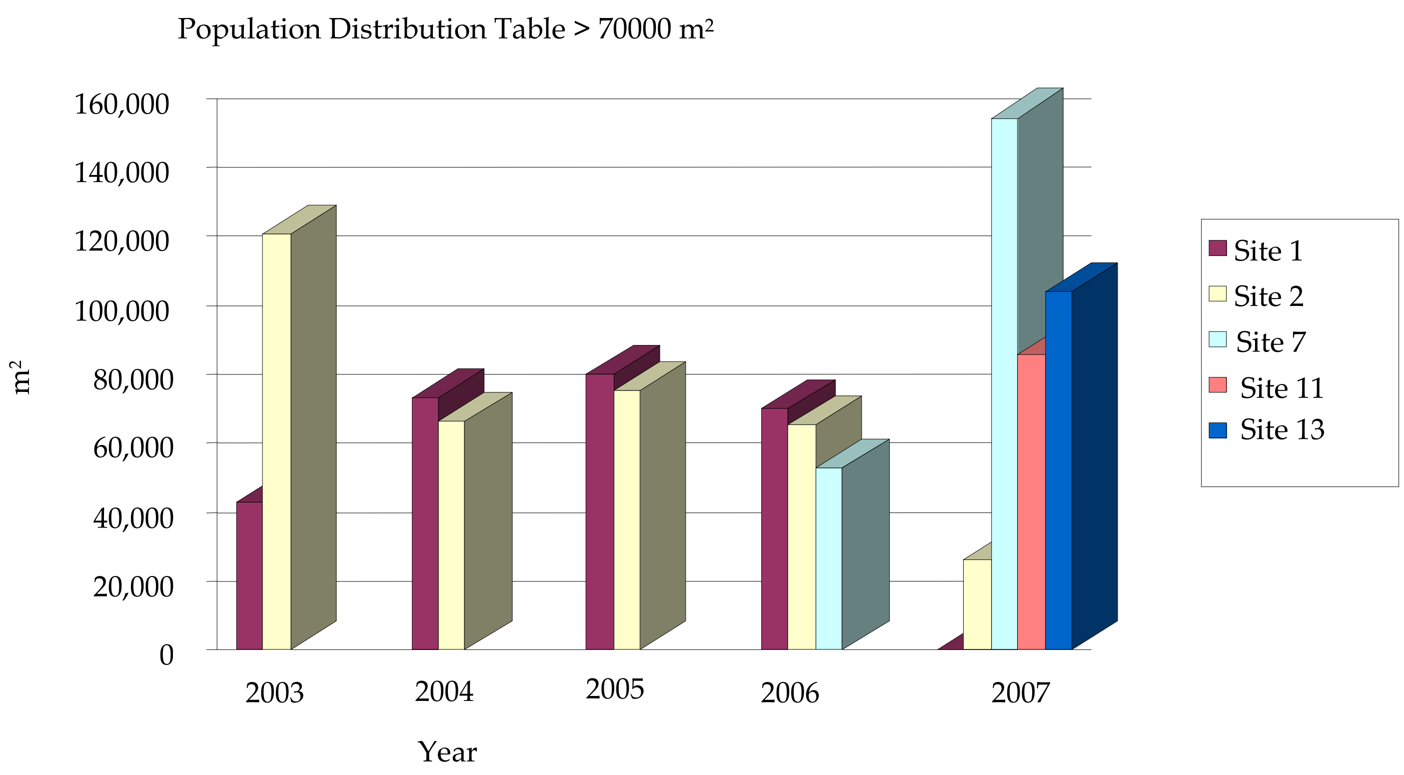


Table 3-7 The distribution area where the size is more than 70.000 m^2



The associated blank areas in the early years were not found at that time

Contrary to statements that have been made about the species distribution at the early stages of this research, the distribution area is demonstrated to be much larger than was thought.

3.2 Population Demography

3.2.1 Plant Demography

Plant demography studies provide information about the population sizes and the vital rates of aboveground stages. These findings come from several studies conducted at different years at different Sites. Results given in Table 3-8. are from plant demography studies conducted during 2004 – 2008 within the scope of this thesis; for years 2004 and 2005, data from Çakaroğulları (2005) are given in Table 3-9. Results show that Site 2 is much more productive than Site 1, especially in terms of 4 to 8 times higher fecundity values.

The averages of all these fecundity values were used to construct mean and standard deviation matrices for the population modeling explained in Chapter 2.

Besides estimation of population sizes and vital rates, (aboveground parts from rosette to bud and bud to flow) plant demography studies also provided qualitative information for the consideration of density dependence; like the possible causes of deaths, abnormal growths, conspecific interactions and interactions with the other plant species, dispersal-ants and herbivory-pigeons.

Table 3-8 Plant Demography Results between years 2004-2008

Years	2004	2005	2006		2007		2008	
Study Sites	Site 2	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
Capitula classes (median)	7 (0.84)*	6 (0.54)*	0 (0.196)*	3 (0.37)*	0	0 (0.07)*	4 (0.82)*	5 (0.94)*
Average number of seeds/capitula	10.29 (0.45)*	(11.18)[1]	(5.787)[1]	(10.05)[1]	0	(9.76)[1]	(6.58)[1]	(10.12)[1]
Average number of seeds/ind (F)	72.03	(72.37)[2]	(6.172)[2]	(49.91)[2]	0	(4.67)[2]	(17.47)[2]	(47.82)[2]
Number of individuals/m²	98.8 (1.89)*	80.12 (1.33)*	3.188 (0.429)*	54.2 (2.19)*	0	4.56 (0.61)*	41.58 (2.78)*	34.27 (2.69)*

* represents standard errors.
[1] Numbers were calculated with Equation 2.
[2] Numbers were calculated with Equation 3.

Table 3-9 Plant Demography data between years 2004-2005 (Çakaroğulları 2005)

Years	2004		2005	
Study Sites	Site 1	Site 2	Site 1	Site 2
Range of capitula/individual	0 -10	0-23	0 -11	0 -23
Average number of seeds/capitula	7.12 (0.423)[1] (6.84)[2]	10.37 (0.403)[1] (10.51)[2]	6.60 (0.338)[1] (6.13)[2]	10.97 (0.344)[1] (10.15)[2]
Average number of seeds/individual	(17.4)[4] (18.03)[3]	(67.08)[4] (71.18)[3]	(21.65)[4] (21.38)[3]	(84.14)[4] (89.11)[3]
Number of individuals/m²	70.20 (7.72)[1]	101.90 (5.84)[1]	54.72 (11.52*)[1]	78.84 (11.92*)[1]

[1] Numbers in parenthesis are standard errors of the mean given as average.
[2] Numbers were calculated with Formula 1.
[3] Numbers were calculated with Formula 2.
[4] The values were obtained by multiplication of average numbers of flowerheads/individual and average number of seeds/flowerheads.

Plant demography studies only provide estimation of survival rates partially i.e. only the survival from rosette to flowering (Table 3-10).

Table 3-10 Survival rates of plants from rosette to flowering

Survival rates of plants from rosette to flowering				
Years	2005	2006	2007	2008
Site 1	-	0.284	(-) *	0.858
Site 2	0.85	0.82	0.381	0.826

* No plant emergence occurs that year

Another group of data revised from Çakaroğulları (2005) to obtain the survival rates from rosette to flowering for years 2004 and 2005. These values were estimated by multiplying two probabilities which were given as the survival rate of *rosette* to *budding stage* and *budding stage* to *flowering stage* in her study (Table 3-11).

Table 3-11 Survival rates plants from rosette to flowering (revised from Çakaroğulları 2005)

Survival rates plants from rosette to flowering		
Years	2004	2005
Site 1	0.92	0.929
Site 2	0.931	0.78

3.2.2 Density and Population Size

The density and population size estimates for two study Sites during 2004-2008 are given in Table 3-12.

Results show that both Sites are experiencing population decline until 2007, but Site 1 does not compensate consecutive bad years and finally no individual was observed in 2007. In year 2008, growth of populations observed due to the rainy season and Site 1 recovered itself and attained population size similar to earlier years. These findings also can be more clarified by the Figure 3-3 and Figure 3-4.

Table 3-12 Estimates of Density and Population Size for study Sites during 2004-2008

Density and Population Size Estimations										
Years	**2004**		**2005**		**2006**		**2007**		**2008**	
Study Sites	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
individual /m^2	70.27 (1.63)	98.8 (1.89)	52.34 (1.61)	80.12 (1.33)	3.188 (0.42)	54.2 (2.19)	0	4.56 (0.61)	41.58 (2.78)	34.27 (2.69)
Study Area Size (m^2)	8988	8979	8988	8979	8691	8979	-	1708	8972	8878
Population Size	631.557	887.125	470.388	719.397	27.703	486.662	0	7788	373.055	304.249

Numbers in parenthesis are standard errors.

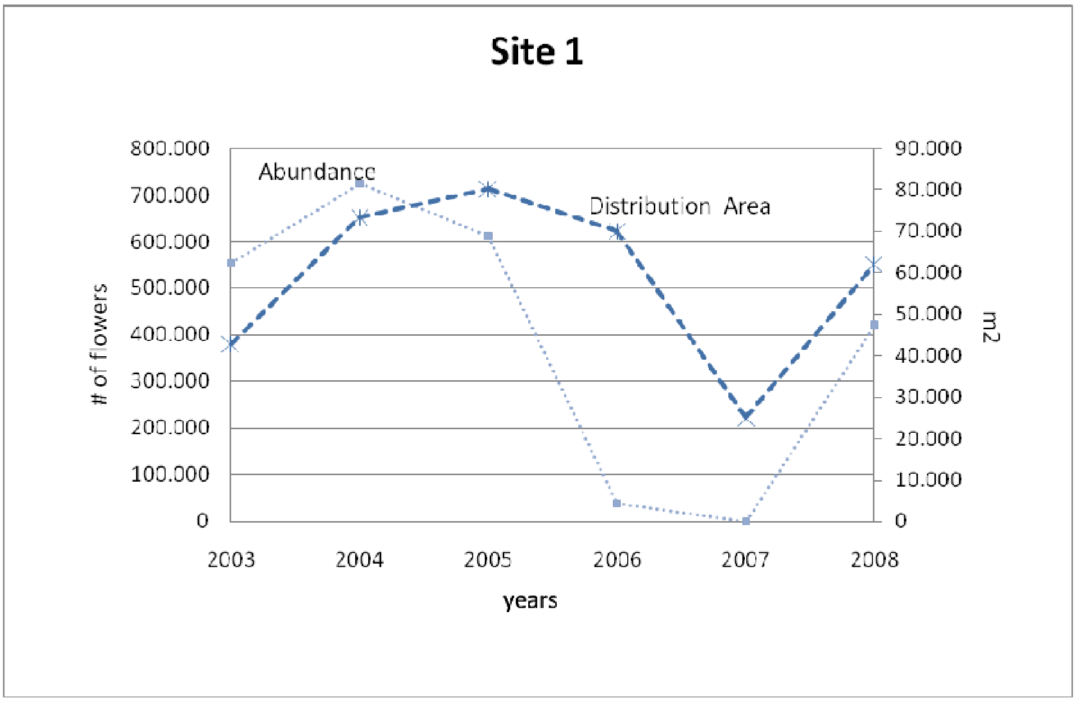


Figure 3-3 Comparison population trends for Site 1

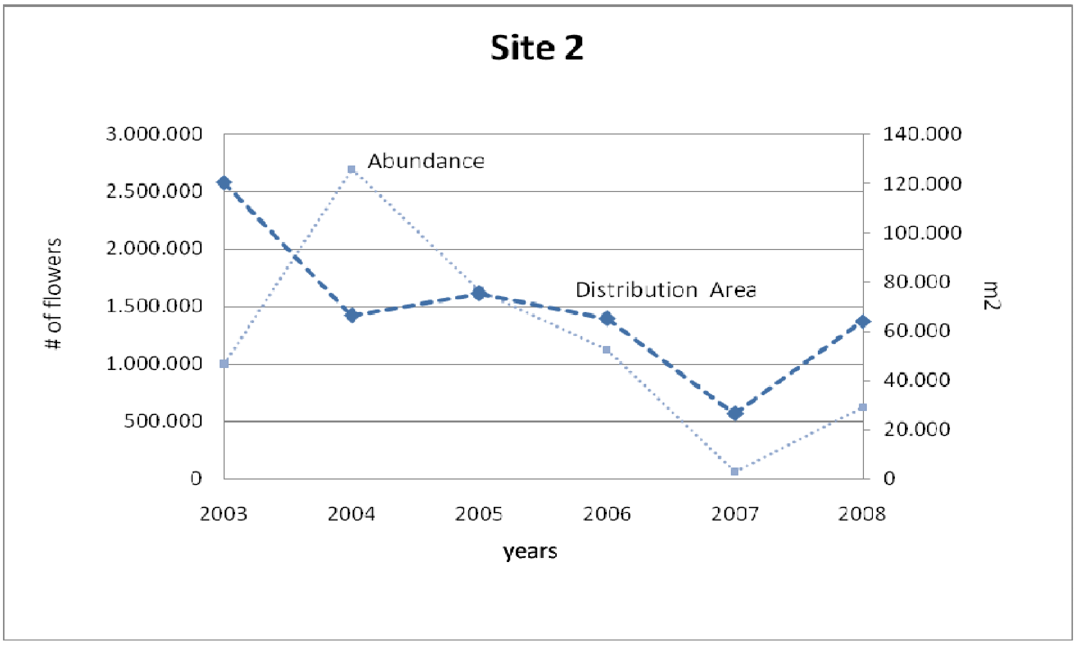


Figure 3-4 Comparison population trends for Site 2

3.3 Seed Demography

Seed demography studies involved two groups of experiments which were performed at the field, seed basket and seed cage experiments, namely. The first group of experiments provided estimates of germination success with respect to soil depth, and seed age, the results of which are given in Table 3-13. Results show that germination success of 0-year old seeds (fresh seeds) are significantly higher than the 1- year old seeds but this difference is more pronounced at Site 1 than the Site 2 at every depth. Moreover, Site 1 shows higher germination success through the deeper soil but Site 2 shows just opposite. To reveal overall in-situ germination success, arithmetic averages of first three depths (0-10 cm) were taken, as considering both germination rates and decayed seed rates (Table 3-14)* Numbers in parenthesis are standard errors.

Furthermore, this finding is supported by seed bank density results which demonstrate most of the seeds found in 5 cm and no seeds captured at 15 cm. Another significant finding is that percentage of decayed seed is much higher at Site 2 (0.25) than that of Site 1 (0.07). This can be explained by the soil texture differences between two Sites. Site 1 has more rigid and compact soil structure compared to Site 2 which has been experienced agricultural practices for many years, but Site 1 hasn't. So, soil at Site 2 might possess high amount of water and seeds in the experimental sacks might have been decayed due to this situation and it might have been some higher germination rate than the observed.

Table 3-13 Seed basket experiments results

Germination success (%)					
Transitions (years)		2005-2006		2006-2007	
Study Sites		Site 1		Site 2	
Age of seeds		0	1	0	1
Soil depth	0-2 cm	31(0,85)	16(0,41)	23(2,84)	14(0,65)
	5 cm	47(1,03)	12(0,41)	22(1,85)	15(0,48)
	10 cm	48(0,41)	11(0,48)	25(1,31)	13(0,48)
	15 cm	47(2,46)	9(0,75)	12(0,58)	7(0,25)

* Numbers in parenthesis are standard errors.

Table 3-14 Germination success for fresh and 1 year old seeds

Transitions (years)	2005-2006	2006-2007
Age of seeds	0 (fresh seeds)	1
Site 1	0.420(0,05)	0.130(0,02)
Site 2	0.233(0,08)	0.140(0,02)

* Numbers in parenthesis are standard errors.

3.3.1 Emergence, Survival and Persistence

Seed cage experiments present emergence success, persistence rate of seeds and best estimates of survival rates of individuals, providing whole life cycle of an individual seed through germination – emergence – growth and flowering (adult) stage. Therefore, seed cage experiments presented not only survival rates but also emergence and persistence of seeds, and these values were estimated by two transitions between years 2006 - 2008. The results of these experiments are given in Table 3-15.

Table 3-15 Seed Demography Results

Demographic parameters	Site 1		Site 2	
	2006-07	2007-08	2006-07	2007-08
G_0 (Emergence of fresh seeds)	0.388	-	0,263	0,442
G_1 (Emergence of 1 year old seeds)	0,071	0,203	0,079	0,189
P1 (persistence of seeds for 1 year)	0.117	-	0,175	0,133
P2 (persistence of seeds in the seedbank for 2 or more years)	0,067	0,189	0,108	0,178
S_{e-r} (emergence to rosette survival, *rosette success*)	0,194	-	0,159	0,755

- The empty cells represent no occurrence of flowers on 2007

Seed demography results show that emergence rate of 0-year old seeds is higher at Site 1 but no significant difference between the Sites for the emergence of 1-year old seeds. This trend in emergence success is also attuned with the in-situ germination rates of seeds. Even these data illustrate that a significant losses does not occur during transition from germination to emergence, it should be noted that experiments for each group were made in different years.

Most significant finding about seed cage experiments is that drought in year 2006-07 severely affected rosette successes (S_{e-r}) when compared 2007-08 which was a rainy year.

3.3.2 Estimation of absolute survival rates

Absolute survival rate means survival from emergence to flowering stage. So it covers survivals from emergence to rosette and rosette to flowering which the former provided by seed demography data and the latter provided by plant demography data. And their multiplication gives survival from emergence to flowering which is the absolute survival rate.

Two groups of plant demography data (Table 3-8, Table 3-9) and seed demography data given in Table 3-15 were used to estimate the absolute survival rates given in Table 3-16, Table 3-17. The averages of all these survival rates are used to construct the mean and standard deviation matrix for population modeling studies.

Table 3-16 Absolute Survival Rates

Derived from	**Plant demography**				**Seed demography**	
Years	2005	2006	2007	2008	2007	2008
Site 1	Not studied	0.214	(-) *	0,648	0.064	**
Site 2	0.642	0.619	0.061	0,624	0.079	0,660

* No plant emergence occurs that year

**Since no occurance observed in 2007 the rate couldn't be calculated

Table 3-17 Absolute Survival Rates (revised from Çakaroğulları , 2005)

Absolute Survival Rates Derived from Plant demography data		
Years	2004	2005
Site 1	0.695	0.701
Site 2	0.703	0.589

3.3.3 Seed Bank Density

Estimations of seed bank densities come from two groups of data; soil core samplings carried out in 2006 in the scope of this study and studies of Yıldırım (2004-2006, unpublished data). Soil core results demonstrate that most seeds remain in the top 5 cm and no seeds were captured at 10 - 15 cm soil depth (Table 3-18). This phenomenon is in line with the information from literature that most of the seed bank is found in the few top centimeters of soil for annual plants.

When the results of study Sites are compared, Site 2 possess more seeds in the soil than the Site 1, and they were kept closer to the surface layer.

Table 3-18 Results of Soil Core Samples for the Study Sites, 2006

<table>
<tr><th colspan="2">Estimations in 2006</th><th colspan="2">Average number of seeds</th><th colspan="2">Total number of seeds captured</th><th colspan="2">Average number of seeds in 0-10 cm</th><th colspan="2">Number of seeds in first 10 cm/m^2</th></tr>
<tr><td colspan="2">Study Sites</td><td>Site 1</td><td>Site 2</td><td>Site 1</td><td>Site 2</td><td>Site 1</td><td>Site 2</td><td>Site 1</td><td>Site 2</td></tr>
<tr><td rowspan="3">Soil Depth</td><td>0-5 cm</td><td>1.75 (0.31)*</td><td>3.25 (0.59)*</td><td>14</td><td>26</td><td rowspan="2">2.375</td><td rowspan="2">3.875</td><td rowspan="2">416.67</td><td rowspan="2">679.82</td></tr>
<tr><td>5-10 cm</td><td>0.625 (0.183)*</td><td>0.625 (0.263)*</td><td>5</td><td>5</td></tr>
<tr><td>10-15 cm</td><td>0</td><td>0</td><td>0</td><td>0</td><td>Not applicable</td><td>Not applicable</td><td>Not applicable</td><td>Not applicable</td></tr>
</table>

* Numbers in parenthesis are standard errors.

Another group of seed bank estimates comes from Yıldırım's studies for 2004 and 2005 (Table 3-19, Table 3-20).

Table 3-19 Seed bank estimations at some distribution areas (from Yıldırım, 2004)

Estimations in 2004		Number of seeds in soil samples		Number of seeds within 10 cm / m^2		
Seed viability		viable	unviable	viable	unviable	total number of seeds
Sampling Sites	Side of Lake Mogan (natural area)	2.5	3.5	203.1	284.3	487.4
	Site 1 forestation area (practiced area)	5.8	0.8	471.2	65	536.2
	Front side of Aquapark (cultivated land)	13.8	2.6	1121.2	211.2	1312.4

Table 3-20 Seed bank estimations at some distribution areas (from Yıldırım, 2005)

Estimations in 2005		Number of seeds in soil samples		Number of seeds within 10 cm / m^2		
Seed viability		viable	unviable	viable	unviable	total number of seeds
Sampling Sites	Site 2 (practiced area)	6	5.4	487.5	438.7	926.2
	Farm next to Site 2 (practiced area)	5.4	2.8	438.7	227.5	666.2
	Site 1 forestation area (natural area)	3.4	10	276.2	812.5	1088.7
	Front side of Aquapark (disturbed land)	0.8	1	65	81.2	146.2

3.4 Effects of Agricultural Practices

Results of agricultural practices -herbicide application, tillage practices and stubble burn application- conducted on the experimental parcels at the field throughout the study are summarized in Table **3-21**. It is clear that herbicides cause increased mortality before seed dispersal and therefore significantly decreases the population's fecundity value, even if various herbicide applications considered. It may be misleading to come to quick conclusion by just reading this table for stubble burn and tillage effects without considering underlying processes. The following sections elaborate on these processes.

Table 3-21 The effects of agricultural practices during the research

Years	Site 2 (Controls)				Herbicide Effects				Stubble Burn Effects		Tillage Effects			
											At Cultivation		At Fallow	
							2006							
	2004	2005	2006	2007	2004	2005	Parcel 1	Parcel 2	2006	2007*	2006	2007	2006	2007
Capitula classes	7 (0.84)	6 (0.54)	3 (0,37)	0 (0.07)	1 (0.36)	0 (0.04)	0 (0,15)	0 (0,18)	9 (0.59)	2 (0.13)	9 (0,78)	4 (0.27)	10 (1,01)	4 (0.28)
Average number of seeds per capitula	10.29 (0.45)	11.18	10.05	9.76	6.11 (0.51)	3.25 (0.25)	2 (0.325)	1,5 (0.31)	14.82	9.74	14.68	10.2	17.25	10.1
Average number of seeds per individual	72.03	72.37	49.91	4.67	6.11	3.25	0.83	1.14	167.8 9	17.81	163.7 6	22.12	208.69	32.62
Number of individual per m^2	98.8 (1.895)	80.12 (1.33)	54.2 (2.19)	4.56 (0.61)	35.2	0.1	1.5	1.75	90.17 (1.95)	14.86 (1.55)	88.24 (2.63)	21.71 (2.52)	91.12 (2.29)	23 (1.6)

3.5 Herbicide Applications

3.5.1 Effects of Herbicide on Survival and Reproduction

It is clear that it causes the death of the species before the seed dispersal stage and significantly decreases the fecundity values. While 95% of the individuals die with the application of 2,4-D ester (2006); this rate reaches 99% when 2,4-D and Tamadol mixture is applied (2005) (which most farmers prefer). In addition to that, local farmer's herbicide application period is traditionally a few weeks later, just prior to flowering, when they use higher dosages or even mixtures to get more effective results. At any rate, negative effects of 2,4 -D ester like abnormal growth and development disorders were observed (Appendix B). Moreover, the comparison of different herbicide usage results can be drawn from Table **3-21**.

3.5.2 Effects of Herbicide on Germination

In addition to the individuals at budding and flowering stages are affected, is also found that, herbicide application has adverse effects on viability of seeds so lowers the germination rates. The germination success of the seeds collected from the limited number of individuals (except for year 2004) which reached the seed dispersing stage is depicted in Table 3-22. In that, the most severe damage is again caused by the mixed herbicide usage.

Table 3-22 Effects of herbicide on germination success

Germination Success (%)	2004 2,4D ester	2005 (mixture)	2006 2,4-D ester
Herbicide Group	34 %	14.29 %	16.53 %
Control Group	44 %	76 %	74 %

3.5.3 Results of Stubble Burn Experiments

The results of the stubble burn experiments are demonstrated in two aspects, the effects on plant demography and the effects on seed demography, specifically the viability of the seeds in the seed bank at different depths.

3.5.4 Effects of Stubble Burn on Plant Demography

Results of stubble burn on plant demography are summarized in Table 3-23, which are measured in the field in experimental parcels.

It may seem that stubble burn has no affect or even positive effect on plant demography, when the 2007 (a year after stubble was burned) vital rates are compared with the control parcel of that year, but this would be a misstatement. This can be explained by the practices followed on the stubble burn parcel before it was burnt in 2006 August. Firstly this parcel was plowed in spring 2005 as with the other tillage parcels. Then it was sown with wheat in fall 2005. So, the next year (2006) stubble parcel gave quite high vital rates similar to cultivation parcels'; actually for this year until it was burnt, the stubble parcel acted as a second cultivation parcel. Then it was burnt in 2006 August; thus, the timing of the burning happens after the life cycle of plant completes. This allowed contribution of large amount of seeds input to the seed bank at that year although some were lost due to burning. Therefore, relatively higher values for the stubble parcel than for the control were measured in 2007 (Appendix D). Those values were slightly lower than the cultivation parcel which is also the control plot for the stubble parcel in 2007. To conclude, it is shown that stubble burn leads to a decrease in the reproductive values (flower sets-capitula class) and density to some degree.

3.5.5 Effects of Stubble Burn on Germination Success: Seed Demography

Effects of stubble burn on seed demography are drawn from "stubble burn experiment on soil pool" which was conducted at the garden of Biology Department, METU, and the germination experiments to determine the viability of those burnt seeds.

Results of stubble experiment on soil the pool are given in Figure 3.5 which demonstrates the changes in temperature during stubble burning depending on time and depth. During the experiment only a noticeable temperature increase (max 85°C) were detected at the ground level (0-2 cm) measurement nodes (Figure 3-5).

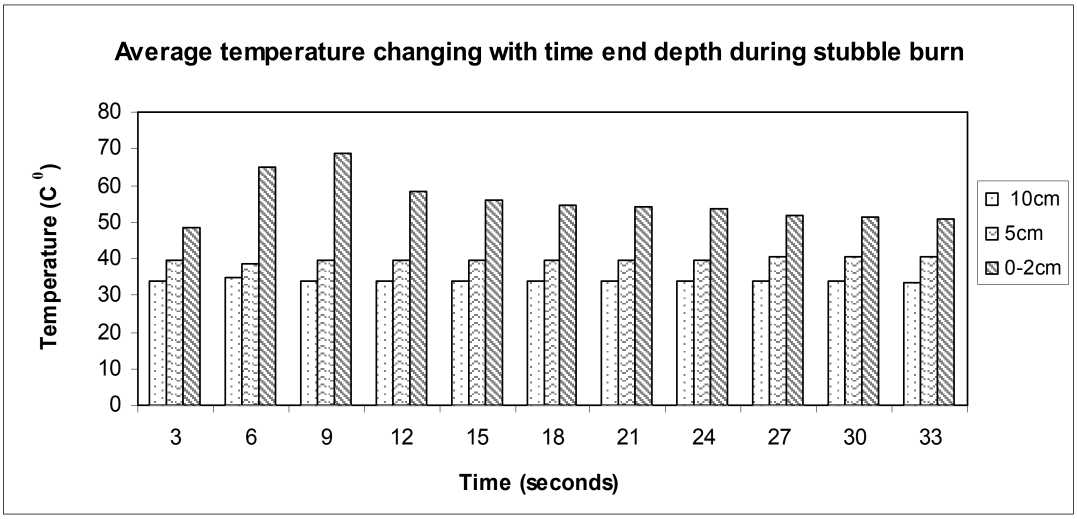


Figure 3-5 Temperature changes during stubble burn depending on time and depth

The seeds collected after the experiment were subjected to germination experiments under optimum conditions and the results of these experiments demonstrate a very low germination rate of the seeds at surface layer, as depicted in Table 3-23. However, seeds from the depth of 5 cm have higher germination success that is consistent with the control groups.

Table 3-23 Effects of stubble burn on germination success

Soil Depth	Total number of seeds (20 X 5)					Average number of germinated seed	Total number of germinated seed	germination success (%)
0-2 cm	3	2	3	2	1	2.2	11	11
5 cm	16	15	17	16	15	15.8	79	79

As a conclusion, it is understood that stubble burn does not harm seeds at levels deeper than 5 cm and only has detrimental effect on the surface level seeds.

3.5.6 Results of Tillage Effect

The results of the tillage experiments are demonstrated in two aspects, the effects tillage at fallow, and the effects of tillage at cultivation.

3.5.6.1 Effects of Tillage At Cultivation

The results of tillage at cultivation parcel in 2006 show similar vital rates to the stubble burn parcel of that year and this is not surprising since both experienced same practices expect for the burn activity, but since this occurred after the plant cycle was completed, the stubble burn parcel acts as a second cultivation parcel for that year.

Tillage at cultivation parcel results show that, although 99% of the flowers disappear during the plowing at 2005 (it was observed that a few survived individuals could reach 50th flower), next year (2006) plant density increased 1.7 times and healthier, bigger individuals could grow at the cultivation parcel (Appendix C)). Moreover, reproductive success was significantly increased (3 times more capitula class and average number of seeds per individual) compared to the control parcel (Table **3-21**).

Another positive effect of the tillage is that while the average number seeds per capitula have remained around 10 throughout the study – representing the seed capacity of the individuals in the Site 2- this capacity increased in the plowed parcels. This is also seen on individuals that have produced bigger, fleshy, brighter colored capitula.

3.5.6.2 Effects of Tillage at Fallow

Tillage at fallow parcel demonstrated similar results with the tillage at cultivation just slightly higher values for all vital rates than that for the cultivation parcel, and this can be explained by relatively less competition from other species (including wheat sown as a companion crop) (appendix C).

3.6 Modeling and Simulation Results

3.6.1 Preparation of Results for Data Entry

Preparation of data for Ramas Metapop involves estimations of means and standard deviations of population demographic parameters came from both plant and seed demography studies throughout the study years. Available data provide estimates of means and their standard deviations of fecundity and survival rates from 5 years (2004-2008), but only permits estimates of emergence success and persistence rates from 3 years data -two transition years (2006-2008).

But for Site 1 only one transition year from 2006 to 2007 could be used for the estimates of G_0 and P1 values, so within year standard deviations were used. Since no emergence occurs at Site 1 in 2007, thereby it was not possible to collect fresh seeds to put in seed cages to estimate second data set of G_0 and P1 as for 2007-2008.

Survival rates were estimated for three different levels as low, medium and high. Since it is considered that the highest uncertainty may arise from the derivation of S values, in order to evaluate the effects of this uncertainty lowest and highest observed S values and a medium S value (average of observed survival values with extreme years removed) has been used to construct three different sets of stage matrix but the rest of the demographic parameters are all same.

These different stage matrices and their standard deviation matrices which build base of models for population viability analysis are given in Table 3-24, Table 3-25, Table 3-26.

Table 3-24 Estimations of Averages and Their Standard Deviations for the demographic parameters with Low S values

LOW S				
	Site 1		Site 2	
	Means	Standard Deviations	Means	Standard Deviations
F	15,76	6,623	60,530	13,500
S	0,109	0,079	0,119	0,036
G_0	0,388*	0,059	0,353	0,1266
G_1	0,137	0,093	0,134	0,0778
P1	0,117*	0,033	0,154	0,0297
P2	0,128	0,086	0,143	0,0495

* These parameters were estimated from 1 year transition

Table 3-25 Estimations of Averages and Their Standard Deviations for the demographic parameters with Medium S values

MEDIUM S				
	Site 1		Site 2	
	Means	Standard Deviations	Means	Standard Deviations
F	15,76	6,623	60,530	13,500
S	0,337	0,305	0,388	0,283
G_{0*}	0,388	0,059	0,353	0,1266
G_1	0,137	0,093	0,134	0,0778
P1*	0,117	0,033	0,154	0,0297
P2	0,128	0,086	0,143	0,0495

* These parameters were estimated from 1 year transition

Table 3-26 Estimations of Averages and Their Standard Deviations for the demographic parameters with High S values

HIGH S				
	Site 1		Site 2	
	Means	**Standard Deviations**	**Means**	**Standard Deviations**
F	15,76	6,623	60,530	13,500
S	0,612	0,229	0,657	0,059
G_{0*}	0,388	0,059	0,353	0,1266
G_1	0,137	0,093	0,134	0,0778
P1*	0,117	0,033	0,154	0,0297
P2	0,128	0,086	0,143	0,0495

* These parameters were estimated from 1 year transition.

By using three different sets of demographic parameter, three different *Mean Matrices* and *Standard Deviation Matrices* were constructed for both study Sites, which are the major input for Ramas Metapop (Appendix H Figure 22- 27).

3.6.2 Data (Results) Entry into Ramas Metapop

Before data entry into Ramas Metapop, basic considerations about the model like duration and replications (iterations) for the simulations, density dependence, stochasticity, dispersal, catastrophes and management options are decided. These are summarized on Ramas Metapop pop up screen as in Figure 3-6Ramas Metapop pop up screen.

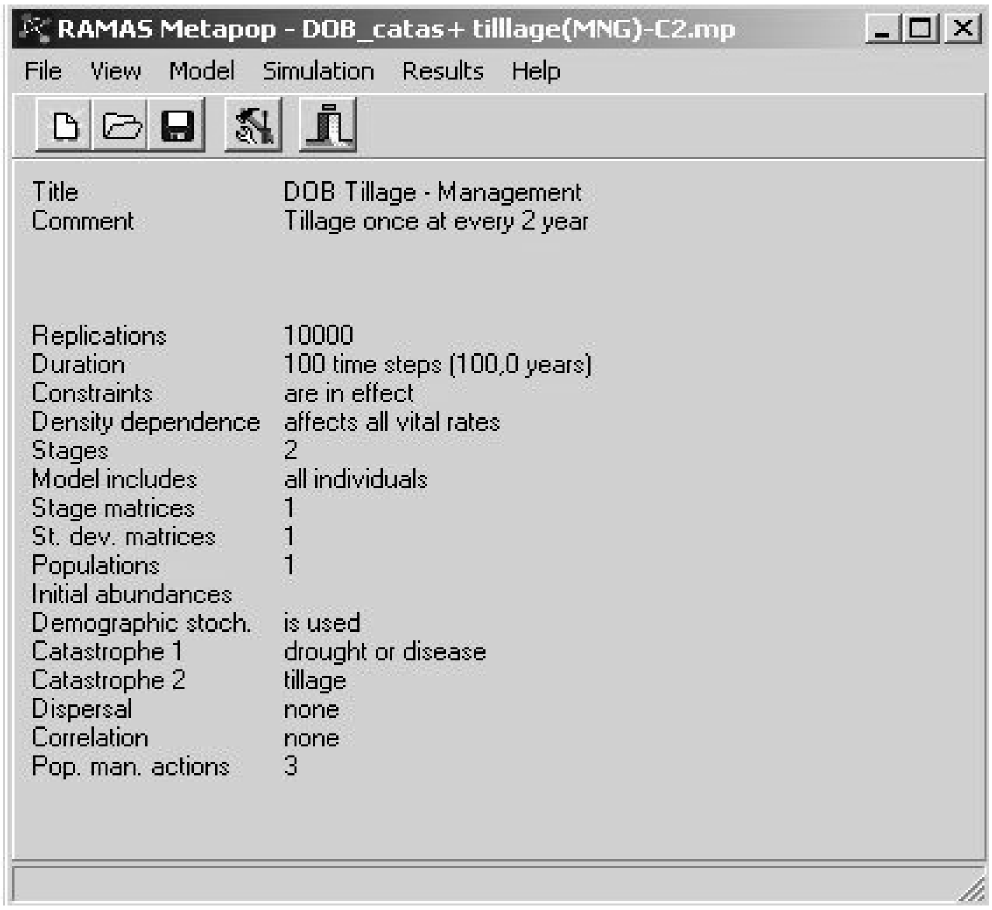


Figure 3-6 Ramas Metapop pop up screen

In order to increase the robustness of the conclusions that are going to be drawn from simulations and to observe the effects of different stage matrix elements and density dependences more than a hundred scenarios with different variation has been run. 84 scenarios have been simulated for Site 1 and Site 2 and Table 3-27 summarizes the approach that resulted in the running of 84 scenarios.

Table 3-27 Simulation Scenarios

Density Dependence (Scramble or Ceiling)	Survival Rate Levels	Scenarios with/out catastrophes and management action	Populations (Site 1,2)	Total Scenarios
2	3	7	2	84

3.6.3 The results of R_{max} Calculations

The results of R_{max} calculations for both sites are given in Figure 3-7, Figure 3-8.

