THE POPULATION BIOLOGY OF A NARROW ENDEMIC, CENTAUREA TCHIHATCHEFFII FISCH. & MEY. (COMPOSITAE), IN ANKARA, TURKEY

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ABSTRACT

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Centaurea tchihatcheffii Fisch. & Mey. is a critically endangered annual plant species with a narrow distribution in Gölbaşı, Ankara. The aim of this study is to understand the population dynamics of the species to help find the best way to conserve species for long term viability.

The two healthiest subpopulations containing more than 1.5 million individuals were studied to estimate demographic parameters i.e. survival and reproduction rates by monitoring marked individuals, to identify pollinators, dispersers and pollen & seed predators and to investigate population status, natural threats and their effects.

The species is considered a weed in cereal plantations, showing adaptations of ruderal habit: High population densities (~18.5-63.2 individuals/0.5 m^2), persistent seed bank with many viable seeds (~20,000/m^2), rapid growth matching favorable weather conditions (almost 15 weeks from rosette to flowering), high survival with premature deaths making up only 2-20% of natural deaths mostly at rosette stage, no density dependent mortality, seed production by selfing and crossing via generalist pollinators, high reproduction rates (1200-7000 seeds/m^2) and promotion of growth on aerated soil whereas inhibition with herbicides. Insect and avian predators do not cause an important damage to population. Absence of mutualists aiding in pollination (honeybee) and dispersal (ants) is out of question.

There is no natural limitation on population persistence. The major threats are anthropogenic, i.e. cereal cultivation, construction and collection of individuals from natural populations. Conservation of remaining subpopulations as a reserve and alternative methods in cereal cultivation like reduced or no herbicide application should be considered as high priority conservation strategies.

Keywords: *Centaurea*, Critically endangered, Population dynamics, Natural threats, Conservation

ÖZ

DAR BİR ANKARA ENDEMİĞİNİN, CENTAUREA TCHIHATCHEFFII FISCH. & MEY. (COMPOSITAE), POPÜLASYON BİYOLOJİSİ

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Centaurea tchihatcheffii Fisch. & Mey. tek yıllık, sadece Gölbaşı, Ankara'da bulunan, dar yayılımlı ve nesli tehlike altında olan (CR) bir bitki türüdür. Bu çalışmanın amacı, türün neslinin uzun sürede devamlılığını sağlayacak en iyi koruma yönteminin belirlenebilmesinin ilk adımı olarak populasyon dinamiğini anlamaktır.

Türün 1,5 milyon bireyini içeren en sağlıklı iki alt-popülasyonunda yapılan çalışmalar; popülasyonun durumunun belirlenmesi, doğal tehditlerin ve bunların etkilerinin ortaya konması, işaretli bireylerin gözlenmesi üzerinden yaşam ve üreme başarısı gibi demografik parametrelerin belirlenmesi; tozlaştırıcı, tohum yayan, polen ve tohum yiyen türlerin belirlenmesi şeklinde özetlenebilir.

Tahıl tarlalarında yetişen tür, pekçok yönüyle yabancıot davranışı sergiler: Yüksek popülasyon yoğunluğu (~18.5-63.2 birey/0.5 m^2), çok sayıda canlı tohum içeren kalıcı tohum bankası (~20,000/m^2), uygun iklim koşullarını yakalayan hızlı gelişim (rozet ile çiçeklenme evresi arası 15 hafta), yüksek yaşama oranı, erken ölümlerin çoğunlukla geç çimlenme nedeniyle %2-20 oranında rozet evresinde görülmesi, yoğunluğa bağlı ölümün olmaması, kendi kendine ya da genel tozlaştırıcılarla

çapraz tozlaşarak tohum üretmesi, yüksek üreme oranı (1200-7000 tohum/m^2) ve havalandırılmış toprakta iyi gelişim gösterirken ot ilacından olumsuz etkilenmesi. Türün böcek ve kuş avcılarının popülasyona ciddi bir zararı yoktur. Tozlaşma vektörleri (balarıları) ve tohum taşıyıcı türlerin (karıncalar) eksikliği söz konusu değildir.

Popülasyonun kalıcılığını engelleyecek doğal bir tehdit söz konusu değildir. En ciddi tehditler tahıl tarımı, yapılaşma ve doğal popülasyondan toplama yapılması vb. insan kaynaklıdır. Birkaç altpopülasyonun rezerv olarak korunması ve tahıl tarımında ilaçlamanın azaltılması ya da kaldırılması öncelikli koruma stratejileri olarak değerlendirilmelidir.

Anahtar kelimeler: *Centaurea*, 'Kritik' tehlikede , Popülasyon dinamikleri, Doğal tehditler, Koruma

‘The race to save biodiversity is being lost, and it is being lost because the factors contributing to its degradation are more complex and powerful than those forces working to protect it.’

Wood A

(http://img-fan.theonering.net/rolozo/images/matthews/treebeard.jpg)

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Semra, Mine and me: three knights...

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CR	categorized as 'critically endangered' according to IUCN criteria
VU	categorized as 'vulnerable' according to IUCN criteria
IUCN	Interational Union for Conservation of Nature
SDO	Süleyman Demirel Forest
SPA	Specially Protected Area
1st site/area	Study site in Süleyman Demirel Forest
2nd site/area	Study site covering the area of General Directorate of Opera and Ballet and the arable land next to it
DOB	Area belonging to General Directorate of Opera and Ballet

CHAPTER 1

INTRODUCTON

1.1. Studying Population Biology as a Tool of Plant Conservation

Biodiversity is the biological diversity of all living beings, involving three levels: genetic diversity, habitat diversity and species diversity having aspects of species richness, species evenness and species dominance (Botkin and Keller, 2000; Leveque and Monolou, 2003).

The 2000 IUCN Red List of Threatened Species (IUCN, 2000) which aims to present a snapshot of the state of the world's plant diversity at the end of the second millennium lists 7022 species that are threatened to some degree with eventual extinction (Heywood, 2003).

There are several approaches to justify the conservation of biodiversity. Environmental values can be based on four categories of justification in that sense: Utilitarian (economic benefits concerned), ecological (life support functions), aesthetic (appreciation of the beauty of nature) and moral (all living things have right to exist) (Botkin and Keller, 2000).

Less than a century ago, the behavior of Western societies changed profoundly: They have gradually moved from their initial impulse to control a hostile natural world towards a more respectful approach to life, seeking a balance that meets the demands of humanity without destroying the diversity of living world (Leveque and Mounolou, 2003).

It is urgently necessary to take action to preserve biological diversity if we do not want to be agents and witnesses of mass extinctions (Leveque and Mounolou, 2003). Efforts to slow biodiversity losses include the introduction of legislation, the establishment of conservation policies, assignment of conventions, designation of protected areas, taking agricultural lands out and conservation gain projects (Primack, 1993; Spellerberg, 1996).

Two of many efforts, namely Bern Convention "Annex I" and IUCN Red List of Threatened Species indicate a knapweed species living only in Gölbaşı, Ankara that should be conserved immediately (Council of Europe, 1979 and IUCN, 2005). The Bern Convention, a binding international legal instrument in the field of nature conservation, aims to conserve wild flora and fauna and their natural habitats and promote European co-operation in that field (Bern Convention, 1979). It covers the flora species including *Centaurea tchihatcheffii* that should be strictly conserved in Annex I. The Red Data Book of Turkish Plants which is a list at the national level prepared according to IUCN criteria categorizes *Centaurea tchihatcheffii* Fisch. & Mey. as 'Critically Endangered: CR' (Ekim *et al*, 2000).

The conservation biologist is faced with the task of evaluating the causes of endangerment of a target species and ensuring its continued survival in nature (Iriondo *et al*., 2003). The wide array of threats to rare plants can be grouped into three categories: Environmental threats, disturbed biotic interactions and genetic threats. The most frequently cited environmental threats to plant populations are habitat destruction, degradation, and fragmentation, changes in land use, overexploitation and herbicides etc. All are directly altering plant habitats. Disturbed biotic interactions e.g. grazing, pollen and dispersal limitation can be listed as intrinsic factors, managing of which is an extremely difficult task (Brigham and Schwartz, 2003).

The biological information necessary for developing the recovery guidelines includes the assessment of the biological status of the species whether decreasing, increasing or stable, the identification of the life history stages most critical for population growth, and the determination of the main biological causes of demographic variation at these stages (Schemske *et al*., 1994). Growth or decline of a population is determined by its vital rates i.e. birth, growth and death (Caswell, 1989). By focusing on the vital rates in the context of the life cycle, demography adresses both the dynamics and the structure of populations.

Vital rates of a population in turn are conditioned by genetic and environmental factors (see Iriondo *et al*., 2003). Ecological interactions between the plant and its environment including other species can influence population growth rates via their effects on fecundity, growth or survivorship of individuals (Schemske *et al*.., 1994). So the first step is to study population biology and to understand population dynamics of a population to develop conservation strategies for long term viability of species.

1.2. *Centaurea tchihatcheffii*

1.2.1. Taxonomy

Centaurea tchihatcheffii is a rare endemic annual plant species belonging to the daisy family (Asteraceae). Asteraceae is one of the largest flowering plant families comprising more than 23000 described species (Lundberg and Bremer, 2003). It is represented by 133 genera and 1156 species in Turkey (Seçmen *et al*., 2000). The genus *Centaurea* contains 530 to 550 species and is distributed from Spain across southern Europe to Turkey and Iran (Klokov *et al*., 1963). Turkey is one of the main centres of diversity for the genus *Centaurea* L. It is the third largest genus, in terms of species number in Turkey where 187 taxa in 34 sections occur mainly in the Mediterranean and Irano-Turanian regions. There are 112 endemic taxa of *Centaurea* and the endemism value is about 60% in Turkey (Türkoğlu *et al*., 2003).

1.2.2. Description and Unique Characters

C. tchihatcheffii grows up to 30-40 cm, branching from near base. It is quite similar to *C. depressa* Bieb. and *C. cyanus* L. in habit, being in the same section. Involucre is broadly campanulate. Appendage has a narrow brown border with white cilia.

Marginal flowers are pinkish red (purple in dried specimens), becoming white, funnel-shaped with crenate margin; central flowers are white. Anther tube is rose-purple (Ekim, 1994) (see Photo C.7, C.8, C.9, .10 and C.11 in Appendix C).

The peculiar form of the funnel-shaped marginal flowers with crenate margin is unique to this genus. The anther tube is provided with glands at the tip of the appendages, a character so far only known in this species (Davis, 1975). The striking color unique to this species caused the plant to be named as 'yanardöner' by local people meaning iridescent. Flowering begins at the end of April and ends at the beginning of July. It releases all of its mature seeds within that period.

Its natural habitat is the Central Anatolian steppe. It also grows in and between cultivated fields (mostly *Triticum*) as a weed. It perefers sandy soils (Ekim, 1994).

Although this species has no medicinal value, other species of the same genus (i.e. *C. cyanus* and *C. scabiosa*) are used against coughs, as liver tonic, itch eliminator, and ophthalmic remedies; for *C. calcitrapa, C. solstitialis* and *C. melitensis* a hypoglycemic effect, and for *C. calcitrapa*, *C. iberica* and *C. jacea* an antipyretic effect have been demonstrated (Flamini *et al.*, 2002). One of its close relatives, *C. cyanus*, has been used as a traditional medicine: Flowerheads of this plant are well-known crude drugs used in European traditional medicine in the treatment of minor ocular inflammation, and as diuretic and cholagogic agents. Antimicrobial, anti-inflammatory and immunological activities of *C. cyanus* flowers have also been reported (Sarker, 2001). With further research it is thought that *Centaurea tchihatcheffii* has a potential as a medicinal plant.

1.2.3. Past Distribution

Although the type specimen was collected by Tchihatcheff from Afyonkarahisar in 1848, there has not been a second record since then (Ekim *et al.*, 2000). During correspondances of Prof.Dr. Mecit Vural with the authorities of the herbarium having the type specimen and with other botanists having original literature about the species, it was understood that the record from Afyonkarahisar was erroneous (M. Vural, pers. comm.).

In previous years, the species was widespread around Mogan Lake in Gölbaşı district, 20 km south of Ankara, but now it grows only in two locations there, quite separated from each other (Ekim and Byfield, 2003), showing a narrow distribution as an endemic.

The area enclosing Mogan and Eymir Lakes and the close vicinity was declared as a Specially Protected Area (SPA) due to natural, recreational and archaeological values of wetland-swamp areas in 1990 by Ministry of Environment (Çevre Bakanlığı, 2004). The aim of declaring a SPA in general is to take actions to solve environmental problems and conserve environmental wealth by saving ecological balances and sustainable use of natural resources. Moreover, the whole area was assigned as Important Bird Area (1989) and Important Plant Area (2003) by WWF-Türkiye projects (WWF Türkiye, 2005). The area covers the geographic range of *C.tchiahatcheffii.*

The dominant vegetation of Mogan SPA is steppe with 437 terrestrial plant taxa listed. *C.tchihatchefii* is the only 'CR' species. *Erysimum torulosum* and *Dianthus ancyrensis* are two other species having high threat categories i.e. vulnerable "VU". Most of the sites have a low slope. As a consequence, many of those places were converted to agricultural areas. Dry agriculture of cereals, especially of wheat, in rotation with fallow is common (Çevre Bakanlığı, 2002).

Although the species is represented by a small number of individuals east of the Mogan Lake, the core of the population exists west of the lake. The healthiest subpopulation was observed in a pine plantation area which was a cereal field 20 years ago, namely the Süleyman Demirel Forest "SDO" (Ekim, 1994 and Ekim and Bayfield, 2003). It was reported that the subpopulation was faced with local extinction in 2000, with no individuals observed (Vural ve Adıgüzel, 2001). Then it recovered with 85 individuals in 2001 and more than 900,000 individuals in 2003.

It is reported that the population density in wheat plantations was 6 individuals/m^2 in 1970s (Kurçman in Yıldırım, 2001). It was also stated that the species gradually disappeared from most areas where it previously occurred; individuals were detected only in SDO throughout the years and no individuals were observed in cultivated areas in 2001 (Yıldırım, 2001).

According to Rabinowitz' classification, combinations of three factors determine commonness and rarity: (1) geographic range of species (extensive versus restrictive), (2) habitat tolerance (broad versus narrow), (3) local population size (large versus small) (Molles, 2002). Based on the past distribution, it can be claimed that the species has restrictive geographical range, narrow habitat tolerance and small local population size.

1.2.4. Threats in the Past

Yıldırım claims that the major threat on individuals in existing wheat cultivation areas is weed management practices. It is concluded that herbicide (2,4-D Ester) application kills the plants, being the major threat in agricultural areas. The major threats in other places are burning the vegetation prior to tree plantation and collection for ornamental purposes (Yıldırım, 2001).

Herbicide applications, collecting from the natural habitat for sale and afforestation efforts in the Süleyman Demirel Forest caused the population to be stuck in a patch size of 3-5 km^2 in that area in 2001. The possible reasons for negative effect of afforestation activity are herbicide application before planting, root competition and shading effect (Vural and Adgüzel, 2001; Ekim, 1994; Ekim *et al*., 2000). In 2000, no individuals were observed in once most reproductive soils of the area (Ekim and Byfield, 2003). The anthropogenic factors listed above caused the population size to decrease to critical values: Only 85 individuals were observed in afforestation area in 2001. (Vural and Adıgüzel, 2001).

The area belongs to the Ministry of Forestry under the name of Süleyman Demirel Forest Area (SDO) since 1993. Until 1998, there has been no serious damage report.

Within the period 1999-2004, the management authority was transferred to Ankara Governorship Environmental Protection Foundation (ANÇEVA). It was planned to convert the area into a recrational area after afforestation. The afforestatation efforts at some time between 1998 and 2000 caused a sharp decrease in the species' population size. The failure of afforestation activities due to unsuitable soil and a change in construction plans for recreational purposes are some of the promising developments for viability of the species.

Centaurea tchihatcheffii has economical value as an ornamental because of its striking flowers. In late April and May, its cut flowers collected from natural populations appeared in the street florists in Ankara recent years (Ekim, 1994), which is another threat.

1.2.5. Life History of the Species

Plants display an immense variety of life histories, and their modes of reproduction, birth, growth and death each span a wide range of alternative strategies (Silvertown and Doust, 1993).

1.2.5.1. Traits of Being Annual

One example to solutions of the problem of life in a seasonal environment would be the annual habit (Harper, 1977). Plants that reproduce just once during their lifetimes tend to occur in ephemeral or harsh habitats. Temporary, often frequently disturbed habitats support ruderals that are characterized as allocating most of their resources to reproduction, called *r*-selected species (Barbour *et al.*, 1999).

The annual cycle of *C. tchihatcheffii* begins with germination and seedling emergence in autumn. Emergence begins at the rainy season in autumn but can continue into early spring. Seedlings grow into rosettes of basal leaves in winter and early spring, and develop long taproots that facilitate their survival during dry periods, similar to its relative, facultative winter annual *C. solstitialis* (Roché *et al.*. 1994).

A common adaptation among Mediterranean annuals is to avoid the summer drought by flowering early and maturing seed before depletion of soil moisture (Roché and Thill, 2001). Like many of the annual grasses of Mediterranean climates and of arable lands, in *C.tchihatcheffii* a phase of growth (October to May) is followed by an episode of flowering and the main meristems are used in the formation of the inflorescences — effectively putting an end to further potential for vegetative growth. Most of these annuals have a precisely triggered transition from the vegetative to reproductive phase depending on the photoperiod. They are species with life cycles that are synchronized with recurrent seasonal events. They are examplified by the weeds of arable lands (Harper, 1977).

In general, the biggest seed banks in terms of number of seeds per unit area are associated with arable sites (Kigel and Galili, 1995). In an unstable habitat, the ability to produce numerous offspring is a more important component of fitness than the ability to compete with neighboring plants. Selection acts to maximize the intrinsic rate of increase (*r*). This extreme occurs in habitats where mortality is through density independent factors. This life history extreme characterized by short lived species, such as monocarpic annual plants and ruderals like weeds which allocate very little energy to either growth or maintenance but a great deal toward reproduction (Barbour, 1999). Therefore, in such environments mortality tends to be independent of density and *r*-selected plants are favored, forming first seral stages in succession (Fenner, 1985). *C. thcihatcheffi* is considered to be an *r*-selected species.

1.2.5.2. Traits of Being a Weed

There are many definitions of the term 'weed'. Commonly, a species is considered to be a weed if in any specified geographical area, its populations grow entirely or predominantly in situations markedly distributed by man (without, of course, being a deliberately cultivated plant) (Baker, 1974). Moyer et al. (1994) state that plants thriving on cultivated or disturbed land are primarily annual weeds. According to these definitions, *C. tchihatcheffii* can clearly be named as a weed; the species has several of the ideal weed characteristics listed below.

Baker's list (1974) of ideal weed characteristics is summarized below:

- ✓ Germination requirements fulfilled in many environments
- ✓ Discontinuous germination (internally controlled) and great longevity of seed
- ✓ Rapid growth through vegetative phase to flowering
- ✓ Continuous seed production for as long as growing conditions permit
- ✓ Self compatible but not completely autogamous or apomictic
- ✓ When cross-pollinated, unspecialized pollinators or wind utilized
- ✓ Very high seed output in favorable environmental circumstances
- ✓ Produces some seed in a wide range of environmental conditions; tolerant and plastic
- ✓ Has adaptations for short and long-distance dispersal.
- ✓ Has ability to compete interspecifically by special means (rosette, choking growth, allelochemicals)

Centaurea (knapweed) species are among the most widespread invaders of North American prairies historically dominated by C3 and C4 grasses (Table 1.1). Their domination can be attributed to their ability to shift plant–plant interactions though allelochemical, microbial or resource depletion mechanisms (Suding *et al.*, 2004). Members of the knapweed complex possess a number of traits that are advantageous over those of perennial grasses for site occupation. Favorable germination characteristics, growth rates, root penetration, seed output, and extended growing periods all contribute to successful knapweed establishment (Larson and Kiemnec, 2003). *C. tchihatcheffii* shares some of the properties of its weed relatives like fast growth rate and high seed output.

The number of weed species listed in the weed flora of Turkey is 1420, Ankara having 112 of them. In her study of weed flora of central Anatolia, Yıldırım (2001) reported 10 *Centaurea* species including both *C. tchihatcheffii* and *C. depressa*.

The annual weed characteristics are the ability to germinate and grow rapidly and produce seeds between seed-bed tillage and harvest (Baker, 1974). Seeds from these plants often remain dormant for several years when they are buried by tillage and may germinate when brought to the surface and exposed to appropriate light, moisture and temperature by future tillage operations (Moyer *et al.*, 1994).

In cultivated fields where the majority of weed species are annuals, the seed bank (the collection of viable seeds present on or within the soil) is the only source for renewal of populations and the principal source of weed infestation in crops. In most weed species, the seeds are clustered around the mother plant. In soils under cultivation, the spatial pattern of seeds immediately following seed rain is to a varied extent altered by cultivation practices such as ploughing, harvesting, irrigation, weeding, etc. (Shaukat and Siddiqui, 2004). Disturbance events like tillage remove existing vegetation and provide space for the massive, simultaneous recruitment of new populations, usually from seed. The existence of a seed pool confers an age structure on an annual population. The seed pool, being a buffer for genetic homogeneity and local extinctions, is periodically recharged after each successful generation of adults has flowered, and it accumulates a heterogeneous population of seeds that vary in age, depth of burial in the soil and state of dormancy. All of these characteristics affect the probability of a seed germinating, and all change with time (Silvertown and Doust, 1993). Most winter annual composites recruit heavily from newly dispersed seed rather than from seedbanks so the annual replenishment of seed banks (Roché and Thill, 2001).

It is more usual for weed communities to be overpowered by native vegetation if disturbance is discontinued (Baker, 1974). If all disturbance ceases, the short life cycles advantageous at first, are not adaptable to conditions imposed by incoming plants with longer life cycles (k-selected species) (Smith, 1996). But it is important that where grassland had a history of past arable cultivation, the seeds of arable weeds were often present, even when the last arable practice was more than 70 years before, searched by Milton in Central Wales (Harper, 1977).

Name of species & habit	Natural Distribution area	Harms	Competitive abilities
C. solstitialis Facultative annual	Mediterranean origin	Reducing of native plant diversity, Decreasing recreation value of land, Reducing forage production and grazing capacity, Poisoning livestock	Early rapid and continuous root growth and resistance to drought, low palatability to herbivores, physical defense traits, preferential outcrossers, annual replenishment of seed bank with high number of seed
C. diffusa Opportunistic biennial forb	Europe and Asia	Potential to enhance soil erosion Threat to native plant biodiversity	Unplatable to herbivores, Root and biomass competitor
C. maculosa Herbaceus perennial	Eurasia	Reducing livestock and wildlife forage, Increasing surface water runoff and soil sedimentation Lowering plant diversity	Seed bank of high seed number with long viability Few natural enemies Allelopathic compounds
C. calcitrapa Short-lived perennial	Southern Europe and North Africa	Displacing more valuable forage species on rangelands, Causing barriers to the movement of livestock and humans.	High level of germination in a wide range of temperature Physical defense traits

Table 1.1 Examples of *Centaurea* species defined as ınvasive weed in North America**(Benefield *et al*, 2001), (Roché and Thill, 2001), (Seastedt, 2003), (DiTomaso *et al*, 2003), (Story *et al*, 2001), (Pitcairn *et al*, 2002), (Blicker, 2003)

1.2.5.3. Reproductive Strategies of *Centaurea*

Unfortunately there have been no ecological studies considering species' adaptations of reproduction. In this case, the starting points for this study are studies done on other *Centaurea* species and anecdotal information obtained by other researchers.

As Baker stated (1974), unspecialized pollinators or wind is effective in pollination of weeds. For example, a close relative of *C. tchihatcheffii, C. solstitialis* 'yellow starthistle', is a preferential outcrosser attracting generalist insect pollinators with pollen and nectar. When conditions are not favorable for pollinators, selfing becomes the dominant mode of pollination, without notable loss in fecundity (Roché 1996; Roché and Thill, 2001).

Like some of *Centaurea* species (*C. eriophora*: Witztum *et al.*, 1996; *C. melitensis*: Porras and Munos, 2000; Viegi *et al.*, 2003 and *C. solstitialis*: Benefield *et al.*, 2001), *C. tchihatcheffii* bears achenes having both pappus (feathery structure derived from calyx, Fenner, 1985) and elaisome (see Photo C.6 in APPENDIX C). Achene of *C. tchihatcheffii* is 3.5-4(-5) mm long with 1-3 mm pale brown pappus arising from calyx (Kaya and Genç, 2002). The achene weighs 0.0037g on average. Seeds do not necessarily remain where they land after dispersal. The achenes of composites may blow along the ground until they accumulate near obstacles or fall down crevices. Soils that have cracked after drought provide just such crevices and the seeds of composites that fall into the cracks are often held in position by the pappus which remains at the soil surface with the achene dangling into the crack (Harper, 1977).

It is reported for other species that the pappus is ineffective in keeping the achene wind-borne but does serve to regulate the movement of the achene on the ground in response to wind for better orientation in soil thus not falling far from the mother plant (Witztum *et al.*, 1996).

In some species like *C. melitensis,* seed heteromorphism is observed as an adaptation to unstable habitats. Dimorphic achenes (pappus, nonpappus and pappus of different origin) of *C.solstitialis* appear to be associated with success in exploiting highly variable soil moisture regimes in semi-arid environments (Larson and Kiemnec, 1997).

Two kinds of flowers on the same plant (i.e. cleistogamy) is common in composites: A cleistogamous capitulum is one that never opens but that produces self-fertilized seeds, and a chasmogamous capitulum is one that opens in a normal way to be pollinated by insects or wind. It is interesting that in all the species that display this syndrome there is a consistent correlation between poor seed dispersal (having advantage of parent's favorable environment) of cleistogamous seed and good dispersal (escaping from density's negative effects) of chasmogamous ones. Evolution in these plants seems to have favoured a strategy in which progeny genetically like their parents are kept at home while out-crossed progeny are dispersed, probably an adaptation for disturbed habitats (Silvertown and Doust, 1993; Kigel and Galili, 1995). *C.melitensis* produces two types of cleistogamuos capitula produced at the beginning and end of flowering season adapted to selfing and chasmogamous capitula in middle adapted to crossing are produced. Porras and Monus (2000) claim that seeds of cleistogamous capitula are the dormant ones of seed bank resting on anthills but chasmogamous ones are the ones readily germinating. Therefore, achene dimorphism is one of the important features that should be studied to understand the reproduction strategy of the species

C. tchihatcheffii produces seeds contain elaisomes. The term elaisome is used for all fleshy and edible parts of seeds dispersed by ants. Ants generally take the seeds with elaisomes to their nests to remove and consume elaisomes. The undamaged seed is discarded either in an old gallery or a refuse pile. It is a way of dispersal and additionally escaping from predation by being buried inside the nest and becoming surrounded by the nutrient-enriched substratum for a successful germination (Kigel and Galili, 1995; Fenner, 1985, Smith 1996). It was reported that *C. tchihatcheffii* seeds are carried by ants and that ants spend time on involucrate bracts (M. Vural, pers.comm.).

A rare endemic of Spain, *C. corymbosa* is threatened because of rarity of long distance dispersal events despite having seeds with elaisomes and traits such as prolonged juvenile period, monocarpy, and self-incompatibility and pollen limitation (Colas and Olivieri, 1997).

The relationships of *Centaurea* species with animals have been a subject of research since some organisms are potential biocontrol agents for noxious weeds of North America. The insects of main concern are gall flies ovipositioning on flowerheads (Rieder *et al.*, 2001; Myers and Harris 1980; Seasted *et al.*, 2003) and root feeding insects (Clark *et al.*, 2001; Seasted *et al.*, 2003). The rust fungus is another organism having biological control potential (Berner and Paxson, 2003).

Researches carried out to understand the relations of *Centaurea* species with plants mainly concern comparisons with native plants of America (Larson and Kiemnec, 2003) or other weeds (Roché and Thill, 2001).

There is no report of any kind of relationship of a mammalian other than humans with knapweeds.

1.2.6. Previous Research on *Centaurea tchihatcheffii*

Unfortunately there have been few studies or literature on *C. tchihatcheffii.* Taxonomic information for the species is provided at Flora of Turkey (Davis, 1975). Information about taxonomic characters, past distribution based on observations, and threats can be found in Ekim (1994), Ekim *et al.* (2000), Vural and Adıgüzel (2001), Yıldırım (2001), Ekim and Byfield (2003) and. Gömürgen and Adıgüzel (2001) conducted a study on chromosome numbers and karyotype analysis of the species. Kaya and Genç (2002) presented a study on anatomy and palynology of species. In-vitro propagation of the species was studied by Özel (2002). Pollen morphology of the species was also studied by Pehlivan (1995) as part of a study on some endemic *Centaurea* species of Turkey.

An ongoing joint research carried out by researchers from three institutions (of which the author of this thesis is a member) is supported by TUBITAK.

It is important to mention the efforts of Professor Vural to avoid the species' extinction. By reporting the desperate situation of species and threats on populations especially at the Süleyman Demirel Forest to Ministry of Environment and Forestry, he succeded to attract the attention of decision-makers to the site. First, all activities threatening the species in the area have been stopped. Then to raise public awareness, many visits to the site were made with officers and the media. The species became popular. As an extension of those efforts, recently a book on this species, edited by Boşgelmez (2005) and titled '*Centaurea tchihatcheffii*' aiming to raise the public awareness, also containing results of some scientific research, has been published.

Unfortunately there are no studies on the ecology of the species. Some anecdotal information provided by Professor Vural was the starting point for this study. One such example is the ant-plant relations. The ants were observed on flowerheads and while carrying seeds. Bees were observed as the main pollinators and he reported that plants grow best in aerated soils (M. Vural, pers. comm.).