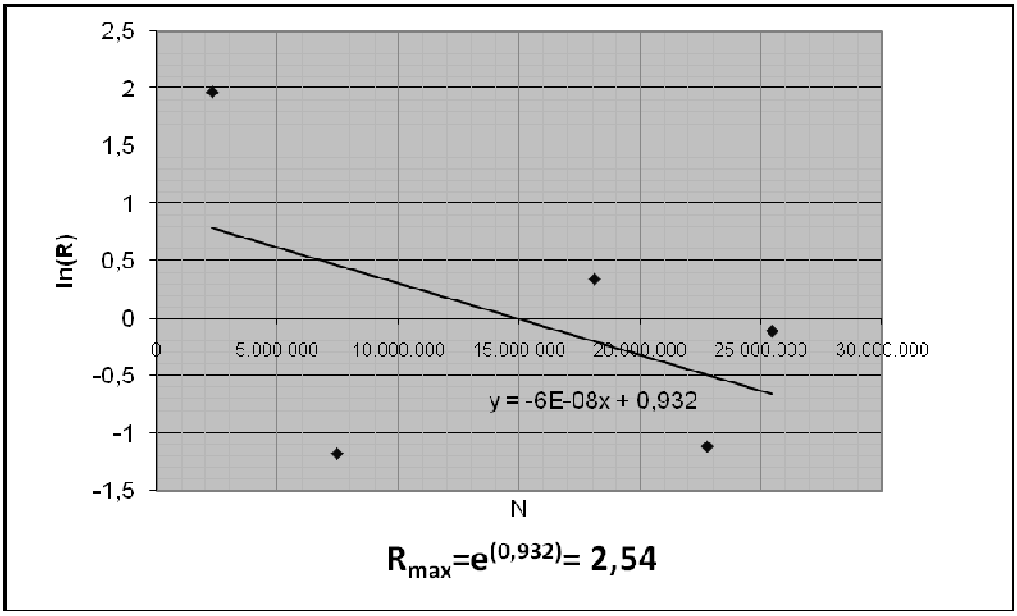


Figure 3-7 Rmax estimation for Site 1

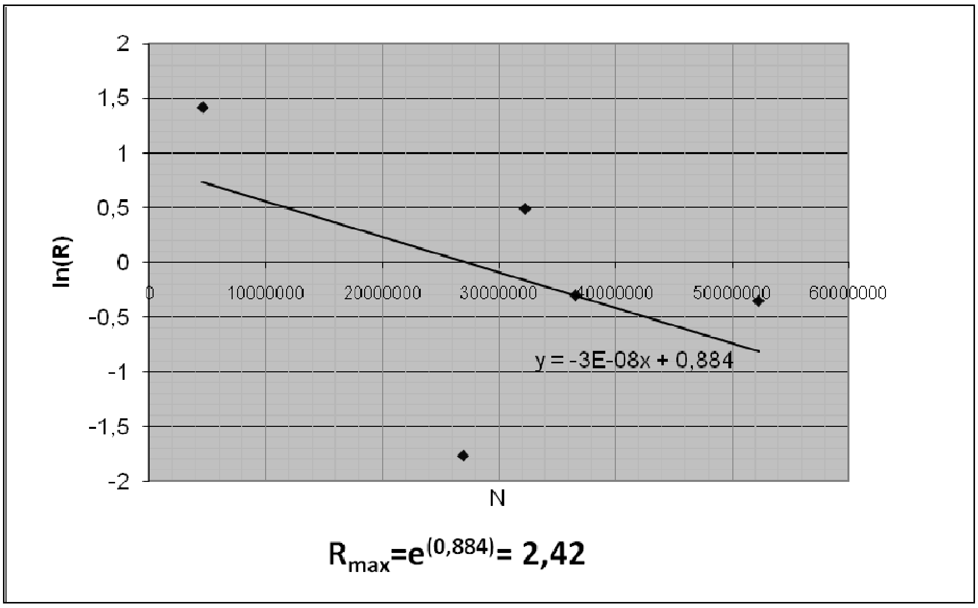


Figure 3-8 Rmax estimation for Site 2

As a result of these derivations Rmax is estimated as 2.54 for Site 1 and is estimated as 2.42 for Site 2.

3.6.4 Stochasticity and Catastrophes

Integration of stochasticity to the model is done by adding environmental stochasticity as a demographic stochasticity that affects all vital rates.

Incorporation of catastrophes to the model is required detailed information like the frequency of catastrophe, the probability of catastrophe, and also on which demographic parameters and stages are affected to a what extent. In this model, drought and disease are incorporated as natural catastrophes since populations experienced both events once throughout study years (0.8 % incidence at every 5 years) that affects both Sites in a similar way.

3.7 Results of Simulation Scenarios

3.7.1 Site 1 MODELS

3.7.1.1 Site 1 Model S2

Scenario 1: Temporal trend in K

The scenario 1 trajectory shows that even density dependence creates a decreasing tendency at high population sizes, it can be stabilized around 6 millions. But mean to extinction risk is 95.3 years.

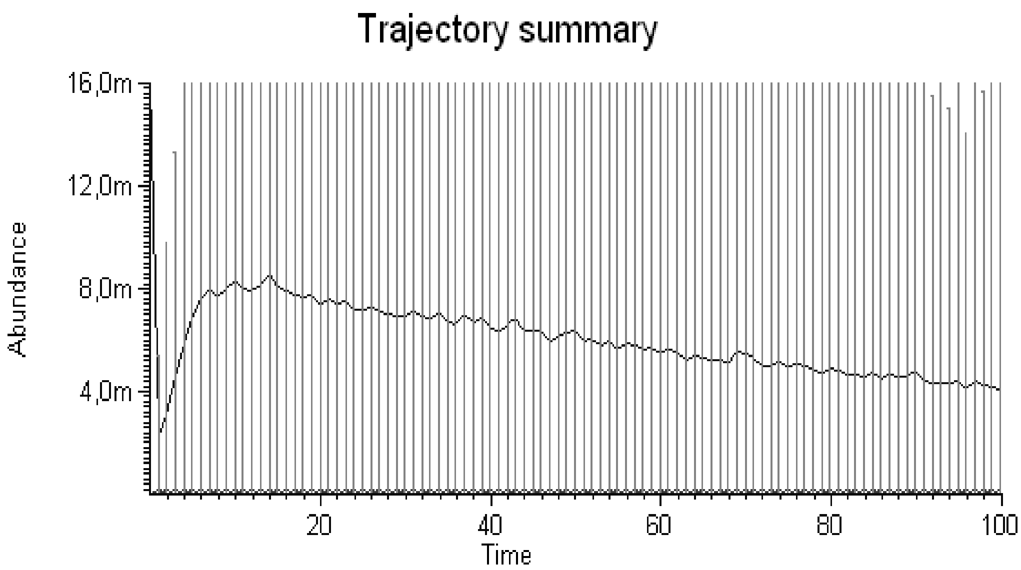


Figure 3-9. Site 1-S2_Scenario 1, Population Trajectory

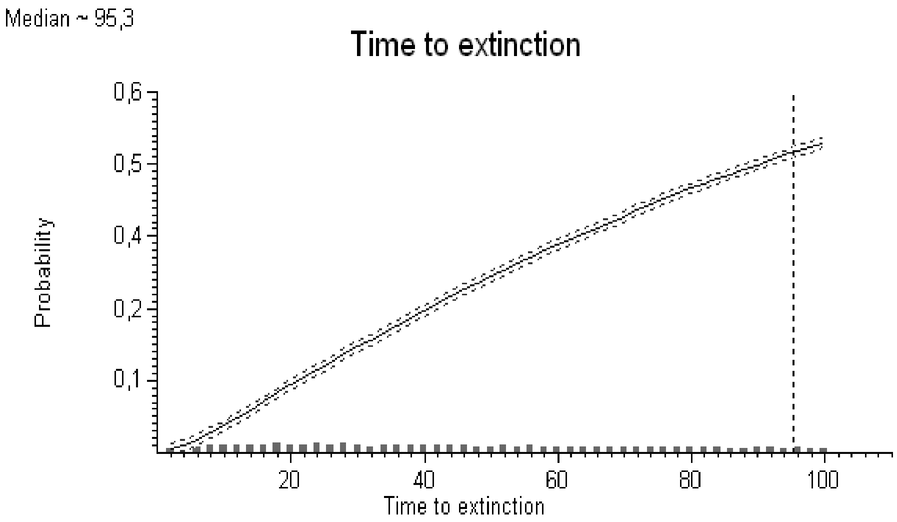


Figure 3-10. Site 1-S2_Scenario 1, Time to Quasi-Extinction Curve

Scenario 2: *Catastrophe*

The trajectory shows that after a rapid decline to few millions, population is decreasing to its *mean time to extinction* within 15,3 years which is more clearly illustrated in Figure 3-12.

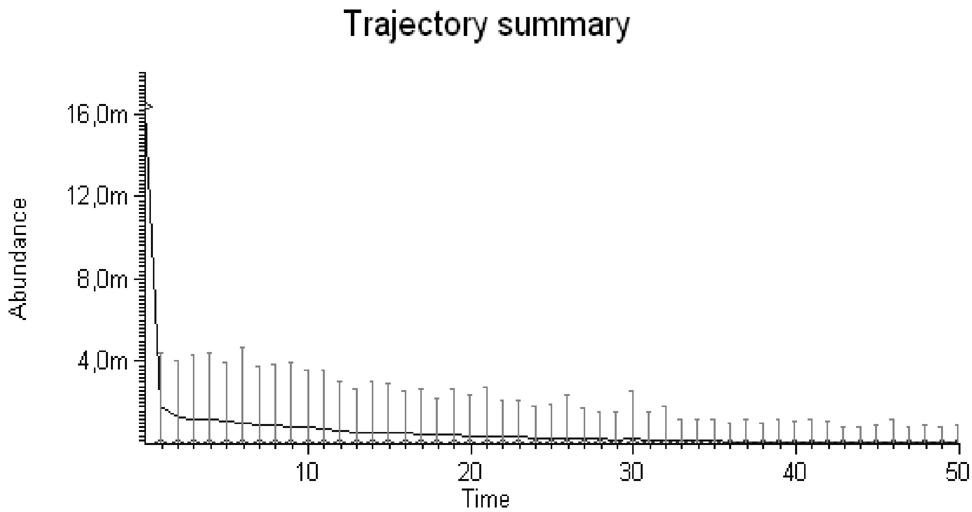


Figure 3-11. Site 1-S2_Scenario 2, Snapshot of Population Trajectory

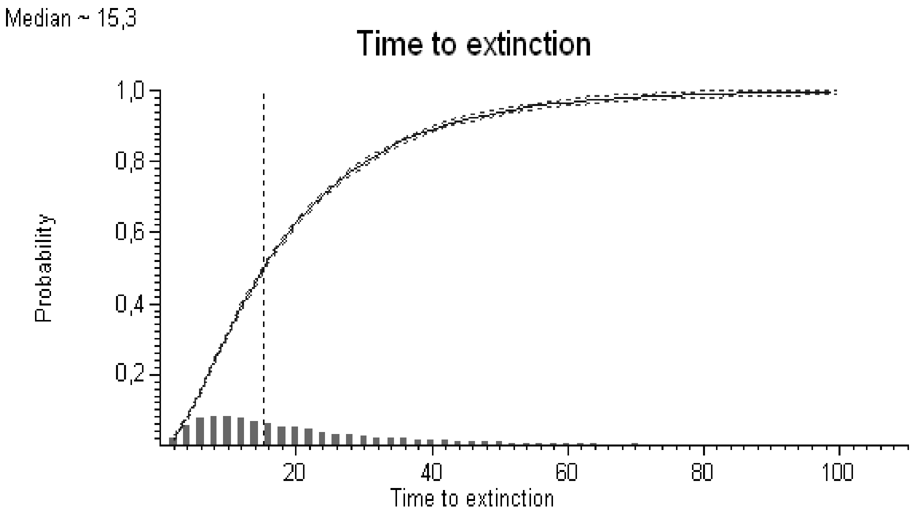


Figure 3-12. Site 1-S2_Scenario 2, Time to Quasi-Extinction Curve

Scenario 3: *Catastrophe* + Tillage (bf)

Pop trajectory shows that after a rapid decline to few millions, population is decreasing frequently to mean time to extinction within 12,1 years (Figure 3-14).

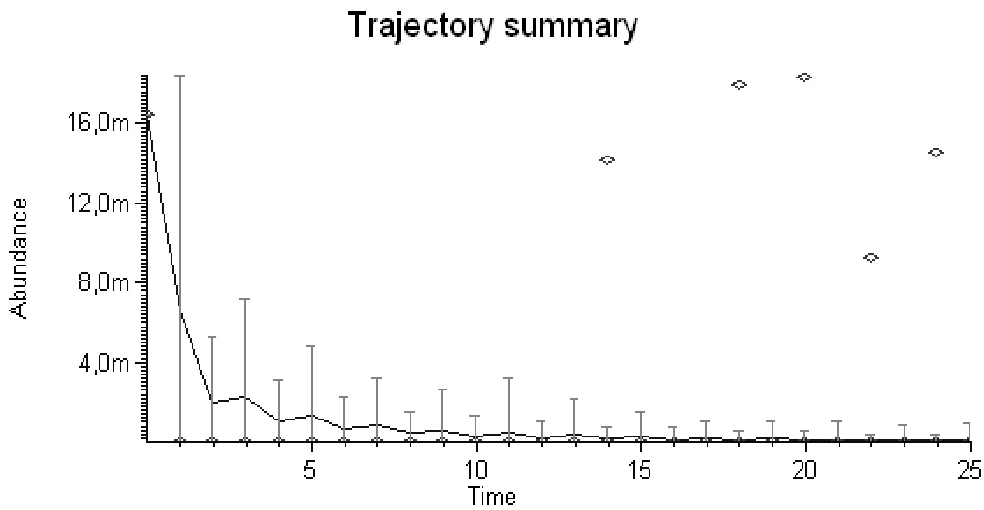


Figure 3-13. Site 1-S2_Scenario 3, Snapshot of Population Trajectory

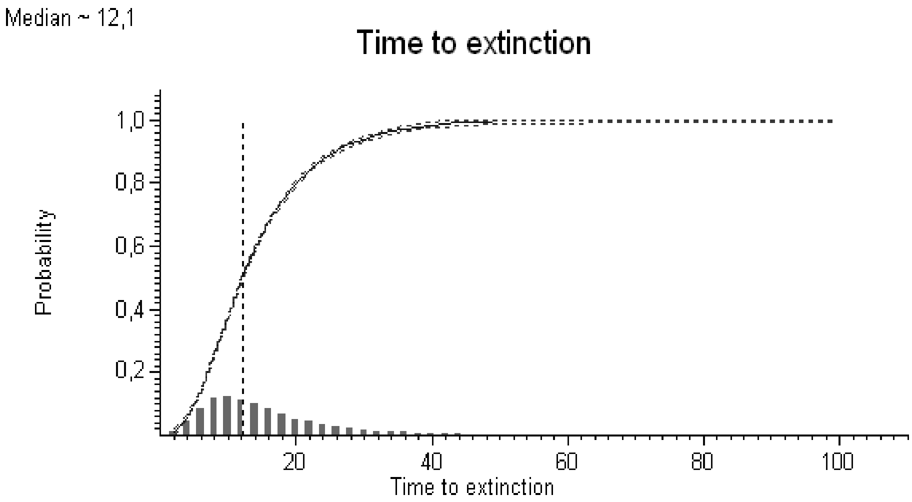


Figure 3-14. Site 1-S2_Scenario 3, Time to Quasi-Extinction Curve

Scenario 4: *Catastrophe* + tillage + herbicide

Population trajectory strictly declines to a few hundred thousands. And just within 3,8 years population goes to extinct (Figure 3-16).

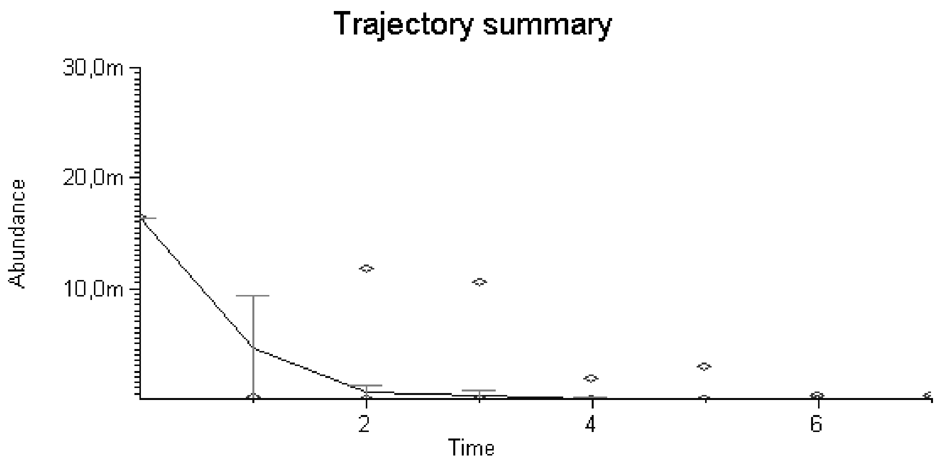


Figure 3-15. Site 1-S2_Scenario 4, Snapshot of Population Trajectory

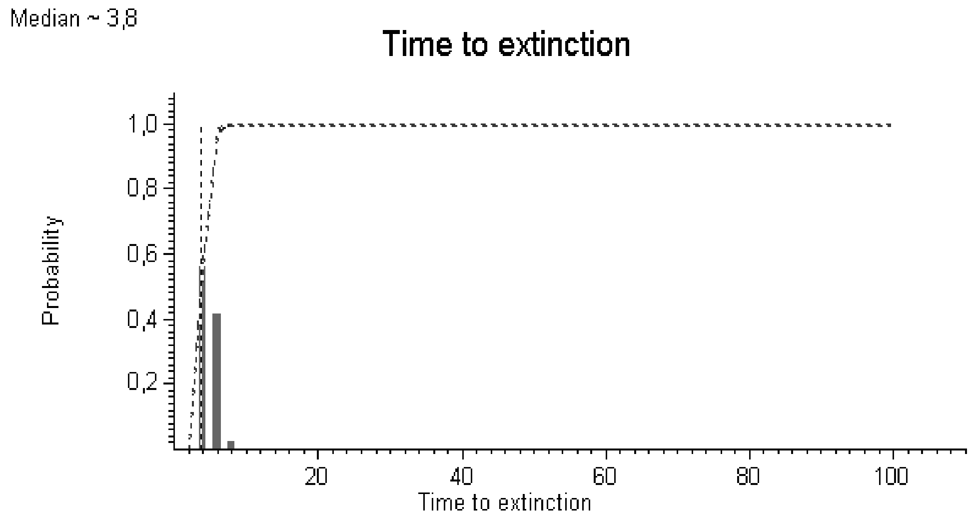


Figure 3-16. Site 1-S2_Scenario 4, Time to Quasi-Extinction Curve

Scenario 5: *Catastrophe* + Tillage + Herbicide +Stubble Burn

This is the worst scenario that the species can be faced with but negative effects of stubble burn do not create too much pressure on the above pessimistic scenario 4 because the agriculture with herbicide itself is already fatal.

Since the stubble burn practice is not a current threat and it obvious that for all models Scenario 5 leads to ultimate extinction hereafter this scenario results' will not be given.

Scenario 6: *Catastrophe* + Tillage (Management)

The pop trajectory shows that after an initial decreasing, population is stabilized around 6 millions even catastrophes at every 5 years just creates a slightly decreasing trend. Positive effect of tillage can be seen more clearly in Figure 3-18.

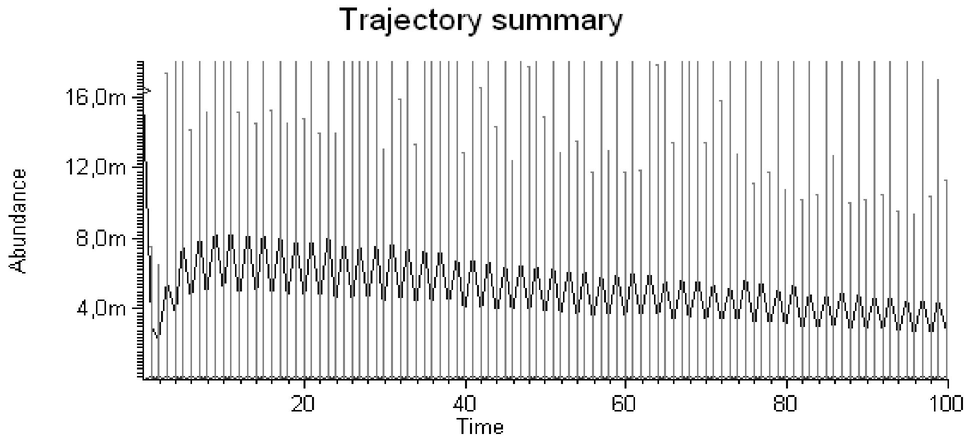


Figure 3-17. Site 1-S2_Scenario 6, Population Trajectory

Following fig. illustrates that this management action can only decrease higher extinction risks down to 0.50 in 100 years.

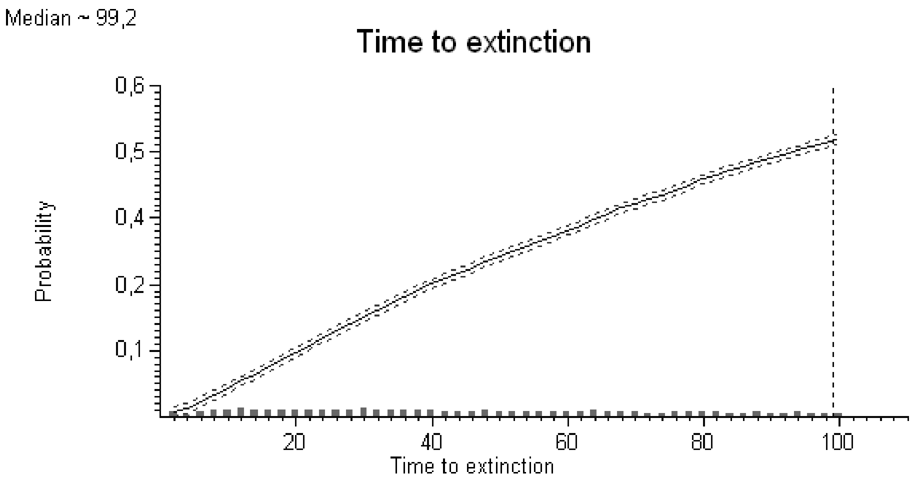


Figure 3-18. Site 1-S2_Scenario 6, Time to Quasi-Extinction Curve

3.7.1.2 Site 1 Model C2

Scenario 1: Temporal trend in K

The trajectory shows that population sizes approach to the ceiling, and but just reach 15 millions and remains at that level under the conditions of no any natural catastrophes, anthropogenic factors and management options. And the probability of extinction in 100 years is less than 0.01.

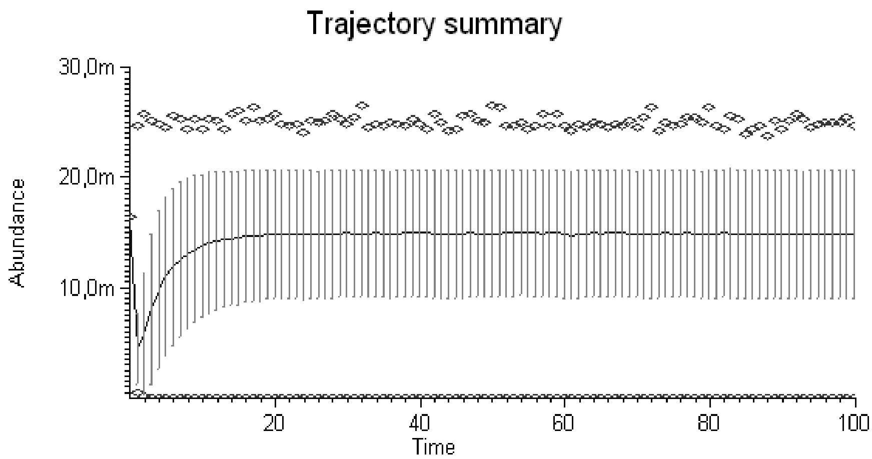


Figure 3-19. Site 1-C2_Scenario 1, Population Trajectory

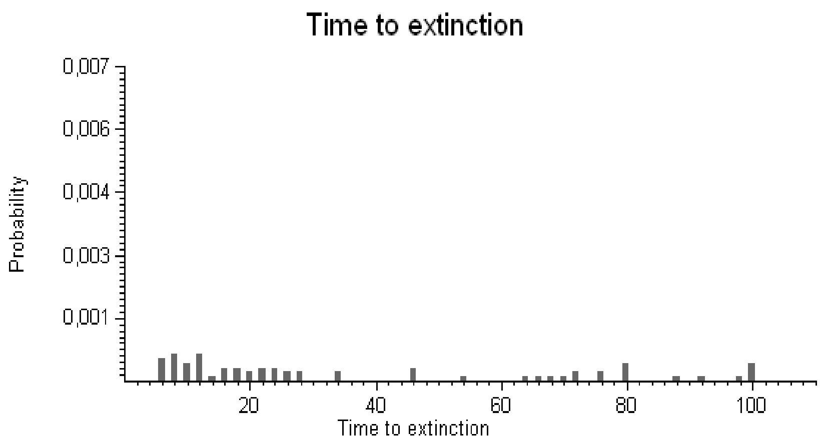


Figure 3-20. Site 1-C2_Scenario 1, Time to Quasi-Extinction Curve

Scenario 2: *Catastrophe*

The trajectory shows that population declines rapidly to a few millions, and downs to *mean time to extinction* in 11 ,3 years which is more clearly illustrated in Figure 3-21, Figure 3-22.

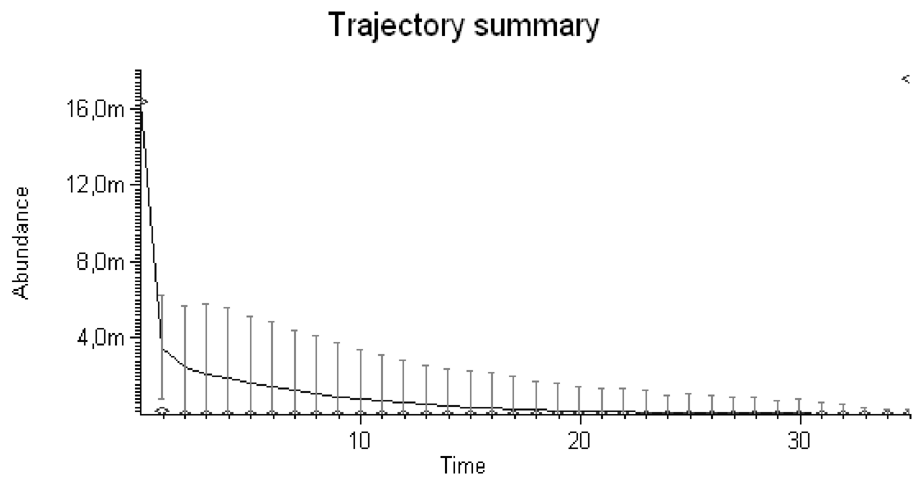


Figure 3-21. Site 1-C2_Scenario 2, Snapshot of Population Trajectory

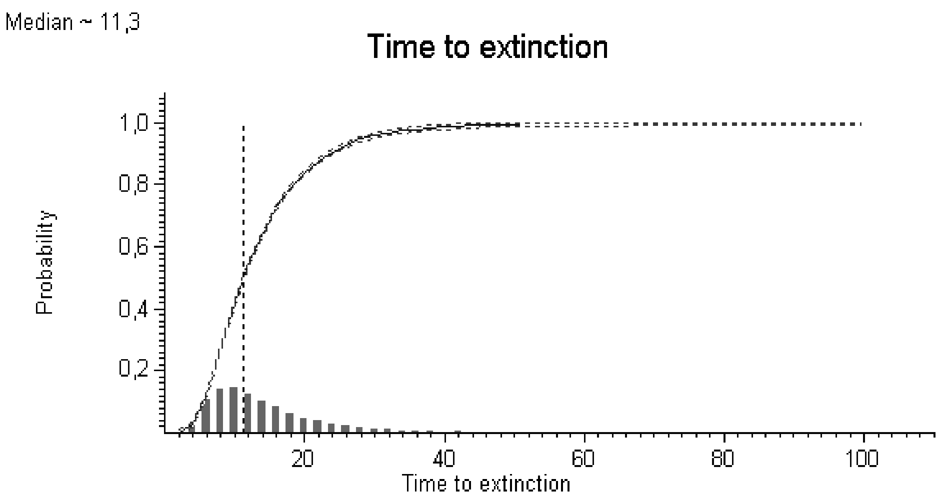


Figure 3-22. Site 1-C2_Scenario 2, Time to Quasi-Extinction Curve

Scenario 3: *Catastrophe* + Tillage (bf)

Pop trajectory shows that population is decreasing frequently with a cyclic trend of tillage and its mean time to extinction is 11,2 years (Figure 3-23, Figure 3-24).

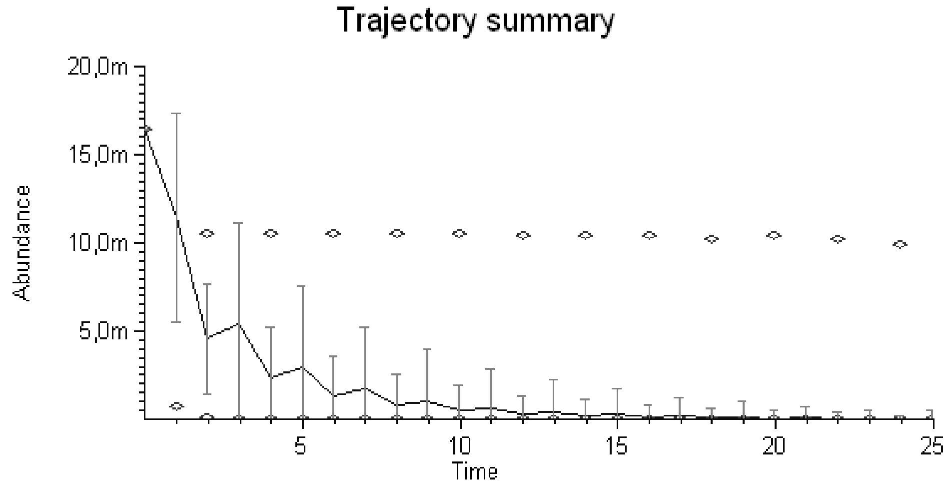


Figure 3-23. Site 1-C2_Scenario 3, Snapshot of Population Trajectory

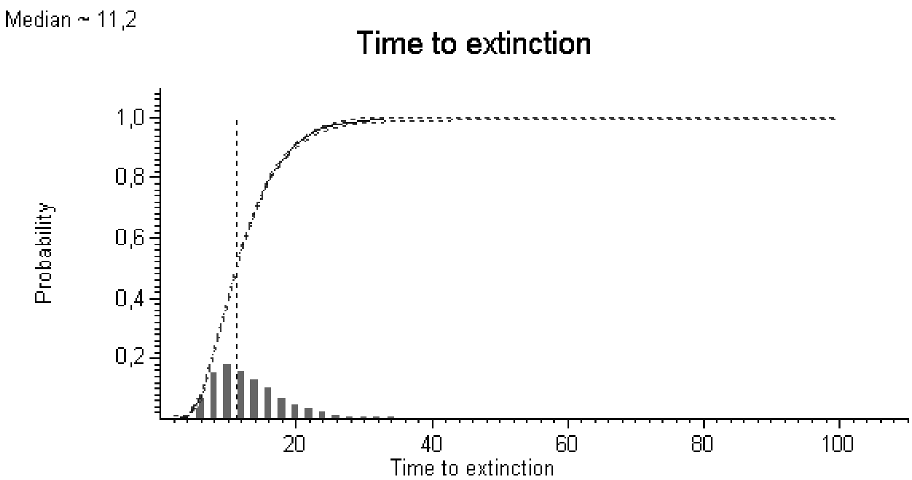


Figure 3-24. Site 1-C2_Scenario 3, Time to Quasi-Extinction Curve

Scenario 4: *Catastrophe* + tillage + herbicide

Population trajectory strictly declines to a few hundred thousands. And just within 4 years population goes to extinct (Figure 3-25, Figure 3-26).

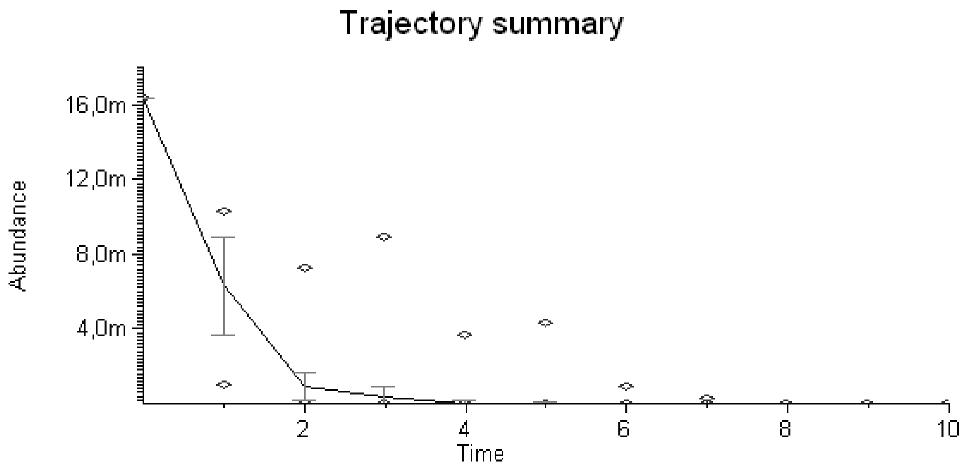


Figure 3-25. Site 1-C2_Scenario 4, Snapshot of Population Trajectory

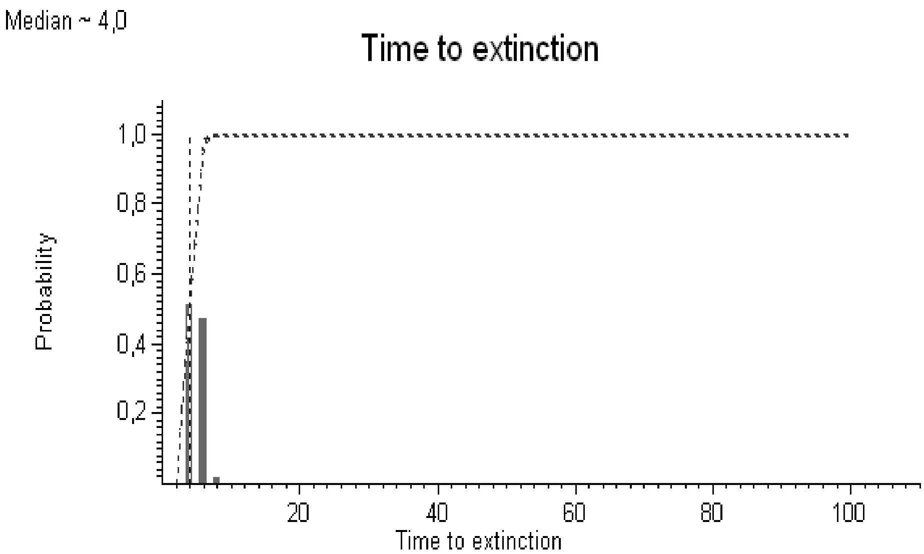


Figure 3-26. Site 1-C2_Scenario 4, Time to Quasi-Extinction Curve

Scenario 6: *Catastrophe* + Tillage (Management)

The trajectory shows that population sizes approach to the ceiling, and but just reach 10 millions and remains at that level. And the probability of extinction in 100 years is less than 0.1.

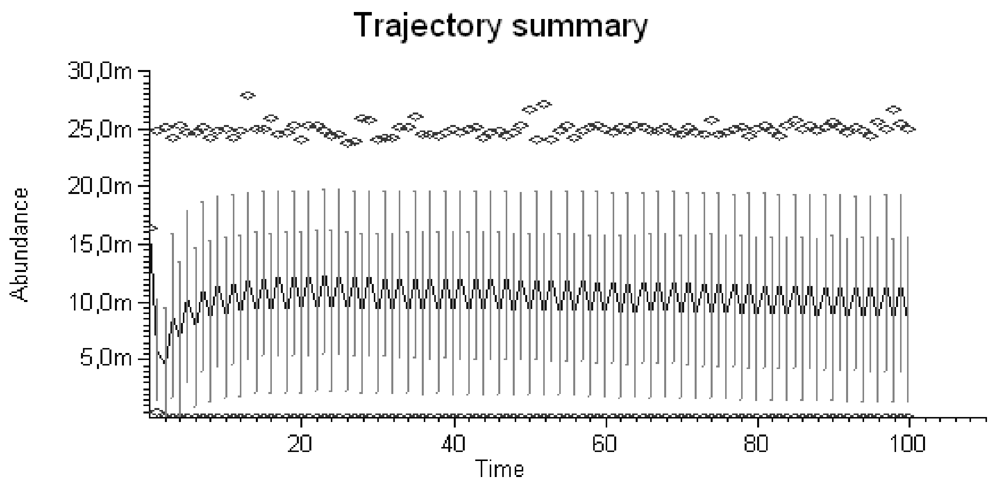


Figure 3-27. Site 1-C2_Scenario 6, Population Trajectory

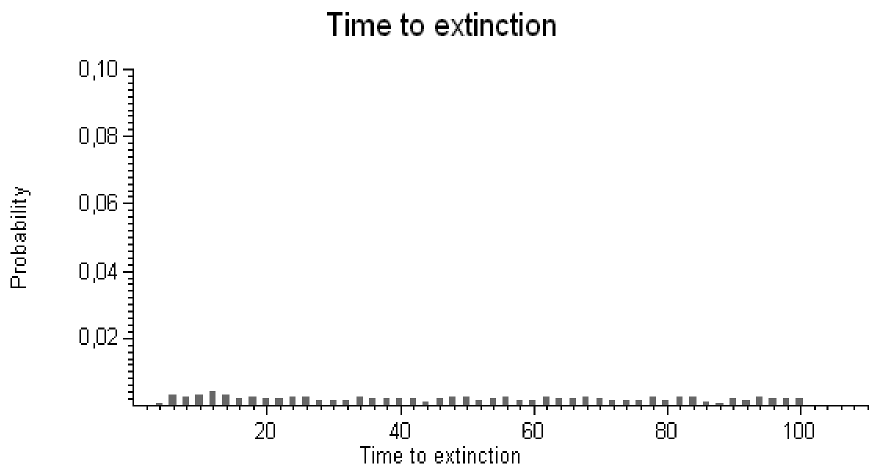


Figure 3-28. Site 1-C2_Scenario 6, Time to Quasi-Extinction Curve

3.7.2 Site 2 MODELS

3.7.2.1 Site 2 Model S1

Scenario 1: Temporal trend in K

The scenario 1 trajectory shows that the population size is stabilized at around 20 millions under the conditions of no any natural catastrophes, anthropogenic factors and management options.