1.3. Aim and Justifications

The aim of this study is to understand the population dynamics of the species in order to find the best way to conserve the species for the long term. The primary task is to find vital rates of survival and reproduction and estimate demographic parameters of population. Finding critical stages in its life cycle and understanding reasons of mortality at those stages, as well as recording vital rates would reveal intrinsic causes of decreases in population size. Combined with effects of other organisms on the population, the question to answer is whether the plant species is limited due to intrinsic or extrinsic causes.

Another aim of the study is to provide basic data for a population viability analysis. PVA collates empirical data on the entire life cycle of a wild population and uses quantitative modeling to project future populations, e.g. the finite rate of increase, extinction probability, time to extinction, or future population size or structure. Most plant PVAs are based on stage or size-classified matrices factors. More commonly, environmental stochasticity or various types of disturbances or catastrophes have been considered (Menges, 2000). Data obtained from this study will be combined with germination ecology and seed bank dynamics findings by others and applied to population viability analysis.

It is well known that most plant scientists in Turkey improve our taxonomic knowledge in terms of morphology, genetics, palynology or biochemistry. This population biology study on a steppe plant for conservation considerations will hopefully both attract the attention of decision makers on steppe plants and be an example in use of population biology parameters to find the right conservation strategy for each species listed as CR in Red Data Book of Turkish Plants (Ekim *et al.*, 2000).

CHAPTER 2

MATERIALS AND METHODS

2.1. Study Area

2.1.1. Location

The study area is located at south of Gölbaşı, Ankara in Turkey (Figure 2.1). Elevation changes from 940 to 1000 m from sea level.

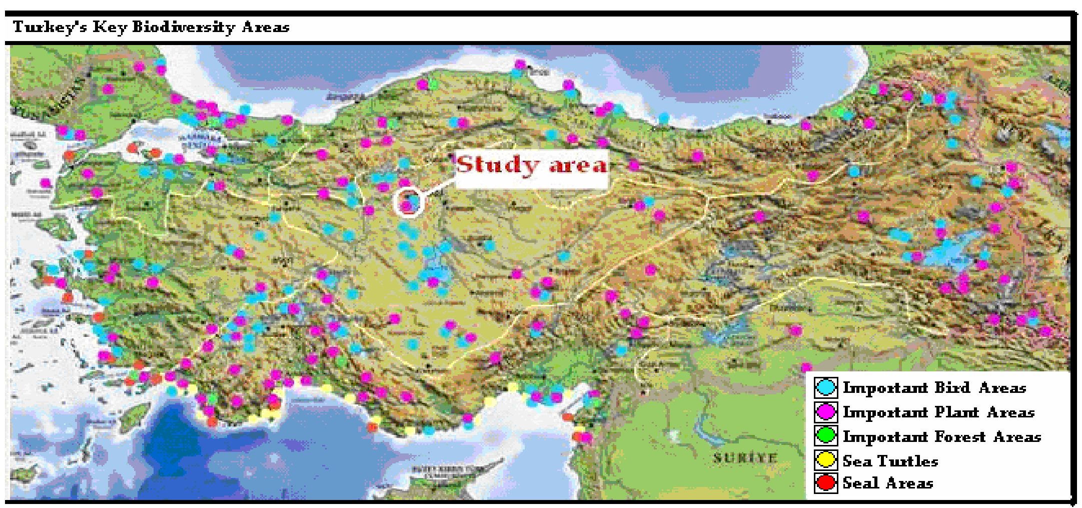

Figure 2.1 Location of the study area (WWF-Turkey, 2005)

Although the species exists on many small patches within its distributional range, the field work were conducted only in two largest patches due to constraints on time and transportation (Figure 2.2).

The field work was first carried out in an area on a hill west side of 10th km of Haymana Motorway, between the motorway and the lake. The area was designated as a recreational area by Ministry of Environment and Forestry, mentioned as Süleyman Demirel Forest (SDO) ("Recrational Area") earlier. The site has a shore to Mogan Lake. Although the hill supports knapweed populations on hillsides close to and along the shore, the 3-year study was carried out only on the hillside facing north, namely first area/site. (39º 44′ 475-32º 47′ 121).

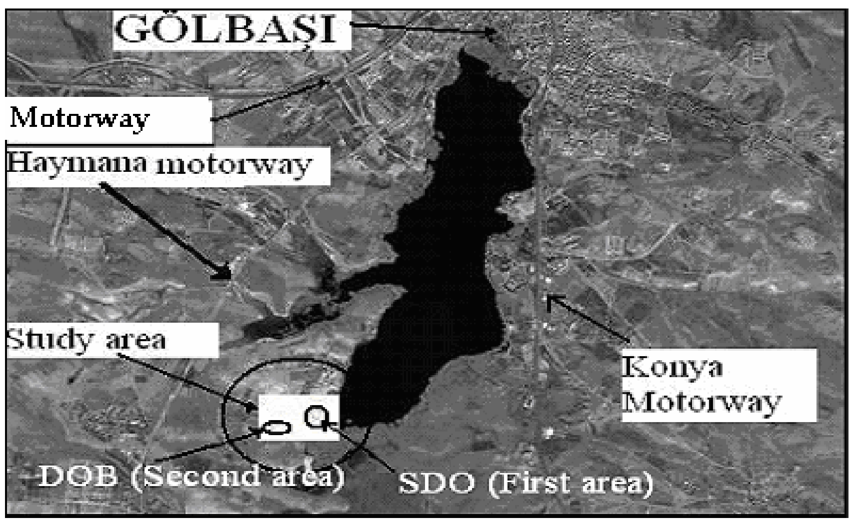

Figure 2.2 Location of the study sites shown in circles (Source: Y. Baytok, unpublished data)

On May 2003, the healthiest subpopulation of the species was discovered almost 2 km away from the first subpopulation. The individuals were distributed within a fenced area belonging to "Devlet Opera ve Balesi Genel Müdürlüğü" (State Opera and Ballet General Directory, DOB) of Ministry of Culture and Tourism (39º 44′ 537-32º 45′ 775) and on farmland next to it, named together as the second area/site.

Because the DOB area was winter rye-planted illegally, the first-year study was made in the farmland left as fallow for that year (see Photos E.5 a,b in APPENDIX E). Unfortunately the fallow patch was ploughed in 2004 (see Photo E.6 in APPENDIX E) and planted wheat for the 2005 season (see Photo E.7 in APPENDIX E), so the studies for 2004 and 2005 seasons on 2nd area were completed only in DOB. However, data was collected till March 2004 for the fallow land.

Because the distribution of these two patches are a few kilometers away without any connection, with only small groups of individuals around, the population can be considered as a metapopulation (spatially isolated populations linked by a significant amount of individual exchange, Barbour *et al.*, 1999) composed of at least 2 subpopulations.

2.1.2. Climate and Soil

To understand the climatic conditions prevailing on the field, it was necessary to obtain the meteorological data recorded in closest station to the field. Table and graphs below were obtained from that kind of meteorological data published by Boşgelmez (2005). The data were recorded on İkizce Station of Turkish State of Meteorological Service, located between Ankara and Haymana, 10 km away from the species' geographical border. The annual meteorological factors can be seen in Appendix A.

As it is understood from annual and monthly values of climatic factors, the climate of the area is the typical continental climate common in Central Anatolia with hot and dry summer months and cold winter months (Figure 2.3 and 2.4).

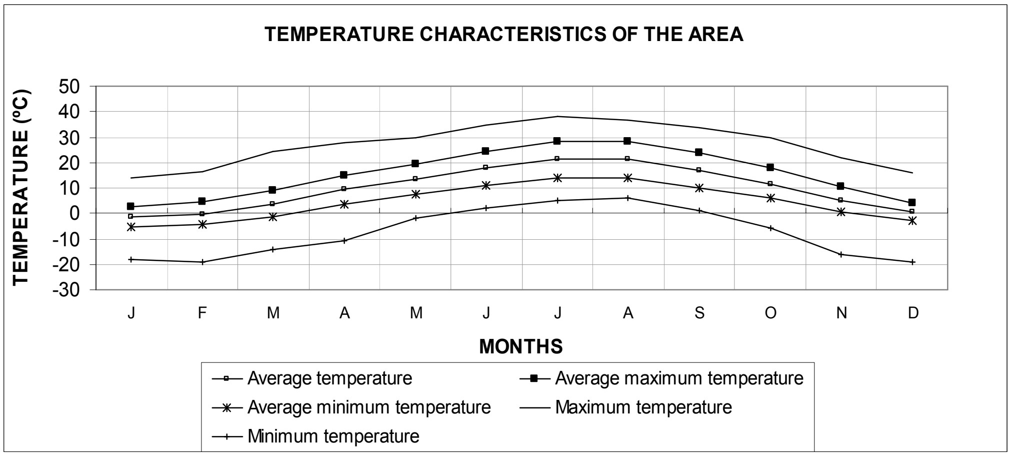

Figure 2.3 Temperature characteristics of the area given as monthly means (Boşgelmez, 2005)

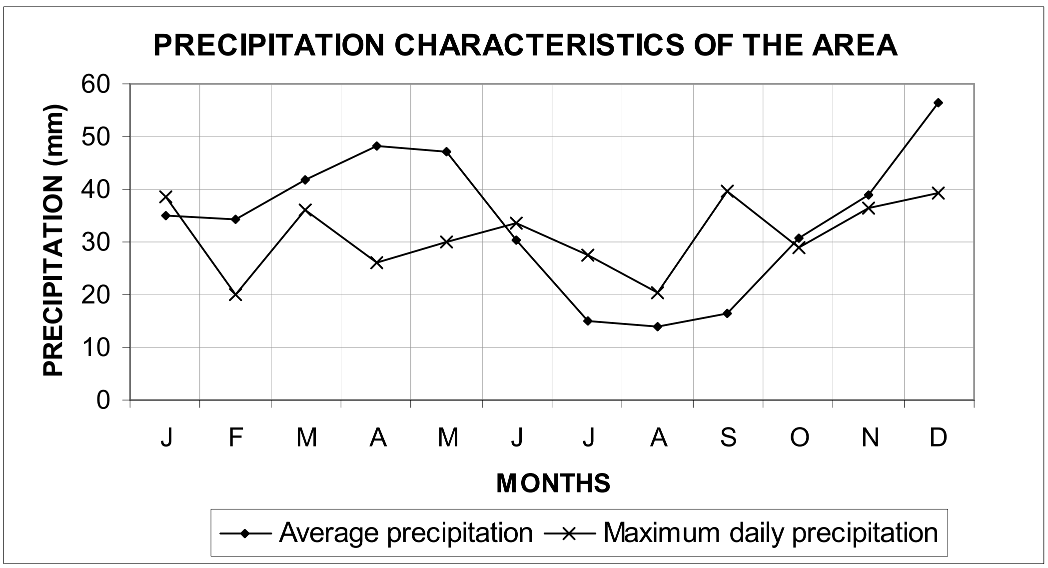

Figure 2.4 Precipitation characteristics of the area given as monthly means (Boşgelmez, 2005)

In a study by Başkan *et al.* (2005), the classification and general characteristics of soils of Gölbaşı is considered. The researchers categorized the soil temperature regime of Ankara as "mesic" (a medium/ balanced soil for temperature) and the soil humidity regime as "xeric" (a dry soil for humidity).

Özcan *et al.* (2005) worked on the soil properties and nutrient content of soils that *C.tchihatcheffii* grows on. According to their findings, the soils are under the effect of

Mogan Lake and grouped as "semi-arid". Typical soil properties of Central Anatolia are observed at these sites.

Özcan *et al.* (2005) found that the soil of the 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. Soil properties for the area where the species is distributed are available in Appendix B.

Most plant species are tolerant of a broad range of soil types; consequently soil factors are not generally a major limitation to plant distribution (Krebs, 1999). After a detailed evaluation of soil data, it can be said that there is no specific soil property that would limit the distribution of species in that area.

2.2. Density Estimation

To find the absolute density of nonmotile organisms, quadrat counts are the best way (Krebs, 1999). A quadrat is an area of any shape that can be delimited so that plant species may be listed, counted, or have their vegetation cover estimated. For herbaceous species, a quadrat that is 0.5 m to 2 m on one side is usually enough (Barbour *et al.*, 1999). The quadrats of desired size are usually placed temporarily in the area and random sampling or systematic sampling is applied as objective sampling methods to prevent bias.

Density estimations were done on flowering individuals because they are the ones contributing next generation, affecting fitness.

Estimations of subpopulation densities in 1st and 2nd sites in 2003 were the based on quadrat counts established for population dynamics studies explained below in detail. The 12 quadrats in 1st and 11 in 2nd site were taken by stratified random sampling. The method is explained in more detail under 'Studies of Survival and Reproduction' part below. For density estimation, the highest number of flowering individuals scored was used for each quadrat.

In 2004 and 2005 a different and supposedly better method was applied to find population densities. In order to best characterize a large population, one would ideally choose to study a set of randomly selected portions of the entire population. Sample quadrats may be located randomly by constructing imaginary axes along adjacent edges of the stand or area being sampled, dividing the axes into units (e.g. meters) and picking pairs of random numbers that designate sampling coordinates (Barbour *et al.*, 1999). Similarly to the way offered by Barbour *et al.* (1999), random sampling with temporary quadrats was performed at the middle or end of the flowering period. That period was thought to be the most appropriate time since the peak of flowering was observed then (see Photo C.1 in APPENDIX C). The methods applied during density estimation studies are summarized in Table 2.1.

During counts, only the individuals more than half of which were inside the frame were counted to prevent bias. For the individuals that are half inside and half outside, only the ones on two fixed edges, a short and a long, were counted. The reason for a smaller size of quadrat in 2005 study was to be more practical.

To estimate population size, the area of patches was estimated with simple measurements of fences encircling the areas.

Table 2.1 Summary of density estimation studies

Study Year	**2003**		**2004**		**2005**	
Study site	**1st site**	**2nd site**	**1st site**	**2nd site**	**1st site**	**2nd site**
Study Period	25.5.2005 7.6.2005	21.5.2005 29.5.2005	15.6.2004	7.6.2004 11.6.2004	5.6.2005 11.6.2005	5.6.2005
Method of density estimation	Maximum number of flowering individuals counted on permanent quadrats		Counting number of flowering individuals in randomly placed temporary quadrats of 20-30 trials (considering edge effect etc.)			
Size of quadrats	50 cm x 100 cm		50 cm x 100 cm		50 cm x 50 cm	
Sample size	12	11	30	20	30	20

2.3. Studies of Survival and Reproduction

Demography is the study of changes in population size and structure through time. Demographic studies try to answer questions like how long an individual is likely to live, when it will produce offspring, how many offspring are likely to be produced etc. (Barbour *et al.*, 1999). Demographic studies follow known individuals in a population to determine their rates of growth, reproduction and survival. Individuals of all ages and sizes must be included in such a study. Either a whole population or a subsample can be followed, measured for size, tagged or marked for future identification; their positions on the site are mapped (Primack, 1995). Estimating growth rates for each age or life stage of the population is laborious, requiring careful and detailed work to enumerate the fates of individual plants by tagging and measuring plants of a range of stage classes, and repeatedly revisiting them to estimate transition rates (Brigham and Schwartz, 2003). In this study, population was observed by tagging some individuals.