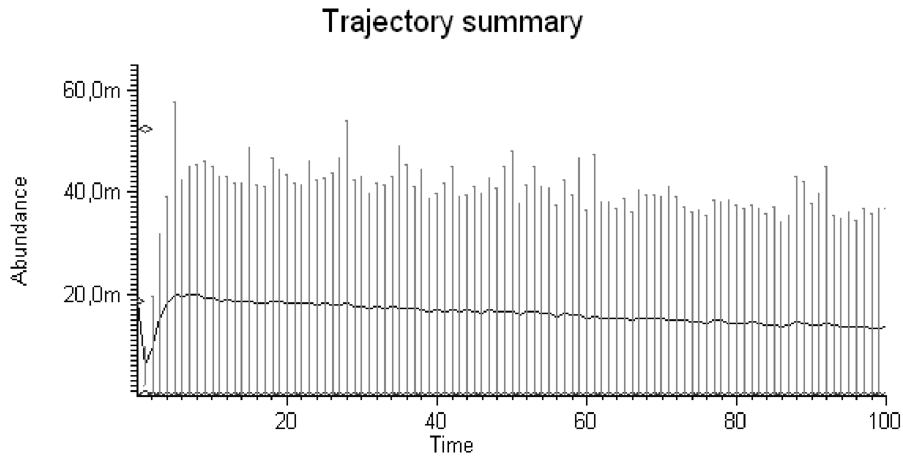


Figure 3-29. Site 2-S1_Scenario1, Population Trajectory

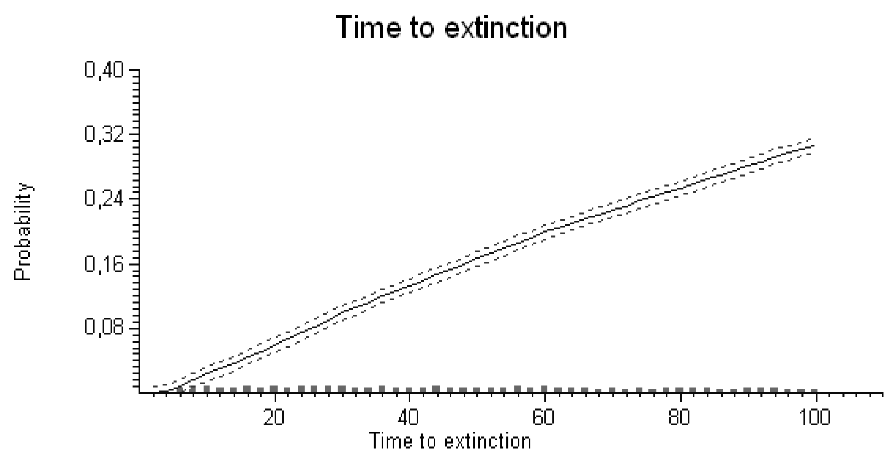


Figure 3-30. Site 2-S1_ Scenario 1, Time to Quasi-Extinction Curve

Scenario 2: *Catastrophe*

The trajectory shows that after a sharp decline to few millions, population is decreasing to its *mean time to extinction* (50% extinction probability) within 30 years which is more clearly illustrated in Figure 3.32

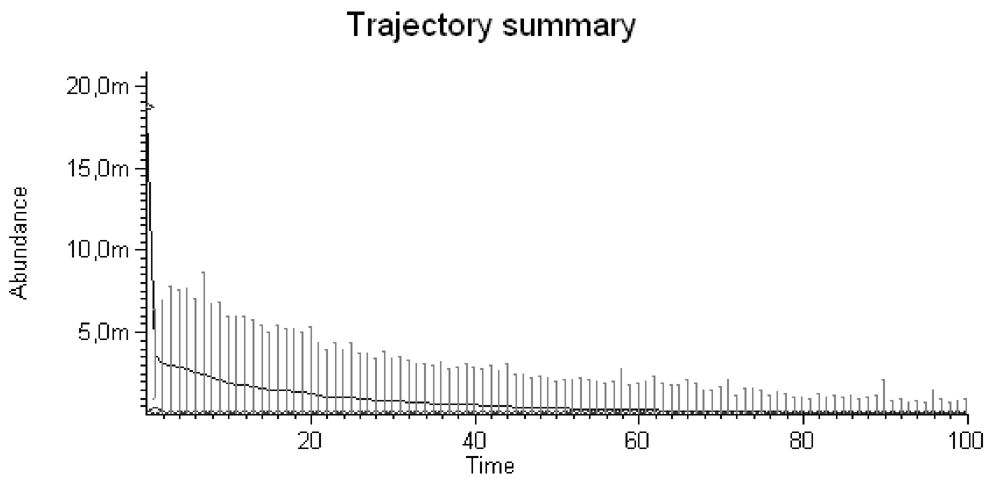


Figure 3-31. Site 2-S1_*Catastrophe*, Population Trajectory

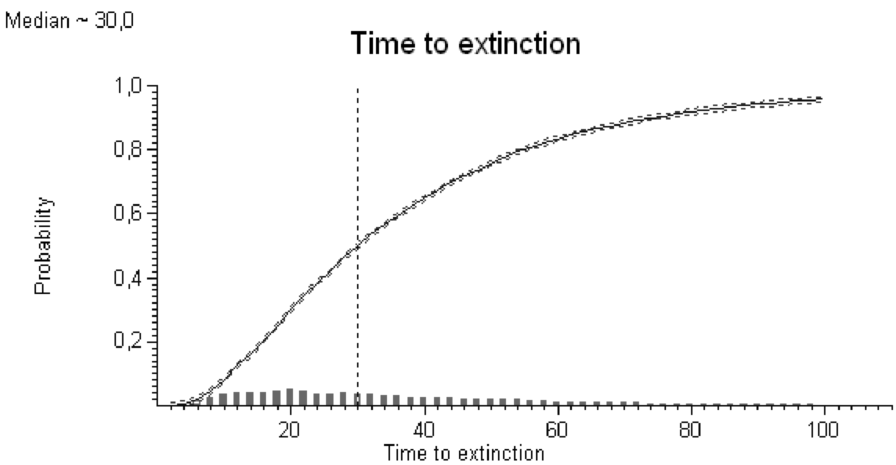


Figure 3-32. Site 2-S1_*Catastrophe*, Time to Quasi-Extinction Curve

Scenario 3: *Catastrophe* + Tillage (bf)

Pop trajectory shows that tillage initiates a cyclic trend but within a few years population sizes can not recover from the low densities when it combines with decreasing effect of natural catastrophe every 5 year. So population is decreasing sharply within 19 years as reaching its mean time to extinction (Figures 3.33, 3.34, 3.35)).

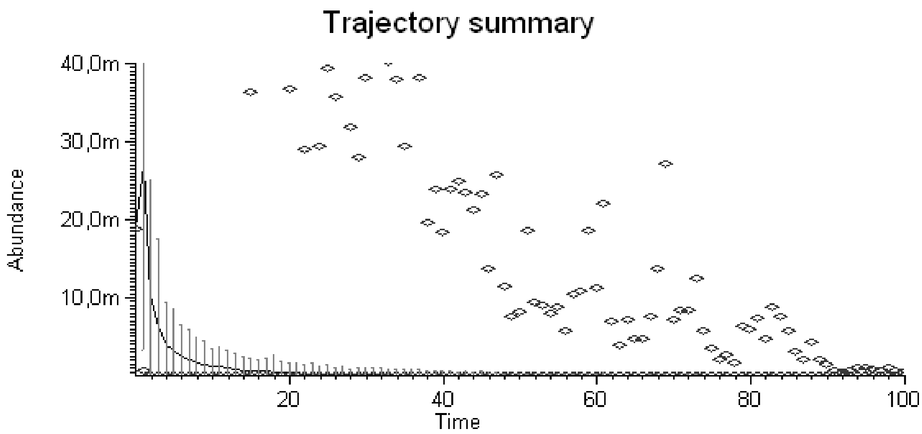


Figure 3-33. Site 2-S1_Scenario 3, Population Trajectory

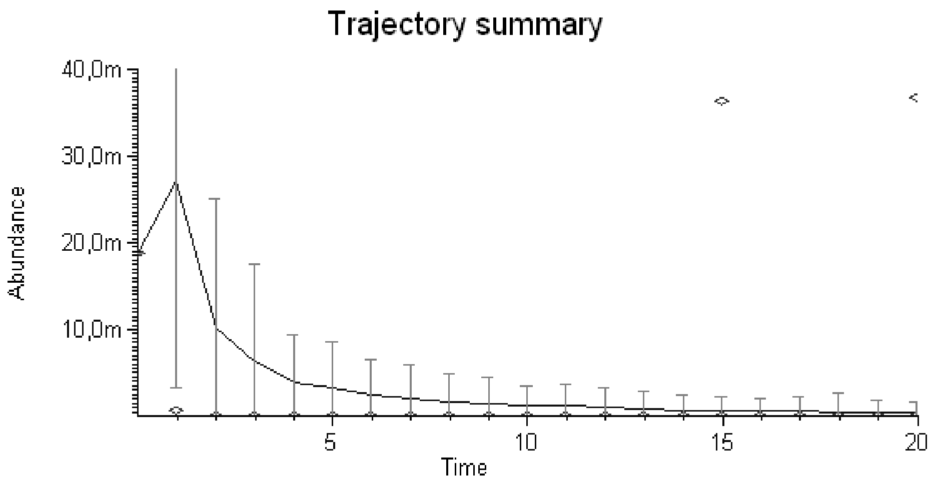


Figure 3-34. Site 2-S1_Scenario 3, Snapshot of Population Trajectory

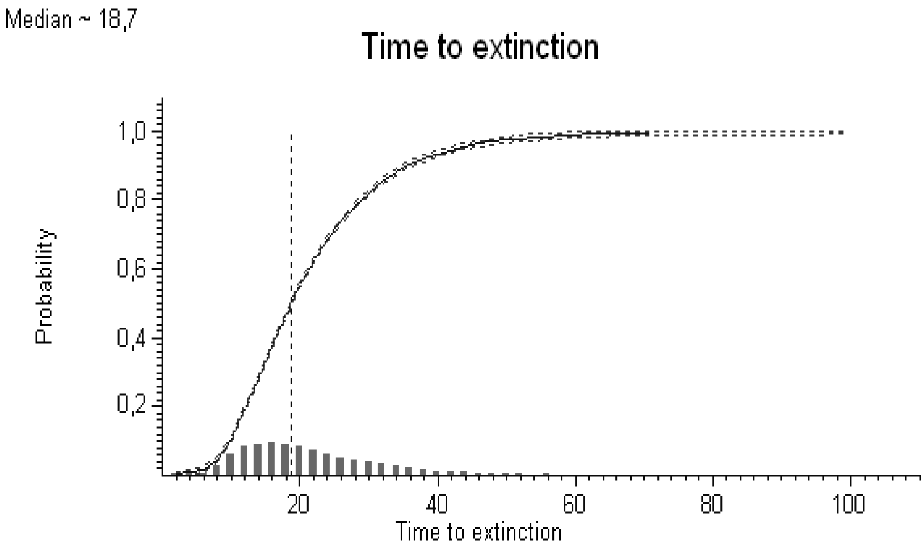


Figure 3-35. Site 2-S1_, Scenario 3, Time to Quasi-Extinction Curve

Scenario 4: *Catastrophe* + tillage + herbicide

Population trajectory declines severely -even starting with the positive effect of tillage due to extremely negative effects of herbicide application in the consecutive year. And just within 4,3 years population goes to extinct (Figure 3.36, 3.37).

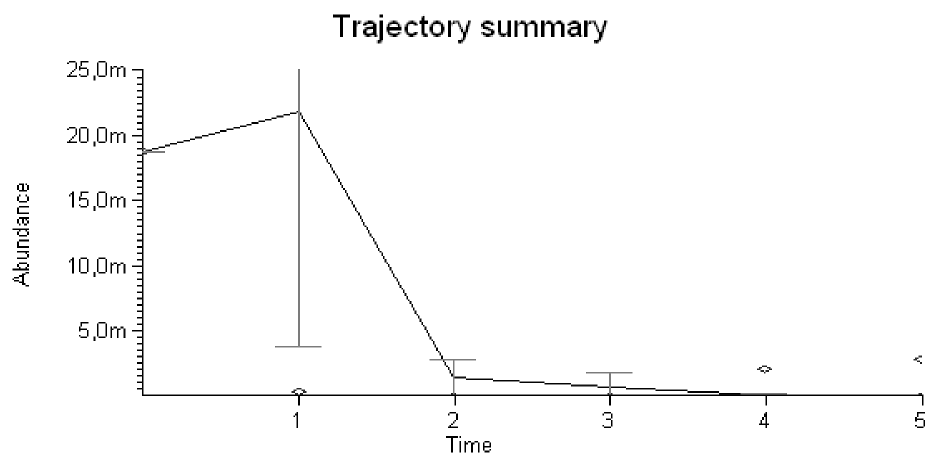


Figure 3-36. Site 2-S1_Scenario 4, Snapshot of Population Trajectory

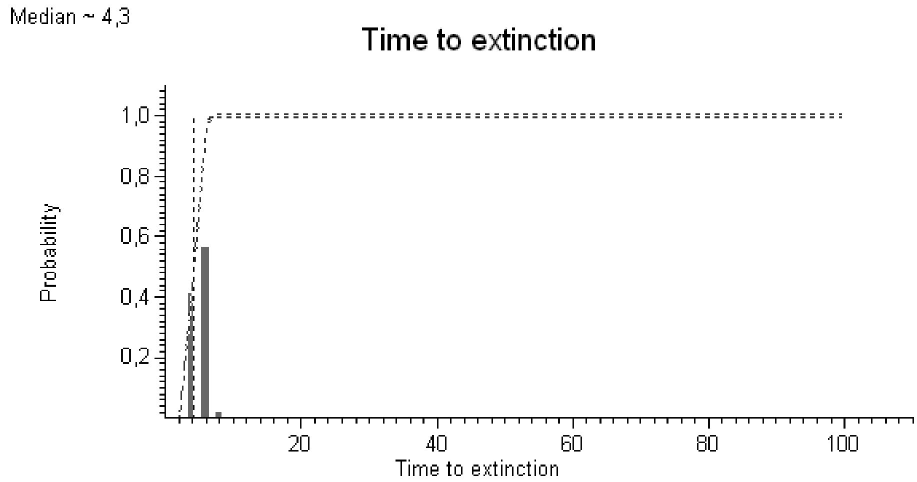


Figure 3-37. Site 2-S1_, Scenario 4, Time to Quasi-Extinction Curve

Scenario 6: *Catastrophe* + Tillage (Management)

The trajectory shows that after an initial decrease, the population is stabilized around 15 million even catastrophes at every 5 years just creates a slightly decreasing trend. Positive effects of tillage (management) can be seen more clearly in Figure 3.39 as cyclic trends.

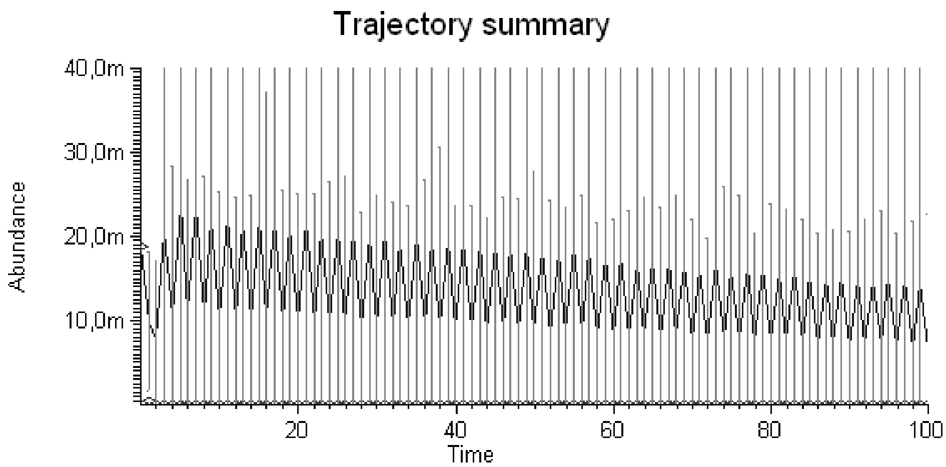


Figure 3-38. Site 2-S1_Scenario 6, Population Trajectory

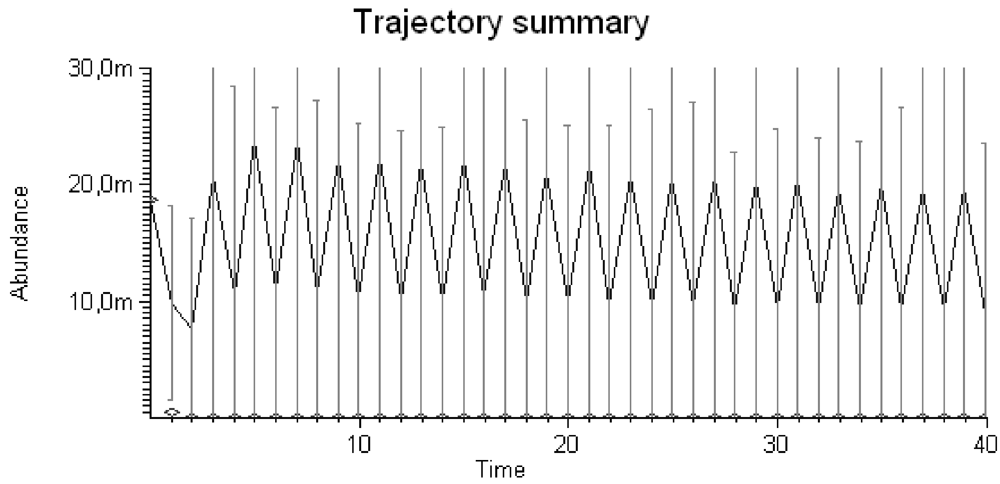


Figure 3-39. Site 2-S1_Scenario 6, Snapshot of Population Trajectory

Following fig. illustrates that this management action can only decrease higher extinction risks down to 0.37 in 100 years.

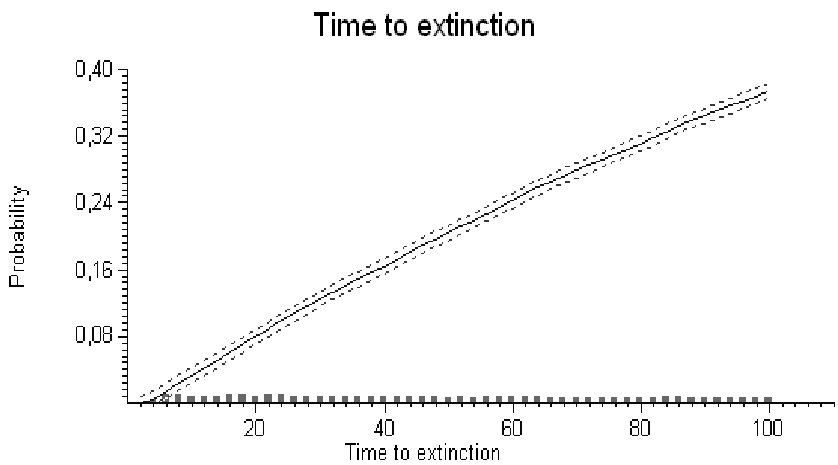


Figure 3-40. Site 2-S1_Scenario 6, Time to Quasi-Extinction Curve

3.7.2.2 Site 2 Model C1

Scenario 1: Temporal trend in K

The scenario 1 trajectory shows that the population size reaches the ceiling, and remains at that level under the conditions of no any natural catastrophes, anthropogenic factors and management options.

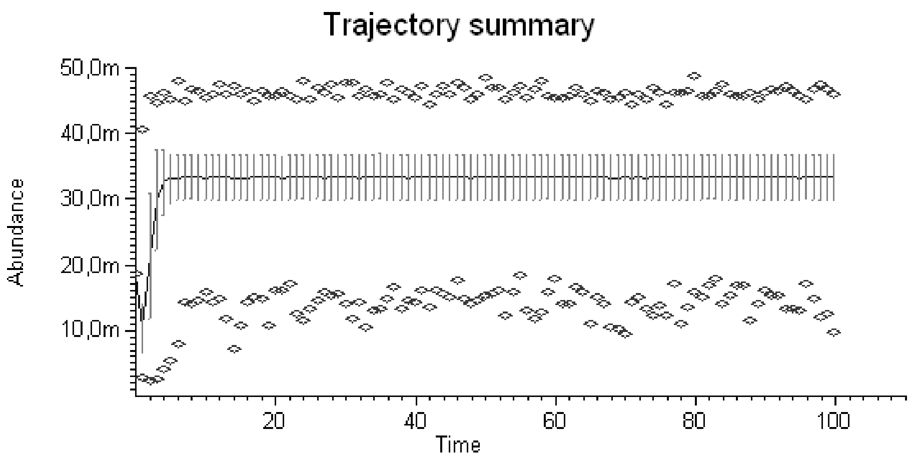


Figure 3-41 Site 2-C1_Scenario 1, Population Trajectory

Scenario 2: *Catastrophe*

The trajectory shows that the population size is stabilized at around 10 millions under natural conditions. And the Figure 3-42 tells that if there are no anthropogenic factors, extinction risk of population in 100 years is 0.30 under natural catastrophes like disease, drought.

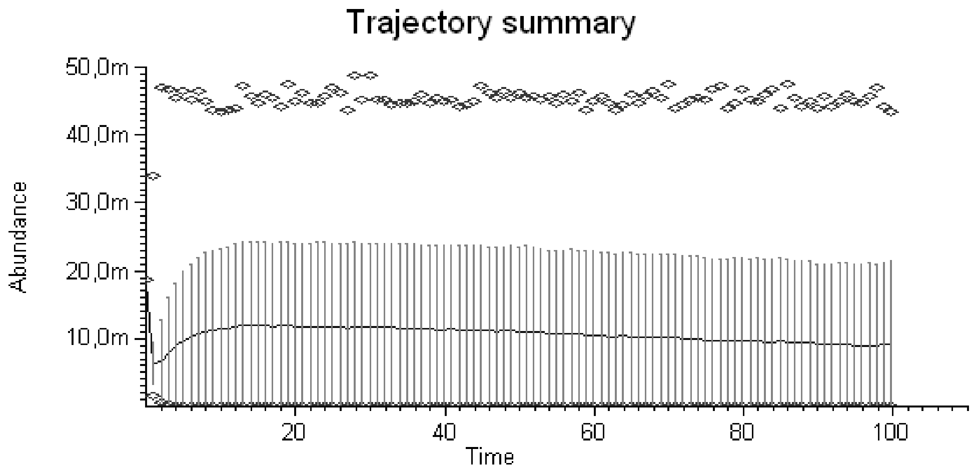


Figure 3-42. Site 2-C1_Scenario 2, Population Trajectory

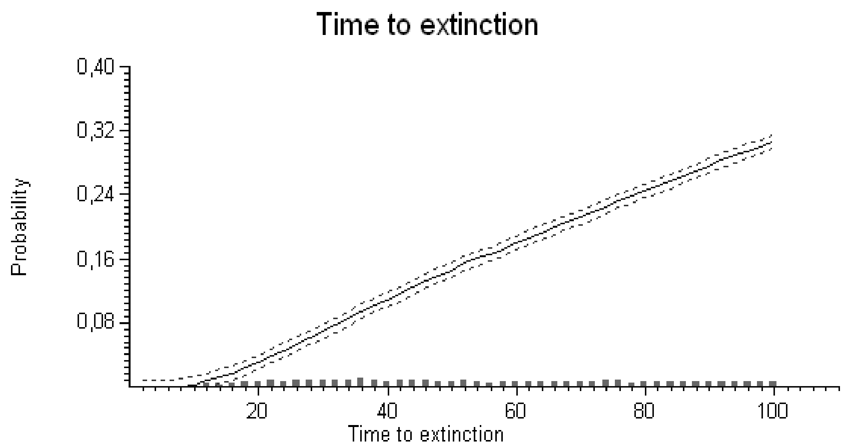


Figure 3-43. Site 2-C1_Scenario 2, Time to Quasi-Extinction Curve
Scenario 3: *Catastrophe* + Tillage (bf)

Pop trajectory shows that tillage initiates a cyclic trend but within a few years population sizes can not be recovered from the low densities and gradually decreasing due to combination of every 5 year decreasing effect of natural catastrophe finally falling to mean time to extinction within 47 years (Figures 3.45, 3.46).

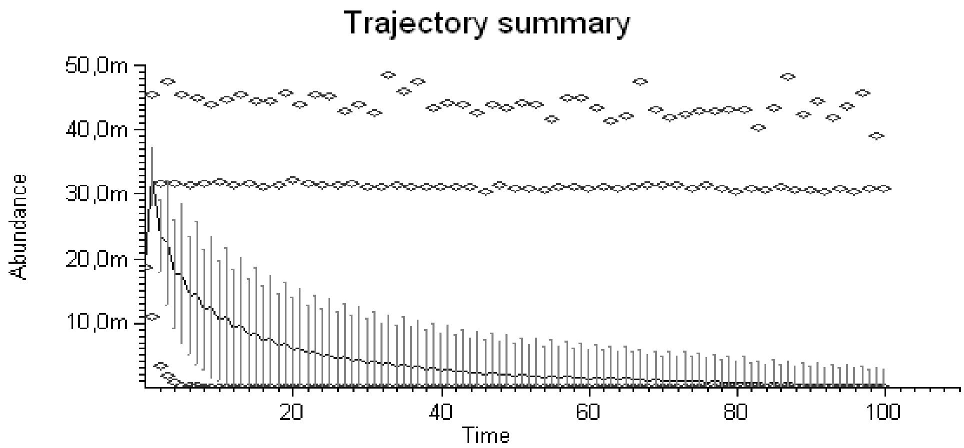


Figure 3-44. Site 2-C1_Scenario 3, Population Trajectory

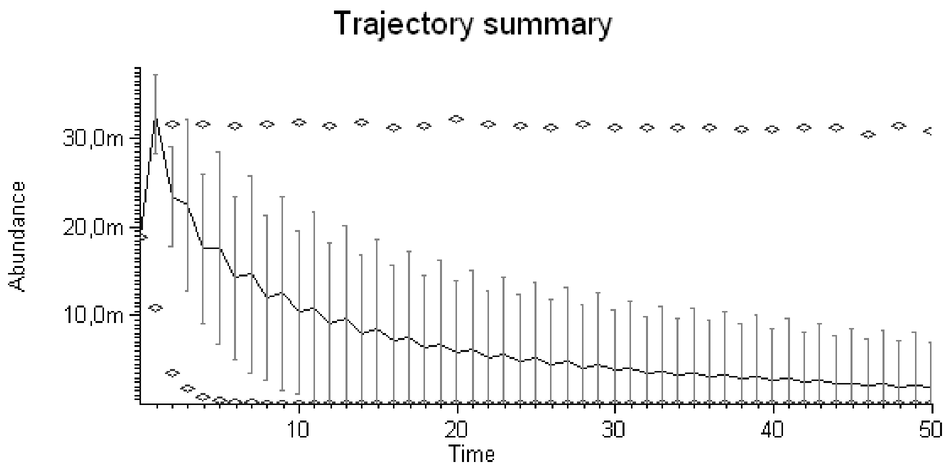


Figure 3-45. Site 2-C1_Scenario 3, Snapshot of Population Trajectory

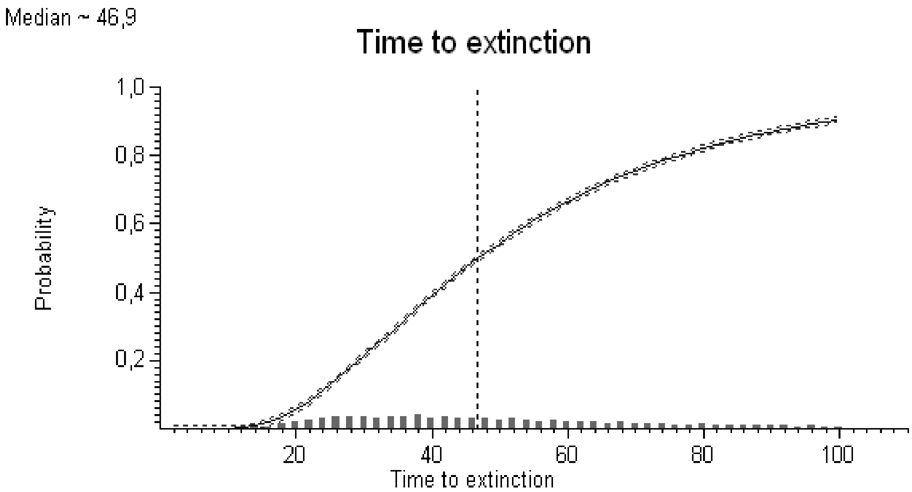


Figure 3-46. Site 2-C1_Scenario 3, Time to Quasi-Extinction Curve

Scenario 4: *Catastrophe* + tillage + herbicide

Despite the starting with the positive effect of tillage, population trajectory declines strictly due to extremely negative effects of herbicide application in the consecutive year. And mean time to extinction is 5.3 years (Figures 3.47, 3.48)).

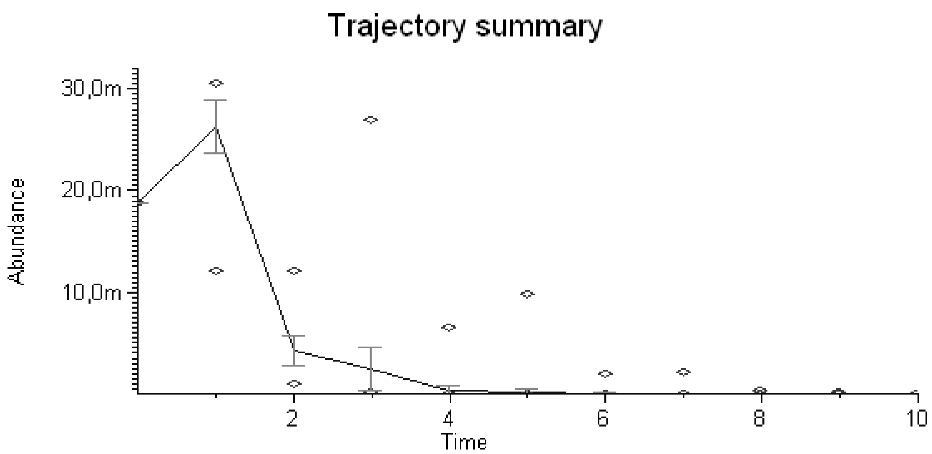


Figure 3-47. Site 2-C1_Scenario 4, Snapshot of Population Trajectory

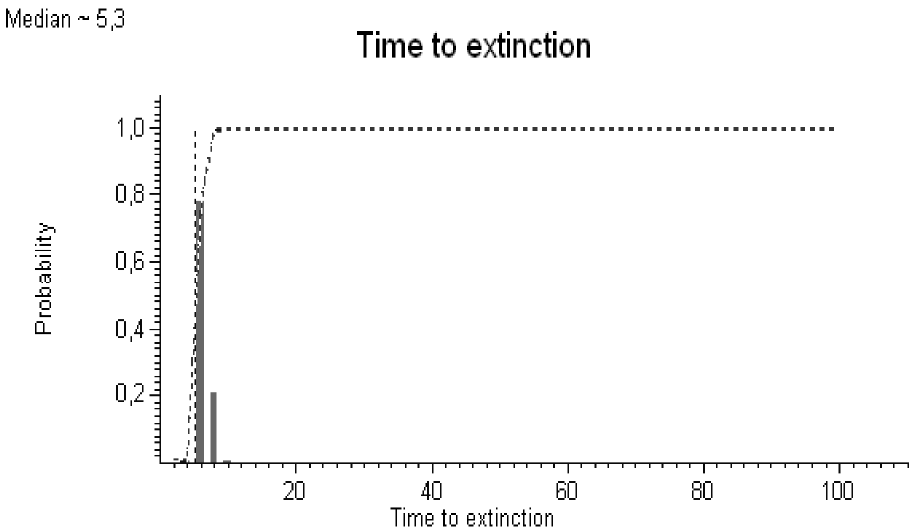


Figure 3-48. Site 2-C1_Scenario 4, Time to Quasi-Extinction Curve

Scenario 6: *Catastrophe* + Tillage (Management)

The trajectory shows that after a sharp increase within a few years, population reaches a steady state around 30 millions just below its ceiling.

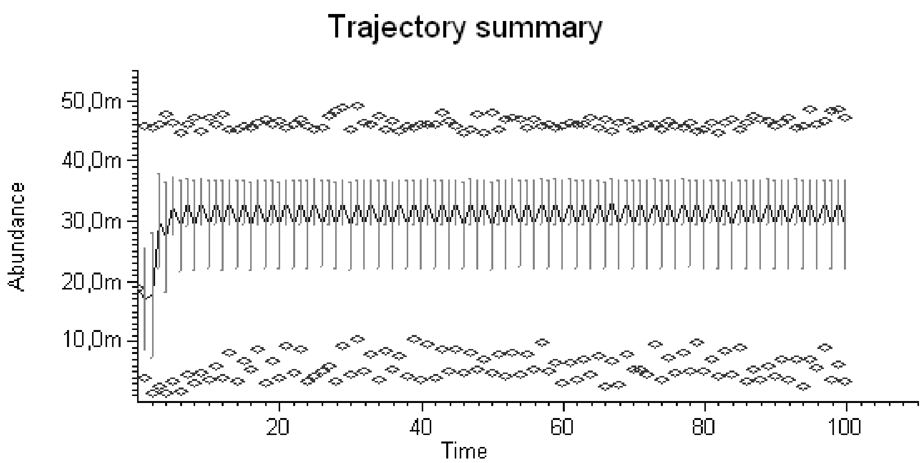


Figure 3-49. Site 2-C1_Scenario 6, Population Trajectory

3.8 RESULTS OF SENSITIVITY ANALYSES

3.8.1 Model Structure Uncertainty- Whole-Model Sensitivity Analysis

Sensitivity analysis is a process of dealing with the uncertainty. It measures the change in the models' predictions in response to changes in the model structure or to changes in the parameter values. In this study both model structure and parameter uncertainty are explored by risk-based sensitivity analysis which is based on population extinction risk or recovery chance.

In this study model uncertainty is explored by performing a whole-model sensitivity analysis to compare models' density dependence types with different levels of survival rate (S) under several scenarios. Hence, comparisons of scenarios of different models provide to evaluate the relative extinction risks.

Above simulation models are decided by performing sensitivity analysis for model uncertainty at three levels of survival values with two different density dependence types- scramble and ceiling. In the following part, the process of deciding and reducing of 6 models for each Site to more realistic ones, i.e. whole-model sensitivity analysis is explained.

3.8.2 Site 1 Model Sensitivity

For Site 1, population trajectories of Model S1 shows that population sizes are keeping at low levels but not reflecting any extinction risks despite bad scenarios (except for the farming with herbicide scenario). This can be explained as if the eigenvalue is below 1.0 as the case of Model S1 (0.72), scramble density dependence should not be used because results may be overly optimistic i.e. underestimated extinction risks.

Comparison of *Density dependence in R curves* for Site 1 Models illustrates that in Model S1 square marker lies below the density dependence curve, it may indicate that the density dependence may be an optimistic assumption that may lead to overestimation of population viability. Therefore, Model S2 showing the most appropriate relation to the density dependence in R curves (Figure 3.57) is taken as to represent the results of scenarios with scramble density dependence for Site 1.

When we look at the results of ceiling models of Site 1, Models C1 and C3 do not seem much realistic since former estimates quite high extinction risk even under the natural conditions (mean time to extinction is 4.5 years) and the latter does not estimates any extinction risks despite bad scenarios (except for the farming with herbicide scenario). This can also be drawn from the *Density dependence in R* curves (Figure 3.60); Model C2 showing the most appropriate relation is taken as to represent the results of scenarios with ceiling density dependence for Site 1.

As a result, Model S2 and Model C2 are considered to be discussed for the PVA conclusions Site 1 as comparing scramble density dependence and ceiling density dependence types.

3.8.3 Site 2 Model Sensitivity

The scramble type density dependence creates a decreasing tendency when the population reaches carrying capacity (K) or above. But if the population sizes at very high levels above the K is reached within a few years due to the very high eigenvalues so as the decrease from that high pop sizes will also be high. And these up and downs leads to a sharp declining trend to extinction within few years. This is the pattern is shown in the even in the base scenario trajectories of Model S2 and S3 for Site 2 (Figure 3.50, 3.51); sharp declines in early years that do not carry the population sizes to high values in the following years leads to extinction within few years. Comparison of *Density dependence in R curves* for Site 2 Models also illustrates that Model S2 and Model S3 have very high eigenvalues 8.35 and 14.10, respectively. These curves tell how well the stage matrix represents the conditions at the initial abundance based on the small red square marker (combination of the initial abundance and the eigenvalue), ideally the red square marker lies on the curve. But it is far above the curve in Model S2 and Model S3. Therefore, they are considered to be less realistic and Model S1 has been taken as to represent the results of scenarios with scramble density dependence for Site 2.

Under the ceiling type of density dependence, the population grows exponentially until it reaches the ceiling, and remains at that level until a population decline takes it below the ceiling. The growth or decline or the population at each time step of the simulation depends on the stage matrix and its variation.

When we look at the Ceiling models of Site 2, population trajectories of Model C1 shows more realistic trends due to its lower eigenvalue compared to Models C2 and C3 as keeping population sizes below the ceiling and reflecting extinction risks. Whereas Models C2 and C3 represent quite optimistic trends as having higher eigenvalues that keep population sizes at the ceiling and this may underestimate the extinction risks because they do not estimates any extinction risks despite bad scenarios (except for the farming with herbicide scenario). Therefore, Model C1 showing the most appropriate relation to the density dependence in R curves (Figure 3.53) is taken as to represent the results of scenarios with ceiling density dependence for Site 2.

As a result, Model S1 and Model C1 are considered to be discussing for the PVA conclusions Site 2 as comparing scramble density dependence and ceiling density dependence types.

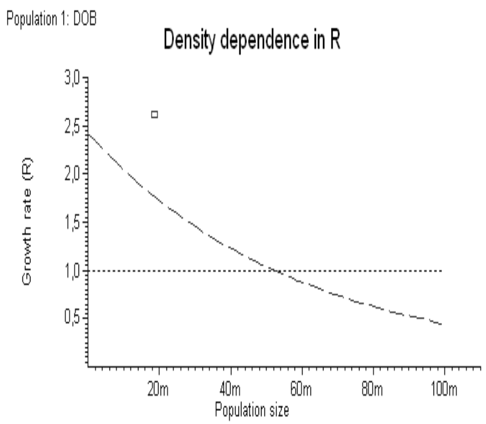


Figure 3-50 Model S1 (λ = 2.61) for Site 2

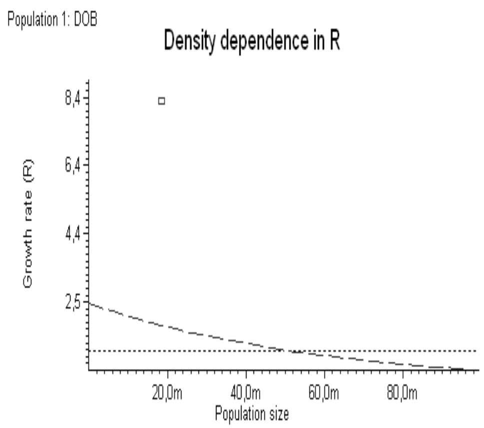


Figure 3-51 Model S2 (λ = 8.35) for Site 2

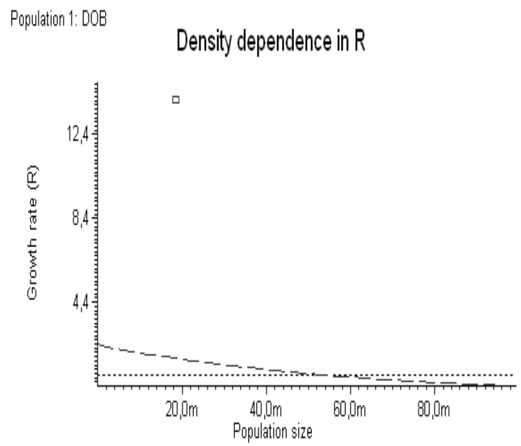


Figure 3-52 Model S3 (λ = 14.1) for Site 2

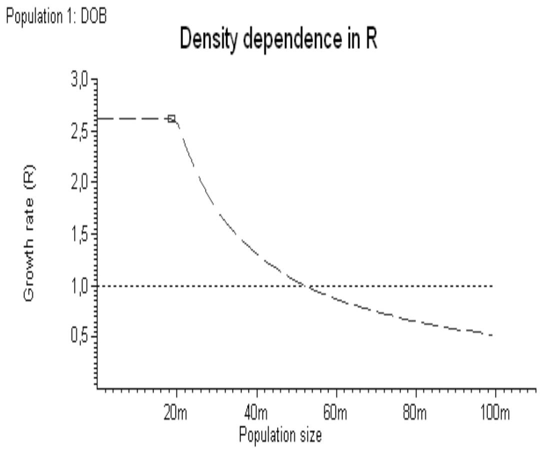


Figure 3-53 Model C1 (λ = 2.61) for Site 2

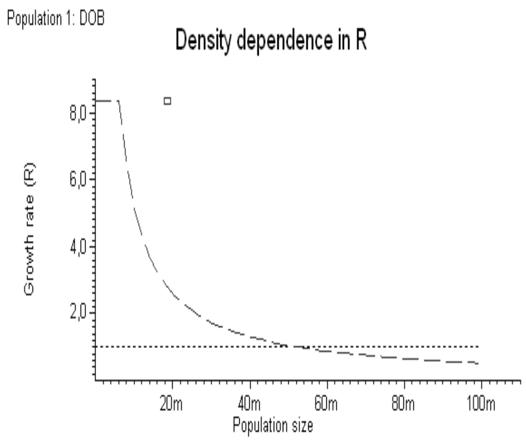


Figure 3-54 Model C2 (λ = 8.35) for Site 2

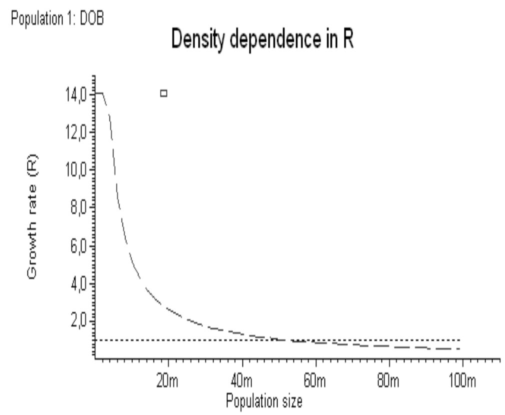


Figure 3-55 Model C3 (λ = 14.1) for Site 2

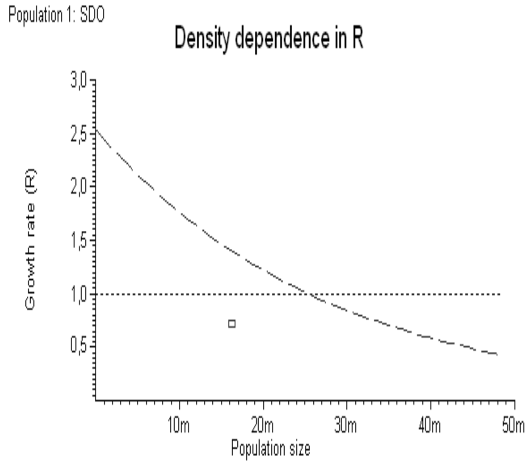


Figure 3-56 Model S1 (λ =0.714) for Site 1

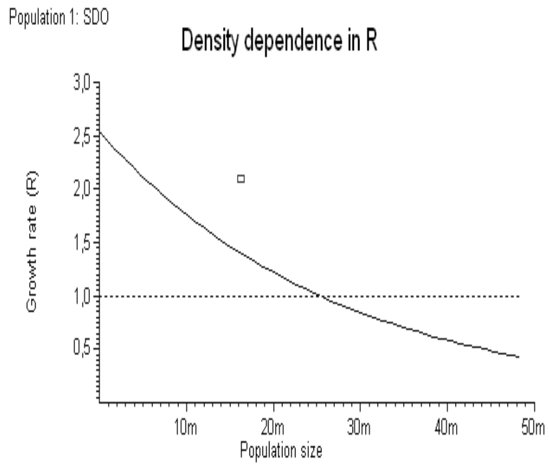


Figure 3-57 Model S2 (λ =2.10) for Site1

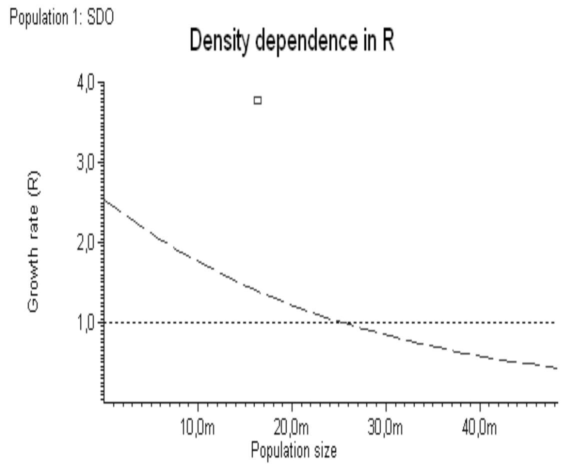


Figure 3-58 Model S3 (λ = 3.78) for Site1

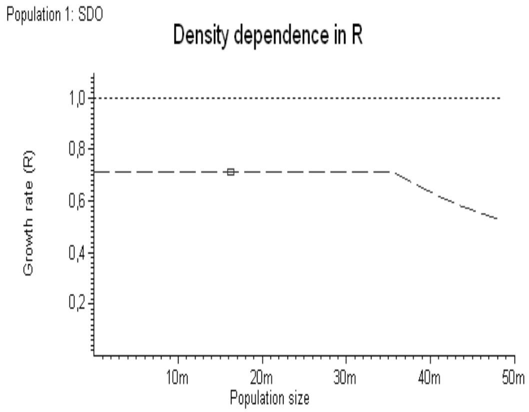


Figure 3-59 Model C1 (λ= 0.714) for Site 1

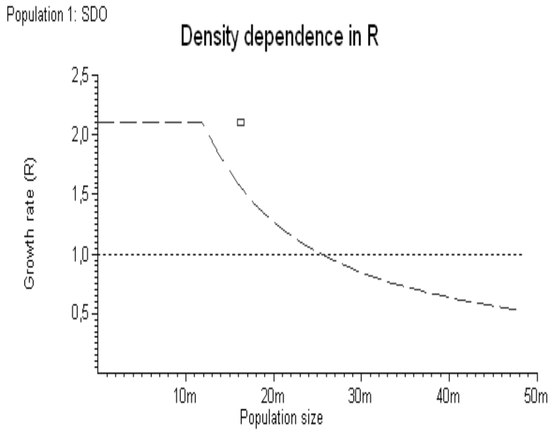


Figure 3-60 Model C2 (λ=2.10) for Site 1

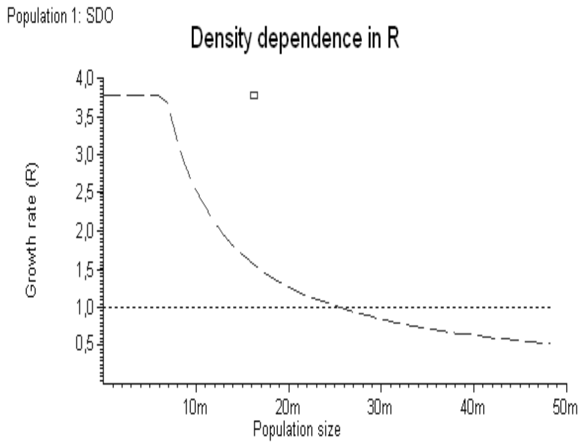


Figure 3-61 Model C3 (λ=3.78) for Site 1

3.8.4 Parameter Uncertainty- Sensitivity Analysis for Selected Parameters

Deciding which model parameters are more important to estimate precisely is i.e., explore uncertainty in parameter, the objective of sensitivity analysis.

In this study, sensitivity analysis is used for parameters of carrying capacity (K) and maximal growth rate (Rmax) since both are the basis of scramble density dependence and K and the stage matrix (vital rates) are the basis of ceiling type density dependence. Hence, sensitivity analysis to Rmax is only performed for scramble type density dependence models since density dependence function of ceiling type does not use this parameter.

3.8.4.1 Sensitivity analysis to K

Both Site 1 and Site 2 models show moderate sensitivity to the carrying capacity (K) changes as 10 % change creates about 5 % change in the extinctions risks with scramble type density dependence. Whereas when the density dependence is ceiling the extinctions risks of both Site 1 and Site 2 pops becomes insensitive to changes in the carrying capacity (K).

3.8.4.2 Sensitivity analysis to Rmax

10 % change in the maximal growth rate (Rmax) creates about 20 % change in the extinctions risks of both Site 1 and Site 2 models. Therefore, both Site 1 and Site 2 models are highly sensitivity to the maximal growth rate (Rmax).

3.8.4.3 Sensitivity Analysis to Demographic Parameters

The sensitivity analyses for demographic parameters (G0, G1, P2, P1, F) show that models are not sensitive to changes in G1, P1 and P2 and moderately sensitive to G0 and F values.

Table 3-28 Sensitivity Results for Demographic Parameters on Site 1-S2 for Scenario 3

Site 1-S2_Scenario 3					
Time To Extinction (y)	**G1**	**P2**	**G0**	**P1**	**F**
base	13,9 y	13,9 y	13,9 y	13,9 y	13,9 y
%10 increase	14,2 y	14 y	13,1 y	14,1 y	13,6 y
%10 decrease	13,7 y	13,5 y	14,6 y	13,5 y	14,2 y
% change	2,16 %	0,72 %	5,76 %	1,44 %	2,16 %
% change	1,44 %	2,88 %	5,04 %	2,88 %	2,16 %

Table 3-29 Sensitivity Results for Demographic Parameters on Site 2-S1 for Scenario 3

Site 2-S1_Scenario 3					
Time To Extinction (y)	**G1**	**P2**	**G0**	**P1**	**F**
base	21,2 y	21,2 y	21,2 y	21,2 y	21,2 y
%10 increase	21,9 y	21,6 y	20,6 y	21,9 y	20,9 y
%10 decrease	21 y	21,1 y	22,6 y	20,9 y	22,2 y
% change	3,30 %	1,89 %	2,83 %	3,30 %	1,42 %
% change	0,94 %	0,47 %	6,60 %	1,42 %	4,72 %

3.9 Metapopulation Model

In appendix H metapopulation simulation model inputs are detailed. Here only the agricultural and management scenarios simulation results for the metapopulation model are given as follows.

Scenario 3: ***Catastrophe*** **+ Tillage (bf)**

Metapopulation trajectory shows that tillage initiates a cyclic trend and population sizes gradually decreasing but still has a persistence change for many years as providing mean time to extinction within 98 years (Figure 2-1Figure 3-62 and Figure 3-64)

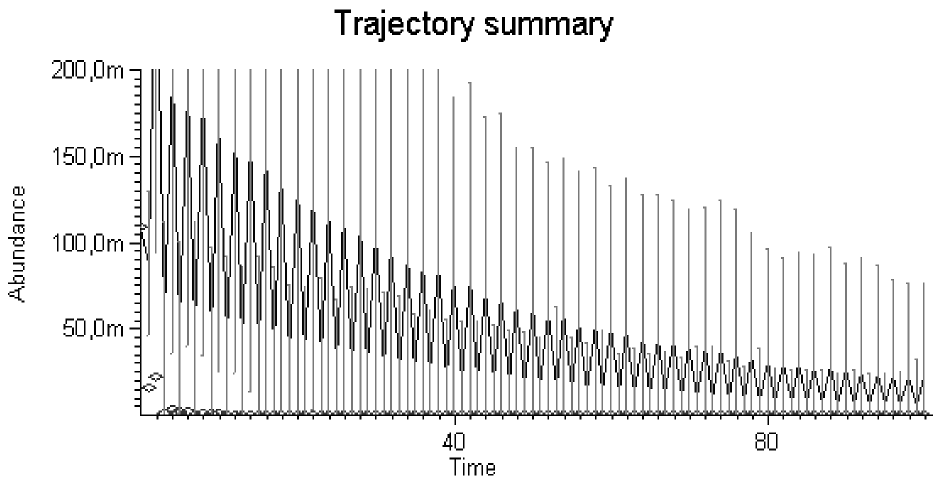


Figure 3-62. Metapopulation Model_Scenario 3, Metapopulation Trajectory

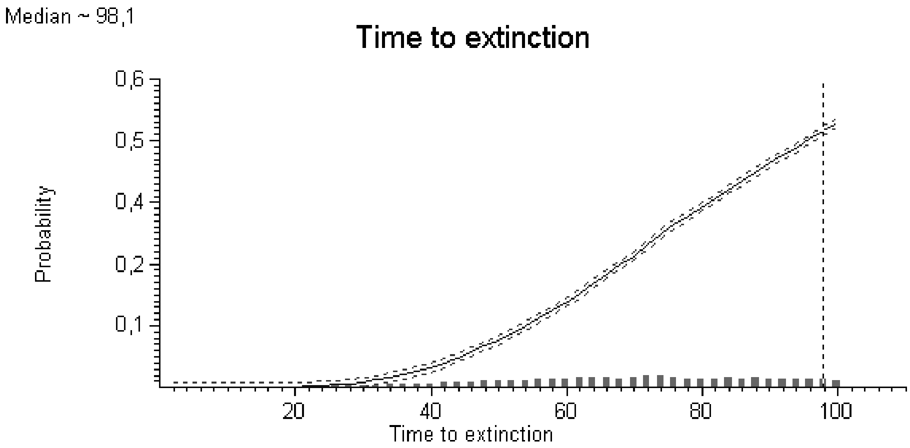


Figure 3-63 Metapopulation Model_Scenario 3, Time to Quasi-Extinction Curve

Scenario 4: *Catastrophe* + tillage + herbicide

Under agriculture with herbicide application metapopulation trajectory strictly declines and within 9 years metapopulation goes to extinct (Figure 3-64 and Figure 3-66).

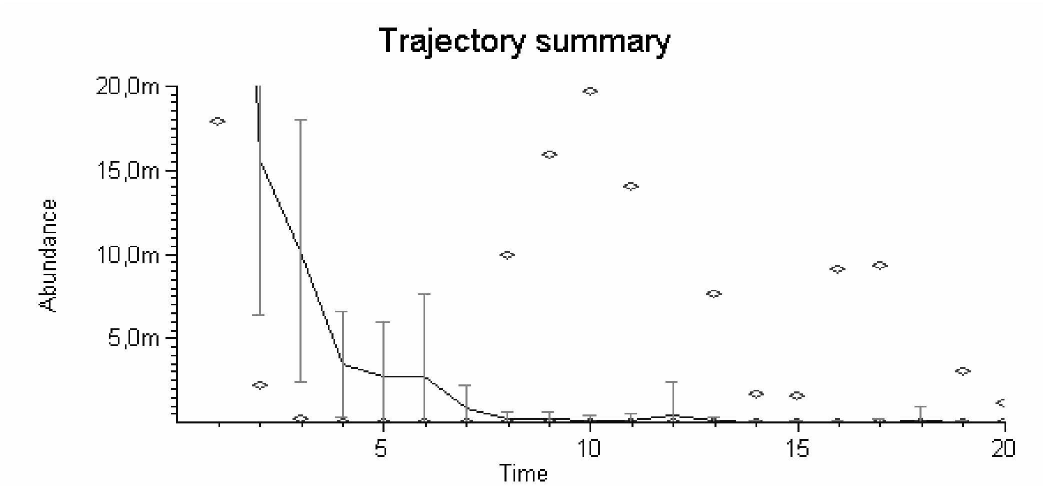


Figure 3-64. Metapopulation Model_Scenario 4, Metapopulation Trajectory

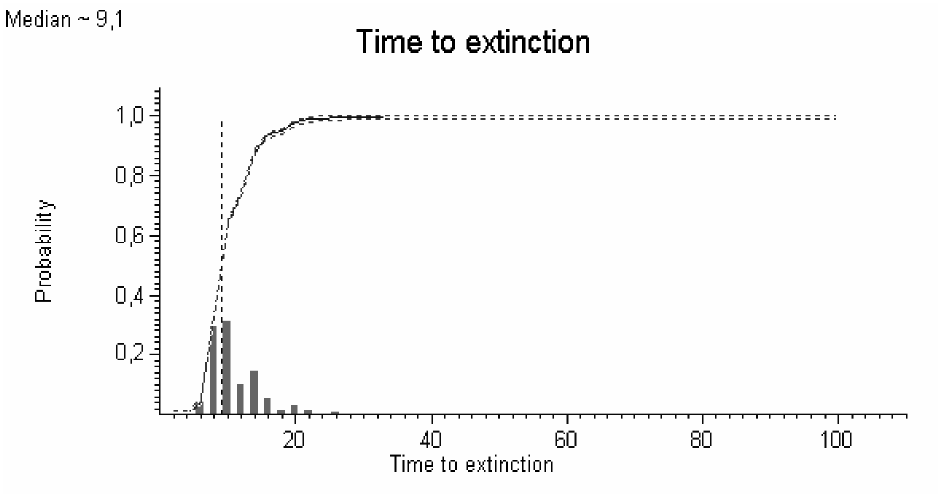


Figure 3-65. Metapopulation Model_Scenario 4, Time to Quasi-Extinction Curve

Scenario 6: *Catastrophe* + Tillage (Management- every 2 years)

The trajectory shows that after a sharp increase within a few years, metapopulation reaches a steady state around 75 millions. So, this conservation scenario provides long term persistence for the species.

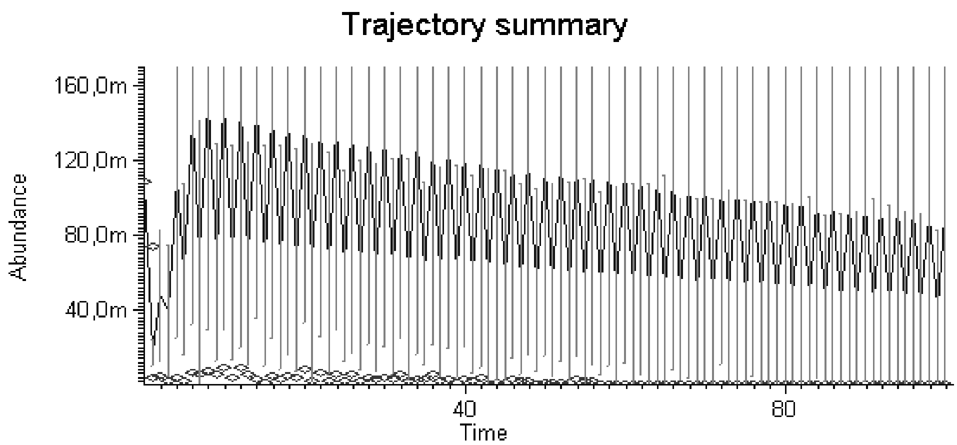


Figure 3-67. Metapopulation Model_Scenario 6, Metapopulation Trajectory

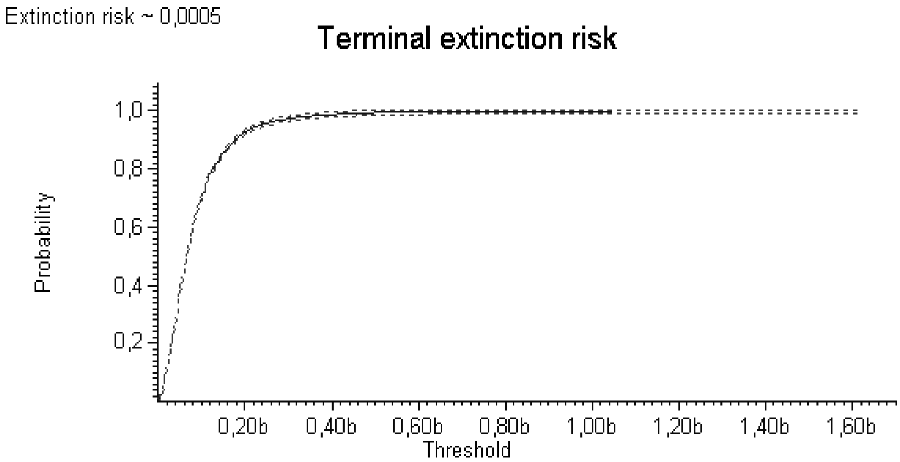


Figure 3-66. Metapopulation Model_Scenario 6, Terminal Extinction Curve

CHAPTER 4

DISCUSSION

4.1 Expanded Species Distribution Range and Estimated Population Sizes

Based on the results of this study and by others, the population status of *C. tchihatcheffii* (as of 2007) can be defined as a large metapopulation with a distributional area of about 700 km^2 with several subpopulations. This is contrary to statements made about the species' distribution in the early stages of this research.

Even tough this is a significant and promising improvement over the previously known highly restricted range, most newly discovered subpopulations are very small and do not influence much the threat status of the species. Since farming and urban settlements continually divides and destroys remaining subpopulations, unless specific conservation strategies are proposed and applied, this wider distribution area do not constitute a sufficiently large metapopulation for the persistence of the species in the long run.

Another significant issue is that dispersal among subpopulations is almost non-existent. Plant demography studies showed that even a few meters wide corridor created due to gas pipeline construction was not colonized by the species, even though population densities and seed production were high. During field visits there was no observation that would indicate possible wind dispersal. Ant dispersal is probable but not effective more than several meters in any one year (Çakaroğulları 2005). Therefore, dispersal by natural means is only occurs a short distance and recolonization of locally extinct subpopulations or new ground is very difficult.

4.1.1 Plant Demography

Throughout the monitoring for Site 1 and 2, the years 2003-2005 can be considered as "good years" for populations in terms of abundance and distribution. After 2005 a sudden drop in the abundance and distribution area has been observed in both Sites. Both populations have been experiencing a continuous decline started in 2005, but the year 2007 was the worst as an immediate decrease in abundance and distribution due to recurring drought. Therefore, the 2006-2007 can be regarded as "bad years" for populations, especially for the Site 1 where there was no emergence of the study species observed. Furthermore, in 2007, Site 2 experienced a sharp decline in abundance from over 1,000,000 individuals to around 60,000. Fortunately, in year 2008, significant growth occurred and the abundances reached to 400,000-600,000 again. This can be explained due to rainy season of autumn (2007) to spring (2008).

The study species is observed to experience large fluctuations in population size, but as drought is replaced by rains it responds with great success by using its seed bank as a buffer. For example, at Site 1 there was no emergence from fresh seeds detected in 2007; however, next year there was a good population there. Obviously, all recruitment was from the seed bank (i.e. previous year's seeds).

4.1.2 Seed Demography

Thorough monitoring whole life cycle of an individual seed through germination – emergence – growth and flowering (adult) stage, seed demography studies provide best estimates of survival rates of the species. Several studies have shown that it is possible to get useful information and knowledge from snap-short demographic studies (Löfgren et al. 2000, Magda & Jarry 2000, Wiegand et al.

2000). Despite limited data on only two transition years, the findings were useful for the model.

Specifically, transition from 2006-2007 represents the "bad" and 2007-2008 represents "good" years' survival rates. These "good" and "bad" years provide estimates lower and the upper limits of the stage matrix elements for modeling and the importance of survival rates for population persistence.

A comparison of the two sites reveal that seed bank size estimates for Site 2 are much larger than for Site 1; moreover, at Site 2 seed were found to exist closer to the surface layer. Differences either in soil productivity or in recent disturbance history of the two sites can explain this difference. Site 1 had experienced prescribed burning, surface clearing, herbicide application and planting of fruit trees in late 1990s. These activities obviously caused reduced seed survival and lower overall productivity at Site 1.

In addition (or alternatively) Site 1 might have been subject to diseases more often than Site 2. Drought-like climate conditions within last two years (2006 and 2007) might have affected Site 1 more severely as the soil properties appear to be different than Site 2.

All of the above factors limit the investment on soil bank; they also increase the population's dependence on it. On the other hand, Site 2 is known to be used for rye cultivated until a few years ago, so regular plowing and aeration of soil without herbicide applications are probably the main differences affecting soil structure and seed bank dynamics between two sites. These agricultural practices are considered to contribute significantly to the population's reproductive output and support the seed bank of Site 2. Historically, Site 2 has been more frequently disturbed than Site 1, but it should be noted that agricultural practices were prevented during our studies so the use of tillage advantage was not the case within in last 5 years for Site 2.

It should also be noted that annual fluctuations in population sizes is characteristics of annual plant populations. Yet, how many consecutive "bad years" that annual plant populations can stand for mainly depend on the size and the dynamics of soil seed bank.

Most significant finding of seed bank estimates comes from Yildirim's (2005) studies that provide seed bank estimates as indicating the seed viabilities. Her results show that agricultural sites have more viable seeds in their seed bank than the natural sites. This can be explained by the high death rates of seeds fall on the topsoil through premature germination in autumn. Moreover, agricultural practices like tillage and fallow provide aeration and nourishment of soil, and assortment of layers; therefore, activate and arrange seed bank dynamics at different depths with some regularity.

Another noticeable finding of Yıldırım's studies is that the demonstration of how detrimental can the habitat destruction be on the viability of populations, especially when they are patchily distributed in the structure of many subpopulations with various population sizes, as in the case of *C. tchihatcheffii*. For example, the site having 1312.4 seeds/ m^2 can only hold 146.2 seeds/ m^2 after destroyed by highway construction.

Even there was an increase in the seed bank densities from 2004 to 2005 at Site 1, the majority of these seed densities are not viable. This accumulation of unviable seeds in the seed bank signifies the diminishing of seed bank at Site 1. The following year, seed bank densities declined for both sites but more so at Site 1 and eventually no seed emergence was detected at Site 1 in 2007, despite presence of some seeds (viabilities not known) in the reserve and a few contributions via newly produced seeds of 2006 existed.

4.2 Effects of Agricultural Practices

4.2.1 Results of the Herbicide Applications

4.2.1.1 Effects of the Herbicide

Although the results of the herbicide applications differed depending on the concentration and combination of the chemicals used, it is clear that herbicides cause increased mortality before seed dispersal and therefore significantly decreases the population's fecundity value.

The relatively high survival rate in our 2004 application can be explained due to experimental errors in the first trial; the control parcel was very close to herbicide parcel and parcels were small (8 m^2) in order not to harm overall subpopulation, and more importantly the application dosage was below the recommended dose. In later seasons, herbicide-related mortalities up to 99% have been observed.

4.2.2 Stubble Burn Experiments

To the best of our knowledge, this is the first experiment to show effects of stubble burn on seeds buried at several depths and at the same time recording temperatures at those depths. The results have clearly shown that soil temperatures during the burn did not increase beyond 85°C and such superficial fires are only detrimental for seeds of the study species at or near the surface level (0-2 cm deep). Seeds buried in the soil at levels deeper than 5 cm were not harmed. Although stubble burn is generally cited as detrimental to soil biota, our findings do not show this effect at least for the seed bank.

4.2.3 Effects of Tillage Practice

Tillage applications in the form of plowing and then treating with a cultivator destroys aboveground populations at the application year, but boosts them up next year through accelerating seed bank dynamics (i.e. leads to increased emergence from seed bank and improved survival of plants next year). However, the timing of the tillage is of crucial importance. Tillage before any flowering takes place leads to almost complete loss of that season's seed production. On the other hand, when tillage was carried out during flowering, a considerable proportion of plants succeeded to mature and produce seeds that year.

Tillage practices as a form of disturbance seems crucial for population persistence and regeneration strategies of *C. tchihatcheffii* which clearly govern the seed bank dynamics. The most significant finding is that the timing and frequency of disturbance is a key factor and defines either the persistence or the extinction of such annuals with poor dispersal ability. Therefore, if carried out under controlled conditions, it can act as a management tool.

It is important to mention that although experimental tillage parcel densities reached almost 100 individuals per m^2, not even a single individual died before flowering. This points out that (at least in good years) there is little intraspecific competition for the species, and therefore, no density dependent mortality; other species did not grow in those parcels so probably through interspecific competition the study species suppresses its competitors with its rapid, continuous growth in parallel with the density increase (relatively in control parcel) – despite two consecutive drought years.

4.3 Discussion of Simulation Results

4.3.1 Models for Site 2

Scramble type density dependence with low values of survival rates model- Model S1- shows that even if there are no agricultural threats involved and the population is only subject to natural catastrophes, the species is considered to be facing a very high extinction risk (*Endangered* –EN, according to the criteria "E" of IUCN red listing rules). This means that according to Model S1, any natural population that is similar to Site 2 will have a very high extinction risk even they will be set aside as a reserve.

Considering the fact that the distribution range of the species is exposed to farming with herbicides, Model S1 demonstrates that the populations under study will go extinct within 10 years unless any conservation action will be taken. Moreover, this model clearly demonstrates that herbicide free farming can not be considered as a viable conservation action since it simply downgrades the threat category from *Critically Endangered* (CR) to *Endangered* (EN) (for those two study populations).

This finding should be evaluated carefully. The species is assumed to be disturbance dependent. If this holds, then tillage practice of farming (without herbicide use) could provide that disturbance and so benefit the species. Simulation results support view to the disturbance dependence but also highlight that farming can not provide that disturbance for the sake species since conventional tillage systems boost the above ground populations in alternating years but also destroy them between these alternating years. Therefore, experiencing these effects regularly creates a cyclic trend that leads to decrease in population sizes as projected by the population trajectories.

Based on Model S1, the scenario that can be proposed as a conservation management scenario for the populations under natural catastrophes, provides a decrease in extremely high extinction risks down to 0.37 in 100 years which creates a change in the threat category down from *Critically Endangered* (CR) to *Vulnerable* (VU).

The same model with ceiling type density dependence - Model C1- presents more optimistic results than Model S1. For example, populations under natural catastrophes that are not subject to any anthropogenic threats demonstrate 0.30 extinction risks in 100 years which places them to the lowest threat category- *Vulnerable* (VU). It is almost the same as what the conservation management scenario of Model S1 provides. Moreover, Model C1 illustrates that populations can tolerate herbicide free farming and only in case of farming with herbicide the populations end up going extinct with a high probability. According to Model C1, conservation management scenario results in only a very low threat in the long term.

4.3.2 Models for Site 1

Scramble type density dependence with medium values of survival rates model- Model S2- indicates results that are parallel to Site 2 scramble model as estimating *Endangered* (EN) threat category for natural populations, *Critically Endangered* (CR) category for populations subject to farming with herbicide, *Endangered* (EN) category for populations experiencing herbicide free farming, and finally provides a *Vulnerable* (VU) category for populations under conservation management.

For Site 1, ceiling type density dependence model - Model C2- also presents higher extinction risks that are parallel to its scramble model explained above.

4.3.3 Discussion of Density Dependence Results

Models with scramble density dependence type for both sites result in higher extinction risks. For Site 1, ceiling density dependence type model also gives high extinction risks whereas for Site 2 ceiling density dependence type model provides lower extinction risks. This can be explained as due to higher vital rates for ceiling type density dependence which is the case for Site 2 because it has stage matrix with high vital rates, especially when compared to those of Site 1. This also clarifies the high extinction risks of Site 1 with ceiling density dependence model; even if the stage matrix is estimated with medium values of survival rates it seems that vital rates are not high enough to provide lower extinction risks.

In the light of all these findings, ceiling density dependence model for Site 2 is being considered as too optimistic model to evaluate species threat status because it may underestimate the extinction risk. Therefore, population viability analysis for Site 2 is based on the results of scramble density dependence model which forecasts the threat category in line with the current status of the species. For Site 1, although both density dependence types predicts the threat category in line with the current status of the species, to be on the safe site, population viability analysis for Site 1 is also based on the results of scramble density dependence model which forecasts species vulnerability with a higher risk than that of ceiling density dependence model under conservation management scenario.

Overall comparison of scenarios results for study sites are given in Table 4-1 This table shows that the likelihood of extinction for both subpopulations is significant as 0,95-1 terminal extinction risk within 100 years, *(*or *at the end of 15-30 years 50% extinction risk)* even when no agricultural practices are involved but if natural catastrophes related to climatic variability (e.g. drought) or disease exist. Scenario 7 is the alternative management scenario which can be proposed as conservation option for Site1 but it is not valid for Site 2 which is required be tilled every 2 years.

Table 4-1 Comparison of Scenario Results for Study Sites

	Scenarios	Scenario 2	Scenario 3	Scenario 4	Scenario 6	Scenario 7
		Baseline (natural catastrophe)	Agriculture-Destructive Tillage (before flowering)	Typical agriculture with herbicides	Conservation management- Tillage (every 2 years)	Alternative management- Tillage (every 3 years)
Site 1	**IUCN Threat category**	EN	EN	CR	VU	VU
	Mean time to extinction	15,3 yrs	12,1 yrs	3,4 yrs	99,2 yrs	99 yrs
	Interval extinction risk	1,00	1,00	1,00	0,50	0,50
Site 2	**IUCN Threat category**	EN	EN	CR	VU	EN
	Mean time to extinction	30 yrs	18,7 yrs	4,3 yrs	-	32,6
	Interval extinction risk	0,96	1,00	1,00	0,37	0,91

4.3.4 Discussion of Sensitivity Analyses

Results of a population viability analysis can be used to address various aspects of conservation and management of the species, like considering of further research needs, assessing impact, evaluating conservation management options and forecasting vulnerabilities and assigning threat categories.

This study uses PVA results to explore about all these aspects by incorporating uncertainties at both model structure and parameter levels in the sensitivity analysis. Specifically, by whole-model sensitivity analysis, results of impact assessment and conservation actions of different models were compared as relative values of extinction risks, and finally to decide a more realistic model that relies on absolute extinction risks were made to assigning threat category for both study sites.

Parameter sensitivity analysis is used to plan further research needs. It was found that the most sensitive model parameter was Rmax while K presented moderate sensitivity. Therefore, gathering more data on both above ground and below ground abundances over several years should be considered as a priority for the future field research since this provides better estimates for both Rmax and K. At that point, soil seed bank density estimations and viability of those seeds reveal its importance. Models as predicted moderately sensitive to G0 and F values also highlight that the contribution of seeds to the seed bank is also impotant as emergence success.

4.4 Discussion of Metapopulation Model

Most significant finding about the metapopulation model is that species may survive in nature for many years under herbicide free agriculture (Table 4-2). As the frequency of tillage practice through management action is increased the extinction risks decreases. When considering the cost of management action across all subpopulations, motivating the herbicide free agriculture in the region would be a part of a conservation strategy. Especially, unprotected subpopulations elsewhere can benefit from organic or nature-friendly farming. Nevertheless tillage application every 2 years (scenario 6) should be considered as a safeguard management action at a few protected reserves like the big, healthy subpopulations (i.e. Site 11, 13).

Table 4-2 Comparison of Scenarios Results for the Metapopulations

Scenarios	**Scenario 3**	**Scenario 4**	**Scenario 6**	**Scenario 7**	**Scenario 8**
	Agriculture- Destructive Tillage (before flowering)	Typical agriculture with herbicides	Conservation management- Tillage (every 2 years)	Alternative management- Tillage (every 3 years)	Alternative management- Tillage (every 4 years)
IUCN Threat category	VU	CR	NT	VU	VU
Mean time to extinction	98,1 yrs	9,1 yrs	-	98,3 yrs	97,1 yrs
Interval extinction risk	0,51	1,00	0,0005	0,51	0,52

CHAPTER 5

CONCLUSION

Population viability analysis and corresponding sensitivity analysis predict that populations at both sites have extremely high extinction risk so they are assigned as *Critically Endangered*-CR. Moreover, the likelihood of extinction for both populations is significant even when no agricultural practices are involved but if natural catastrophes like drought or disease occur. Most important finding of this study is about tillage practice which can be a *friend* or *foe* for the species. PVA results demonstrate that timing of tillage is crucial; if it is applied in spring, it can drift population to extinction, especially as it is mostly coupled with herbicide use in conventional farming. If it is applied in summer or fall, it can boost the population and provide soil disturbance without diminishing the above ground population, hence suitable as a conservation management tool for the populations that are designated as a reserve.