One approach to plant demography is to delineate the critical stages in the life history of a plant (Barbour *et al.*, 1999). The methods followed are quite similar to the ones used for matrix population models. It begins with classification of individuals in the population into categories that reflect biologically relevant life history stages. The individuals are marked permanently through their lifetime. In regular intervals they are classified into a particular stage and their reproductive output is recorded (Schemske *et al.*, 1994). Therefore, field research in natural distribution areas were conducted in order to find vital parameters, critical life stages, causes of changes in vital parameters and environmental relations of the plant species with other plants and also animals. So in present study, individuals were followed by dividing life cycle into critical life stages.

To start population dynamics studies in the field, the most appropriate time was decided to be the beginning of spring when snow cover disappears on the soil and the soil compactness and humidity let researchers to study efficiently. The study periods were given in Table 2.2 and 2.3. The ends of study periods corresponded to the end of seed shedding in each year. The reasons for the delay in starting field work in the first and third years were the delay in the discovery of both subpopulations, and continuous heavy rains in early March 2005, respectively.

2.3.1. Quadrat Setup

To understand the life history trends of the population, the number of individuals of different life stages on permanent quadrats was recorded from beginning of spring till the end of seed release for 2003 (See summary in Table 2.2). For that purpose, 50 cm x 100 cm of 12 and 11 rectangular quadrats were set in three transects in 1st and 2nd field, respectively. The reason for choosing that size of quadrats was because the usual 1 x 1 m^2 quadrat size suggested for studying herbaceous plants appeared to be too large for these high-density subpopulations.

Placement of quadrats had vital importance. Systematic sampling has disadvantages of matching periodic variation or trends, and being improper for some statistical tests. With random sampling there is the risk of not to cover all area and clumping all quadrats by chance. Some combination of systematic and random sampling may be useful in practice. The most important message for a field ecologist is to avoid haphazard or judgmental sampling (Krebs, 1999).

To place the permanent quadrats, a random-systematic design was applied as proposed by Krebs (1999). It is the most frequently used design employing both random (or stratified random) and systematic aspects. A starting point – and direction – of a transect within an area is located by some random or in a stratified random plan. Along that starting point, samples are taken according to some systematic plan. It incorporates some degree of randomness, yet it is efficient of field time because the ultimate samples lie along convenient transects, retaining certain attributes of random plot selection; it also guarantees that the plots will sample the full range of variation in area that the species displays (Barbour et al., 1999).

Table 2.2 Summary of survival and reproduction studies in 2003

Study Year	2003	
Study site	**1st site**	**2nd site**
Study Period	26.4.2003 – 22.6.2003	12.5.2003 – 12.7.2003
Number of field visits	10	8
Size of quadrats	50 cm x 100 cm	50 cm x 100 cm
Number of quadrats set	12	11
Number of quadrats followed	12 (3 had no individuals)	7 (4 losses due to agricultural activity)
Number of individuals counted at most	1124	251
Number of closures set for pollinator limitation	17	3
Number of closures set for seed collection	19	0

Very similar to what Barbour proposed, random points were taken on a transect (starting transect) assumed to be the long edge of the rectangular sites studied. Starting from these points, transects perpendicular to the first one were taken and quadrats were placed regularly on these perpendicular transects in groups of 3 or 4 with intervals of 15 to 20 steps according to the length of the perpendicular transects. The setting of quadrats in 2003 had two aims: Understanding population dynamics and finding density of population. The quadrats were placed objectively even if it was too crowded to count or if it contained no individuals.

2.3.2. Determination of Life Stages

After establishing quadrats, the number of individuals in each quadrat was recorded each week and grouped into one of the three life stages as rosette (R), budding (B), or flowering and seed forming (F) individuals.

The division and determination of stages were based on observations. It was observed that the first aerial parts emerging during germination were cotyledon leaves (i.e. embryonic leaves inside the seed, Baytop, 1998). The rosette stage is group of leaves making a circle or whorl around an axis on the ground, composed of true leaves emerging after two cotyledon leaves (Baytop, 1998). Because the individuals can not be observed when newly germinated under snow and since correct identification of individuals to the species until the first 5 true leaves emerge is difficult (due to the presence of one of its close relatives i.e. *Centaurea depressa*), individuals were counted as a unit of study when they exceeded the five true leaves stage and accepted to be in the rosette stage (see Photo C.2 in APPENDIX C).

The individuals were grouped in the budding stage when the first and the central bud appeared as almost 5 mm in diameter in the center of the rosette (see Photo C.3 in APPENDIX C).

After the first capitulum (in other words the flowerhead, i.e. a group of sessile flowers on a short and fleshy receptacle, typical for Asteraceae, Baytop, 1998), matured and opened its marginal pink flowers, the individual was classified as in the flowering stage (see Photo C.4 in APPENDIX C). Because the plants shed seeds just one or two weeks after flowering without an obviously high death rate, and since individuals can flower and release seeds at the same time in different branches, there were no two distinct stages as 'flowering' and 'seed-forming'. The examples for individuals at these stages can be observed in Appendix C.

With this data, it was aimed to find at which percentage plants pass from one stage to another as well as the rates and reasons of the mortality at each stage. Unfortunately, this study enabled us to follow only the beginning and the end of stages for population. 2003 work was considered as preliminary study on the species. So its results were not given in following chapters most of the time because they are insufficient to provide significant information.

A detailed study by marking individuals and collecting capitula and seeds was not conducted in 2003, to avoid harming the population said to be fluctuating. But since the observed density of population was very high, a different method has been developed for the 2004 and 2005 seasons. Another reason for changing the method was the data collected in 2003 being not very informative: Passage from one stage to another was not obvious in numbers and there were some complications due to timing of emergency. In some cases it was suspected whether the counted individuals of (R) stage were new arrivals or counted before. As Harper (1977) indicated with a *Ranunculus acris* example, between two censuses of a population recruits may appear and individuals may die. For this reason some form of marking of individuals is needed for a proper census. Due to deaths and new emergences, the demographic rates were masked in numbers. Therefore, it was decided that the method did not serve to needs of finding vital rates.

The second method was based on following the marked individuals throughout the season. In the 2nd and 3rd years, data collection was made with marked individuals in quadrats like microframes. Counting flowers and collecting seeds were done and it did not put the subpopulations in danger because of the high densities of subpopulations (summarized in Table 2.3). The quadrats were 20 cm x 20 cm in size. Reducing quadrat size aimed to find marked individuals easily by preventing mistakes that would arise from crowding of a larger sized quadrat. The small size of quadrats also enabled to take high-resolution photos of them that made studies easier due to the documentation.

Quadrats were prepared with water-resistant rope and stainless metal. They were labeled with water-resistant pen and tape.

The numbers of quadrats established are given in Table 2.3. The quadrats were set with the method used in 2003. There was no prior limit of number of individuals a quadrat would contain; it was enough if it contained only one individual. The only exception was the setting of last 4 quadrats in 2005. The area is supposed to be stratified as the plant-supported area and the new-colonization area. Based on the size of both areas, it was decided that the last four quadrats should be located in the second one. So the transect was selected randomly inside that area.

Table 2.3 Summary of survival and reproduction studies done in 2004 and 2005

Study Year	2004		2005	
Study site	1st site	2nd site	1st site	2nd site
Study Period	12.3.2004 - 25.6.2004	12.3.2004 – 25.6.2004	16.3.2005 – 25.6.2005	23.3.2005 - 25.6.2005
Number of visits	16	19	15	15
Size of quadrats	20 cm x 20 cm		20cm x 20cm	
Number of quadrats set	19	20	20	19
Number of quadrats followed	19	19	20	18
Range of number of individuals in quadrats	4- >50	6- >30	1- >50	1- >40
Range of number of individuals marked in quadrats	1-10	1-10	1-10	1-9
Total number of individuals marked	102	116	118	116
Total number of individuals followed	99	72	113	109
Total number of flowerheads collected	132	260	278	644
Total number of seeds counted	944	2714	1497	5188

2.3.3. Marking Individuals

The individuals were marked so that each one could easily be observed at regular intervals without a mistake. The target for the number of marked individuals in a quadrat was simply catching all of the individuals the small microframe supports. But because the number of individuals exceeded 30 in some quadrats and individuals became mixed when they produced lateral branches, it was decided that not exceeding 10 in number would be appropriate for the long term study. While choosing the individuals, it was aimed to mark them randomly i.e. not to choose individuals according to their sizes, emergence time, location in quadrat etc.

Marks on the plants were prepared with a water-resistant pen/marker, a tape and a thin cable used in bell circuits. On each quadrat, individuals were marked from 1 to 10 at most with a labeled tape sticked to the cable placed as a circle between the soil and the rosette leaves of the plant.

2.3.4. Estimation of Reproductive Success

In the first year, bags were used to find the average number of seeds each flowerhead produces. The aim was not to lose any seed that would be released from the capitulum like Joley and his colleagues (2003) had done. Closures prepared from a kind of mesh were placed in such a way that the wider surface matched with the circle of marginal flowers, assuming that the mesh size and the placement would not prevent aeration and irradiation. The closures were set after pollination ended; when the pollination ends in a flowerhead, the marginal flowers lose their bright color and dry out. At that time, the receptacle of flowerheads becomes swollen due to ripening of seeds. As it was observed that some small seeds escaped from the mesh and that some capitula produced no seeds, it was decided to find another way of keeping seeds since the closures may have prevented seed maturation and were not able to hold seeds of all sizes.

To find reproductive success in 2004 and 2005, flowerheads and seeds of marked individuals were collected by cutting after they ripened as much as possible. The flowerheads were labeled with the same method of marking individuals to follow the flowerheads of each individual. The number of capitula produced by each individual was recorded.

Reproductive output is measured as the number of achenes produced per head, per plant (Roché and Thill 2001). The flowerheads in which pollination had ended as explained above were cut and each placed in a labeled bag. Very similar to the method used by Benefield and his colleagues (Benefield *et al.*, 2001), seedheads were allowed to dry under room temperature to simulate seed maturation following mowing. Achenes were carefully removed sometimes with tweezers. Through visual evaluation, full (swollen throughout, no concave sides) and partially full (slightly swollen with concave sides) seedheads were counted and some weighed. The empty (thin and flat) seeds were neither counted nor weighed.

To evaluate and present the results of reproductive success, the number of flowerheads an individual produces was accepted as a determinant of grouping the individuals into classes i.e. flowerhead classes.

The method had some constraints. Since it was impossible to catch the flowerheads with seeds ripened; but not dispersed, there were missed flowerheads that released seeds to soil. Therefore formulas were developed.

Obtaining the average seed number of flowerheads of an individual needs some assumptions: Some flowerheads were missed because they ripen and shed seeds in the time interval between two field visits. So the seed set data have blanks for some flowerheads. The value for that parameter was first obtained by simply getting the average by dividing all counted seeds to total capitulum number collected. Since the capitula collection period was linked to weather conditions, some capitula e.g. the first or the last few capitula of individuals can be represented more or less in the capitula pool whose average value was calculated.

A second method was also developed: The average number of seeds of 1st, 2nd, 3rd etc. capitula are calculated singly. Then, the number of plants having 1st, 2nd, 3rd etc. capitula are found. Finally the average is obtained by the equation below.

Formula 1: Average number of seeds/ flowerheads $= \dfrac{\sum_{i=1}^{n} a_i \cdot f_i}{T}$

a_i= Average seed number of *i* th flowerheads,
f_i=total number of individuals having *i* th flowerheads
T=Total number of flowerheads of individuals marked

One problem related with this approach is to evaluate the standard errors. The standard error of average seed number of *i* th flowerheads is different for each *i*th flowerhead.

By following the same logic, a second formula was developed:

Formula 2: Average number of seeds/ individual= $\dfrac{\sum_{i=1}^{n}(m_i)\sum_{i=1}^{n} a_i}{N}$

m_i=number of individuals having *i* flowerheads
a_i= average number of seeds of *i* th flowerhead
N=total number of individuals that dispersed seeds
n=number of flowerheads

The average number of seeds released on a unit area (m^2) was calculated by multiplication on average number of seeds/individual obtained with the second formula and density of individuals on that area.

Fecundity rate (the average number of individuals in the population born per individual alive at time (*t*) that survive to be counted at the next generation, (*t*+1)) and the finite rate of increase (the ratio of population size at time (*t*) to the one at time (*t*+1)) are two important terms describing the population dynamics (Akçakaya *et al.*, 1999). In annual species, fecundity equals to the growth rate. If we assume no environmental variability and no intraspecific competition, an exponential growth model can be applied to find the growth rate. When considering N(t), one should not forget to take the number of individuals already existing as seeds in soil into account. The fecundity rate or the growth rate was calculated from life cycle vaues and seed bank values given in Chapter 3.

2.4. Biomass Calculation

To reveal whether there is any productivity difference between two study sites, a biomass calculation study was done in 2003. A 50 cm X 100 cm frame was randomly thrown in the 1st and 2nd site once and all the *Centaurea tchihatcheffii* individuals included in frame were removed. Samplings were done on 7.6.2003 in the 1st site and 29.5.2003 in the 2nd site only once to avoid harming the population. The plants removed were weighed after drying in room temperature and data were collected according to the weights of individual plants and their parts: root, vegetative part, flower, bud, number of flowers and buds contained by each plant.

For the last two years, the difference of productivity of two sites was estimated from reproductive output.

2.5. Interspecific Relationships

2.5.1. Relations with Other Plants

Unfortunately no study was carried out on the plant's relationships with other plants during the study period. Only observations were made in 2004 and 2005 on other common species at study sites. Most of the time sampling quadrats did not support growth of other plants since the dominant species on the study sites were *C.tchihatcheffii* as indicated by Erik *et al*. (2005).

2.5.2. Relationships with Animals

2.5.2.1. Pollinators and predators:

Different methods were followed for identification of insect species and their effects on population.

To identify the insect species possibly having a relationship with the knapweed species, the insect observed frequently on capitula during field studies were collected and stored to be identified later. The specimens of 2004 were sent to entomology laboratories of Gazi University and Trakya University for identification. Because the specimens were lost in those places, the ones collected in 2005 were identified by using 'A Field Guide in Color to Insects' by Zahradnik, 1977.

Basic observations on visiting behavior of pollinators were recorded anectodally. In 2003, a field experiment was developed to measure the effect of pollinators on viable seed production quantitatively. It was decided to exclude the pollinators from capitula and let only wind pollination to occur on flowers. However, it was observed that the exclosures were not efficient in keeping seeds in and pollinators out, and the experiment was terminated.

It was observed that some capitula were damaged by seed predators leaving eggs on them. The embryo inside most of the seeds was eaten and got stuck to each other; the seeds became unable to fall or be released. To understand the intensity of this infection and the causative agent, a random-systematic sampling was made at both sites towards the end of flowering season in 2004. On 10 transects whose starting point were randomly chosen, 10 points with regular (10-step) intervals were visited. The aim here was both to cover a representative portion of the area and to sample randomly. At each point, the nearest 20 capitula were examined whether there was an insect damage.