Proposed conservation action for both sites, i.e. setting them aside as a reserve and applying tillage in alternating years after the life cycle of species completes, can only decrease their threat category from *Critically Endangered*-CR to Vulnerable – VU. Moreover, Site 1's vulnerability to extinction is higher than that of Site 2. Therefore, this conservation option still should be considered as the best and taken into account immediately as a safeguard management action at least for the few protected reserves, e.g. the big, healthy subpopulations (i.e. Site 11, 13), until further complementary conservation strategies are applied.

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Fortunately, with the aid of a TUBİTAK project and previous research on species, the landowner of the Site 2, the State Opera and Ballet Department announced that the ownership will be transferred to State Environment Protection Agency protection as a reserve. It is also a promising progress that Authority for the Protection of Special Areas has developed a master plan for the conservation of this species and the sustainable use of area for educational purposes at Site 1 (Gülkal, Ö., pers. comm.).

We propose tillage after seed set every other year as a conservation management option for a few big designated reserves of *C. tchihatcheffii* metapopulation to ensure long term survival of the species. As for the most applicable conservation strategy (cost, time and labor efficient), delayed tillage every 4 years should be considered for the rest of the metapopulation. Alternatively, unprotected subpopulations elsewhere can benefit from organic or nature-friendly farming.

In addition to above proposed immediate conservation management option, complementary strategies for the conservation of this critically endangered endemic should be developed like preserving the patches or spot populations in fields or along road edges as ephemeral endangered weeds, through designation of natural reserves, by preserving in botanic gardens, seed production and storage in gene banks.

CHAPTER 6

FURTHER RESEARCH

Monitoring the effects of initiated conservation management sites (if any), performing further field and laboratory experiments on seed dispersal and predation, gathering more data on both above ground and below ground population sizes should be considered as a priority for the future field research since these lead to better models. At this point, soil seed bank dynamics appear to be quite significant for this annual plant, so gathering more data is recommended.

Moreover, both social and economics aspects of conservation management actions should be investigated with a cost-benefit analysis to reveal the model's applicability which in fact is as much as important as model uncertainty.

It should be also noted that there also exist subpopulations which are subject to farming irregularly and alternating cultivations (like wheat or rye) so forecasting these semi-natural (or semi-arable) populations' likelihood of persistence of extinction risk appears to be complicated but are required to be investigated.

REFERENCES

Adams, V.M., Marsh, D.M., Knox, J.S., 2005, Importance of the seed bank for population viability and population monitoring in a threatened wetland herb. Biological Conservation 124, 425–436.

Akçakaya, H.R.; Burgman, M.A.; Ginzburg, R.L., 1999, Applied Population Ecology, Applied Biomathematics, Setauket, New York.

Akçakaya, H.R. and P. Sjögren-Gulve. 2000. Population viability analysis in conservation planning: an overview. *Ecological Bulletins* 48:9-21.

Beissinger, S. R. & Westphal, M. I., 1998, On the use of demographic models of population viability in endangered species management. Journal of Wildlife Management 62: 821-841.

Ben Wu, X. and Smeins F.E., 2000, Multiple-scale habitat modeling approach for rare plant conservation, Landscape and Urban Planning, Volume 51, Issue 1, 11-28

Boyce, M., 1992, Population viability analysis. Annual Reviews in Ecology and Systematic 23: 481-506.

Brigham C.A, Schwartz M.W (Eds.), 2003, Population Viability in Plants Conservation, Management and Modeling of Rare Plants. Springer.

Brook, B.W., Burgman, M., Akçakaya, H.R., O'Grady, J.J. & Burgman, R. (2002) Critiques of PVA ask the wrong questions: throwing the heuristic baby out with the numerical bath water. Conservation Biology 16: 262-263.

Bruna, E.M 2003 Are plant populations in fragmented habitats recruitment limited? tests with an Amazonian herb, *Ecology,* 84(4), 2003, pp. 932–947

Burgman, M. & Possingham, H. (2000) Population viability analysis for conservation: the good, the bad and the undescribed. Pages 97-112 *in* A. G. Young, and G. M. Clarke editors. Genetics, demography and viability of fragmented populations. Cambridge University Press, Cambridge.

Burgman, M. A., Ferson, S. & Akcakaya, H. R. (1993) Risk assessment in conservation biology. Chapman & Hall, London.

Bullied, W.J. Marginet A.M , Van Acker R.C 2003 Conventional- and conservation-tillage systems influence emergence periodicity of annual weed species in canola. Weed Science, 51:886–897.

Çakaroğulları, D. (2005). The population biology of a narrow endemic, *Centaurea tchihatcheffii* fisch. & mey. (compositae), In Ankara, Turkey. M.Sc., Department of Biology, METU.

Çevre Bakanlığı Özel Çevre Koruma Kurumu. 2002. Mogan Gölü Havzası Biyolojik Zenginlikleri. pp. 86-87.

Çevre Bakanlığı Özel Çevre Koruma Kurumu. 2004. Türkiye'de Özel Çevre Koruma. pp. 4,5,23,36,86-87.

Cain,M.L. & Damman, H. (1997) Clonal growth and ramet performance in the woodland herb, Asarum canadense. Journal of Ecology 85: 883-897.

Cardina J, Herms, C.P, Doohan D. J 2002 Crop rotation and tillage system effects on weed seed banks. Weed Science, 50:448–460.

Chapman, A.P., Brook, B.W., Clutton-Brock, T.H., Grenfell, B.T. & Frankham. R. (2000) Population viability analyses on a cycling population: a cautionary tale. Biological Conservation 97: 61-69.

Conner, M. M. & White, G.C. (1999) Effects of individual heterogeneity in estimating the persistence of small populations. Natural Resource Modeling 12: 109-127.

Cully, A. (1996) Knowlton's Cactus (Pediocactus knowltonii) reintroduction. In: Falk, D.A., Millar, C.I., Olwell, M. (Eds.), Restoring Diversity: Strategies for Reintroduction of Endangered Plants. Island Press, Washington, pp. 403–410.

Davis, P.H. (1975) Flora of Turkey and The East Aegean Islands, 5, 581-582

Damman, H. & Cain, M.L. (1998) Population growth and viability analyses of the clonal woodland herb, *Asarum canadense*. Journal of Ecology 86: 13-26.

Dinnétz, P.& Nilsson, T. (2002) Population viability analysis of *Saxifraga cotyledon*, a perennial plant with semelparous rosettes. Plant Ecology 159: 61-71.

Doak, D.F., Thomson D, Jules. E.S, 1999. PVA for Plants: Understanding the Demographic Consequences of Seed Dormancy and Disturbance Events in the Face of Limited Data. Population Viability Analysis Conference:Assessing Models for Recovering Endangered Species

Dolan, R.W. (1994) Patterns of isozyme variation in relation to population size, isolation, and phytogeographic history in royal catchfly (*Silene regia*; *Caryophyllaceae*). American Journal of Botany 81: 965-972.

Ekim, T. (1994) *Centaurea tchihatcheffii*, The Karaca Arboretum Mag., 2, part 3.

Ekim, T.; Koyuncu, M.; Duman, H.; Aytaç, Z.; Adıgüzel, N. (2000) Türkiye Bitkileri Kırmızı Kitabı, 1-41, 221.

Ekim, T.; Byfield, A. 2003. Önemli Bitki Alanı: 88 Mogan Gölü in Türkiye'nin Önemli Bitki Alanları, Özatay, N.; Byfield, A.; Atay, S. 2003. WWF Türkiye (Doğal Hayatı Koruma Vakfı).

Ellner, S.P., Fieberg, J., Ludwig, D. & Wilcox, C.(2002) Precision of population viability analysis. Conservation Biology 16: 258-261.

Enright, N. J., Marsula, R., Byron, B.L. & Wissel, C. (1998) The ecological significance of canopy seed storage in fire-prone environments: a model for non-sprouting shrubs. Journal of Ecology 86: 946-959.

Erik, S.; Mutlu, B.; Topaloğlu, S.; Tarıkahya, B.; Aldemir, A. 2005. *Centaurea tchihatcheffii*'nin tarihçesi, Türkiye florasındaki yeri, yayılış alanları, taksonomik özellikleri ve diğer bitkiler ile olan birlikteliği. in: *Centaurea tchihatcheffii*. Edited by Boşgelmez, A. Ankara. pp. 179-258.

Fritzsch, K., 2004, Plant response to changes in disturbance magnitude, Dissertation, University of Oldenburg.

Gordon, D.R. (1996) Experimental translocation of the endangered shrub Apalachicola rosemary Conradina glabra to the Apalachicola Blues and Ravines Preserve, Florida. Biological Conservation 77, 19–26.

Gömürgen, A.N.; Adıgüzel, N., 2001. Chromosome numbers and karyotype analysis of *Centaurea tchihatcheffii* Fish. and Mey. (Compositae, Carduae). Ot Sistematik Botanik Dergisi. 8(1). pp. 83-86.

Guerrant, E.O. (1996) Experimental reintroduction of *Stephanomeria malheurensis*. In: Falk, D.A., Millar, C.I., Olwell, M. (Eds.), Restoring Diversity: Strategies for Reintroduction of Endangered Plants. Island Press, Washington, pp. 399–402.

Gürkal, Ö. Çevre ve Orman Bakanlığı Özel Çevre Koruma Kurumu Başkanlığı, Ankara.

Greene, C. M. (2003) Habitat selection reduces extinction of populations subject to Allee effects. Theoretical Population Biology 64: 1-10.

Gross, K, Lockwood J.R.III, Frost, C.C. & Morris, W.F. (1998) Modeling controlled burning and trampling reduction for conservation of *Hudsonia montana*. Conservation Biology 12: 1291-1301.

Harrison S. 1999, Is Plant Population Viability Influenced by Metapopulation-level Processes? Population Viability Analysis Conference: Assessing Models for Recovering Endangered Species.

Holsinger, K.E.; Gottlieb, L.D. (1991). Conservation of rare and endangered plants: principles and prospects. In: Falk, D.A., Holsinger, K.E. (Eds.), Genetics and Conservation of Rare Plants. Oxford University Press, New York, pp. 195–208.

Henle, K., Sarre, S. & Wiegand, K. (2004) The role of density regulation in extinction processes and population viability analysis. Biodiversity and Conservation 13: 9-52.

Hof, J., Hull Sieg C. & Bevers, M. (1999) Spatial and temporal optimization in habitat placement for a threatened plant: the case of the western prairie fringed orchid. Ecological Modeling 115: 61-75.

Iriondo J.M.; Albert M., Escudero A. (2003) Structural equation modelling: an alternative for assessing causal relationships in threatened plant populations, *Biological Conservation, 113, 3*

IUCN: International Union for Conservation of Nature and Natural Resources. The IUCN Red List of Threatened Species: IUCN Red List Categories and Criteria 2001, IUCN Red List Categories: Version 3.1. Prepared by the IUCN Species Survival Commission. IUCN, Gland, Switzerland and Cambridge. UK.

IUCN 2007 Red List of Threatened Species. Available from: http://www.flmnh.ufl.edu/fish/organizations/ssg/2006Mayredlist.pdf. Accessed: 2007 October.

Johnson, B.R. (1996) Southern Appalachian rare plant reintroductions on granite outcrops. In: Falk, D.A., Millar, C.I., Olwell, In Restoring Diversity: Strategies for Reintroduction of Endangered Plants. Island Press, Washington, pp. 433–444.

Jusaitis, M.; Polomka, L.; Sorensen B.; (2003) Habitat specificity, seed germination and experimental translocation of the endangered herb *Brachycome muelleri* (Asteraceae), *Biological Conservation*

Kalisz, S. & McPeek, M. (1992) Demography of an age-structured annual: resampled projection matrices, elasticity analysis, and seed bank effects. Ecology 73: 1082-1093.

Kaya, Z.; Genç, Y. 2002. Endemik *Centaurea tchihatcheffii* Fisch. & Mey. Üzerinde Morfolojik, Anatomik ve Palinolojik Araştırmalar II. Ulusal Karadeniz Ormancılık Kongresi. 15-18. Cilt 2. Mayıs. pp. 581-588.

Kaye, T.N., Pendergrass, K.L., Finley, K. & Kauffman, J.B. (2001) The effect of fire on the population viability of an endangered prairie plant. Ecological Applications 11: 1366-1380.

Lande, R. (1993) Risks of population extinction from demographic and environmental stochasticity and random catastrophes. American Naturalist 142: 911-927.

Lawrence W. Lass, Donald C. Thill, Bahman Shafii, and Timothy S. Prather. 2002 Detecting Spotted Knapweed (*Centaurea maculosa*) with Hyperspectral Remote Sensing Technology, Weed Technology. 2002. Volume 16:426–432.

Lennartson, T. & Oostermeijer, G.B. (2001) Demographic variation and population viability in *Gentianella campestris*: effects of grassland management and environmental stochasticity. Journal of Ecology 89: 451-463.

Lennartson, T. (2002) Extinction thresholds and disrupted plant-pollinator interactions in fragmented plant populations. Ecology 83: 3060-3072.

Lesica, P. & Steele, B.M. (1994) Prolonged dormancy in vascular plants and implications for monitoring studies. Natural Areas Journal 14: 209-212.

McLaughlin, J.F., Hellmann, J.J., Boggs, C.L. & Ehrlich, P.R. (2002) The route to extinction: population dynamics of a threatened butterfly. Oecologia 132: 538-548.

Menges, E.S. & Dolan, R.W. (1998) Demographic viability of populations of *Silene regia* in Midwestern prairies: relationships with fire management, genetic variation, geographic location, population size and isolation. Journal of Ecology 86: 63-78.

Menges, E.S. (1998) Evaluating extinction risks in plants. In: Fiedler, P.L. & Kareiva, P.M. (Ed.) Conservation Biology for the Coming Decade, pp. 49-65, Chapman & Hall.

Menges, E.S. (2000) Population viability analysis in plants: challenges and opportunities. Trends in Ecology and Evolution 15: 51-56.

Moles, A T. and Westoby M. 2004. Seedling Survival and Seed Size: A Synthesis Of The Literature Journal of Ecology, 92, 372–383

Moles, A T., Falster D., Leıshman, M.R. and Westoby, M .2004. Small-seeded species produce more seeds per square metre of canopy per year, but not per individual per lifetime Literature Journal of Ecology, 92, 384–396

Nantel, P., Gagnon, D. & Nault, A. (1996) Population viability analysis of American ginseng and Wild leek harvested in stochastic environments. Conservation Biology 10: 608-621.

Navarro L.; Guitia J. (2003) Seed germination and seedling survival of two threatened endemic species of the northwest Iberian peninsula, Biological Conservation 109, 313-320

Özel, Ç.A. (2002) *Centaurea tchihatcheffii'* nin *In Vitro* Cogaltilimi Gazi Üniversitesi Fen Bilimleri Enstitüsü Yüksek Lisans Tezi

Pantone, D.J.; Pavlik, B.M.; Kelley, R.B.(1995) The reproductive attributes of an endangered plant as compared to a weedy congener. Biological Conservation 71, 305–311.

Pavlik, B.M. (1996) Defining and measuring success. In: Falk, D.A., Millar, C.I., Olwell, M. (Eds.), Restoring Diversity- Strategies for Reintroduction of Endangered Plants. Island Press, New York, pp. 127–155.

Pavlik, B.M.; Barbour, M.G. (1988) Demographic monitoring of endemic sand dune plants, Eureka Valley, California. Biological Conservation 46, 217–242.

Pavlik, B.M.,Ferguson, N., Nelson, M. 1993, Assessing limitations on the growth of endangered plant populations, II. Seed production and seed bank dynamics of *Erysium capitatum ssp. Angustatum* and *Oenothera deltoides ssp. Howelii*, *Biological Conservation* 65, 267– 278.

Pavlik, B.M., Manning, E., 1993, Assessing limitations on the growth of endangered plant populations, I. Experimental demography of *Erysium capitatum ssp. Angustatum* and *Oenothera deltoides ssp. Howelii*. *Biological Conservation* 65, 257–265.

Pfleeger, T. and D. Zobel. 1995. Organic pesticide modification of species interactions in annual plant communities, Ecotoxicology 4, 15-37.

Powell, M. Accad A., and Shapcott A. 2005, Geographic information system (GIS) predictions of past, present habitat distribution and areas for re-introduction of the endangered subtropical rainforest shrub *Triunia robusta* (Proteaceae) from south-east Queensland Australia, *Biological Conservation*,Volume 123, Issue 2, 165-175

Primack, R.B.; Miao, S.L. (1992) Dispersal can limit local plant distribution. Conservation Biology 6, 513–519.

Quintana-Ascencio, P.F., Menges, E.S. & Weekley, C.W., 2003, A fire-explicit population viability analysis of *Hypericum cumulicola* in Florida Rosemary Scrub. Conservation Biology 17: 433-449.

Riba, M., Rodrigo, A., Colas, B., and Retana R., 2002, Fire and species range in Mediterranean landscapes: an experimental comparison of seed and seedling performance among *Centaurea* taxa Journal of Biogeography, 29, 135-146.

Reed, J.M., Mills, L.S., Dunning, J.B., Menges, E.S., McKelvey, K.S., Frye, R., Beissinger, S. R., Anstett, M.-C. & Miller, P., 2002, Emerging issues in population viability analysis. Conservation Biology 16: 7-19.

Sainz-Ollero, H., Hernandez-Bermejo, J.E., 1979, Experimental reintroductions of endangered plant species in their natural habitats in Spain, *Biological Conservation* 16, 195–206.

Satterthwaitea, W. , Hollb, K. , Hayes, G., Barbera, A. , 2007, Seed banks in plant conservation: Case study of Santa Cruztarplant restoration, *Biological Conservation* 135, 57–66.

Schemske, D.W.; Husband, B.C.; Ruckelhaus, M.H.; Goodwillie, C.; Parker, I.M.; Bishop, J. (1994) Evaluating approaches to the conservation of rare and endangered plants. Ecology 75, 584–606.

Shimada, M. & Ishihama, F. (2000) Asynchronization of local population dynamics and persistence of a metapopulation: a lesson from an endangered composite plant, *Aster kantoensis*. Population Ecology **42**: 63-72.

Shuster, W.D., Herms, C.P., Frey, M.N., Doohan, D.J., Cardina, J., Comparison of survey methods for an invasive plant at the subwatershed level, *Biological Invasions*, 2005, Vol. 7,No. 3, 393-403.

Tan K., and Vural, M., 2006, *Centaurea tchihatcheffii* Fischer & C.A. Meyer (Asteraceae) Plant Systematics and Evolution.

Thomson D.M. , 2005. Matrix Models as a Tool for Understanding Invasive Plant and Native Plant Interactions, Conservation Biology, Pages 917–928, Volume 19, No. 3

Uygur S., Smith L., Uygur F.N., Cristofaro M., Balciunas J. 2004, Population densities of yellow starthistle (*Centaurea solstitialis*) in Turkey. *Weed Science,* 52:746–753.

U.S. EPA, Office of Pesticide Programs, Endangered Species Protection Program. County Bulletins, Available from: http://www.epa.gov/espp/ Accessed: 2008 October.

V.F. Carrithers, C.T. Roche, D. R. Gaiser, D. Horton, C.I. Duncan, and P. Scherer, 2004, Herbicides Reduce Seed Production in Reproductive-Stage Yellow Starthistle (*Centaurea solstitialis*), Weed Technology 18:1065–1071

Vazquez-Yanes, C. & Orozco-Segovia, A., 1996, Physiological ecology of seed dormancy and longevity, In: Mulkey, S.S., Chazdon, R.L. & Smith, A.P. (Eds), pp. 535–558. *Tropical Forest Plant Ecophysiology*, New York: Chapman & Hall, 675 pp.

Vural, Mecit. (Gazi University, Department of Biology, Ankara, Turkey, e-mail: mvural@gazi.edu.tr)

Vural, M. and Adıgüzel, N. 2001. Yanardönerler ağaçlara karşı. Yeşil Atlas Dergisi. p.125.

Vural, M.; Yıldırım, A.; Bilgin C. C.; Baytok, Y. E., Başaran, S. M., Çakaroğulları, D., 2004 -2007. TÜBİTAK TBAG - 2352, Sonuç Raporu.

Yıldırım, A. 2001. Orta Anadolu Bölgesi Yabancıot Florası. Doktora Tezi. Gazi Üniversitesi Fen Bilimleri Enstitüsü. Ankara. pp. 185, 187-188.

Yıldırım, Ayşegül. Tarım ve Köyişleri Bakanlığı. Zirai Mücadele Merkez Araştırma Enstitüsü. Bağdat Caddesi No: 250 Yenimahalle Ankara.

APPENDICES

APPENDIX A : Population status and distribution based on research period (years)

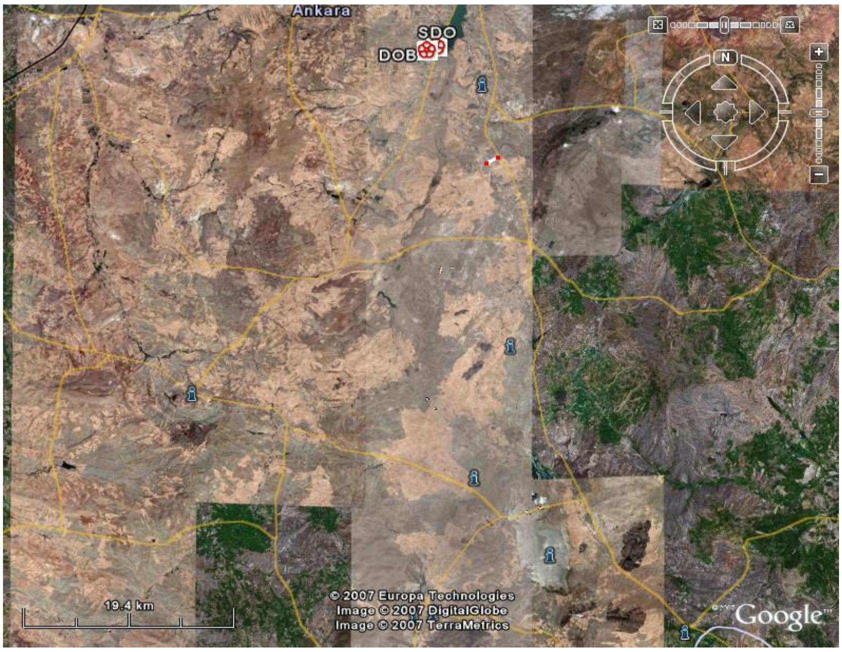

Figure A 1 Population Distribution, 2003* (only two subpopulations were known)

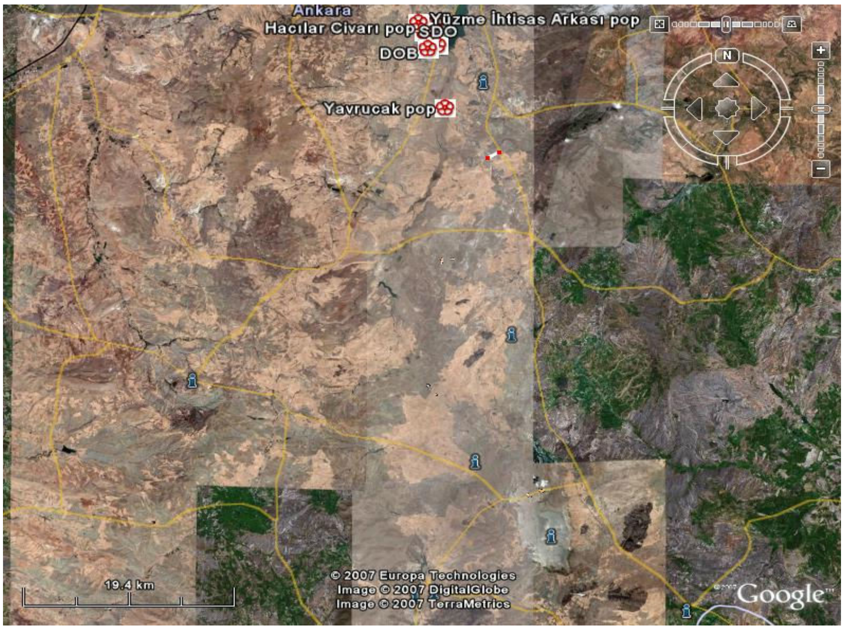

Figure A 2 Population Distribution, 2004* (The area further extended to Yavrucuk village and surroundings)

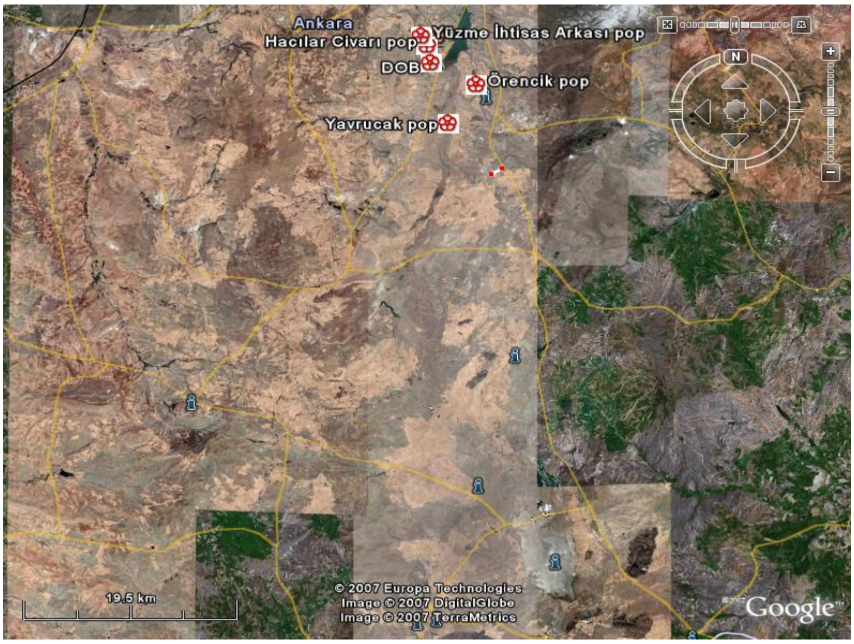

Figure A 3 Population Distribution 2005* (Örencik subpopulation was first spotted)

Figure A 4 Population Distribution 2006* (Intaspace which was a plowed field in 2004-2005, first spotted as a new subpopulation in this year together with the other new subpopulations – Yamaç Paraşütü, Mahmatlı, Gölbek and Çeltek)

Figure A 5 Population Distribution, 2007* (Çalış- Bezirhane and Karagedikli subpopulations were first spotted)

APPENDIX B :Herbicide Applications and Effects

Figure B 1 Herbicide Application, 2004

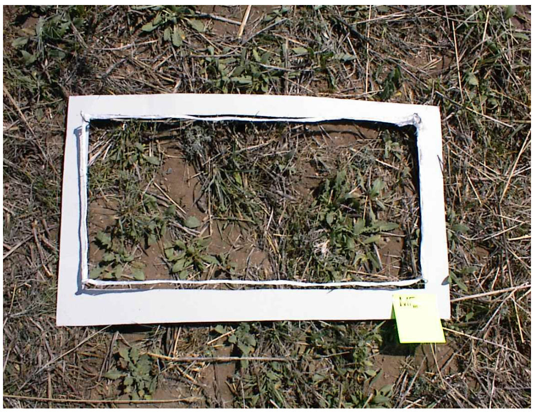

Figure B 2 Effect of herbicide, 2004

Figure B 3 Effect of Herbicide, 2004

Figure B 4 Herbicide Application, 2005

Figure B 5 Herbicide Application, 2005

Figure B 6 Herbicide Effect, 2005

Figure B 7 Herbicide Effect, 2005

Figure B 8 Herbicide Application, **2006**

Figure B9 Herbicide Application, 2006

Figure B 10 Herbicide effect, 2006

Figure B 11 Herbicide effect, 2006

APPENDIX C : Tillage Application and Effects

Figure C 1 Tillage Application, 2005

Figure C 2 Tillage Application, 2005

Figure C 3 Tillage Application, 2005

Figure C 4 Tillage Application, 2005

Figure C 5 Birds in Tillage parcel, 2005

Figure C 6 Birds in Tillage parcel, 2005

Figure C 7 Tillage Parcel after Pullowing, May 2005

Figure C 8 Tillage Parcel after Pullowing**,** May 2005

Figure C 9 Tillage parcel, August 2005

Figure C 10. Cultivation application October 2005.

Figure C 11. Cultivation application October 2005.

Figure C 12 Effect of Tillage, pullowed parcels (after 1 year), May 2006.

Figure C 13 Effects of Tillage, upper left control, front – near fallow parcel May 2006.

Figure C 14 Cultivation parcel, May 2006

Figure C 15 Cultivation parcel, May 2006

APPENDIX D : Stuble Burn Effect

Figure D 1 Prior to Stubble burn on soil pond

Figure D 2 Preparations for stubble burn on soil pond

Figure D 3 Stubble burn preperations on soil pond

Figure D 4 Stubble burn experiment on soil pond, August 2006

APPENDIX E : In-situ Stubble Burn Experiment

Figure E 1 Preparations for stubble burn in stubble parcel

Figure E 2 Stubble Burn Application (DOB), August 2006

Figure E 3 After Stubble burn, August 2006

APPENDIX F Seed Basket Experiment

Figure F 1 Seed Basket, **15 cm**

Figure F 2 Seed Basket, 10 cm

Figure F 3 Seed Basket, **5 cm**

Figure F 4 Seed Basket 0-2 cm (surface)

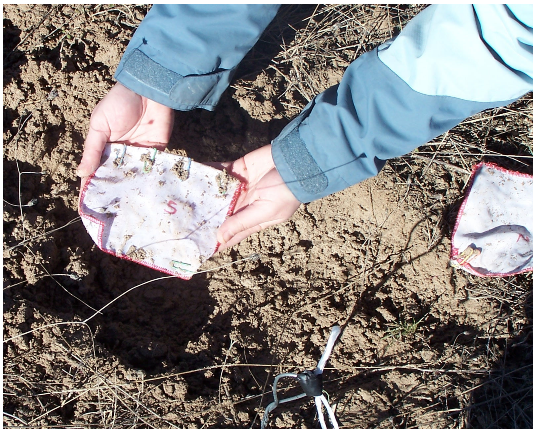

Figure F 5 Seed that are germinating in the seed baskets

Figure F 6 Seed that are germinating in the seed baskets

Figure F 7 Seed that are germinating in the seed baskets, April.

APPENDIX G Soil Core Sampling

Figure G 1 Soil Core Sampling October 2006

Figure G 2 Soil Core Sampling

Figure G 3 Soil Core Sampling at the first 5 cm.

Figure G 4 Aeration of the soil samples

APPENDIX H Modelling Applications on Ramas Metapop

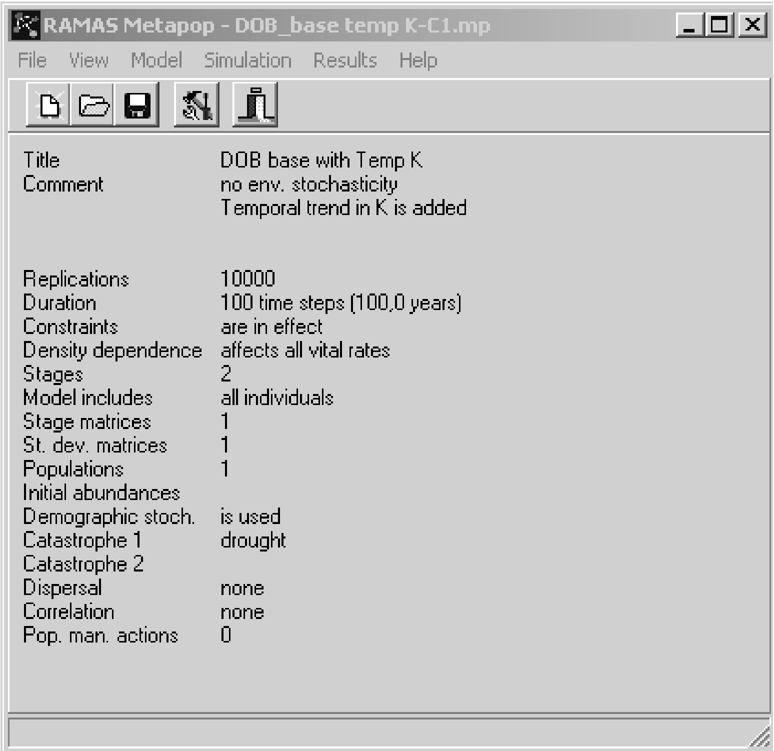

Figure H 1 General summary

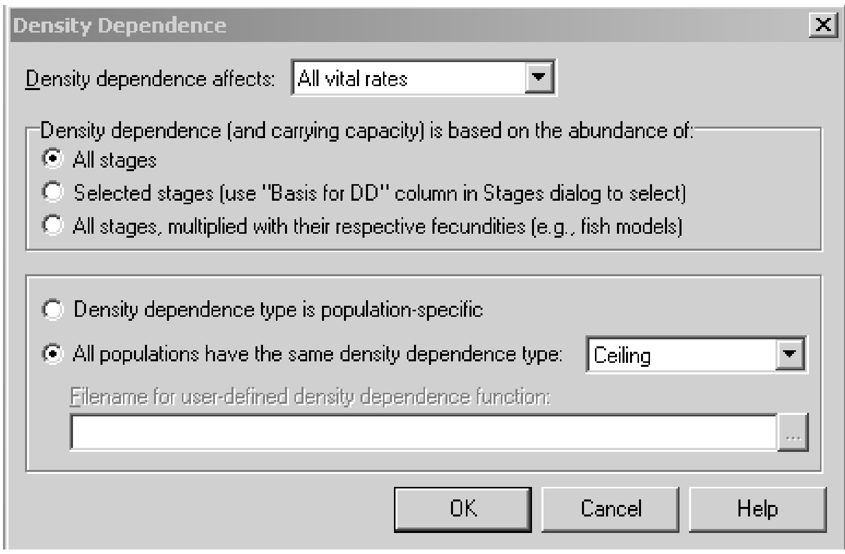

Figure H 2 Density Dependence (Ceiling)

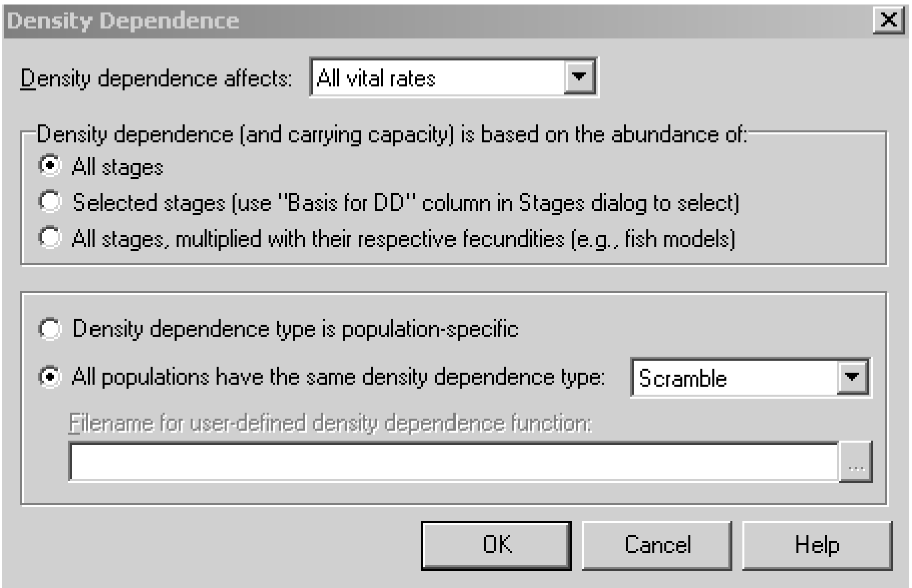

Figure H 3 Density Dependence (Scramble)

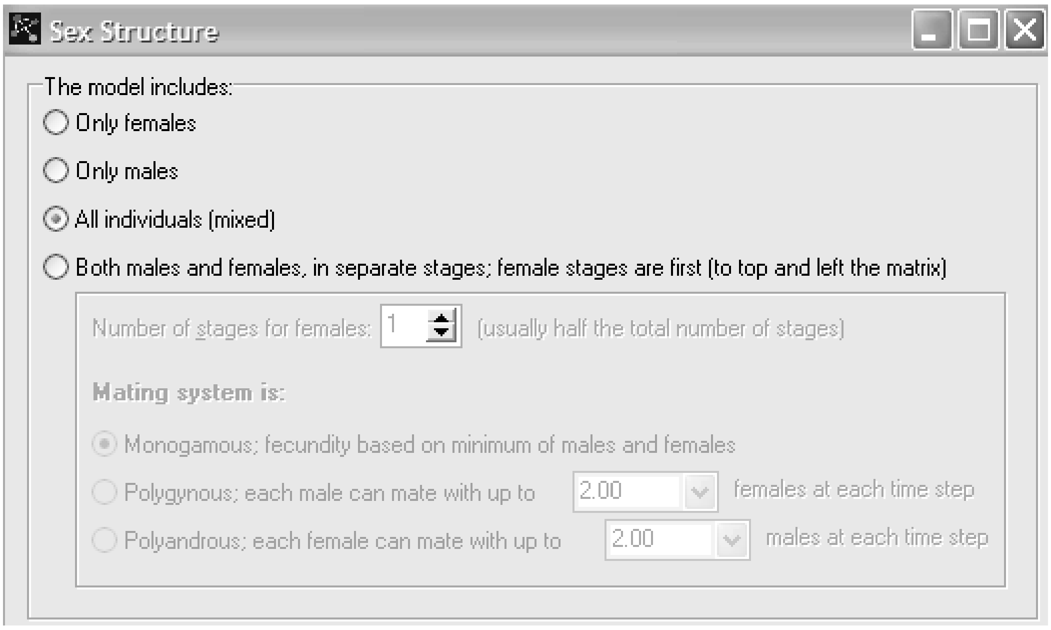

Figure H 4 Sex structure and mating

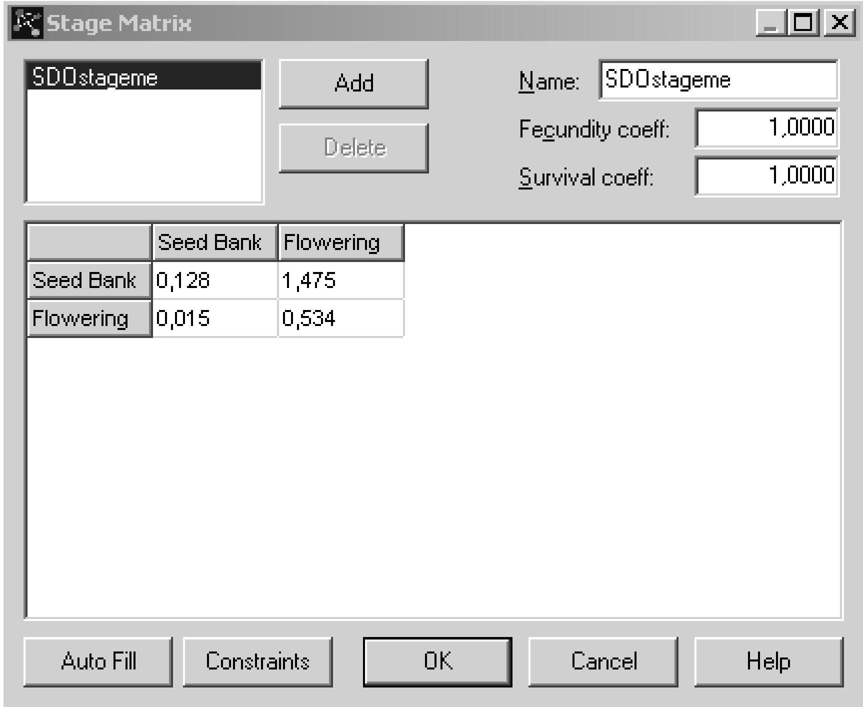

Figure H 5 Mean stage matrix with Low S for Site 1

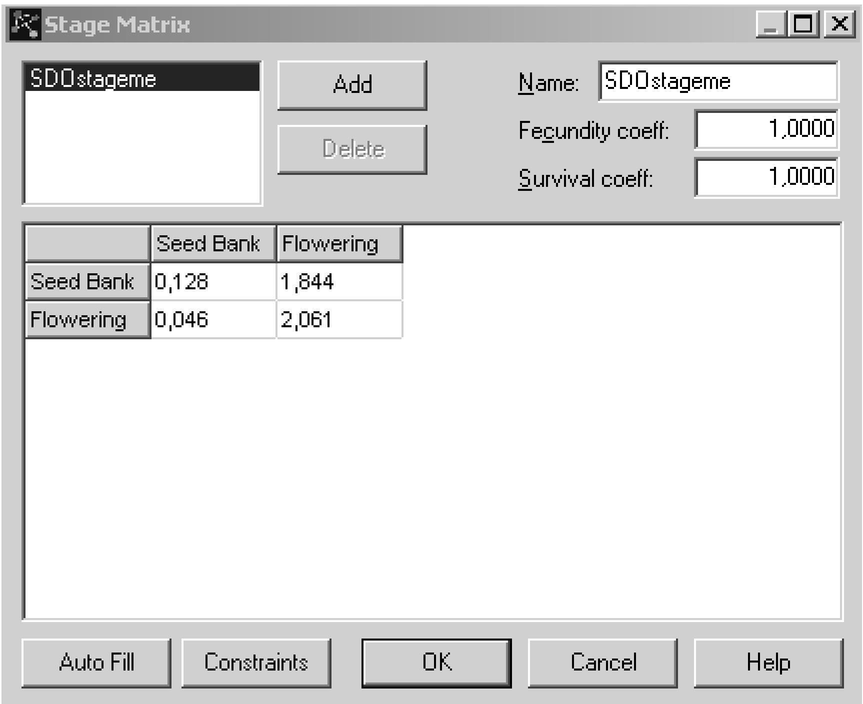

Figure H 6 Mean stage matrix with Medium S for Site 1

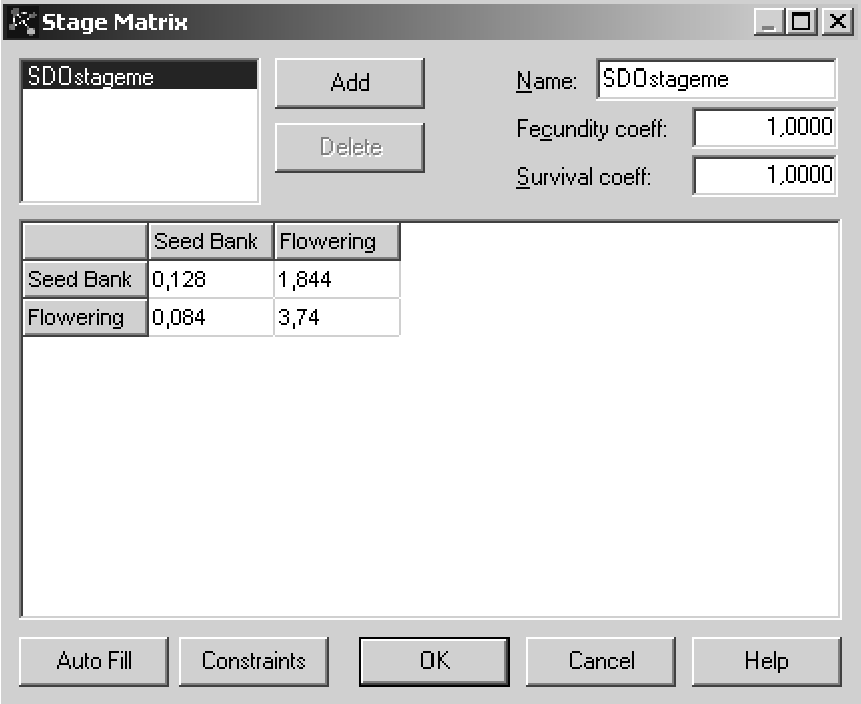

Figure H 7 Mean stage matrix with High S for Site 1

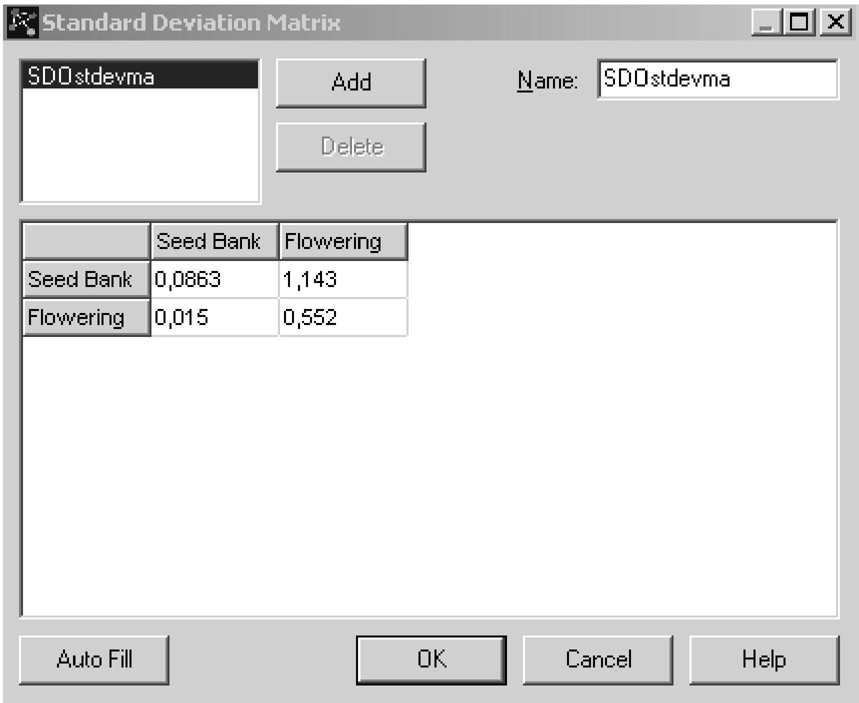

Figure H 8 Standard deviation matrix with Low S for Site1

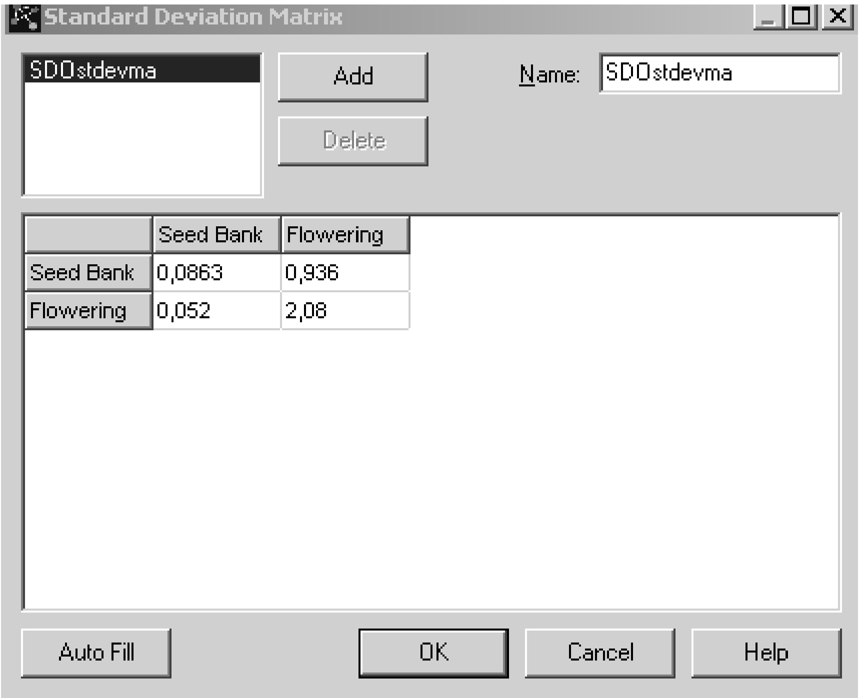

Figure H 9 Standard deviation matrix with Medium S for Site1

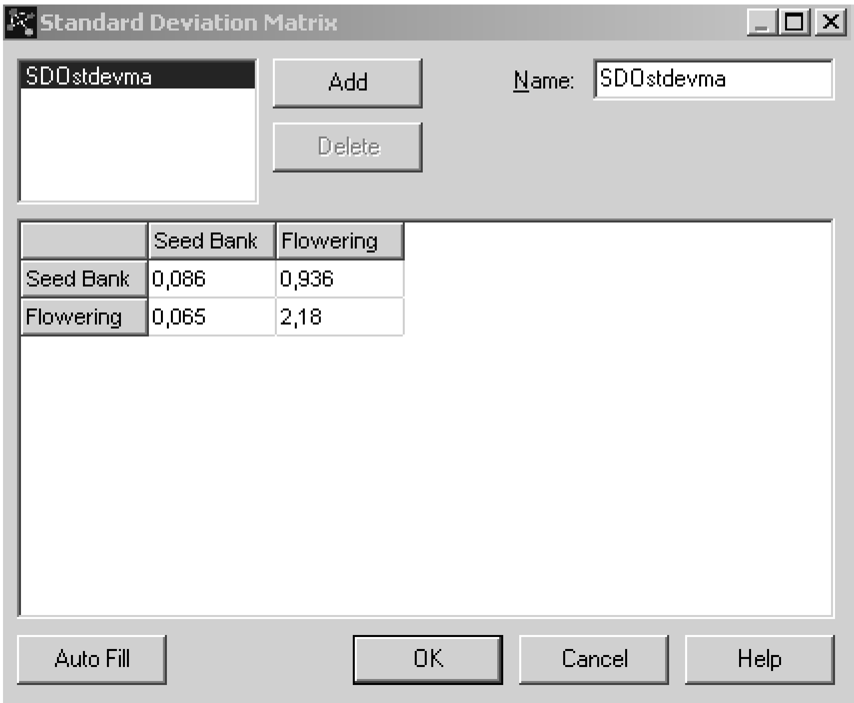

Figure H 10 Standard deviation matrix with High S for Site1

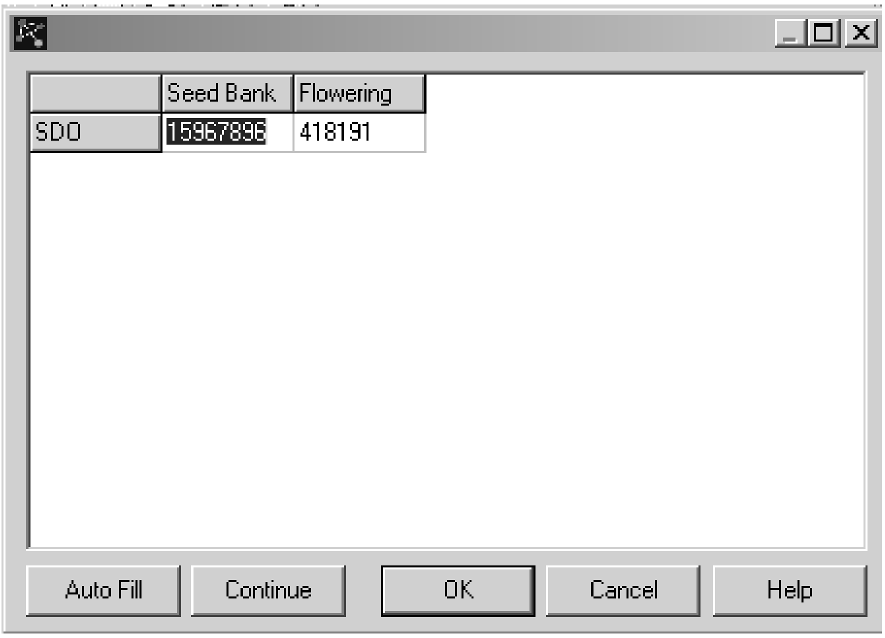

Figure H 11 Initial abundances for Site 1

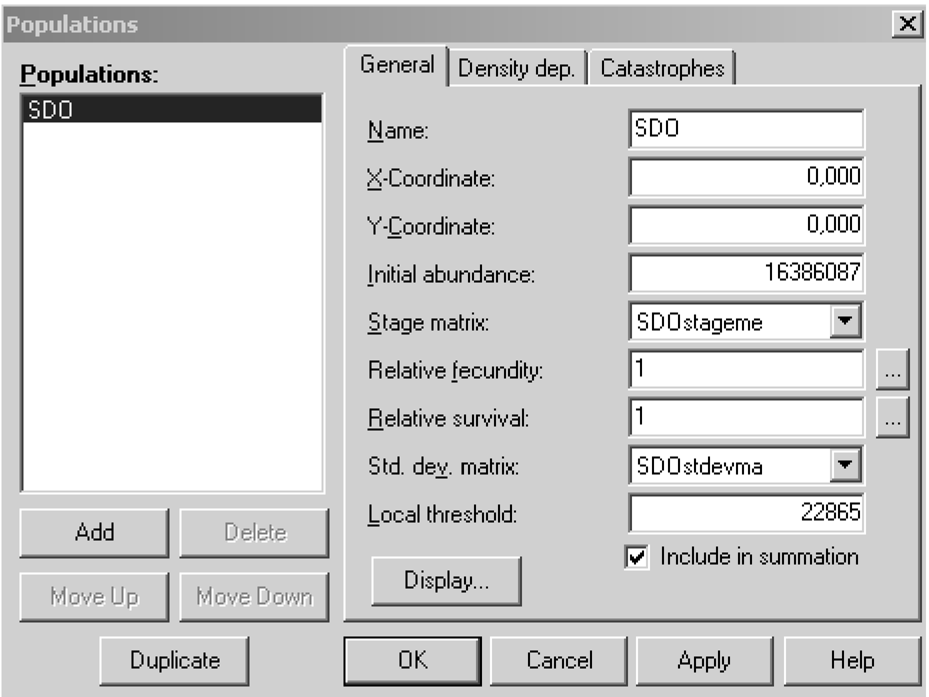

Figure H 12 General information for Site 1 from the “Populations” menu

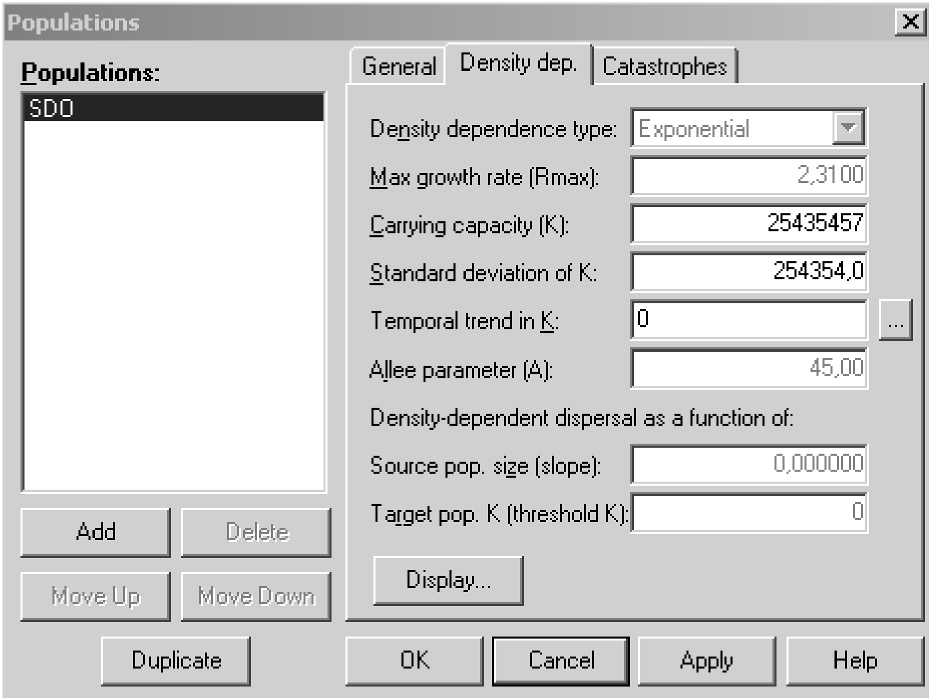

Figure H 13 Density dependence parameters for Site1 (Ceiling type)

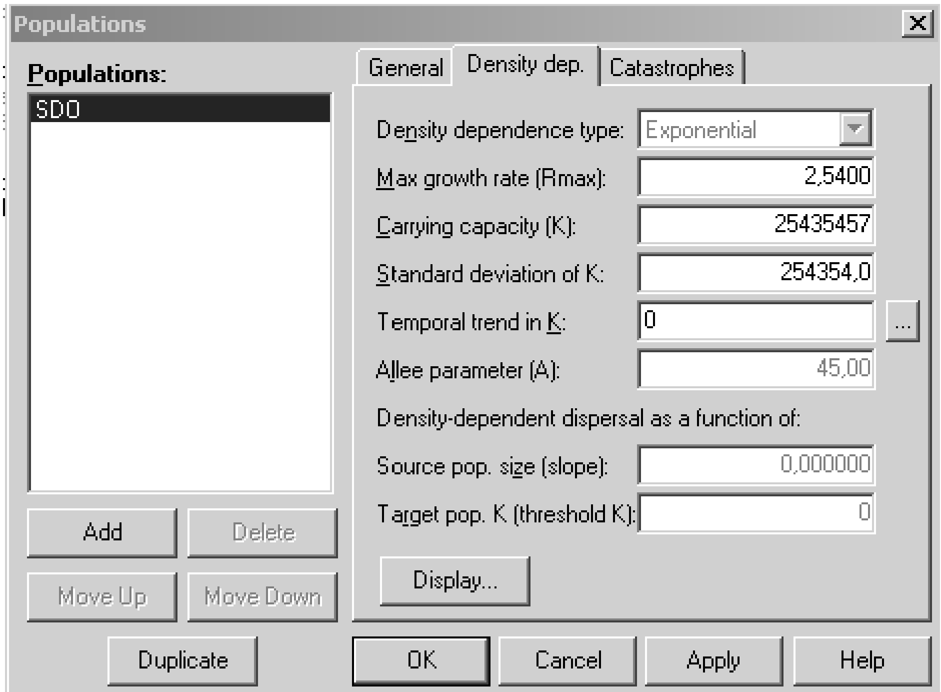

Figure H 14 Density dependence parameters for Site1 (Scramble type)

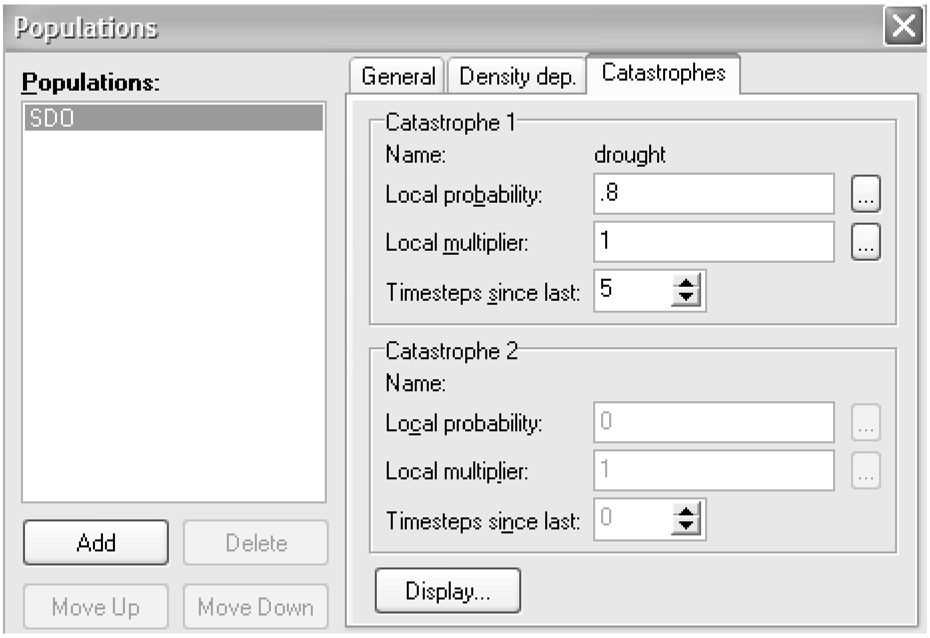

Figure H 15 To incorporate catastrophes to the model

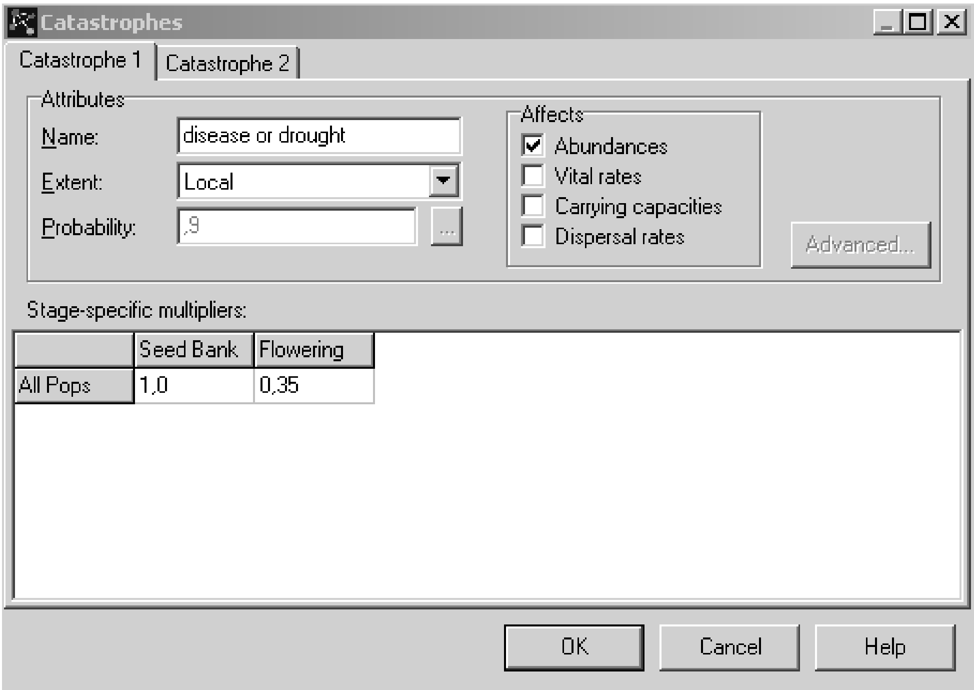

Figure H 16 Catastrophes parameters 1

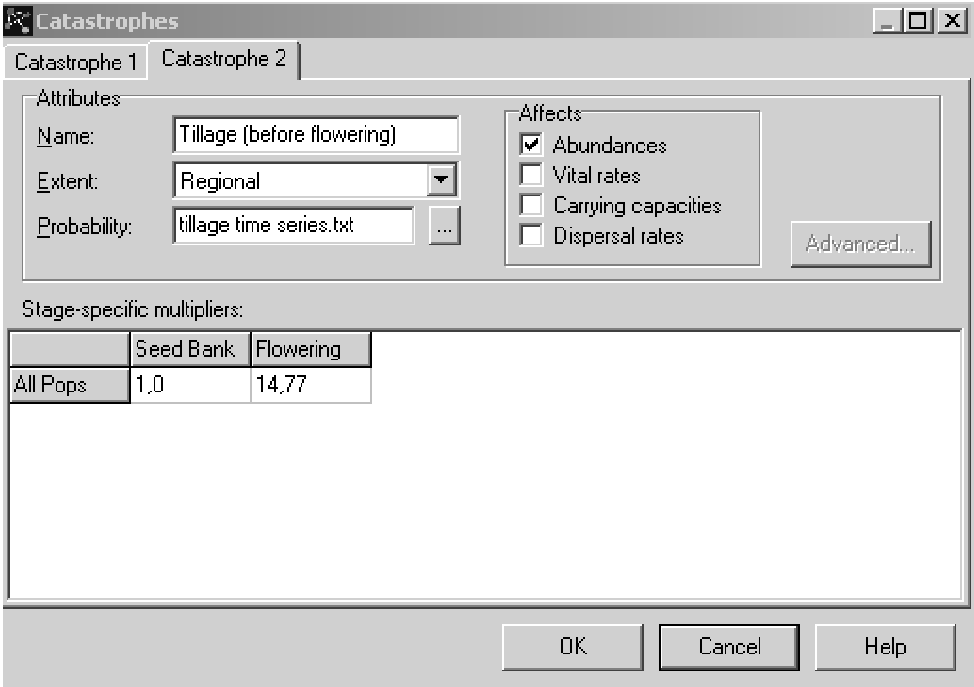

Figure H 17 Tillage effect (as a natural agricultural practice) before flowering –in combination with harvest management action in Figure H.18

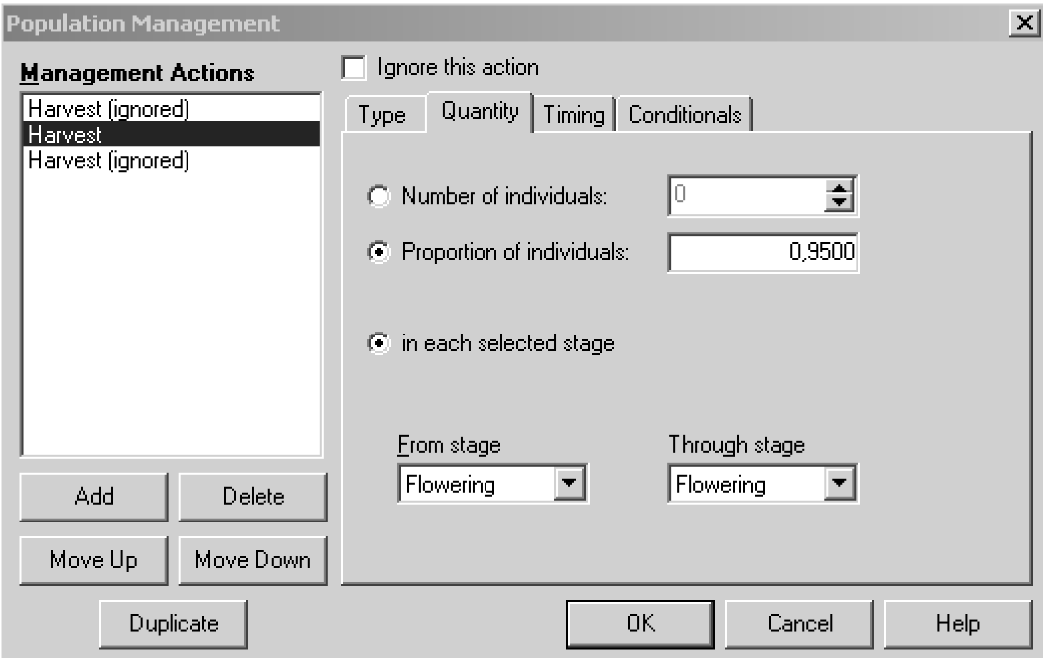

Figure H 18 Tillage effect (as a natural agricultural practice) before flowering in combination with catastrophe in Figure H.17