2.5.2.2. Ants

Two different field studies were conducted to understand the relationships between ants and the knapweed. All field work was targeted to understand myrcohology. No studies were performed to explain the presence of ants on plants' capitula.

A common method was used to find the seed removal rate of ants. For this purpose, seed dishes were prepared and placed at different distances from an ant colony. Similar to the method Anderson and colleagues used (2001) the seed dishes were prepared by filling 6-8 petri dishes with soil and placing 20 seeds onto the surface of each. The seed dishes were placed around an active ant nest entrance, 6 or 8 of them making a circle with a radius of 15-30 cm. The removal frequency was recorded. A few ants were collected as specimens for identification. The experiments were performed 11 times only in 2004.

2.5.2.3. Pigeons

Although no pigeons (*Columba livia*) were observed in 2003, lots of them were observed during each field trip at seed shedding time in 2004 and 2005. So it was decided to make observations and perform some simple experiments to understand what pigeons exploit in the area.

Observations were made with a telescope for four hours totally. Also two seed plates of 10 cm high and 10 x 20 cm in size were placed on the area where the pigeons were observed frequently. In addition, their droppings were examined. Because these methods proved useless in understanding whether the animals actually feed on the plant, it was decided to catch the animals. Two specimens were captured and their crops were examined.

CHAPTER 3

RESULTS AND DISCUSSION

3.1. Distribution and Human Pressure on Current Distribution

After the surveys carried out by project researchers, it was found that the species was distributed only in Gölbaşı, both on eastern and western sides of Mogan Lake. The locations where relatively large patches were observed were marked on the map (Figure 3.1) (Vural *et al.*, 2005).

The western population exists in an abandoned site between buildings near the Konya Highway (Konya Yolu) on the way to Karaoğlan, indicated as (8) in Figure 3.1. The largest population on the western side of the lake exists within a garden of a business office left untouched. A smaller one exists in an abandoned area between newly constructed houses. Also small patches of individuals exist between the houses. Clearly, the distribution was much wider before. Due to widespread constructions, the area of occupancy had decreased.

The location (1) is Hacılar village which contains a few patches of species that can be considered as small. The plants live on small patches near houses or at the edges of arable fields (see Photo E.4 in APPENDIX E). Location (2) close to the 1st one, on the edge of the Haymana Highway close to Aqua Park, supports individuals in low numbers on both sides of the road. The individuals on west of Haymana Highway are again stuck between either houses or agricultural areas. A few individuals occur along small temporary streams.

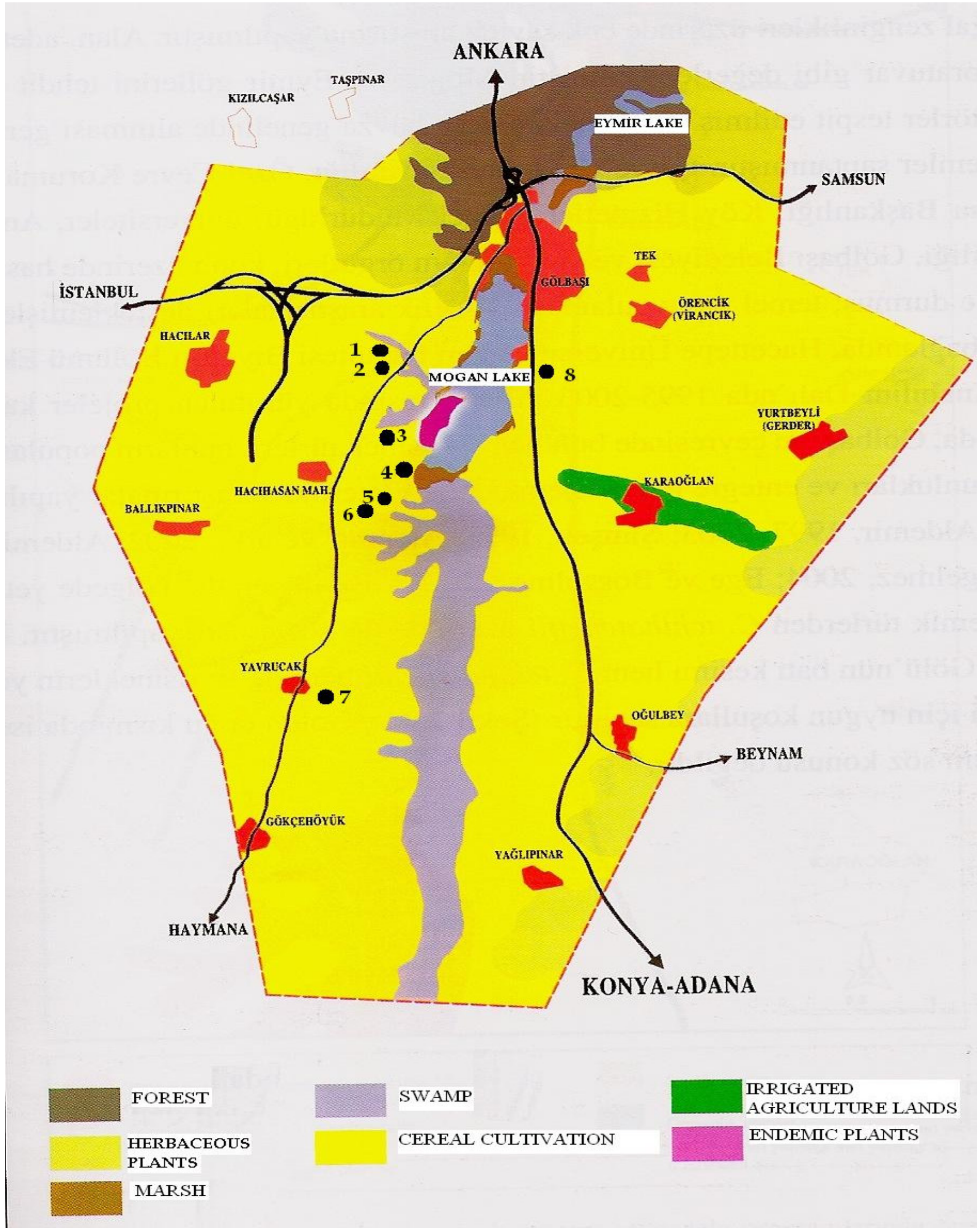

Figure 3.1 Distribution area of *C.tchihatcheffii* with black patches showing subpopulations of considerable size (>500 individuals)
Locations: (1) Hacılar village, (2) roadside near Aquapark, (3) Bizim Çatı/Shore of Lake, (4) 1st site (SDO), (5) 2nd site: farmland, (6) 2nd site: DOB, (7) Yavrucak village, (8) Karaoğlan village

Because the species is distributed at roadsides, construction sites and plantation areas, the map of its patchy distribution changed from year to year. For example, individuals living along the Haymana road were killed because of pipeline construction, road widening and building. However, recruitment was observed at those sites the following year although not reaching the previous densities.

Locations (3), (4), (5) and (6) are all on a hill named 'Kalındil', supporting the healthiest subpopulations. Location (3) is a place next to the 'Bizim Çatı' resort (Photo E.3 in APPENDIX E). The reason for having a healthy population may be the high water table. Also the soil is very rich in Na (Özcan *et al*, 2005). The individuals here are prone to threats of car activities and collection for ornamental purposes. Location (4) is the protected area named either as SDO or 1st site. Although presumably plantation activities caused the subpopulation experience a temporary extinction in 2000, the number of individuals was quite high with recruitment from seed bank.

Location (6) is the DOB area, making up the 2nd site together with a small patch of arable field (5). After agricultural activities were stopped, DOB supported the healthiest population, appearing in pink to red from a distance during May. Although the DOB area is fenced and belongs to Ministry of Culture and Tourism, it is set aside for further construction. If that is the case, an irreversible damage to the viability of the species will occur. Also because the area is not under control, there is still a probability of use of the site illegally for agricultural purposes. The very-healthy populations in fallowed farmland (5) of the 2nd site and also a few patches nearby were destroyed in spring 2004 as preparation for a crop. Therefore, the pacthes are under the danger of future agricultural activities.

The 7th location is thought to be the type locality that was erroneously reported as Afyon in Flora of Turkey (Davis, 1975). The area supports steppe vegetation with a high water table. The individuals at this site have different morphologies than the ones occurring elsewhere. They are small in size and a whitish capitulum color is dominant. The farthest point of distribution towards the south is Yavrucak village. The population size exceeded 2000 in number. The habitat was apparently a meadow with a high water table. In 2004, it was observed that farmers dug a few wells for irrigation of agricultural fields. The soil cracked and now supports very different plants. As a result of a change in the habitat, very few individuals i.e. less than 500 were observed in 2005.

Although many small subpopulations were found inside the distributional range of the species (Y. Ergüner Baytok, unpublished data) still the study sites for this thesis work contained the two healthiest subpopulations.

Increase in patch size was a promising development observed during the study. The borderline of distribution of subpopulation in DOB increased at least 7 m in width. The new colonization area supports plants that are taller i.e. 75 cm and staying longer as seen in four quadrats. In the first year of the study (2003), the number of individuals along the outside of border of DOB was less than 10. In 2005 this number exceeded 200. Recruitment from previously shed seeds or seeds dispersed in the previous year can be the reason for this change.

Current distribution probably can only be answered with the help of the history of construction and agriculture in the area. To answer the question of presence of any natural distribution limitation, it is necessary to find whether the limitation of distribution comes from inaccessability of the safe sites. One way to determine this is to make transplantation experiments whether the species can survive and reproduce (Krebs, 1999). For this purpose, a few translocation (proper for plants recruiting easily from seeds) experiments were made at Yenimahalle (City center), Eymir (Gölbaşı), Hallaçlı (Gölbaşı) and METU (Vural *et al.*, 2005). 50 seeds each were sown at ten 1m^2 quadrats at each experimental site. The individuals grew exceptionally tall, healthy and productive at Hallaçlı. The Eymir transplantation became unsuccessful probably due to unsuitable nursery soil. The Yenimahalle and METU transplantations were moderately successful compared to natural populations. However, it is apparent that *C. tchihatcheffii* is able to survive or even thrive at sites other than Gölbaşı. The potential range is much larger than the current geographical range. Therefore, distribution limitation, i.e. having no corridors to reach other suitable places, and historical changes in distribution can be determining factors of the current distribution of the species.

3.2. Density and Population Size

The density estimates for two study sites in different years are given in Table 3.1.

Table 3.1 Population density and size estimations for 2003, 2004 and 2005

Study year	**2003 (ind / 0,5m²)**		**2004 (ind / 0,5m²)**		**2005 (ind / 0,5m²)**	
Study site	1st site	2nd site	1st site	2nd site	1st site	2nd site
Population density	63,2	18,5	35.10	50.95	27.36	39.42
Standard Error	18.3	7.64	7.72	5.84	11.52*	11.92*
Patch size (m²) (app)	9000	-	9000	8700	9000	9150
Population size (app)	1,137,600	-	635,000	~890,000	~500,000	~725,000

*The standard errors sfor population densities were (d_1=13.68, Std.E_1=2.52 for the d_2=19.71, Std. E_2=2.92 for samples of 0.25 m^2. Due to averaging to 0.5m^2, the standard errors became 4-fold.

As it is apparent in Table 3.1, the population density and population size decreased every year in the 1st site. The first site has a successful recovery story in terms of population size: Before 2000, the area was prepared for tree plantation and probably herbicide application or burning took place to remove possible competitors. In 2000, no individuals were observed at the site. The population size increased to 85 in 2001. Finally it reached 600,000 in 2004. Since the standard error (18.3) and the standard deviation (±63.4) are high, the estimate for 2003 is not reliable. Also it is not appropriate to estimate a range rather than a single value. However, the value for that year is stil higher than the following two (SEE Photo E.1 in APPENDIX E).

Together with the observations, the values of the 1st site show altogether that recruitment from persistent seed bank is high. Seed bank restored the population and reversed local extinction. Therefore, the population should have high resilience (the rate at which a population returns to equilibrium after a disturbance takes it away from the equilibrium) (Smith, 1996). Reappearance of arable weeds following the ploughing up of long established grasslands proves that buried seeds can persist in viable state for many decades (Kigel and Galili, 1995). In 2003, the individuals were observed growing mainly in the aerated soil around the trees and on a small pathway that was tought to be newly constructed (see Photos E.2 a,b APPENDIX E). Therefore the distribution followed tracts of aerated soils, although the systematic sampling did not match it. The next year, individuals were observed also between transects. It is difficult to infer whether new patches arised from seeds of the persistent seed bank or from newly released seeds. However, the area did not have its bright pink color in flowering time, a sign of a decrease in numbers. Fewer individuals were observed on the path. In 2005, a dispersal of the population was observed clearly although there was still a decrease in population density. The newly established patches supported healthier individuals having taller branches and brighter flowerheads. The population size and density have been decreasing at the study site for three years possibly because of competition with other plants and less root elongation in the absence of disturbance.

The density and population size difference between two sites may also lay on land use differences, the second site having more individuals per unit area and in total. The first site experienced the latest disturbance probably in 2000 but it occurred in 2003 in the second site. Soil compaction, seed bank dynamics, number of individuals and productivity may differ for each site. Influencing viable seed numbers, plant development and the number of safe sites, past land use can effect population density and population size (see photos of the two sites: E.8 a,b; E.9 and E.10 in APPENDIX 10).

Population density and size estimations for the 2nd site in 2003 were based on the permanent quadrats established on the fallow land near DOB. Therefore, it is not possible to compare the value with the ones obtained from DOB. The strongest possibility for the observed difference is continual agricultural use without herbicide application. It is known that the healthiest population of the species exists on DOB site in 2004 and 2005 which was planted with winter rye '*Secale cereale*' in 2003 and previously (Y. Ergüner Baytok, pers.comm.) (see Photo D.5 in APPENDIX D). Differences in environmental conditions, biotic neighborhoods and site histories influence the distribution and dynamics of plant populations (Barbour et al, 1999). DOB case is a proof for this: Winter rye "*Secale cereale*" is a smother plant, i.e. a weed supressive plant having allelopathic potential, competing effectively with weeds for light, moisture, and nutrients. Rye and its residues apparently reduce weed seed germination and seedling growth by shading, lowering of soil temperatures, moderating diurnal temperature fluctuations, and acting as a physical barrier to prevent light from reaching the soil surface, and also release secondary metabolites that accumulate near the soil surface to further inhibit weed seed germination and growth. Rye residues are particularly inhibitory to annual broadleaf weeds. Among many cover crops evaluated, rye was most weed suppressive in North Carolina production systems, with a variety of crops produced in rye mulch without herbicides. Early season control of broadleaf weeds was reported as between 80 to 90% (Krebs, 1999; Nagabhushana *et al.*, 2001). Probably because of rye's weed-suppressive properties, the DOB site was not exposed to herbicides (unpublished information, Y. Ergüner Baytok). The land use maintained a persistent weed seed bank with number of aboveground individuals having considerable size. Although the area was not so healthy in 2003 due to competition with rye, in 2004 it supported the healthiest population observed in all the study years. The reason for this is perhaps the recruitment from seed bank. No tillage (which would have caused death of individuals as it happened on the patch nearby) and no plantating of cereals provided optimum conditions for plant growth.