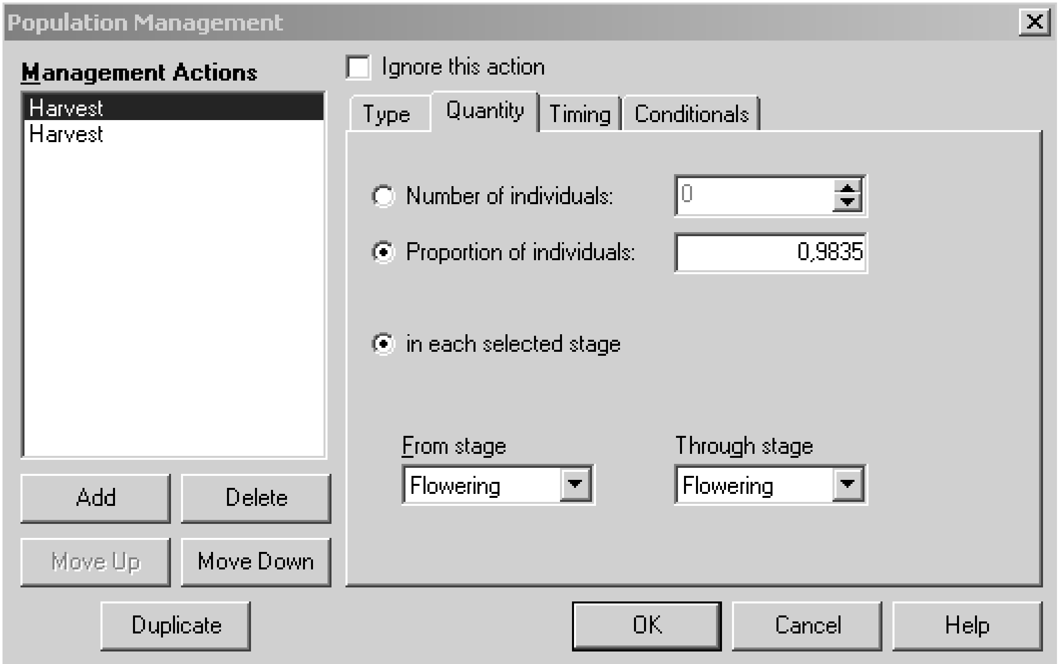

Figure H 19 Effects of Herbicide

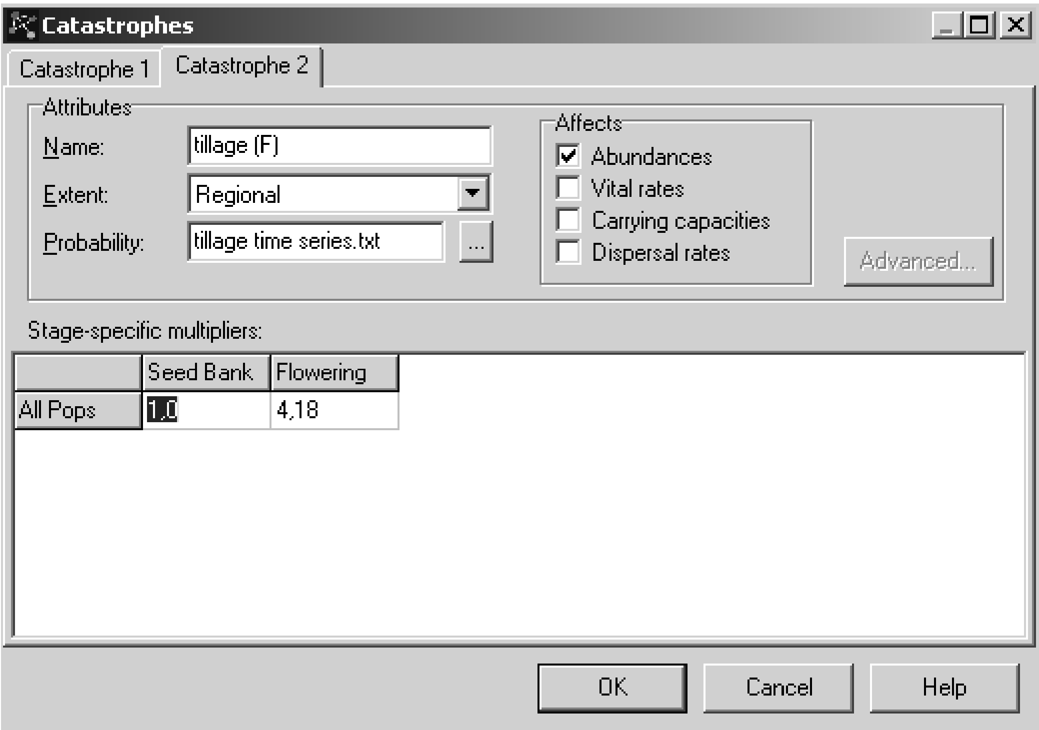

Figure H 20 Tillage effect (as a management action) after flowering

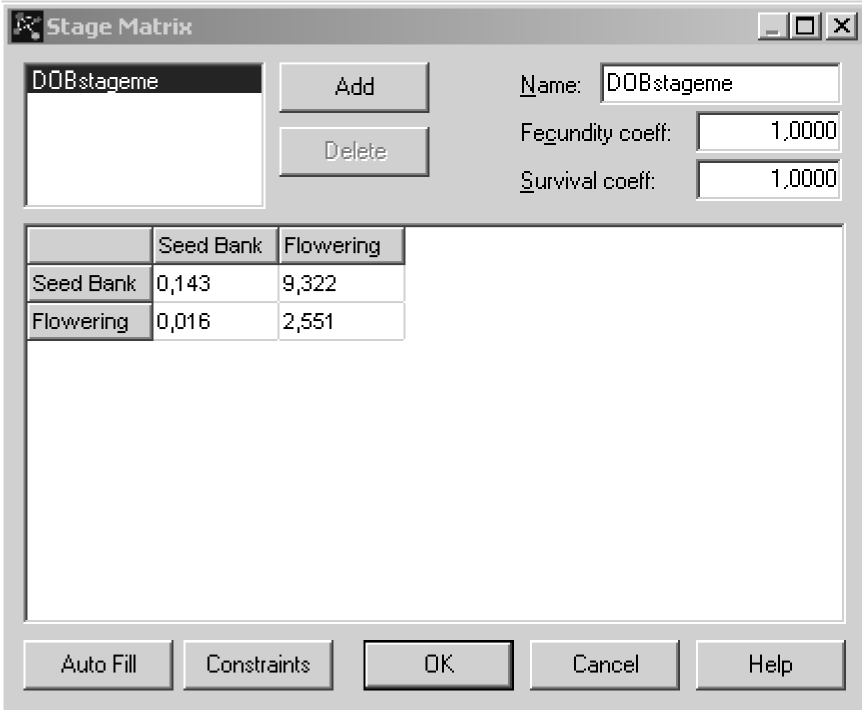

Figure H 21 Mean stage matrix with Low S of Site 2

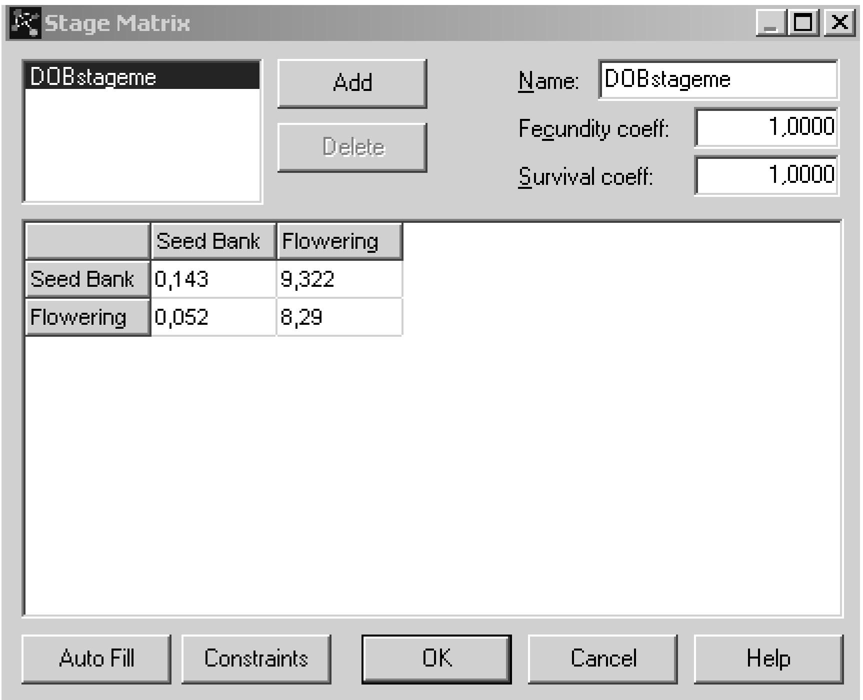

Figure H 22 Mean stage matrix with Medium S of Site 2

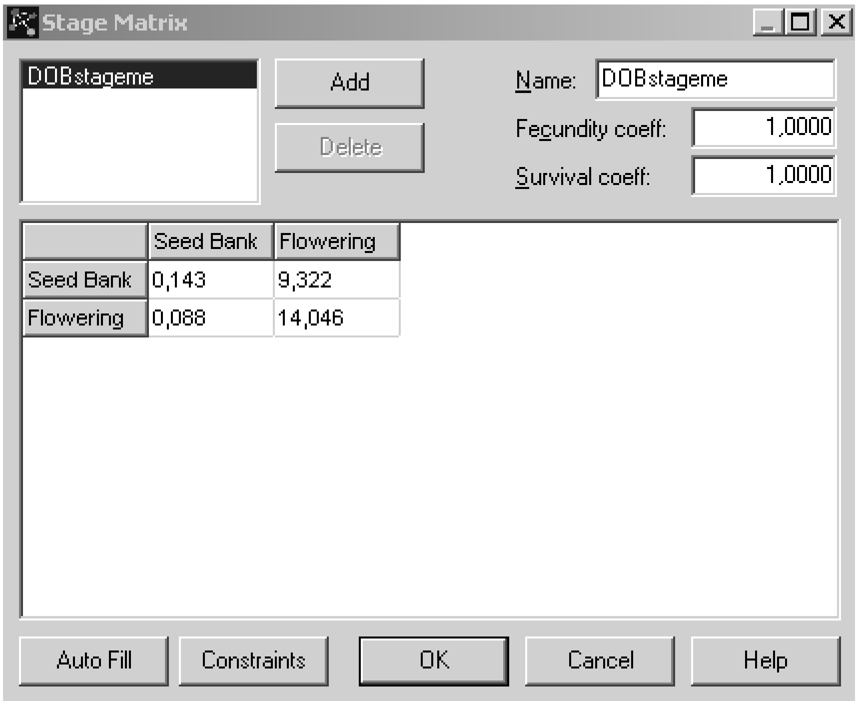

Figure H 23 Mean stage matrix with High S of Site 2

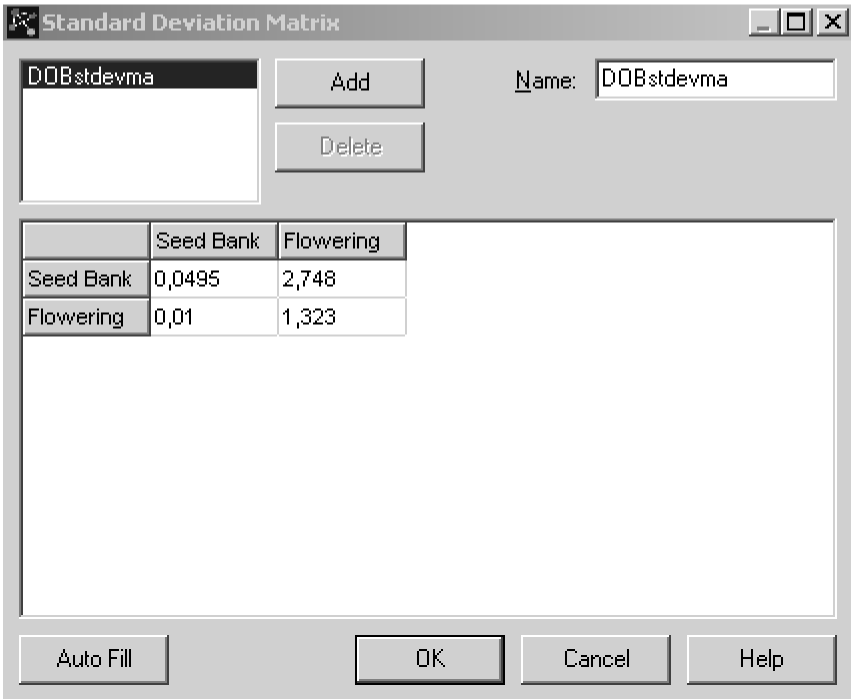

Figure H 24 Standard deviation matrix with Low S for Site 2

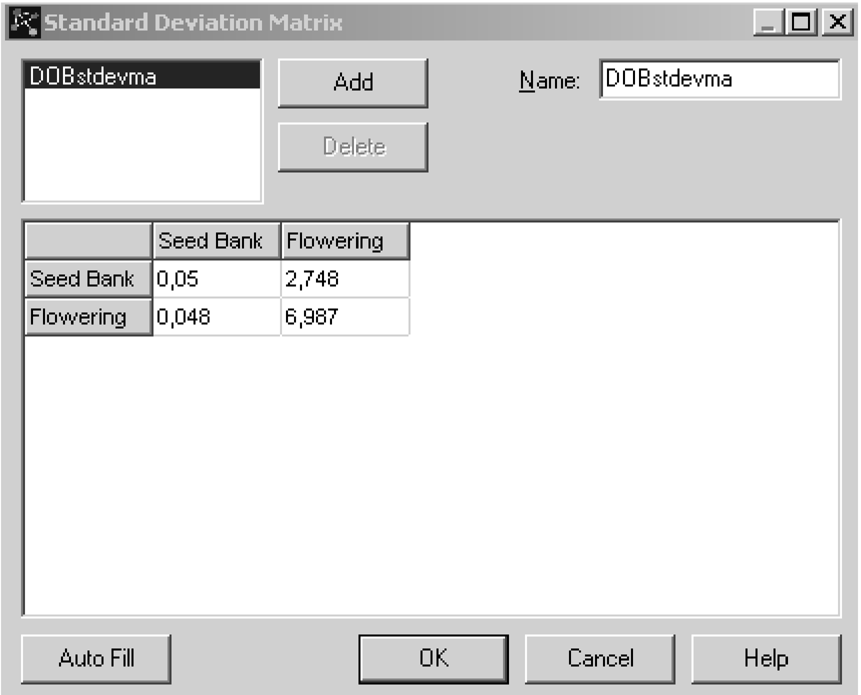

Figure H 25 Standard deviation matrix with Medium S for Site 2

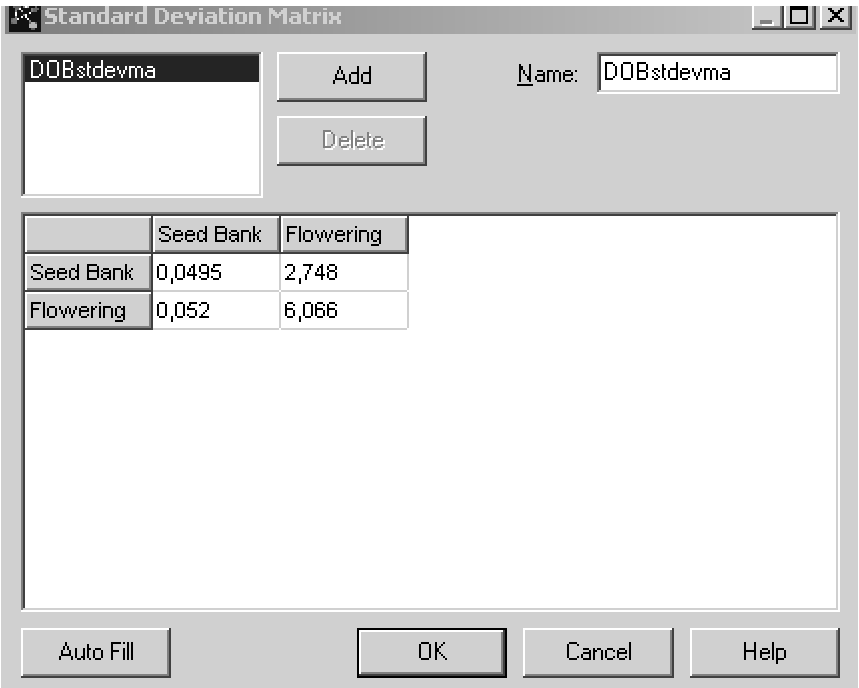

Figure H 26 Standard deviation matrix with High S for Site 2

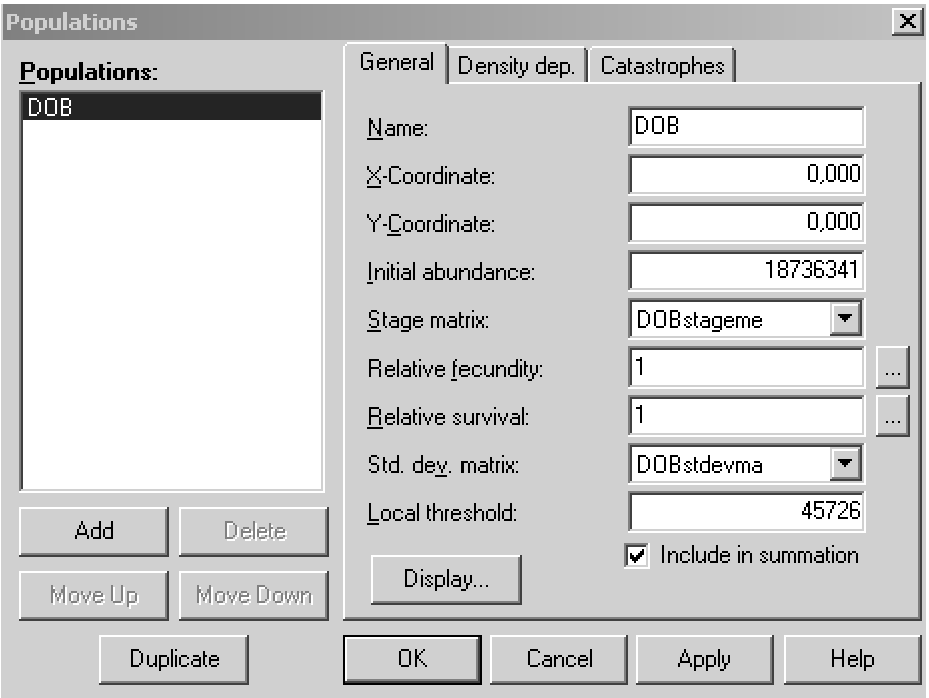

Figure H 27 General information for Site 2 from the "Populations" menu

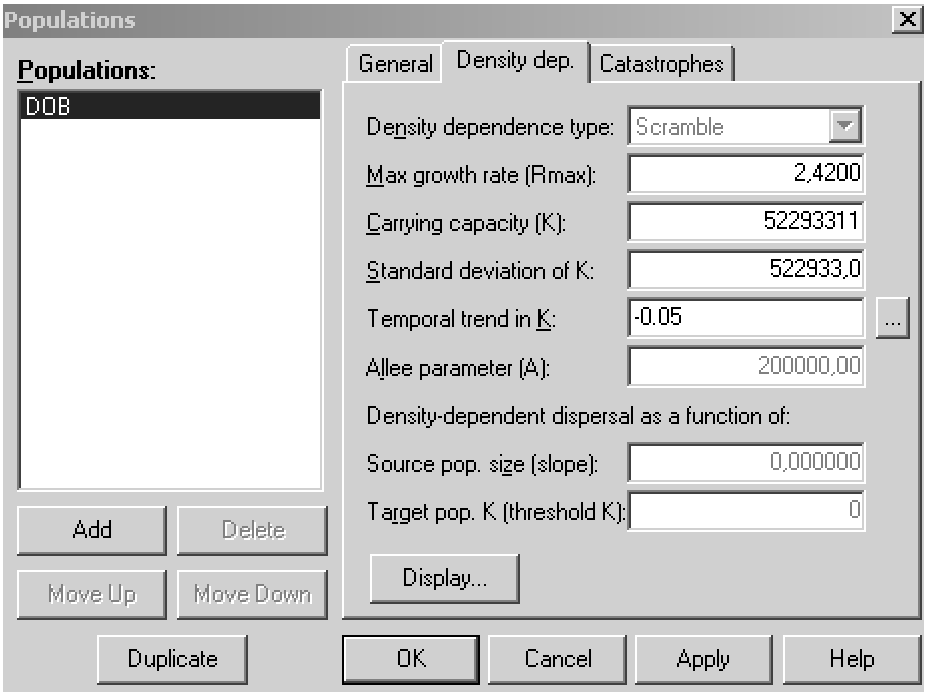

Figure H 28 Density dependence parameters for Site2

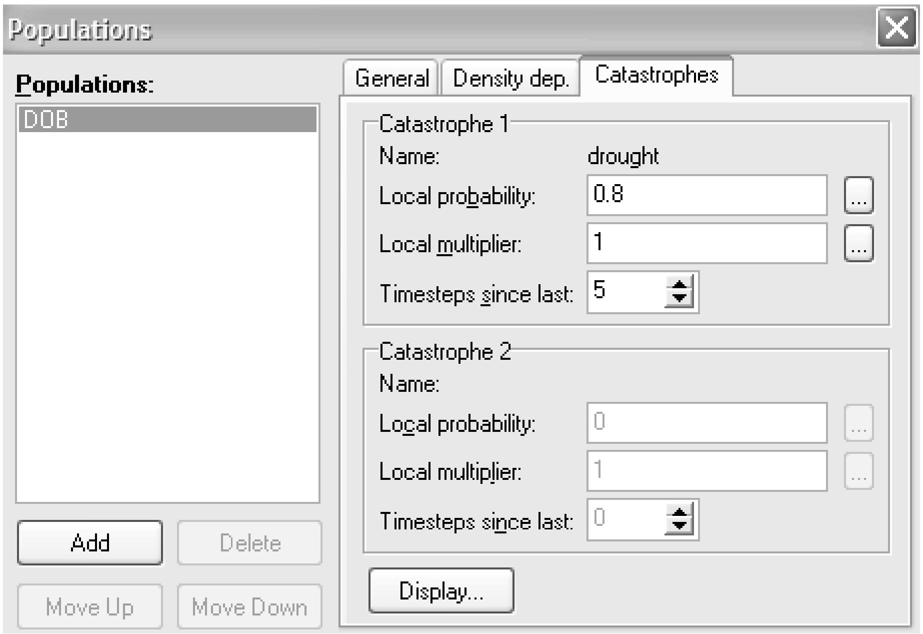

Figure H 29 Catastrophes parameters for Site 2

APPENDIX I:Life Cycle Stages

Figure I 1 Emergence

Figure I 2 Rosette

Figure I 3 Budding

Figure I 4 Flowering-seed dispersing

APPENDIX J Simulation Models

J.1. Model Summary and Assumptions for Site1-S2 Scenario 1

Title: SDO baseline

Comments: No catastrophes

Temporal trend in K

Replications: 10000

Duration: 100 time steps (100,0 years)

Stage structure

There are 2 stages

For all stages:

Average weight=-1

Stage matrix

SDOstageme	Seed Bank	Flowering
Seed Bank	0,128	1,844
Flowering	0,046	2,061

Constraints

Proportion of each stage matrix element that is survival (as opposed to fecundity)

	Seed Bank	Flowering
Seed Bank	1,0	0,0
Flowering	1,0	0,0

Stochasticity

Demographic stochasticity is used

Environmental stochasticity distribution: Lognormal

Extinction threshold for metapopulation = 0

Explosion threshold for metapopulation = 0

When abundance is below local threshold: assume dead

Within-population correlation: All correlated (F, S, K)

(F = fecundity, S = survival, K = carrying capacity)

Standard deviations matrix

SDOstdevma	Seed Bank	Flowering
Seed Bank	0,0863	0,936
Flowering	0,052	2,08

Catastrophes

There are no catastrophes.

Initial abundances

	Seed Bank	Flowering
SDO	15967896	418191

Populations

General

Population is SDO

Initial abundance is 16386087

Local threshold is 22865,0

The population is included in the summation

Density dependence

Density dependence type is Scramble

Density dependence is based on the abundances of all stages

Density dependence affects all vital rates

Max. growth rate (Rmax) is 2,54

Carrying capacity (K) is 18017956

Standard deviation of K is 1801796,0

Temporal trend in K is -0.05

Population management

Population management is not used

J.2. Model Summary and Assumptions for Site1_S2 Scenario 2!

Title: Disease or drought with Tillage before flowering

Comments:Tillage before flowering

Replications: 10000

Duration: 100 time steps (100,0 years)

Stage structure

There are 2 stages

For all stages:

Average weight=-1

Stage matrix

SDOstageme	Seed Bank	Flowering
Seed Bank	0,128	1,844
Flowering	0,046	2,061

Constraints

Proportion of each stage matrix element that is survival (as opposed to fecundity)

	Seed Bank	Flowering
Seed Bank	1,0	0,0
Flowering	1,0	0,0

Stochasticity

Demographic stochasticity is used

Environmental stochasticity distribution: Lognormal

Extinction threshold for metapopulation = 0

Explosion threshold for metapopulation = 0

When abundance is below local threshold: assume dead

Within-population correlation: All correlated (F, S, K)

(F = fecundity, S = survival, K = carrying capacity)

Standard deviations matrix

SDOstdevma	Seed Bank	Flowering
Seed Bank	0,0863	0,936
Flowering	0,052	2,08

Catastrophes

There are 2 catastrophes, which are independent.

Catastrophe 1:

Name: disease or drought

Extent: Local

Probability: see "Populations" below

Affects abundances

Local multipliers: see "Populations" below

Stage-specific multipliers:

Seed Bank	Flowering
1,0	0,35

Catastrophe 2:

Name: Tillage (before flowering)

Extent: Regional

Probability = 0.00(at time step 1, see tillage time series.txt)

Affects abundances

Local multipliers: see "Populations" below

Stage-specific multipliers:

Seed Bank	Flowering
1,0	14,77

Initial abundances

	Seed Bank	Flowering
SDO	15967896	418191

Populations

General

Population is SDO

Initial abundance is 16386087

Local threshold is 22865,0

The population is included in the summation

Density dependence

Density dependence type is Scramble

Density dependence is based on the abundances of all stages

Density dependence affects all vital rates

Max. growth rate (Rmax) is 2,54

Carrying capacity (K) is 18017956

Standard deviation of K is 1801796,0

Temporal trend in K is -0.05

Catastrophes

Catastrophe 1 local probability is 0.8

Catastrophe 1 local multiplier is 1

Time steps since last disease or drought (catastrophe 1) is 5

Time steps since last Tillage (before flowering) (catastrophe 2) is 1

Population management

Harvest

all populations

95% of the individuals from stage Flowering

from time step 0 to 100, every 2 time steps

J.3. Model Summary and Assumptions for Site1_S2 Scenario 3

Title: Disease or drought with Tillage before flowering

Comments:Tillage effect before flowering

Replications: 10000

Duration: 100 time steps (100,0 years)

Stage structure

There are 2 stages

For all stages:

Average weight=-1

Stage matrix

SDOstageme	Seed Bank	Flowering
Seed Bank	0,128	1,844
Flowering	0,046	2,061

Constraints

Proportion of each stage matrix element that is survival (as opposed to fecundity)

	Seed Bank	Flowering
Seed Bank	1,0	0,0
Flowering	1,0	0,0

Stochasticity

Demographic stochasticity is used

Environmental stochasticity distribution: Lognormal

Extinction threshold for metapopulation = 0

Explosion threshold for metapopulation = 0

When abundance is below local threshold: assume dead

Within-population correlation: All correlated (F, S, K)

(F = fecundity, S = survival, K = carrying capacity)

Standard deviations matrix

SDOstdevma	Seed Bank	Flowering
Seed Bank	0,0863	0,936
Flowering	0,052	2,08

Catastrophes

There are 2 catastrophes, which are independent.

Catastrophe 1:

Name: disease or drought

Extent: Local

Probability: see "Populations" below

Affects abundances

Local multipliers: see "Populations" below

Stage-specific multipliers:

Seed Bank	Flowering
1,0	0,35

Catastrophe 2:

Name: Tillage (before flowering)

Extent: Regional

Probability = 0.00(at time step 1, seetillage time series.txt)

Affects abundances

Local multipliers: see "Populations" below

Stage-specific multipliers:

Seed Bank	Flowering
1,0	14,77

Initial abundances

	Seed Bank	Flowering
SDO	15967896	418191

Populations

General

Population is SDO

Initial abundance is 16386087

Local threshold is 22865,0

The population is included in the summation

Density dependence

Density dependence type is Scramble

Density dependence is based on the abundances of all stages

Density dependence affects all vital rates

Max. growth rate (Rmax) is 2,54

Carrying capacity (K) is 18017956

Standard deviation of K is 1801796,0

Temporal trend in K is -0.05

Catastrophes

Catastrophe 1 local probability is 0.8

Catastrophe 1 local multiplier is 1

Time steps since last disease or drought (catastrophe 1) is 5

Time steps since last Tillage (before flowering) (catastrophe 2) is 1

Population management

Harvest

all populations

95% of the individuals from stage Flowering

from time step 0 to 100, every 2 time steps

J.4. Model Summary and Assumptions for Site1_S2 Scenario 4

Title: SDO Tillage (bf) + Herbicide

Comments:Agriculture with Herbicide

Replications: 10000

Duration: 100 time steps (100,0 years)

Stage structure

There are 2 stages

For all stages:

Average weight=-1

Stage matrix

SDOstageme	Seed Bank	Flowering
Seed Bank	0,128	1,844
Flowering	0,046	2,061

Constraints

Proportion of each stage matrix element that is survival (as opposed to fecundity)

	Seed Bank	Flowering
Seed Bank	1,0	0,0
Flowering	1,0	0,0

Stochasticity

Demographic stochasticity is used

Environmental stochasticity distribution: Lognormal

Extinction threshold for metapopulation = 0

Explosion threshold for metapopulation = 0

When abundance is below local threshold: assume dead

Within-population correlation: All correlated (F, S, K)

(F = fecundity, S = survival, K = carrying capacity)

Standard deviations matrix

SDOstdevma	Seed Bank	Flowering
Seed Bank	0,0863	0,936
Flowering	0,052	2,08

Catastrophes

There are 2 catastrophes, which are independent.

Catastrophe 1:

Name: disease or drought

Extent: Local

Probability: see "Populations" below

Affects abundances

Local multipliers: see "Populations" below

Stage-specific multipliers:

Seed Bank	Flowering
1,0	0,35

Catastrophe 2:

Name: tillage (bf)

Extent: Regional

Probability = 0.00(at time step 1, seetillage time series.txt)

Affects abundances

Local multipliers: see "Populations" below

Stage-specific multipliers:

Seed Bank	Flowering
1,0	14,77

Initial abundances

	Seed Bank	Flowering
SDO	15967896	418191

Populations

General

Population is SDO

Initial abundance is 16386087

Local threshold is 22865,0

The population is included in the summation

Density dependence

Density dependence type is Scramble

Density dependence is based on the abundances of all stages

Density dependence affects all vital rates

Max. growth rate (Rmax) is 2,54

Carrying capacity (K) is 18017956

Standard deviation of K is 1801796,0

Temporal trend in K is -0.05

Catastrophes

Catastrophe 1 local probability is 0.8

Catastrophe 1 local multiplier is 1

Time steps since last disease or drought (catastrophe 1) is 5

Time steps since last tillage (bf) (catastrophe 2) is 1

Population management

Harvest

all populations

98,4% of the individuals from stage Flowering

from time step 1 to 100, every 2 time steps

Harvest

all populations

95% of the individuals from stage Flowering

from time step 0 to 100, every 2 time steps

J.5. Model Summary and Assumptions for Site1_S2 Scenario 5

Title: SDO disease or drought + Tillage + Herbicide + Stubble Burn

Comments:Worst agricultural practices

Replications: 10000

Duration: 100 time steps (100,0 years)

Stage structure

There are 2 stages

For all stages:

Average weight=-1

Stage matrix

SDOstageme	Seed Bank	Flowering
Seed Bank	0,128	1,844
Flowering	0,046	2,061

Constraints

Proportion of each stage matrix element that is survival (as opposed to fecundity)

	Seed Bank	Flowering
Seed Bank	1,0	0,0
Flowering	1,0	0,0

Stochasticity

Demographic stochasticity is used

Environmental stochasticity distribution: Lognormal

Extinction threshold for metapopulation = 0

Explosion threshold for metapopulation = 0

When abundance is below local threshold: assume dead

Within-population correlation: All correlated (F, S, K)

(F = fecundity, S = survival, K = carrying capacity)

Standard deviations matrix

SDOstdevma	Seed Bank	Flowering
Seed Bank	0,086	0,936
Flowering	0,052	2,08

Catastrophes

There are 2 catastrophes, which are independent.

Catastrophe 1:

Name: drought disease

Extent: Local

Probability: see "Populations" below

Affects abundances

Local multipliers: see "Populations" below

Stage-specific multipliers:

Seed Bank	Flowering
1,0	0,35

Catastrophe 2:

Name: tillage (bf)

Extent: Regional

Probability = 0.00(at time step 1, seetillage time series.txt)

Affects abundances

Local multipliers: see "Populations" below

Stage-specific multipliers:

Seed Bank	Flowering
1,0	14,77

Initial abundances

	Seed Bank	Flowering
SDO	15967896	418191

Populations

General

Population is SDO

Initial abundance is 16386087

Local threshold is 22865,0

The population is included in the summation

Density dependence

Density dependence type is Scramble

Density dependence is based on the abundances of all stages

Density dependence affects all vital rates

Max. growth rate (Rmax) is 2,54

Carrying capacity (K) is 25435457

Standard deviation of K is 254354,0

Temporal trend in K is -0.05

Catastrophes

Catastrophe 1 local probability is .8

Catastrophe 1 local multiplier is 1

Time steps since last drought disease (catastrophe 1) is 5

Time steps since last tillage (bf) (catastrophe 2) is 1

Population management

Harvest

all populations

98,4% of the individuals from stage Flowering

from time step 1 to 100, every 2 time steps

Harvest

all populations

95% of the individuals from stage Flowering

from time step 0 to 100, every 2 time steps

Harvest

all populations

89% of the individuals from stage Flowering

from time step 2 to 100, every 2 time steps

J.6. Model Summary and Assumptions for Site1_S2 Scenario 6

Title: SDO Tillage - Management

Comments:Tillage once at every 2 year

Replications: 10000

Duration: 100 time steps (100,0 years)

Stage structure

There are 2 stages

For all stages:

Average weight=-1

Stage matrix

SDOstageme	Seed Bank	Flowering
Seed Bank	0,128	1,844
Flowering	0,046	2,061

Constraints

Proportion of each stage matrix element that is survival (as opposed to fecundity)

	Seed Bank	Flowering
Seed Bank	1,0	0,0
Flowering	1,0	0,0

Stochasticity

Demographic stochasticity is used

Environmental stochasticity distribution: Lognormal

Extinction threshold for metapopulation = 0

Explosion threshold for metapopulation = 0

When abundance is below local threshold: assume dead

Within-population correlation: All correlated (F, S, K)

(F = fecundity, S = survival, K = carrying capacity)

Standard deviations matrix

SDOstdevma	Seed Bank	Flowering
Seed Bank	0,0863	0,936
Flowering	0,052	2,08

Catastrophes

There are 2 catastrophes, which are independent.

Catastrophe 1:

Name: drought or disease

Extent: Local

Probability: see "Populations" below

Affects abundances

Local multipliers: see "Populations" below

Stage-specific multipliers:

Seed Bank	Flowering
1,0	0,35

Catastrophe 2:

Name: tillage (F)

Extent: Regional

Probability = 0.00(at time step 1, seetillage time series.txt)

Affects abundances

Local multipliers: see "Populations" below

Stage-specific multipliers:

Seed Bank	Flowering
1,0	4,18

Initial abundances

	Seed Bank	Flowering
SDO	15967896	418191

Populations

General

Population is SDO

Initial abundance is 16386087

Local threshold is 22865,0

The population is included in the summation

Density dependence

Density dependence type is Scramble

Density dependence is based on the abundances of all stages

Density dependence affects all vital rates

Max. growth rate (Rmax) is 2,54

Carrying capacity (K) is 18017956

Standard deviation of K is 1801796,0

Temporal trend in K is -0.05

Catastrophes

Catastrophe 1 local probability is 0.8

Catastrophe 1 local multiplier is 1

Time steps since last drought or disease (catastrophe 1) is 5

Time steps since last tillage (F) (catastrophe 2) is 1

Population management

Population management is not used

J.7. Model Summary and Assumptions for Site 2_S1 Scenario 1

Title: DOB Baseline

Comments: no catastrophes

Temporal trend in K

Replications: 10000

Duration: 100 time steps (100,0 years)

Stage structure

There are 2 stages

For all stages:

Average weight=-1

Stage matrix

DOBstageme	Seed Bank	Flowering
Seed Bank	0,143	9,322
Flowering	0,016	2,551

Constraints

Proportion of each stage matrix element that is survival (as opposed to fecundity)

	Seed Bank	Flowering
Seed Bank	1,0	0,0
Flowering	1,0	0,0

Stochasticity

Demographic stochasticity is used

Environmental stochasticity distribution: Lognormal

Extinction threshold for metapopulation = 0

Explosion threshold for metapopulation = 0

When abundance is below local threshold: assume dead

Within-population correlation: All correlated (F, S, K)

(F = fecundity, S = survival, K = carrying capacity)

Standard deviations matrix

DOBstdevma	Seed Bank	Flowering
Seed Bank	0,0495	2,748
Flowering	0,01	1,323

Catastrophes

There are no catastrophes.

Initial abundances

	Seed Bank	Flowering
DOB	18107209	629132

Populations

General

Population is DOB

Initial abundance is 18736341

Local threshold is 45726,0

The population is included in the summation

Density dependence

Density dependence type is Scramble

Density dependence is based on the abundances of all stages

Density dependence affects all vital rates

Max. growth rate (Rmax) is 2,42

Carrying capacity (K) is 33353352

Standard deviation of K is 3335335,0

Population management

Population management is not used

J.8. Model Summary and Assumptions for Site2-S1 Scenario 2

Title: DOB disease or drought

Comments:only one catastrophe is added

Replications: 10000

Duration: 100 time steps (100,0 years)

Stage structure

There are 2 stages

For all stages:

Average weight=-1

Stage matrix

DOBstageme	Seed Bank	Flowering
Seed Bank	0,143	9,322
Flowering	0,016	2,551

Constraints

Proportion of each stage matrix element that is survival (as opposed to fecundity)

	Seed Bank	Flowering
Seed Bank	1,0	0,0
Flowering	1,0	0,0

Stochasticity

Demographic stochasticity is used

Environmental stochasticity distribution: Lognormal

Extinction threshold for metapopulation = 0

Explosion threshold for metapopulation = 0

When abundance is below local threshold: assume dead

Within-population correlation: All correlated (F, S, K)

(F = fecundity, S = survival, K = carrying capacity)

Standard deviations matrix

DOBstdevma	Seed Bank	Flowering
Seed Bank	0,0495	2,748
Flowering	0,01	1,323

Catastrophes

There is 1 catastrophe.

Catastrophe 1:

Name: drought or disease

Extent: Local

Probability: see "Populations" below

Affects abundances

Local multipliers: see "Populations" below

Stage-specific multipliers:

Seed Bank	Flowering
1,0	0,35

Initial abundances

	Seed Bank	Flowering
DOB	18107209	629132

Populations

General

Population is DOB

Initial abundance is 18736341

Local threshold is 45726,0

The population is included in the summation

Density dependence

Density dependence type is Scramble

Density dependence is based on the abundances of all stages

Density dependence affects all vital rates

Max. growth rate (Rmax) is 2,42

Carrying capacity (K) is 33353352

Standard deviation of K is 3335335,0

Temporal trend in K is -0.05

Catastrophes

Catastrophe 1 local probability is 0.8

Catastrophe 1 local multiplier is 1

Time steps since last drought or disease (catastrophe 1) is 5

Population management

Population management is not used

J.9. Model Summary and Assumptions for Site 2_S1 Scenario 3

Title: Disease or drought with Tillage before flowering

Comments: Tillage effect before flowering

Replications: 10000

Duration: 100 time steps (100,0 years)

Stage structure

There are 2 stages

For all stages:

Average weight=-1

Stage matrix

DOBstageme	Seed Bank	Flowering
Seed Bank	0,143	9,322
Flowering	0,016	2,551

Constraints

Proportion of each stage matrix element that is survival (as opposed to fecundity)

	Seed Bank	Flowering
Seed Bank	1,0	0,0
Flowering	1,0	0,0

Stochasticity

Demographic stochasticity is used

Environmental stochasticity distribution: Lognormal

Extinction threshold for metapopulation = 0

Explosion threshold for metapopulation = 0

When abundance is below local threshold: assume dead

Within-population correlation: All correlated (F, S, K)

(F = fecundity, S = survival, K = carrying capacity)

Standard deviations matrix

DOBstdevma	Seed Bank	Flowering
Seed Bank	0,0495	2,748
Flowering	0,01	1,323

Catastrophes

There are 2 catastrophes, which are independent.

Catastrophe 1:

Name: drought or disease

Extent: Local

Probability: see "Populations" below

Affects abundances

Local multipliers: see "Populations" below

Stage-specific multipliers:

Seed Bank	Flowering
1,0	0,35

Catastrophe 2:

Name: tillage

Extent: Regional

Probability = 0.00(at time step 1, seetillage time series.txt)

Affects abundances

Local multipliers: see "Populations" below

Stage-specific multipliers:

Seed Bank	Flowering
1,0	14,77

Initial abundances

	Seed Bank	Flowering
DOB	18107209	629132

Populations

General

Population is DOB

Initial abundance is 18736341

Local threshold is 45726,0

The population is included in the summation

Density dependence

Density dependence type is Scramble

Density dependence is based on the abundances of all stages

Density dependence affects all vital rates

Max. growth rate (Rmax) is 2,42

Carrying capacity (K) is 33353352

Standard deviation of K is 3335335,0

Temporal trend in K is -0.05

Catastrophes

Catastrophe 1 local probability is 0.8

Catastrophe 1 local multiplier is 1

Time steps since last drought or disease (catastrophe 1) is 5

Time steps since last tillage (catastrophe 2) is 1

Population management

Harvest

all populations

95% of the individuals from stage Flowering

from time step 0 to 100, every 2 time steps

J.10. Model Summary and Assumptions for Site 2_S1 Scenario 4

Title: DOB Tillage (bf) + Herbicide

Comments:Agriculture with Herbicide

Replications: 10000

Duration: 100 time steps (100,0 years)

Stage structure

There are 2 stages

For all stages:

Average weight=-1

Stage matrix

DOBstageme	Seed Bank	Flowering
Seed Bank	0,143	9,322
Flowering	0,016	2,551

Constraints

Proportion of each stage matrix element that is survival (as opposed to fecundity)

	Seed Bank	Flowering
Seed Bank	1,0	0,0
Flowering	1,0	0,0

Stochasticity

Demographic stochasticity is used

Environmental stochasticity distribution: Lognormal

Extinction threshold for metapopulation = 0

Explosion threshold for metapopulation = 0

When abundance is below local threshold: assume dead

Within-population correlation: All correlated (F, S, K)

(F = fecundity, S = survival, K = carrying capacity)

Standard deviations matrix

DOBstdevma	Seed Bank	Flowering
Seed Bank	0,0445	2,748
Flowering	0,01	1,323

Catastrophes

There are 2 catastrophes, which are independent.

Catastrophe 1:

Name: drought or disease

Extent: Local

Probability: see "Populations" below

Affects abundances

Local multipliers: see "Populations" below

Stage-specific multipliers:

Seed Bank	Flowering
1,0	0,35

Catastrophe 2:

Name: tillage

Extent: Regional

Probability = 0.00(at time step 1, seetillage time series.txt)

Affects abundances

Local multipliers: see "Populations" below

Stage-specific multipliers:

Seed Bank	Flowering
1,0	14,77

Initial abundances

	Seed Bank	Flowering
DOB	18107209	629132

Populations

General

Population is DOB

Initial abundance is 18736341

Local threshold is 45726,0

The population is included in the summation

Density dependence

Density dependence type is Scramble

Density dependence is based on the abundances of all stages

Density dependence affects all vital rates

Max. growth rate (Rmax) is 2,42

Carrying capacity (K) is 33353352

Standard deviation of K is 3335335,0

Temporal trend in K is -0.05

Catastrophes

Catastrophe 1 local probability is 0.8

Catastrophe 1 local multiplier is 1

Time steps since last drought or disease (catastrophe 1) is 5

Time steps since last tillage (catastrophe 2) is 1

Population management

Harvest

all populations

98,4% of the individuals from stage Flowering

from time step 1 to 100, every 2 time steps

Harvest

all populations

95% of the individuals from stage Flowering

from time step 0 to 100, every 2 time steps

J.11. Model Summary and Assumptions for Site 2_S1 Scenario 5

Title: DOB disease or drought + Tillage + Herbicide + Stubble Burn

Comments:Worst agricultural practices

Replications: 10000

Duration: 100 time steps (100,0 years)

Stage structure

There are 2 stages

For all stages:

Average weight=-1

Stage matrix

DOBstageme	Seed Bank	Flowering
Seed Bank	0,143	9,322
Flowering	0,016	2,551

Constraints

Proportion of each stage matrix element that is survival (as opposed to fecundity)

	Seed Bank	Flowering
Seed Bank	1,0	0,0
Flowering	1,0	0,0

Stochasticity

Demographic stochasticity is used

Environmental stochasticity distribution: Lognormal

Extinction threshold for metapopulation = 0

Explosion threshold for metapopulation = 0

When abundance is below local threshold: assume dead

Within-population correlation: All correlated (F, S, K)

(F = fecundity, S = survival, K = carrying capacity)

Standard deviations matrix

DOBstdevma	Seed Bank	Flowering
Seed Bank	0,0495	2,748
Flowering	0,01	1,323

Catastrophes

There are 2 catastrophes, which are independent.

Catastrophe 1:

Name: drought or disease

Extent: Local

Probability: see "Populations" below

Affects abundances

Local multipliers: see "Populations" below

Stage-specific multipliers:

Seed Bank	Flowering
1,0	0,35

Catastrophe 2:

Name: tillage

Extent: Regional

Probability = 0.00(at time step 1, seetillage time series.txt)

Affects abundances

Local multipliers: see "Populations" below

Stage-specific multipliers:

Seed Bank	Flowering
1,0	14,77

Initial abundances

	Seed Bank	Flowering
DOB	18107209	629132

Populations

General

Population is DOB

Initial abundance is 18736341

Local threshold is 45726,0

The population is included in the summation

Density dependence

Density dependence type is Scramble

Density dependence is based on the abundances of all stages

Density dependence affects all vital rates

Max. growth rate (Rmax) is 2,42

Carrying capacity (K) is 33353352

Standard deviation of K is 3335335,0

Temporal trend in K is -0.05

Catastrophes

Catastrophe 1 local probability is 0.8

Catastrophe 1 local multiplier is 1

Time steps since last drought or disease (catastrophe 1) is 5

Time steps since last tillage (catastrophe 2) is 1

Population management

Harvest

all populations

98,4% of the individuals from stage Flowering

from time step 1 to 100, every 2 time steps

Harvest

all populations

95% of the individuals from stage Flowering

from time step 0 to 100, every 2 time steps

Harvest

all populations

89% of the individuals from stage Flowering

from time step 2 to 100, every 2 time steps

J.12. Model Summary and Assumptions for Site 2_S1 Scenario 6

Title: DOB Tillage - Management

Comments:Tillage once at every 2 year

Replications: 10000

Duration: 100 time steps (100,0 years)

Stage structure

There are 2 stages

For all stages:

Average weight=-1

Stage matrix

DOBstageme	Seed Bank	Flowering
Seed Bank	0,143	9,322
Flowering	0,016	2,551

Constraints

Proportion of each stage matrix element that is survival (as opposed to fecundity)

	Seed Bank	Flowering
Seed Bank	1,0	0,0
Flowering	1,0	0,0

Stochasticity

Demographic stochasticity is used

Environmental stochasticity distribution: Lognormal

Extinction threshold for metapopulation = 0

Explosion threshold for metapopulation = 0

When abundance is below local threshold: assume dead

Within-population correlation: All correlated (F, S, K)

(F = fecundity, S = survival, K = carrying capacity)

Standard deviations matrix

DOBstdevma	Seed Bank	Flowering
Seed Bank	0,0495	2,748
Flowering	0,01	1,323

Catastrophes

There are 2 catastrophes, which are independent.

Catastrophe 1:

Name: drought or disease

Extent: Local

Probability: see "Populations" below

Affects abundances

Local multipliers: see "Populations" below

Stage-specific multipliers:

Seed Bank	Flowering
1,0	0,35

Catastrophe 2:

Name: tillage

Extent: Regional

Probability = 0.00(at time step 1, seetillage time series.txt)

Affects abundances

Local multipliers: see "Populations" below

Stage-specific multipliers:

Seed Bank	Flowering
1,0	4,18

Initial abundances

	Seed Bank	Flowering
DOB	18107209	629132

Populations

General

Population is DOB

Initial abundance is 18736341

Local threshold is 45726,0

The population is included in the summation

Density dependence

Density dependence type is Scramble

Density dependence is based on the abundances of all stages

Density dependence affects all vital rates

Max. growth rate (Rmax) is 2,42

Carrying capacity (K) is 33353352

Standard deviation of K is 3335335,0

Temporal trend in K is -0.05

Catastrophes

Catastrophe 1 local probability is 0.8

Catastrophe 1 local multiplier is 1

Time steps since last drought or disease (catastrophe 1) is 5

Time steps since last tillage (catastrophe 2) is 1

Population management

Population management is not used

The population is included in the summation

J.13. Model Summary and Assumptions for Metapopulation Scenario 1

Title: Metapopulation model, baseline

Comments:Temporal trend in K

Replications: 10000

Duration: 100 time steps (100,0 years)

Stage structure

There are 2 stages

For all stages:

Relative dispersal=-1

Average weight=-1

Stage matrix

SDOstageme	Seed Bank	Flowering
Seed Bank	0,128	1,844
Flowering	0,046	2,061

DOBstageme	Seed Bank	Flowering
Seed Bank	0,143	9,322
Flowering	0,016	2,551

Constraints

Proportion of each stage matrix element that is survival (as opposed to fecundity)

	Seed Bank	Flowering
Seed Bank	1,0	0,0
Flowering	1,0	0,0

Stochasticity

Demographic stochasticity is used

Environmental stochasticity distribution: Lognormal

Extinction threshold for metapopulation = 0

Explosion threshold for metapopulation = 0

When abundance is below local threshold: assume dead

Within-population correlation: All correlated (F, S, K)

(F = fecundity, S = survival, K = carrying capacity)

Standard deviations matrix

SDOstdevma	Seed Bank	Flowering
Seed Bank	0,0863	0,936
Flowering	0,052	2,08

DOBstdevma	Seed Bank	Flowering
Seed Bank	0,0495	2,748
Flowering	0,01	1,323

Catastrophes

There is 1 catastrophe.

Catastrophe 1:

Name: drought or disease

Extent: Local

Probability: see "Populations" below

Affects abundances

Local multipliers: see "Populations" below

Stage-specific multipliers:

Seed Bank	Flowering
1,0	0,35

Initial abundances

	Seed Bank	Flowering
SDO	15967896	418191
DOB	18107209	629132
S3 Hacilar-d	883595	5000
S4 BackSide-d	1454825	2200
S5 Next Side-d	2183003	12300
S6 Orencik-s	59449	0
S7 Intaspace-d	23114140	154300
S8 Yavrucuk-d	727667	500
S9 Parapent-s	162622	30
S10 Mahmatli-d	975	20
S11 Karagedi-d	14399770	187645
S12 Calis-d	7282247	128147

	Seed Bank	Flowering
S13 Golbek-d	20613157	439281
S14 Celltek-s	1829200	0

Spatial structure

There are 14 populations (see "Populations" below for coordinates)

Dispersal

There is no migration/dispersal among the populations.

Correlation

Environmental fluctuations among populations are correlated, with correlation coefficients ranging from 0.006 to 0.915

Populations

General

All populations are included in the summation

Density dependence

Density dependence type is Scramble

Density dependence is based on the abundances of all stages

Density dependence affects all vital rates

Temporal trend in K is -0.05

Catastrophes

Catastrophe 1 local multiplier is 1

Time steps since last drought or disease (catastrophe 1) is 5.

Population management

Harvest

SDO

95% of the individuals from stage Flowering

from time step 0 to 100, every 6 time steps

Harvest

DOB to S5 Next Side-d

95% of the individuals from stage Flowering

from time step 0 to 100, every 2 time steps

Harvest

S6 Orencik-s

95% of the individuals from stage Flowering

from time step 0 to 100, every 6 time steps

Harvest

S7 Intaspace-d to S8 Yavrucuk-d

95% of the individuals from stage Flowering

from time step 0 to 100, every 2 time steps

Harvest

S9 Parapent-s

95% of the individuals from stage Flowering

from time step 0 to 100, every 6 time steps

Harvest

S10 Mahmatli-d to S13 Golbek-d

95% of the individuals from stage Flowering

from time step 0 to 100, every 2 time steps

Harvest

S14 Celtek-s

95% of the individuals from stage Flowering

from time step 0 to 100, every 6 time steps

Population	X-coordinate	Y-coordinate	Initial abundance	Stage matrix	Std. dev. matrix	Local threshold	Max. growth rate (Rmax)	Carrying capacity (K)	Standard deviation of K	ophe 1 local probabi
SDO	6,092	6,234	16386087	SDOstageme	SDOstdevma	22865,0	2,54	25435457	254354,0	.8
DOB	2,828	7,156	18736341	DOBstageme	DOBstdevma	45726,0	2,42	52293311	522933,0	0.8
S3 Hacilar-d	0,0	2,65	888595	DOBstageme	DOBstdevma	8886,0	2,42	1777191	177719,0	0.8
S4 BackSide-d	0,154	0,0	1457025	DOBstageme	DOBstdevma	13166,0	2,42	2914050	291405,0	0.8
S5 Next Side-d	5,404	0,093	2195303	DOBstageme	DOBstdevma	2379,0	2,42	4390605	439061,0	0.8
S6 Orencik-s	17,609	13,01	59449	SDOstageme	SDOstdevma	594,0	2,54	118898	11890,0	.8
S7 Intaspace-d	1,361	17,374	23268440	DOBstageme	DOBstdevma	104971,0	2,42	46536880	4653688,0	0.8
S8 Yavrucuk-d	8,172	26,192	728167	DOBstageme	DOBstdevma	7282,0	2,42	1456334	145633,0	0.8
S9 Parapent-s	26,828	34,495	162652	SDOstageme	SDOstdevma	1627,0	2,54	325304	32530,0	.8
S10 Mahmatli-d	45,094	61,75	995	DOBstageme	DOBstdevma	100,0	2,42	1990	199,0	.8
S11 Karagedi-d	10,674	55,863	14587415	DOBstageme	DOBstdevma	145874,0	2,42	29174830	2917483,0	0.8
S12 Calis-d	3,482	102,833	7410394	DOBstageme	DOBstdevma	74104,0	2,42	14820787	1482079,0	0.8
S13 Golbek-d	40,432	131,304	21052438	DOBstageme	DOBstdevma	210524,0	2,42	42104876	4210488,0	0.8
S14 Celltek-s	35,511	149,316	1829200	SDOstageme	SDOstdevma	18292,0	2,54	3658400	365840,0	.8

J.14. Model Summary and Assumptions for Metapopulation Scenario 2

Title: Metapopulation model, base with Temp K & Catastrophe

Comments: Only one catastrophe is added

Replications: 10000

Duration: 100 time steps (100,0 years)

Stage structure

There are 2 stages

For all stages:

Relative dispersal=-1

Average weight=-1

Stage matrix

SDOstageme	Seed Bank	Flowering
Seed Bank	0,128	1,844
Flowering	0,046	2,061

DOBstageme	Seed Bank	Flowering
Seed Bank	0,143	9,322
Flowering	0,016	2,551

Constraints

Proportion of each stage matrix element that is survival (as opposed to fecundity)

	Seed Bank	Flowering
Seed Bank	1,0	0,0
Flowering	1,0	0,0

Stochasticity

Demographic stochasticity is used

Environmental stochasticity distribution: Lognormal

Extinction threshold for metapopulation = 0

Explosion threshold for metapopulation = 0

When abundance is below local threshold: assume dead

Within-population correlation: All correlated (F, S, K)

(F = fecundity, S = survival, K = carrying capacity)

Standard deviations matrix

SDOstdevma	Seed Bank	Flowering
Seed Bank	0,0863	0,936
Flowering	0,052	2,08

DOBstdevma	Seed Bank	Flowering
Seed Bank	0,0495	2,748
Flowering	0,01	1,323

Catastrophes

There is 1 catastrophe.

Catastrophe 1:

Name: drought or disease

Extent: Local

Probability: see "Populations" below

Affects abundances

Local multipliers: see "Populations" below

Stage-specific multipliers:

Seed Bank	Flowering
1,0	0,35

Initial abundances

	Seed Bank	Flowering
SDO	15967896	418191
DOB	18107209	629132
S3 Hacilar-d	883595	5000
S4 BackSide-d	1454825	2200
S5 Next Side-d	2183003	12300
S6 Orencik-s	59449	0
S7 Intaspace-d	23114140	154300
S8 Yavrucuk-d	727667	500
S9 Parapent-s	162622	30
S10 Mahmatli-d	975	20
S11 Karagedi-d	14399770	187645
S12 Calis-d	7282247	128147
S13 Golbek-d	20613157	439281
S14 Celltek-s	1829200	0

Spatial structure

There are 14 populations (see "Populations" below for coordinates)

Dispersal

There is no migration/dispersal among the populations.

Correlation

Environmental fluctuations among populations are correlated, with correlation coefficients ranging from 0.006 to 0.915

Populations

General

All populations are included in the summation

Density dependence

Density dependence type is Scramble

Density dependence is based on the abundances of all stages

Density dependence affects all vital rates

Temporal trend in K is -0.05

Catastrophes

Catastrophe 1 local multiplier is 1

Time steps since last drought or disease (catastrophe 1) is 5

Time steps since last tilllage (catastrophe 2) is 0

Population	X-coordinate	Y-coordinate	Initial abundance	Stage matrix	Std. dev. matrix	Local threshold	Max. growth rate (Rmax)	Carrying capacity (K)	Standard deviation of K	Catastrophe 1 local probability	Catastrophe 2 local multiplier
SDO	6,092	6,234	16386087	SDOstageme	SDOstdevma	22865,0	2,54	25435457	254354,0	.8	
DOB	2,828	7,156	18736341	DOBstageme	DOBstdevma	45726,0	2,42	52293311	522933,0	0.8	1
S3 Hacilar-d	0,0	2,65	888595	DOBstageme	DOBstdevma	8886,0	2,42	1777191	177719,0	0.8	1
S4 BackSide-d	0,154	0,0	1457025	DOBstageme	DOBstdevma	13166,0	2,42	2914050	291405,0	0.8	1
S5 Next Side-d	5,404	0,093	2195303	DOBstageme	DOBstdevma	2379,0	2,42	4390605	439061,0	0.8	1
S6 Orencik-s	17,609	13,01	59449	SDOstageme	SDOstdevma	594,0	2,54	118898	11890,0	.8	
S7 Intaspace-d	1,361	17,374	23268440	DOBstageme	DOBstdevma	104971,0	2,42	46536880	4653688,0	0.8	1
S8 Yavrucuk-d	8,172	26,192	728167	DOBstageme	DOBstdevma	7282,0	2,42	1456334	145633,0	0.8	1
S9 Parapent-s	26,828	34,495	162652	SDOstageme	SDOstdevma	1627,0	2,54	325304	32530,0	.8	
S10 Mahmatli-d	45,094	61,75	995	DOBstageme	DOBstdevma	100,0	2,42	1990	199,0	.8	1
S11 Karagedi-d	10,674	55,863	14587415	DOBstageme	DOBstdevma	145874,0	2,42	29174830	2917483,0	0.8	1
S12 Calis-d	3,482	102,833	7410394	DOBstageme	DOBstdevma	74104,0	2,42	14820787	1482079,0	0.8	1
S13 Golbek-d	40,432	131,304	21052438	DOBstageme	DOBstdevma	210524,0	2,42	42104876	4210488,0	0.8	1
S14 Celltek-s	35,511	149,316	1829200	SDOstageme	SDOstdevma	18292,0	2,54	3658400	365840,0	.8	

Population management

Harvest

SDO

95% of the individuals from stage Flowering

from time step 0 to 100, every 6 time steps

Harvest

DOB to S5 Next Side-d

95% of the individuals from stage Flowering

from time step 0 to 100, every 2 time steps

Harvest

S6 Orencik-s

95% of the individuals from stage Flowering

from time step 0 to 100, every 6 time steps

Harvest

S7 Intaspace-d to S8 Yavrucuk-d

95% of the individuals from stage Flowering

from time step 0 to 100, every 2 time steps

Harvest

S9 Parapent-s

95% of the individuals from stage Flowering

from time step 0 to 100, every 6 time steps

Harvest

S10 Mahmatli-d to S13 Golbek-d

95% of the individuals from stage Flowering

from time step 0 to 100, every 2 time steps

Harvest

S14 Celltek-s

95% of the individuals from stage Flowering

from time step 0 to 100, every 6 time steps

J.15. Model Summary and Assumptions for Metapopulation Scenario 3

Title: Metapopulation model**,** Disease or drought with Tillage before flowering

Comments: Tillage effect at Cultivation

Replications: 10000

Duration: 100 time steps (100,0 years)

Stage structure

There are 2 stages

For all stages:

Relative dispersal=-1

Average weight=-1

Stage matrix

SDOstageme	Seed Bank	Flowering
Seed Bank	0,128	1,844
Flowering	0,046	2,061

DOBstageme	Seed Bank	Flowering
Seed Bank	0,143	9,322
Flowering	0,016	2,551

Constraints

Proportion of each stage matrix element that is survival (as opposed to fecundity)

	Seed Bank	Flowering
Seed Bank	1,0	0,0
Flowering	1,0	0,0

Stochasticity

Demographic stochasticity is used

Environmental stochasticity distribution: Lognormal

Extinction threshold for metapopulation = 0

Explosion threshold for metapopulation = 0

When abundance is below local threshold: assume dead

Within-population correlation: All correlated (F, S, K)

(F = fecundity, S = survival, K = carrying capacity)

Standard deviations matrix

SDOstdevma	Seed Bank	Flowering
Seed Bank	0,0863	0,936
Flowering	0,052	2,08

DOBstdevma	Seed Bank	Flowering
Seed Bank	0,0495	2,748
Flowering	0,01	1,323

Catastrophes

There is 1 catastrophe.

Catastrophe 1:

Name: drought or disease

Extent: Local

Probability: see "Populations" below

Affects abundances

Local multipliers: see "Populations" below

Stage-specific multipliers:

Seed Bank	Flowering
1,0	0,35

Initial abundances

	Seed Bank	Flowering
SDO	15967896	418191
DOB	18107209	629132
S3 Hacilar-d	883595	5000
S4 BackSide-d	1454825	2200
S5 Next Side-d	2183003	12300
S6 Orencik-s	59449	0
S7 Intaspace-d	23114140	154300
S8 Yavrucuk-d	727667	500
S9 Parapent-s	162622	30
S10 Mahmatli-d	975	20
S11 Karagedi-d	14399770	187645
S12 Calis-d	7282247	128147
S13 Golbek-d	20613157	439281
S14 Celltek-s	1829200	0

Spatial structure

There are 14 populations (see "Populations" below for coordinates)

Dispersal

There is no migration/dispersal among the populations.

Correlation

Environmental fluctuations among populations are correlated, with correlation coefficients ranging from 0.006 to 0.915

Populations

General

All populations are included in the summation

Density dependence

Density dependence type is Scramble

Density dependence is based on the abundances of all stages

Density dependence affects all vital rates

Temporal trend in K is -0.05

Catastrophes

Catastrophe 1 local multiplier is 1

Time steps since last drought or disease (catastrophe 1) is 5

Time steps since last tilllage (catastrophe 2) is 0

Population	SDO	DOB	S3 Hacilar-d	S4 BackSide-d	S5 Next Side-d	S6 Orencik-s	S7 Intaspace-d	S8 Yavrucuk-d	S9 Parapent-s	S10 Mahmatli-d	S11 Karagedi-d	S12 Calis-d	S13 Golbek-d	S14 Celltek-s
X-coordinate	6,092	2,828	0,0	0,154	5,404	17,609	1,361	8,172	26,828	45,094	10,674	3,482	40,432	35,511
Y-coordinate	6,234	7,156	2,65	0,0	0,093	13,01	17,374	26,192	34,495	61,75	55,863	102,833	131,304	149,316
Initial abundance	16386087	18736341	888595	1457025	2195303	59449	23268440	728167	162652	995	14587415	7410394	21052438	1829200
Stage matrix	SDOstageme	DOBstageme	DOBstageme	DOBstageme	DOBstageme	SDOstageme	DOBstageme	DOBstageme	SDOstageme	DOBstageme	DOBstageme	DOBstageme	DOBstageme	SDOstageme
Std. dev. matrix	SDOstdevma	DOBstdevma	DOBstdevma	DOBstdevma	DOBstdevma	SDOstdevma	DOBstdevma	DOBstdevma	SDOstdevma	DOBstdevma	DOBstdevma	DOBstdevma	DOBstdevma	SDOstdevma
Local threshold	22865,0	45726,0	8886,0	13166,0	2379,0	594,0	104971,0	7282,0	1627,0	100,0	145874,0	74104,0	210524,0	18292,0
Max. growth rate (Rmax)	2,54	2,42	2,42	2,42	2,42	2,54	2,42	2,42	2,54	2,42	2,42	2,42	2,42	2,54
Carrying capacity (K)	25435457	52293311	1777191	2914050	4390605	118898	46536880	1456334	325304	1990	29174830	14820787	42104876	3658400
Standard deviation of K	254354,0	522933,0	177719,0	291405,0	439061,0	11890,0	4653688,0	145633,0	32530,0	199,0	2917483,0	1482079,0	4210488,0	365840,0
Catastrophe 1 local probability	.8	0.8	0.8	0.8	0.8	.8	0.8	0.8	.8	.8	0.8	0.8	0.8	.8
Catastrophe 2 local multiplier		1	1	1	1		1	1		1	1	1	1	

Population management

Harvest

SDO

95% of the individuals from stage Flowering

from time step 0 to 100, every 6 time steps

Harvest

DOB to S5 Next Side-d

95% of the individuals from stage Flowering

from time step 0 to 100, every 2 time steps

Harvest

S6 Orencik-s

95% of the individuals from stage Flowering

from time step 0 to 100, every 6 time steps

Harvest

S7 Intaspace-d to S8 Yavrucuk-d

95% of the individuals from stage Flowering

from time step 0 to 100, every 2 time steps

Harvest

S9 Parapent-s

95% of the individuals from stage Flowering

from time step 0 to 100, every 6 time steps

Harvest

S10 Mahmatli-d to S13 Golbek-d

95% of the individuals from stage Flowering

from time step 0 to 100, every 2 time steps

Harvest

S14 Celltek-s

95% of the individuals from stage Flowering

from time step 0 to 100, every 6 time steps

Harvest

SDO

98,4% of the individuals from stage Flowering

from time step 1 to 100, every 6 time steps

Harvest

DOB to S5 Next Side-d

98,4% of the individuals from stage Flowering

from time step 1 to 100, every 2 time steps

Harvest

S6 Orencik-s

98,4% of the individuals from stage Flowering

from time step 1 to 100, every 6 time steps

Harvest

S7 Intaspace-d to S8 Yavrucuk-d

98,4% of the individuals from stage Flowering

from time step 1 to 100, every 2 time steps

Harvest

S9 Parapent-s

98,4% of the individuals from stage Flowering

from time step 1 to 100, every 6 time steps

Harvest

S10 Mahmatli-d to S13 Golbek-d

98,4% of the individuals from stage Flowering

from time step 1 to 100, every 2 time steps

Harvest

S14 Celltek-s

98,4% of the individuals from stage Flowering

from time step 1 to 100, every 6 time step

J.16. Model Summary and Assumptions for Metapopulation Scenario 4

Title: Metapopulation model, Tillage (bf) + Herbicide

Comments: Tillage at Cultivation with Herbicide

Replications: 10000

Duration: 100 time steps (100,0 years)

Stage structure

There are 2 stages

For all stages:

Relative dispersal=-1

Average weight=-1

Stage matrix

SDOstageme	Seed Bank	Flowering
Seed Bank	0,128	1,844
Flowering	0,046	2,061

DOBstageme	Seed Bank	Flowering
Seed Bank	0,143	9,322
Flowering	0,016	2,551

Constraints

Proportion of each stage matrix element that is survival (as opposed to fecundity)

	Seed Bank	Flowering
Seed Bank	1,0	0,0
Flowering	1,0	0,0

Stochasticity

Demographic stochasticity is used

Environmental stochasticity distribution: Lognormal

Extinction threshold for metapopulation = 0

Explosion threshold for metapopulation = 0

When abundance is below local threshold: assume dead

Within-population correlation: All correlated (F, S, K)

(F = fecundity, S = survival, K = carrying capacity)

Standard deviations matrix

SDOstdevma	Seed Bank	Flowering
Seed Bank	0,0863	0,936
Flowering	0,052	2,08

DOBstdevma	Seed Bank	Flowering
Seed Bank	0,0495	2,748
Flowering	0,01	1,323

Catastrophes

There are 2 catastrophes, which are independent.

Catastrophe 1:

Name: drought or disease

Extent: Local

Probability: see "Populations" below

Affects abundances

Local multipliers: see "Populations" below

Stage-specific multipliers:

Seed Bank	Flowering
1,0	0,35

Catastrophe 2:

Name: tilllage

Extent: Regional

Probability = 1.00(at time step 1, seetillage time series(2y).txt)

Affects abundances

Local multipliers: see "Populations" below

Stage-specific multipliers:

Seed Bank	Flowering
1,0	4,18

Initial abundances

	Seed Bank	Flowering
SDO	15967896	418191
DOB	18107209	629132
S3 Hacilar-d	883595	5000
S4 BackSide-d	1454825	2200

	Seed Bank	Flowering
S5 Next Side-d	2183003	12300
S6 Orencik-s	59449	0
S7 Intaspace-d	23114140	154300
S8 Yavrucuk-d	727667	500
S9 Parapent-s	162622	30
S10 Mahmatli-d	975	20
S11 Karagedi-d	14399770	187645
S12 Calis-d	7282247	128147
S13 Golbek-d	20613157	439281
S14 Celltek-s	1829200	0

Spatial structure

There are 14 populations (see "Populations" below for coordinates)

Dispersal

There is no migration/dispersal among the populations.

Correlation

Environmental fluctuations among populations are correlated, with correlation coefficients ranging from 0.006 to 0.915

Populations

General

All populations are included in the summation

Density dependence

Density dependence type is Scramble

Density dependence is based on the abundances of all stages

Density dependence affects all vital rates

Temporal trend in

K is -0.05

Catastrophes

Catastrophe 1 local multiplier is 1

Time steps since last drought or disease (catastrophe 1) is 5

Catastrophe 2 local multiplier is 1

Time steps since last tilllage (catastrophe 2) is 0

Population	X-coordinate	Y-coordinate	Initial abundance	Stage matrix	Std. dev. matrix	Local threshold	Max. growth rate (Rmax)	Carrying capacity (K)	Standard deviation of K	Catastrophe 1 local probability
SDO	6,092	6,234	16386087	SDOstageme	SDOstdevma	22865,0	2,54	25435457	254354,0	.8
DOB	2,828	7,156	18736341	DOBstageme	DOBstdevma	45726,0	2,42	52293311	522933,0	0.8
S3 Hacilar-d	0,0	2,65	888595	DOBstageme	DOBstdevma	8886,0	2,42	1777191	177719,0	0.8
S4 BackSide-d	0,154	0,0	1457025	DOBstageme	DOBstdevma	13166,0	2,42	2914050	291405,0	0.8
S5 Next Side-d	5,404	0,093	2195303	DOBstageme	DOBstdevma	2379,0	2,42	4390605	439061,0	0.8
S6 Orencik-s	17,609	13,01	59449	SDOstageme	SDOstdevma	594,0	2,54	118898	11890,0	.8
S7 Intaspace-d	1,361	17,374	23268440	DOBstageme	DOBstdevma	104971,0	2,42	46536880	4653688,0	0.8
S8 Yavrucuk-d	8,172	26,192	728167	DOBstageme	DOBstdevma	7282,0	2,42	1456334	145633,0	0.8
S9 Parapent-s	26,828	34,495	162652	SDOstageme	SDOstdevma	1627,0	2,54	325304	32530,0	.8
S10 Mahmatli-d	45,094	61,75	995	DOBstageme	DOBstdevma	100,0	2,42	1990	199,0	.8
S11 Karagedi-d	10,674	55,863	14587415	DOBstageme	DOBstdevma	145874,0	2,42	29174830	2917483,0	0.8
S12 Calis-d	3,482	102,833	7410394	DOBstageme	DOBstdevma	74104,0	2,42	14820787	1482079,0	0.8
S13 Golbek-d	40,432	131,304	21052438	DOBstageme	DOBstdevma	210524,0	2,42	42104876	4210488,0	0.8
S14 Celltek-s	35,511	149,316	1829200	SDOstageme	SDOstdevma	18292,0	2,54	3658400	365840,0	.8

Population management

Population management is not used

J.17. Model Summary and Assumptions for Metapopulation Management Scenario

Title: Metapopulation management scenario base with Temp K

Comments:Tillage after flowering applied every 2 year for DOB like subpopulations and every 6 year for SDO like subpoulations

Replications: 10000

Duration: 100 time steps (100,0 years)

Stage structure

There are 2 stages

For all stages:

Relative dispersal=-1

Average weight=-1

Stage matrix

SDOstageme	Seed Bank	Flowering
Seed Bank	0,128	1,844
Flowering	0,046	2,061

DOBstageme	Seed Bank	Flowering
Seed Bank	0,143	9,322
Flowering	0,016	2,551

Constraints

Proportion of each stage matrix element that is survival (as opposed to fecundity)

	Seed Bank	Flowering
Seed Bank	1,0	0,0
Flowering	1,0	0,0

Stochasticity

Demographic stochasticity is used

Environmental stochasticity distribution: Lognormal

Extinction threshold for metapopulation = 0

Explosion threshold for metapopulation = 0

When abundance is below local threshold: assume dead

Within-population correlation: All correlated (F, S, K)

(F = fecundity, S = survival, K = carrying capacity)

Standard deviations matrix

SDOstdevma	Seed Bank	Flowering
Seed Bank	0,0863	0,936
Flowering	0,052	2,08

DOBstdevma	Seed Bank	Flowering
Seed Bank	0,0495	2,748
Flowering	0,01	1,323

Catastrophes

There are 2 catastrophes, which are independent.

Catastrophe 1:

Name: drought or disease

Extent: Local

Probability: see "Populations" below

Affects abundances

Local multipliers: see "Populations" below

Stage-specific multipliers:

Seed Bank	Flowering
1,0	0,35

Catastrophe 2:

Name: tilllage

Extent: Regional

Probability = 1.00(at time step 1, seetillage time series(2y).txt)

Affects abundances

Local multipliers: see "Populations" below

Stage-specific multipliers:

Seed Bank	Flowering
1,0	4,18

Initial abundances

	Seed Bank	Flowering
SDO	15967896	418191
DOB	18107209	629132
S3 Hacilar-d	883595	5000
S4 BackSide-d	1454825	2200
S5 Next Side-d	2183003	12300
S6 Orencik-s	59449	0
S7 Intaspace-d	23114140	154300
S8 Yavrucuk-d	727667	500
S9 Parapent-s	162622	30
S10 Mahmatli-d	975	20
S11 Karagedi-d	14399770	187645
S12 Calis-d	7282247	128147
S13 Golbek-d	20613157	439281
S14 Celltek-s	1829200	0

Spatial structure

There are 14 populations (see "Populations" below for coordinates)

Dispersal

There is no migration/dispersal among the populations.

Correlation

Environmental fluctuations among populations are correlated, with correlation coefficients ranging from 0.006 to 0.915

Populations

General

All populations are included in the summation

Density dependence

Density dependence type is Scramble

Density dependence is based on the abundances of all stages

Density dependence affects all vital rates

Temporal trend in K is -0.05

Catastrophes

Catastrophe 1 local multiplier is 1

Time steps since last drought or disease (catastrophe 1) is 5

Catastrophe 2 local multiplier is 1

Time steps since last tilllage (catastrophe 2) is 0

Population management

Population management is not used

Population	X-coordinate	Y-coordinate	Initial abundance	Stage matrix	Std. dev. matrix	Local threshold	Max. growth rate (Rmax)	Carrying capacity (K)	Standard deviation of K	Catastrophe 1 local probability
SDO	6,092	6,234	16386087	SDOstageme	SDOstdevma	22865,0	2,54	25435457	254354,0	.8
DOB	2,828	7,156	18736341	DOBstageme	DOBstdevma	45726,0	2,42	52293311	522933,0	0.8
S3 Hacilar-d	0,0	2,65	888595	DOBstageme	DOBstdevma	8886,0	2,42	1777191	177719,0	0.8
S4 BackSide-d	0,154	0,0	1457025	DOBstageme	DOBstdevma	13166,0	2,42	2914050	291405,0	0.8
S5 Next Side-d	5,404	0,093	2195303	DOBstageme	DOBstdevma	2379,0	2,42	4390605	439061,0	0.8
S6 Orencik-s	17,609	13,01	59449	SDOstageme	SDOstdevma	594,0	2,54	118898	11890,0	.8
S7 Intaspace-d	1,361	17,374	23268440	DOBstageme	DOBstdevma	104971,0	2,42	46536880	4653688,0	0.8
S8 Yavrucuk-d	8,172	26,192	728167	DOBstageme	DOBstdevma	7282,0	2,42	1456334	145633,0	0.8
S9 Parapent-s	26,828	34,495	162652	SDOstageme	SDOstdevma	1627,0	2,54	325304	32530,0	.8
S10 Mahmatli-d	45,094	61,75	995	DOBstageme	DOBstdevma	100,0	2,42	1990	199,0	.8
S11 Karagedi-d	10,674	55,863	14587415	DOBstageme	DOBstdevma	145874,0	2,42	29174830	2917483,0	0.8
S12 Calis-d	3,482	102,833	7410394	DOBstageme	DOBstdevma	74104,0	2,42	14820787	1482079,0	0.8
S13 Golbek-d	40,432	131,304	21052438	DOBstageme	DOBstdevma	210524,0	2,42	42104876	4210488,0	0.8
S14 Celltek-s	35,511	149,316	1829200	SDOstageme	SDOstdevma	18292,0	2,54	3658400	365840,0	.8

CURRICULUM VITAE

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Personal Born in 1975, İzmir

Education

2000–2008 **PhD in Conservation Biology**
Department of Biological Sciences,
Middle East Technical University, Ankara, Turkey

- Lately she developed new interdisciplinary course on ecological and environmental issues named Conservation: Linking Ecology and the Social Sciences as a lecture.
- She has done her research on plant conservation and ecological modeling.
- Thesis subject is "Population status, threats and conservation approaches for a highly threatened endemic plant, *Centaurea tchihatcheffii* in Ankara, Turkey".
- She took several courses like Advanced Ecology, Biodiversity Conservation, Conservation Biology, and Population Viability Analysis.

1998–2000 **Masters Degree in Ecology**
Department of Biological Sciences,
Middle East Technical University, Ankara, Turkey

- She did her research on freshwater ecosystems.

- Thesis subject was "Temporal and Spatial fluctuations of Chlorophyll-*a* at Lake Karagöl, Ankara".
- She took several courses like Field Ecology, Plants in Changing Environments, Major Concepts in Ecology, Nature Services: Societal Dependence on Natural Ecosystems, and Numerical Taxonomy.

1993–1998 **Bachelor of Science**

Department of Education, Biology Teaching Department,

Middle East Technical University, Ankara, Turkey

- Satisfactorily completed the necessary courses for the science program

Experience

2007- still **AKADEMİKA Danışmanlık ve Eğitim Hizmetleri**

İstanbul

Freelance Consultant

- Works as a part-time trainer for education programs on *environmental awareness*

2003-2007 **TÜBİTAK Research Project**

Ankara

Researcher

- Worked as a researcher for the project of "Conservation biology of an endangered species Centaurea tchihatcheffii Fisch. & Mey. (Compositae): Germination ecology, population viability analysis and conservation strategies"

2006- 2007 **BBF Partners AG**

İstanbul

Freelance Consultant

- Worked in a feasibility study for the **"Almond Orchard Design"** in Turkey. Coordinated the top-down technical analyses for the project. Defined candidate areas, gathered climate and soil data, interviewed with the experts and government authorities. The project and financial feasibility including candidate field visits has successfully been done as a result of her work. In this study she works in collaboration with an international agro-consulting firm.

2005 **Applied Plant Conservation Program,**

Denver Botanic Gardens, Denver Colorado USA

Conservation Intern

- During the internship, worked with Denver Botanic Gardens' conservation and research staff and gained extensive hands-on experience in three different project areas:
- Research (focus on rare plant monitoring, noxious weed control, ex-situ/ in-situ plant conservation, population modeling, etc.)
- Horticulture (e.g. endangered species garden design and curation)
- Education (e.g. class development and design)
- Involved in several field projects at different regions of Colorado
- Completed one independent research project

2003 **Global Environment Facility (GEF) II Project, "Biodiversity and Natural Resource Management"**

Köprülü Kanyon National Park Antalya, Turkey

Field Ecologist

- Involved in the National Park Management Strategy Development
- Performed *Rapid Ecological Assessment* with team scientists and applied *Threat Analysis*
- Conducted field visits, and gave guidance to the preparation of National Park Management Plan and provided background knowledge about the following subjects:
- Forest ecology, flora and fauna mapping and zone planning

- Rapid Ecological Assessment draft report and Threat Analysis reports
- IUCN Protected area management categories, IUCN threat criteria
- Species Red List, endemism, rarity and indicator species
- Remote Sensing and GIS technologies

2001-2002 **METU Development Foundation Private College**

Middle East Technical University, Ankara

Biology Teacher

- 11th, 9th grade biology teaching and prep level science teaching
- Environment Club Coordinator
- Managed an International Student Project

1999-2000 **SEBİT Education and Information Tech. Inc.**

Ankara

Biology Editor and Ecology Consultant

- She worked as the scientific consultant for the science material other than biology and ecology subjects of the developed media.
- She was the editor of biology and ecology subsections of the media. She both introduced the static texts and referred visual media that will support the understanding of the subjects

1999-2000 **Middle East Technical University,**

Ankara

Project Assistant

- Worked as the Project Assistant of her Master Thesis' field studies financed by Research Projects Fund.

1998–1999 **Ertuğrul Gazi Primary School,**
Ankara

English Teacher (Voluntary)

- Taught English for 4th and 5th grades

Workshops & Congress & Achievements

2007 Preparation of paper on modeling submission with the international collaboration from Colorado (in progress)

2006 I. National Ecology and Environment Congress oral presentation "Population status, threats and conservation approaches for highly threatened endemic plant, *Centaurea tchihatcheffii*"

2005 Local Workshop, "Yanardöner: Population Biology and Conservation Approaches", aided by Middle East Technical University, Ankara

2004 V. National Ecology and Environment Congress, paper presentation "Temporal and Spatial fluctuations of Chlorophyll-*a* at Lake Karagol"

2003 Awarded with a support from "Bilimadamı Yetiştirme Programı (BAP)" of TUBITAK

2003 "Red Lists, Threatened species and National Protection Action Plans Workshops: 1st workshop, Latest methods and Applications in Turkey". Aided by UNDP GEF/SPG, Middle East Technical University, Ankara

Extracurricular Activities

- She is a member of Society for Conservation Biology
- She has worked for the volunteer summer science school of the Middle East Technical University for the college students and has been awarded with contribution certificates.
- She has performed volunteer Search and Rescue and Humanitarian Aid Activities afterwards of the İzmit Earthquake in 1999.
- She is a good mountain biker, hiker, volleyball player and swimmer.