However, in 2005 no tillage for two years showed its negative effect as soil compaction and colonization by other steppe species with high competitive abilities took place. Therefore, fewer individuals were observed although they were still high in density and very attractive in appearance.

It is stated by Erik *et al.* (2005) that in areas left untouched and preserved in this way like the 1st site, the species can not compete with long and dense steppe plants and its population is lost, but in fallow areas, tillage or aerated soil facilitate growth of the plant with easy germination and elimination of others. In accordance, the newly created soil pathways supported healthy individuals because of aerated soil, as also supported by Erik *et al*. (2004). Populations of annual weeds that are adapted to conventional tillage systems should decline if these weeds are controlled for the first few years with a no-till system, because viable seeds are not brought up from deeper soil layers to the surface by cultivation (Moyer et al, 1994).

3.2.1. Threat Category Based on Population Size Estimation

The World Conservation Union (IUCN), through its Species Survival Commission (SSC) has for four decades been assessing the conservation status of species, subspecies, varieties and even selected subpopulations on a global scale in order to highlight taxa threatened with extinction, and therefore promote their conservation. The most objective, scientifically-based information on the current status of globally threatened biodiversity is based on 'IUCN Red List Categories and Criteria' system. According to the criteria, if a taxon is thought to be going to be extinct very soon, it is listed as Critically Endangered 'CR' (IUCN, 2001). 2001 Categories & Criteria (version 3.1) gives a detailed methodology for assigning species to the CR category: A taxon is Critically Endangered when the best available evidence indicates that it meets any of the five criteria and it is therefore considered to be facing an extremely high risk of extinction in the wild. The criteria are based on the following population parameters:

A. Reduction in population size through time
B. Size of geographic range in the form of either extent of occurrence or area of occupancy or both.
C. Population size estimated to number fewer than 250 mature individuals and continuing to decline.
D. Population size estimated to number fewer than 50 mature individuals.

E. Quantitative analysis showing 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).

Red Data Book of Turkish Plants lists 33 'CR' *Asteraceae* taxa (Ekim *et al.*, 2000). *Centaurea tchihatcheffii* is listed to meet criterion B as its extent of occurence is less than 100 km^2, its area of occupancy is less than 10 km^2 and there are extreme fluctuations in the area of occupancy, number of locations or subpopulations and number of mature individuals due to agricultural activities. Possibly it also meets the 'criterion A' since according to Vural (pers. comm) the population size is fluctuating for the last 10 years but because insufficient quantitative data exist of previous years this can not be shown clearly. Therefore, the species is listed as 'CR' in the Turkish Red Data Book (2000). There are 11 other endemic *Centaurea* species listed as 'CR'.

One way of finding the threat category of a species is to use software utilizing quantitative data on the species. RAMAS Red List version 2.0 is a software implementing IUCN threatened species criteria (IUCN 2001). The characteristics such as the number and distribution of individuals, fluctuations and decline in abundance and distribution and risk of extinction, which are the basis of IUCN rules, are used as input data; the output is a classification into one of the categories. It can incorporate uncertainties in the input data which can be represented by fuzzy numbers. A fuzzy number represents an uncertain number, i.e., a number whose value is not precisely known even though it may in fact be fixed and unchanging. Input data such as the number of mature individuals can be specified either as a number, or as a range of numbers, or a range of numbers plus a best estimate.

After the analysis of data with RAMAS Red List version 2.0, *Centaurea tchihatcheffii* is classified as Critically endangered with A2a+4c and B2bc(iii) criteria. The result is mostly due to reduction in population size through time.

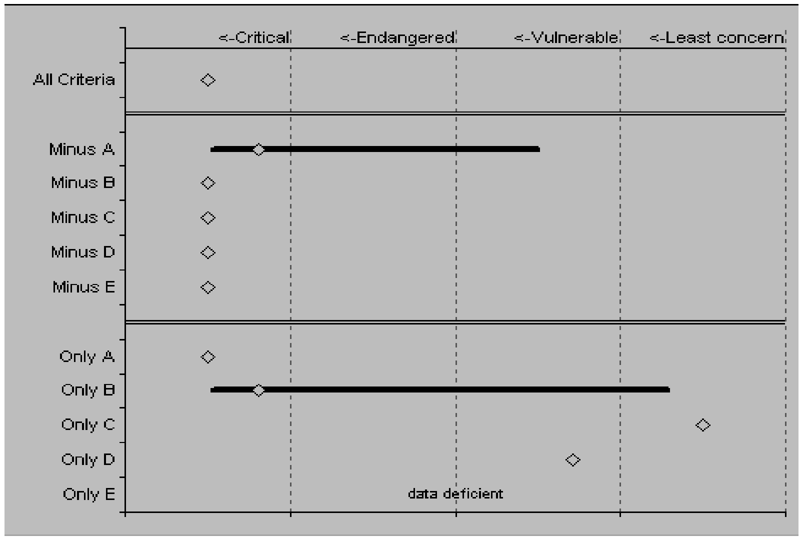

Figure 3.2 Threat Category of *C.tchihatchefii* with Contributions of Different Criteria

3.3. Survival and Reproduction Success

All the methods and sampling design in field were explained in the previous chapter. Unfortunately, there occurred some undesirable loss of setups, design and marked individuals or marks. Below given is the list of those losses and the sample sizes that parameter estimates were based on (Table 3.2).

Table 3.2 Marked individual losess and possible reasons

Study Year	**Number of losses**		**The values used in estimations**		**Possible reasons**
	Quadrats	Individuals / marks	Number of quadrats	Number of individuas	
2003	4	-	17	-	Tillage in field
2004	5	47	34	171	Tillage, cows, rain, and wind
2005	1	19	39	211	Cows, wind, high density made one quadrat unobservable

A few quadrats were set in the agricultural field near DOB in 2003 and 2004. In 2004, the farmer ploughed the site 3 or 4 times and losses occurred. In 2003, the reason was tillage of a nearby field, the farmer making a path accross the study site.

As in some other *Centaurea* species, *C. thihatcheffii* has very low palatability to livestock. Cows grazed on the field to exploit the residues of crops and other plants. Their movements caused collapse of quadrat setup. Also their exploitation on other plants removed knapweed's leaves, buds or flowerheads, giving damage to plants and making observations unvalid. Sometimes the wind caused removal of marks or the rain caused marks to be wiped away quickly.

3.3.1. General Development and Phenology

C. tchihatcheffii seeds begin to germinate in late autumn. Germination continues till the mid spring. The ones germinated before or during winter usually reach the rosette stage (R) then rest. During that period, the most prominent change occurs in leaf color: They turn to reddish-purple. A possible reason for this is anthocyanin accumulation (A. Yıldırım, pers.comm.). Although there are a few theories about this adaptation (decreasing frost damage, protection against UV), neither has widespread acceptance (Kigel and Galili 1995). With increasing temperatures and irradiation the growing season begins. In Table 3.3, timing of events critical in the life history of the plant is given. 2003 data is insufficient to reveal timings important for the species both due to timing of field work and counting errors arising from lack of experience so only 2004 and 2005 results are given in Table 3.3. It is very meaningful to compare them with prevailing weather conditions (given in Figure 2.3 and 2.4) with phenology of the species.

March, which is the earliest appropriate time for field work, corresponds to rosette stage of many plants. From 2004 and 2005 data it is concluded that maximum rosette number was observed at the end of March and in the first 2 weeks of April (Table 3.3). The end of March is the period in which temperature and precipitation begins to increase sharply. The first budding dates correspond almost with the same periods which seem to be very suitable for growth of plants. First a central bud is formed at the center of the rosette. Then lateral branches grow from the rosette and form 2nd, 3rd etc. flowerheads at the tips of branches. Those lateral branches may form secondary laterals and flowerheads on them. All the stems formed in this way are in fact hollow inside, probably an adaptation to arid conditions. Towards the end of April and the beginning of May, the plants shift predominantly to budding stage (B) and form the first flowers. During May, they increase their flower number and quickly shed their seeds because the period which more than half was flowering and when the first seeds were dispersed overlapped. Although the temperature continues to increase after May, precipitation decreases sharply creating drought conditions unsuitable for plant growth. The mid July is the period of the highest temperatures and the lowest precipitation. At that time all the *C. tchihatcheffii* individuals dry out as they shed their seeds (see Photo C.5 in APPENDIX C).

The phenology calendar shows that the two sites differ markedly in phenology: Plants develop one or two weeks earlier in the 2nd site than in the 1st site but the end of the growing season is always later for the second site, meaning that the growing season is longer there. This can be due to the aspect or soil productivity differences between the two sites.

Also there is one or two-weeks of shift in timings of peak and half values and also of first seed dispersal between 2004 and 2005. The delay may result from weather conditions. Fluctuations in weed populations from year to year are frequently attributed to the influence of weather (Silwertown and Doust, 1993). Vural has numerous translocation efforts. In one of them, in Istanbul - having a mild Mediterranean climate, plants shed their seeds in April, which is the earliest time recorded (M.Vural, pers. comm).

Table 3.3 *Centaurea* calendar for 2004 and 2005

Year	Weeks / Study Site	Before March (4)	March (4)	April (1)	April (2)	April (3)	April (4)	May (1)	May (2)	May (3)	June (4)	July (1)
2004	1st	Rosette	Rosette, Budding	Rosette M, Budding	Rosette, Budding	Rosette, Budding	Rosette, Budding H, Flowering	Rosette, Budding, Flowering	Rosette, Budding, Flowering H*	Budding, Flowering *	Budding, Flowering *	
	2nd	Rosette	Rosette M, Budding	Rosette, Budding	Rosette, Budding H	Rosette, Budding	Rosette, Budding, Flowering	Rosette, Budding, Flowering H*	Rosette, Budding, Flowering *	Budding, Flowering *	Budding, Flowering *	Budding, Flowering *
2005	1st	Rosette	Rosette	Rosette	Rosette M	Rosette, Budding	Rosette, Budding	Budding, Flowering	Budding H, Flowering	Budding, Flowering H*	Budding, Flowering *	
	2nd	Rosette	Rosette	Rosette M	Rosette, Budding	Rosette, Budding	Rosette, Budding H, Flowering	Budding, Flowering	Budding, Flowering H*	Budding, Flowering *	Budding, Flowering *	Budding, Flowering *

Rosette, Budding, Flowering, M: Maximum number observed for this stage, H: More than half of the individuals in this stage

3.3.2. Survival Success

To display the survival success of individuals quantitatively, deaths observed in different months and stages were converted into percent mortalities: The number of individuals died at that period or stage/ total number of living individuals observed at that site is given as a percentage (Table 3.4). It is apparent that most of the individuals managed to grow and disperse seeds before they died. The deaths occurring in rosette and budding stages make up a low percentage in 2004. Only three individuals out of (91+77) observed in two sites flowered but could not shed seeds, making this value 1.89%. Although the mortalities in R and B stages changed little between years for the first site, they shifted very much for the 2nd site between two years. Natural premature deaths were observed more in April and May, observed more in R and B stages and increasing almost three fold compared to percentages observed in 2004. Since the observation plots did not support individuals of other species, interspecific competition can be ruled out.

Table 3.4 Percent mortalities in months and stages for 2004 and 2005

Study Year		**2004**		**2005**	
Study Site		**1st site**	**2nd site**	**1st site**	**2nd site**
Percent mortality in months:	**March**	0	2.7	0	0
	April	0	0	0.91	7.33
	May	3.03	4.2	1.82	11.93
	June	**96.96**	**93.05**	**97.27**	**80.73**
Percent mortality in stages	**Rosette**	2.02	5.56	3.64	18.35
	Budding	6.06	1.39	3.64	4.59
	Completing life cycle	**91.92**	**93.05**	**92.72**	**77.06**

The change in death rates in R and B stages between the two years in DOB may have resulted from a change in land use. The most influential impact to the population on DOB site is stopping the agricultural activities going illegally on the site. Although it was not asked of the farmer, he stopped using the site at the end of 2004. If he continued to use the site, it would be left to fallow, and after four or five times of tillage in the fallow year; crop seeds would have been sown. Preliminary results of experiments on tillage effect show that although the treatment killed most of the individuals, plants escaping from tillage increased in size in a way that they had a size and number of flowerheads many times more than observed in control group, making up for the losses (Y. Ergüner Baytok, pers.comm.).

The range of number of individuals existing in the 0.2 x 0.2 m plots sometimes reached 50. Even then, mortality in those quadrats during the growing season was low. Moreover, sometimes it was observed that three individuals rooted within the same 4 cm^2 could grow very well, reaching the level of fecundity of other observed individuals. Besides, the individuals that died earlier were not in dense patches. Therefore, it is concluded that there is no density dependent mortality.

Since the life history of the plant ends with flowering and seed dispersal, and then drying out, the reasons for some plants not achieving this is an important question to be answered. Such premature deaths occurred in March, April and May. The possible reasons for plant deaths in stages R or B are listed in Table 3.5. The reasons are based on observations of marked individuals.

It is thought that most pf the premature deaths are dur to late emergence. Being not germinated in autumn, those insividuals appeared later in growing season.

Fenner (1985) claim that early stages of seedling growth have high mortality rates, most probably due to desiccation, i.e. inability to reach moist soil layers below surface by rapid root growth.

Table 3.5 Possible reasons for premature deaths in 2004 and 2005

Study year	2004		2005	
Study site (Percentage in total ind.)	**1st site (3.03 %)**	**2nd site (6.9 %)**	**1st site (2.73 %)**	**2nd site (19.26 %)**
Possible reasons and percentages:				
Late emergence	77.7	40	0	60
Weak individuals (genetic constraints etc.)	11.1	56	0	20
Abnormal growth	0	4	0	0
Infection	0	0	100	20
Reason unknown	11.1	0	0	0

The effect of priority of emergence on size and subsequent fate is an extremely common phenomenon that has been observed in a great many populations. Other than competitive advantage, there may be some other cause, such as deterioration in the weather putting late-emerging seedling at a disadvantage. The effect of emergence order on plant fate is largely due to the influence this has on plant size (Silvertown and Doust, 1993). Rapid root growth into deeper areas or the soil is often effective in increasing drought resistance; young plants will therefore suffer worst from drought (Krebs, 1999). In many species tested, larger seeds have an advantage in the timing of emergence and effect may persist at maturity. Seed and seedling sizes are positively correlated and early plant size is an important indicator of final plant size and reproductive output (Kigel and Galili, 1995). One of the most acute hazards for a tiny seedling is dessication at a time when the root system is scarcely established (Harper, 1993).

During the beginning of marking each year, it was observed that some individuals were very weak compared to others. It is difficult to know whether they germinated later or not since no information was available on what happened during winter. But perhaps there were parental effects or genetical constraints on them. Seed mass can be another reason: It may affect different juvenile and adult characters and is probably one of the earliest indicators of offspring quality (Kigel and Galili, 1995). The fitness of an individual plant is strongly related to its size. Small plants not only bear the brunt of mortality in crowded populations but, if they survive, also produce fewer seeds than large plants (Silvertown and Doust, 1993). Possibly microclimatic conditions can be more effective on weak individuals.

The abnormal growth observed in only one individual at the 2^{nd} site in 2004 occurred as the individual died out with three very healthy unopened buds. A developmental problem may have caused this.

An infection mentioned above was observed at the 1^{st} site in 2005. It caused white to brownish spots on vegetative parts of the plants and weakened them although not killing. Unfortunately the diagnosis of the infection was not possible.

Since it is not easy to tell the reason of plant's death from field observations, reasons for some are unknown. However, root infections are common among weedy *Centaurea* species (see Introduction for relevant references). To understand the cause of deaths for sure, detailed observations or some lab work for diagnosis are necessary for further research.

3.3.3. Reproductive Success

Since, in the first year, the method for observation of population dynamics did not give any results about the average number of flowerheads produced by each individual, the information about this parameter can only be inferred from biomass results. 86 and 59 individuals were sampled with this method at the 1^{st} and 2^{nd} sites, respectively. In Figure 3.3, it is seen that most of the plants at the first site had 1, 2 or 3 flowerheads. At the second site (not DOB but the adjoining fallow area) there is a shift towards the 4-flowerhead stage although sampling was done here 1 week earlier. The plants removed from the first site had 1-to-10 flowerheads but in the second site, they had 0-to-7 flowerheads. These ranges are concordant with the ones observed in 2004 and 2005 for those periods.

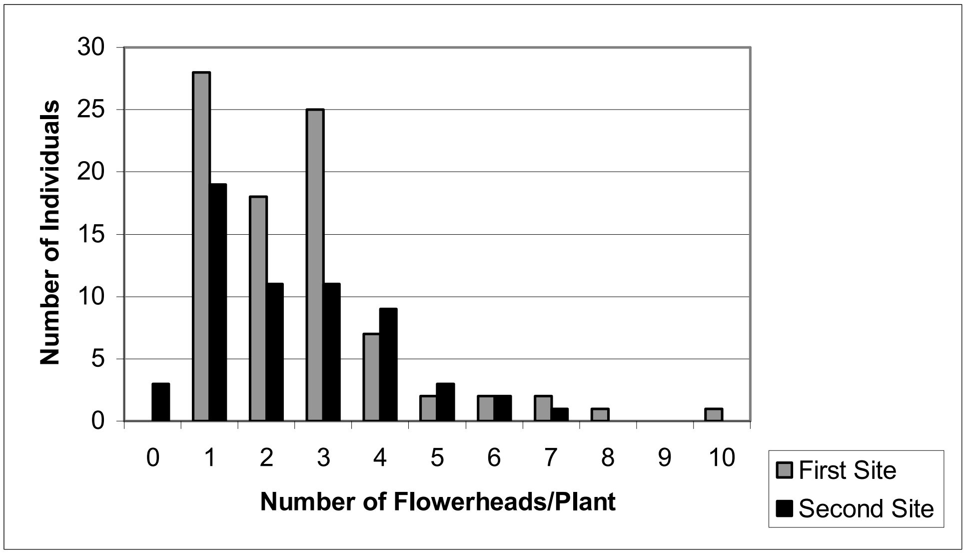

Figure 3.3 Flowerhead Numbers of Individuals Sampled for Biomass Estimation

To find the average number of seeds produced by each flowerhead, 19 flowerheads on different individuals were bagged at different times. 174 seeds were obtained totally with an average of 9.15. Since it is observed that some small seeds were able to escape from the meshes of the closure, a different method was used in the following two years as explained in previous chapter.

In 2004, only three individuals among all flowering plants did not produce seeds. By using Formula 1, average number of seeds per flowerheads for 2004 was obtained to be 6.84 and 10.51 for 1^{st} and 2^{nd} site respectively. The values are 6.13 and 10.15 for 2005 similar to 2004 results.

Formula 2 is applied to get the average number of seeds of an individual the values obtained are 18.03 and 71.18 for 1st and 2nd site respectively in 2004 and they are 21.38 and 89.11 for 2005.

The range of number of flowerheads/individual and number of seeds/flowerhead were based on the marked individuals but individuals having much higher values were observed. Some individuals may reach to 70 flowerheads like the ones escaped from plowing in a tillage experiment (Y. Ergüner Baytok, unpubl. data). Also we know that some flowerheads can exceed 40 seeds. Some individuals grow exceptionally, having lots of lateral branches. Unfortunately they were not marked.

Table 3.6 Reproductive success estimates for 2004 and 2005

Study year	**2004**		**2005**	
Study site	**1st site**	**2nd site**	**1st site**	**2nd site**
Number of flowering individuals	96	72	102	84
Range of flowerheads/individual	0-10	0-23	0-11	0-23
Average number of flowerheads/ individual	**2.48** (0.241)*	**6.54** (0.78)*	**3.28** (0.214)*	**7.67**(0.509)*
Number of flowerheads whose seeds counted	133	259	227	473
Range of seeds/flowerheads	0-25	0-34	0-25	0-37
Average number of seeds/ flowerheads	**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]
Average number of seeds/unit area (m^2)	**1271.12**	**7253.242**	**1410.011**	**8697.136**

[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.
[5] The average number of seeds released on unit area is calculated by multiplication of estimates obtained with Formula 2 by the density of that site given in Table 3.1.

Sometimes an increase in number of flowerheads does not contribute to the reproductive output. Similar to that reported by Clavijo (2002) for *Centaurea eriophora*, plants that have senesced all their leaves sometimes develop small lateral branches of 1-2cm long bearing a few small leaves and ending in a capitulum smaller than the previous ones, having lower reproductive value. Most of such flowerheads of *C. tchihatcheffii* produced no seeds.

The values of reproductive success can be summarized as the average number of seeds per unit area. On average, one individual produces more than 18 potential individuals in the first and more than 70 in the second site, making more than 1200 and 7000 seeds per unit area respectively. The numbers are high although the average flowerhead and seed number per individual is not so. High seed numbers per individual is a function of plant density. So plants produce enough seeds for population's persistence.

As it is seen from the table, there is an apparent difference in terms of reproductive success i.e. average number of flowers/individual, average number of seeds/individual and average number of seeds/individual between the two sites in both 2004 and 2005. The second site is much more successful than the first one having values several-fold higher probably due to its land use history. The slight increase in reproductive success in spite of a decrease in density for both sites in 2005 compared to 2004 should be related to more favorable conditions, especially higher precipitation observed during flowering since the continuous rain caused a 10-day delay in field work.

Seed production in natural populations can be limited by pollen limitation, resource limitation, herbivory or predation of reproductive structures and adverse environmental conditions (Kigel and Galili, 1995). The results of two years of work show that there is no severe limitation on seed production.

3.3.4. Seed Bank

The results of studies done by Yıldırım and colleagues (A. Yıldırım, pers.comm.) showed that the species have a persistent seed bank with high number of viable seeds. The height of the soil volume that all seeds are present was assumed to be 20 cm which is the depth of the sampler.

Table 3.7 Seed bank values of two sites for 2004 (A. Yıldırım, unpublished data)

Site (Year: 2004)	Number of total seeds/m²	Number of viable seeds/m²	Ratio of viable seeds/total seeds
DOB	34,770	18,300	0.526316
DOB adjoining arable land	25,010	16,470	0.658537
SDO	41,540	10,540	0.253731

It would be useful to compare the results of seed bank analysis with the number of seeds released each year, assuming that it is constant. The seed number released and stored in first 20 cm of the soil is about three times that of released annually at the DOB site. Probably the site has more viable seeds within deeper soil. At the SDO site, although the seed bank had higher number of seeds, they were not as viable. The reason for this can be resting conditions of the seeds. Seeds are more prone to lose viability on surface of undisturbed soil than the ones buried deeper.

3.4. Biomass Difference between Two Sites

The biomass obtained from sample of 1st site is 97.015 g with 86 individuals whereas the sample taken from the 2nd site is 103.57 with 59 individuals. The difference is 6.555

(6.75% of the 2nd site's biomass). To be able to say it is significant, we should use some statistical methods but we had only two sampling so it is impossible. When t-test was used, it showed there was no significant difference (p=0.347) between sites in terms of productivity when total biomass was compared. The difference can be the result of sampling error or date difference. The mean biomass of flowerhead classes of two sites and root/shoot ratios are given in Figures 3.4 and 3.5. The mean biomass of flowerhead classes do not differ much between two sites (p=0.267, pooled Std.Dev=1.05). It was observed that 2nd site supported less but larger plants with more flowerheads, covering more area. Although sampling size did not enable to sample individuals from higher flowerhead classes, a tendency of increasing mean biomass at higher classes shows that if sampling size was increased, the 2nd site would have appeared as more productive significantly.

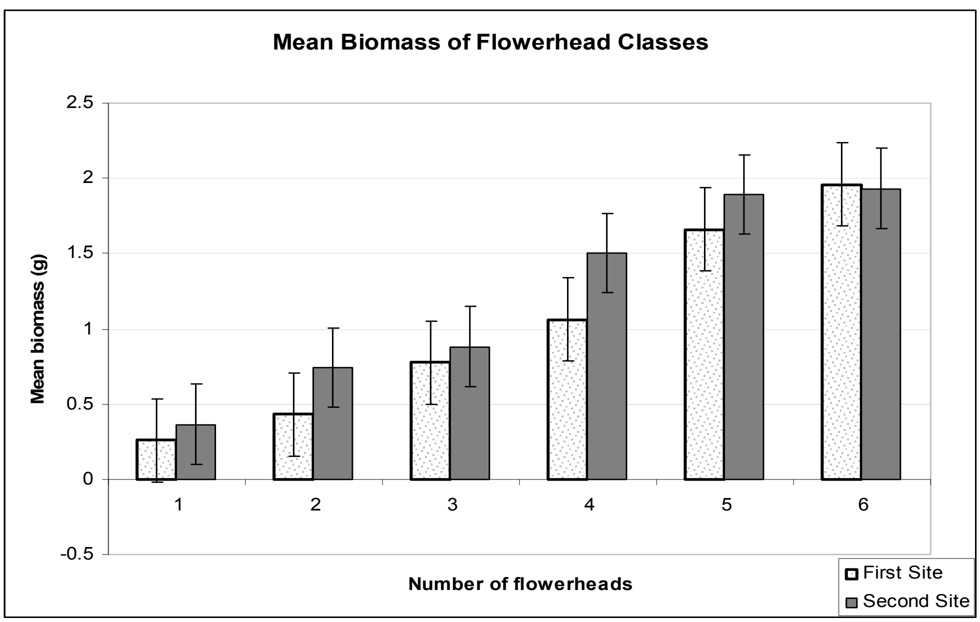

Figure 3.4 Mean biomasses of flowerhead classes of first and second sites

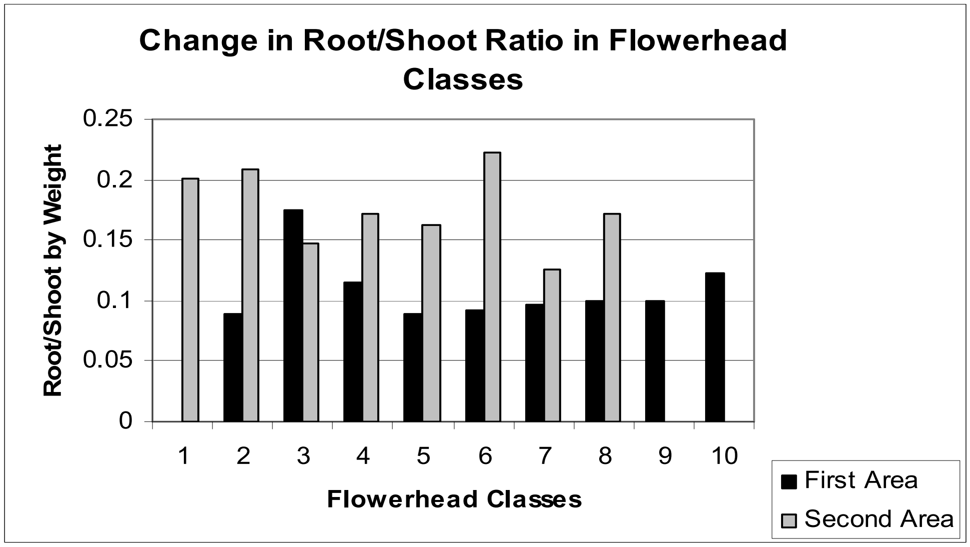

Figure 3.5 Root/ shoot ratios of flowerhead classes of first and second sites

The root/shoot ratio appeared to be significantly different between two sites ($p=0.003$ and pooled Std.Dev =0.03196). Success, measured as producing more flowerheads, can be attributed to a higher root/shoot ratio so using resources more efficiently compared to the first site.

3.5. Reproductive Strategy

3.5.1. General

The reproductive strategy involves allocating a given fraction of resources to reproduction, fruiting at the appropriate time and producing the optimum number of seeds of the optimum size (Fenner, 1985). Most of the information given below was obtained by detailed observations on population or samples.

C. tchihatcheffii is a monocarpic (semelparous) plant. It has a mixed mating model: The plant is cosexual having the disc flowers all hermaphrodite on flowerheads. The ray flowers are sterile.

3.5.2. Abortion

More than 400 flowerheads were collected and examined under the dissecting microscope to get basic information of the reproductive strategy of the species. The disc flowers ripen from edges towards the center but there were always some ray flowers remaining undeveloped even all the capitulum died and dried (see Photo C.8 in APPENDIX C) so abortion of some flowers must have taken place. In many plants, only a small fraction of the ovules produced eventually develop into ripe seeds. There are four main causes of mortality of ovules and seeds during predispersal phase: Pollination failure, resource deficiency, predation and developmental failure. Even when pollination is maximized, many plants produce far fewer fruit than flowers. The termination of the development of ovules and fruits appears to be a mechanism whereby the parent plant regulates its reproductive effort in accordance with the resources available (Fenner, 1985).

To find the ratio of seed produced to all disc flowers, the total number of disc flowers in each flowerhead was counted in addition to the seeds. The ratio was calculated to be 0.219 (6.59/30.09) and 0.214 (10.96/51.08) for the first and the second site of 2005, respectively. It is interesting that although the average number of seeds produced per flowerhead is different for each site, the regulation of abortion is the same.

3.5.3. Pollination: Selfing versus Out-crossing

The stigma of a flower is surrounded by anthers. The first ripening flowers (marginal ray flowers) usually never release their pollens and the stigma is not exerted out of the anther cover so they are apparently self-crossers and self-compatible. Towards the center of the flowerhead, the flowers were observed as releasing pollens or exerting stigma with opened lobes dark in color, sometimes both at the same time. Those were the outcrossing flowers. Since the flowerhead classes of specimens were not known, it is difficult to claim that cleistogamy occurs in this species as in other *Centaurea* sp. But it is apparent that each flowerhead first guarantees forming seeds by selfing, then outcrossing; selfing and out-crossing efforts seem to be divided between flowers of a single flowerhead. To prove the same division among different flowerheads, one should examine the flowerheads of known flowering order e.g. 1st, 2nd etc. Detailed studies are necessary to detect all strategies of flowers.

There are glands on sepals of flowers producing pinkish-purple fluids. The color is more apparent in outcrossing flowers. This fluid can be a reward to attract insect vectors for pollination.

Wind pollination is thought to be very effective in pollination since the pollinators were scarce in 2005 due to absence of beehives in the neighborhood. A close relative, the yellow starthistle (*Centaurea solstitialis*), has the same trait of pollination. It is a preferential outcrosser attracting generalist insect pollinators with pollen and nectar. When conditions are not favorable for pollinators, selfing becomes the dominant mode of pollination, without notable loss in fecundity (Roché 1996; Roché and Thill, 2001).

The flowerhead color is a source of dispute among researchers reporting information on the species. The color of most flowerheads was recorded in 2005. From a distance, the area appears red to pink at the 3rd week of flowering. All the flowerheads of the plant flowering at the beginning of flowering period have a darker and more attractive color. The color should function in pollinator attraction visualizind the colors different than humans in flowerheads developing out-crossing flowers. In most cases, they do not get paler. This is observed in only less than 5% of flowerheads. Towards the end of the flowering period, the flowerheads produced are usually smaller and they produce less seed. They usually appear pink to white. Most of the individuals found in Yavrucak village had ray flowers in ligther color. Also flowerheads of weak individuals have the same trait. A possible reason for this is production of less pigment due to scarcity of a resource, i.e. water or some nutrient; it is thought to be a kind of phenotypic plasticity.

3.6. Dispersal

Seed dispersal is often a two-stage process, involving primary dispersal that may be aided by animals or wind, and a secondary phase on the soil surface when water, wind, seed predators or ants move seeds still further (Silvertown and Doust, 1993).

The main dispersal agents are wind (anemonochorous) and ants (zoochorous). As it is recorded for other *Centaurea* species, it was observed that seeds left on plain surfaces on windy days at about 20-50 cm high resisted to blow away, even moving against the wind direction. Therefore wind is thought not to be an effective vector.

There are few ant species involving in myrmecochory (see Photo D.3 a, b in APPENDIX D). During preliminary studies done in 2003, morphologically two different ant species were observed either on the flowerheads or during carrying seeds.

The 11 removal observations made with sets of seed plates show that at the beginning of the flowering season, all seeds were removed within 20 minutes.

The first setup was prepared with one-year-old seeds but the ants did not prefer aged seeds probably due to the aging of attractive elaisome. They were interested in seeds only before the midday and did not always follow the shortest distance to carry the seeds. It was observed that an ant could carry the seed for 5-10 m. Towards the end of the flowering season, the preference of ants on seeds switched to seeds of *C. depressa* which are bigger than those of *C. tchihatcheffii*. A few seeds that were discharged and elaisome-removed were found near entrances.

Many times it was observed that finding shed seeds on the soil is very difficult even with detailed examination. It was thought that wind and ant vectors quickly carry the seeds below the soil surface either into cracks or entrances of ant nests.

Long distance dispersal is typical of plants that occupy patchy environments. Agricultural weeds typically have effective means of dispersal that depend on the wind or animal (including human) vectors (Barbour et al, 1994). Pigeons (*Columba livia*) preying on seeds can also be considered as long-distance dispersers if seeds stick to their feathers.

Although (SPA) contains rodent species, no sign of any mammalian dispersers were observed in the field (Çevre Bakanlığı, 2002).

If a researcher wants to combine life cycles of two sites into a metapopulation model, it is necessary to know the dispersal ability and migration between two subpopulations. Since they are quite away from each other either for ant or wind mediated dispersal, the only possible migration is by means of human vectors (machines of farming) or less probably pigeons carrying seeds between two sites. So both diffusion and jump dispersal are possible ways of dispersal. Weeds are examples of fugitive species which colonize temporary habitats, reproduce and leave quickly before the temporary habitat disappears or competition with other organisms overwhelms them. Devoting most of their effort to dispersal, they produce large number of seeds adapted to long-distance dispersal by wind or by animals to colonize new habitats (Krebs, 1999). Since wind is not thought to be a long-distance vector, animals like pigeons or humans (agricultural activities) can be considered as long-distance vectors.

Habitat fragmentation due to intensified agriculture both reduces total area and connectivity, so the dispersal and migration rates are reduced. All these affect population size and increase extinction rate (Krebs, 1999).

3.7. Some Interspecific Relations

3.7.1. Relationships with Other Plants

There were other weed species reported in quadrats of vegetation study done by Erik *et al.* (2005) in years between 2002 and 2004. For example: *Boreava orientalis, C. depressa, Adonis aestivalis, Anthemis fumariifolia, Lepidium perfoliatum, Hordeum bulbosum and Bromus tectorum*.

In both fields, *Centaurea depressa* which is a wide-spread weed of Central Anatolia was observed (see Photo D.6 in APPENDIX D). It was observed that *C. depressa* flowers later than *C. tchihatcheffii* giving rise to bigger seeds. Many studies have suggested that the sequential flowering of sympatric species that share pollinators is the result of past selection to avoid pollen limitation caused by competition for pollination (Kigel and Galili, 1995).

Stopping agricultural activities decreased the dominance of crops (mostly winter rye) and its weeds (mainly *C. tchihatcheffii* and *C. depressa*) at the second site. Species of steppe vegetation other than weeds like *Tragopogon, Dipsacus* and *Gagea* were also observed in 2004 and 2005. Some other weed species observed are *Adonis aestivalis, Bifora radians, Wiedemannia orientalis* and *Chenopodium* spp. The first site supports also perennials like *Genista* and *Hyocyamus*.

The only possible competition type in the area is exploitation competition but there is no study made directly to measure competitive abilities or agressiveness of the species involved. The secretion of allelo-chemicals directly inhibiting the growth or reproduction of other plants is called allelopathy, counted as a kind of amensalism (Barbour et al, 1994) is common in *Centaurea*. However, there is no such record for this species.

3.7.2. Relations with Pollinator Insects

The main pollinator of the species was observed to be the honey bee, *Apis mellifera* (see Photos D.2 a, b in APPENDIX D). Towards the peak of flowering season, many honey bees were observed. Their pollen sacs were apparently in the color of *C.tchihatcheffii* pollens. It is not known whether they are also interested in any other reward like nectar. During observations it was seen that the bees usually do not spend much time on the individuals of same clump. The number of bees was apparently low in 2005 compared to 2004 due to absence of beehives in close vicinity.

3.7.3. Relations with Seed Predators

The ripening seeds of plants are attacked by sedentary larvae which hatched from eggs laid in the buds. In 2003, seed predation was observed during seed collection. Although the agent could not be identified, eggs and developing larvae damaged many flowerheads. The rate of infection for 2005 was found to be 2.3% totally, being higher in the 2nd site.

An insect species was observed very often during field studies. Spending time on flowerheads, it was thought that it either lays eggs or spends the pupa stage in flowerheads, the latter being more probable. The species is a member of **Hemiptera** (Miridae ’Leaf bug’, Anthocoridae ‘Flower bug’ or Lygaeidae ‘Seed bug’, Photo D.4).

Despite many efforts, it is not proven that pigeons exploit the seeds of the species (see Photo D.7 in APPENDIX D). Two pigeons caught very early in the morning did not have anything in their crops. Since pigeons digest all seeds, examination of droppings gave no result. Based on many observations, pigeons should be considered as seed predators since they are present only where there are seed releasing plants of *C. tchihatcheffii*. Although Erik and his colleagues (2005) do not have any evidence for this, they claim that seed predation by pigeons can cause a decrease in population size due to decrease in the size of seed bank but observations made throughout this study do not support this. Pigeon predation was not so effective in reducing population size the following year since most of the seeds escaped from pigeon predator by becoming buried deep in the soil. Pigeons are perhaps able to remove seeds from flowerheads but flowerheads damaged as such were not recorded.

3.7.4. Relations with Pollen Predators

One of the most common insect groups observed on plant in the field was Carabidae. They were observed in the capitula of plants.

A coleopteran species was frequently observed on flowerheads. Identified as ***Epicometis hirta*** (see Photo D.1 a, b, c in APPENDIX D), the species can be grouped as a pollen predator, a kind of predispersal predator. In 2004, in 100 points visited, 10.4 have infection on 1-2 flowerheads/20 flowerheads examined. So the rate is between 0.007 and 0.014, which is probably not effective in decreasing viable seed production overall.

The ratio was calculated from marked individuals' flowerheads in 2005 and it is found to be very low: 1 in 479 flowerheads only at the 2^{nd} site, so it is decided that pollen predators do not pose a limitation on population persistence.

3.8. Life Cycles

For the ease of understanding what all the values related with survival and reproduction and findings of relationships with other organisms means, it is better to show them as life cycle graphs. The transition values from rosette to flowering stage were extracted from death rates for the two years given in Table 3.4. To find the ratio of seeds giving rise to rosettes, the number of seeds released in the previous season and the number of rosettes counted for that season were used, assuming deaths of new seeds and the contribution of seeds already existing in seed bank compensate each other, i.e. a constant seed bank. It would be better to try a range other than the value for the rate that seeds remain viable in the seed bank. Seeds that neither germinated nor lost due to predation were designated as a loop around seed bank or seed stage. Those values are also rough estimates considering the recruitment from seed bank in 2000 at the SDO site was very high. It would be better to use a range of values based on assumptions if one is to model the population by using these values.

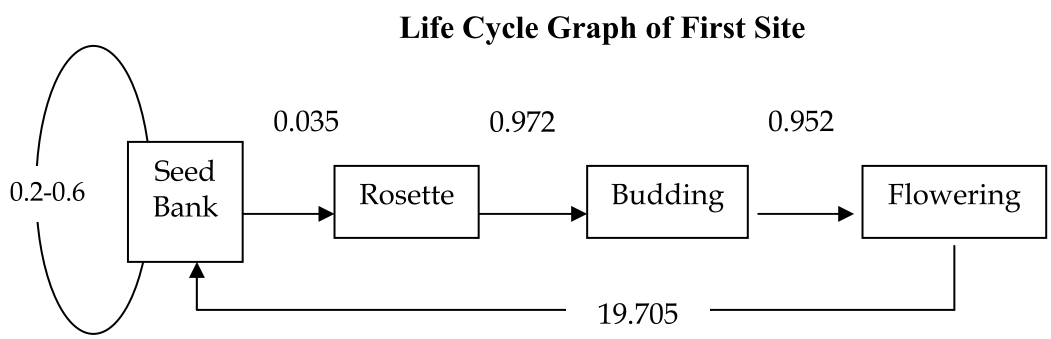

Figure 3.6 Life cycle graph of individuals existing at the first site

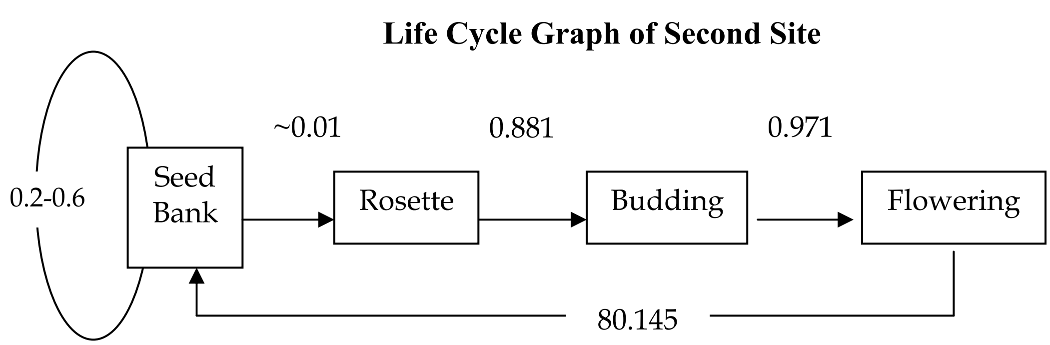

Figure 3.7 Life cycle graph of individuals existing at the second site

The transition rates to budding and flowering stages of two sites are similar and high. The difference in population dynamics seems to arise from seed formation, seed bank dynamics and recruitment to rosette stage.

Two population projections was performed with the values of life cycles and seed numbers provided by Yıldırım (Table 3.7) as starting numbers. If is assumed that the loop value is 0.25 and 0.5 for the first and the second numbers, respectively.

The projection was expected to catch the 2005 values but it is not the case. The values for the study sites are reversed. The reason for this is the higher seed bank in the first site, lower transition from seed to rosette and possible mistakes in seed bank renewal values. So it will be better to perform the projection after reliable values of dormancy and germination ecology is obtained in addition to number of live or death seeds in soil.

It is apparent from life cycle transition values that there is not any intrinsic cause for decrease in population size.

CHAPTER 4

CONCLUSIONS

There was no natural habitat left within the geographical range of the species, i.e. all the steppe areas of Gölbaşı were converted mainly for cereal cultivation. A common reason for the study sites supporting the healthiest subpopulations is recent soil disturbance in addition to being spared from detrimental effects of agriculture that took place in the past. Showing many characters of an annual weed species, high densities, high survival and reproduction rates were recorded on aerated soils of the sites. The success of individuals on newly colonized patches, higher productivity of DOB site by higher root/shoot ratio compared to SDO due to more recent soil disturbance and a decrease in densities at both sites in 2005 due to lack of soil disturbance are proof for the species' adaptation to conventional tillage system on arable lands.

The results of the present study show that there is no natural limit on the metapopulation's long term persistence. The species life history traits and this three-year long study claim that it is very important to take ruderal characteristics into consideration while deciding on the right conservation strategy. Observing the population's status at those sites in the following years has vital importance whether recruitment from seed bank reflected in observed population densities will decrease even further due to lack of disturbance. It should be noted whether reproduction rate will follow favorable weather conditions again. The data of population density and flowerhead number of individuals randomly chosen at maximum flowering time (mid June) will be easy and sufficient for long term monitoring purposes.

It is very important to match the result of conventional tillage system experiment of Baytok (pers. comm.) with the behavior of the species at other places. It is also important to follow sucessful translocation studies of the TUBİTAK project through years whether the species will continue to survive in the new colonization areas or be only able to persist as small populations in private gardens of Gölbaşı. Therefore, the conservationist can decide whether the species is succesful only on aerated soils and disappears in undisturbed areas, and whether the only thing to do is to stop any intervention or regular soil disturbance is required for species persistence in the reserves.

Both evaluation of population status with IUCN criteria and analysis with RAMAS Redlist assign the species to "Critically Endangered" category mainly due to the size of its geographic range. The rarity of the species can be attributed to restrictive geographic range and low habitat tolerance, both of which are influenced by human activities in the area. So before waiting for the results of complementary studies, one should consider the threats and decide on short term actions for conservation of species.

The current human-based threats on the species can be listed as:

- Agricultural activities, especially herbicide application
- Construction of roads, pipelines and buildings
- Change in the water table due to well digging
- Collection of plants for ornamental purposes
- Trampling by vehicles and livestock

Conserving the few remaining subpopulations by setting the land aside as a reserve is the first tihng to remove the pressure of consrtuction and agriculture with herbicide application. Fortunately, Dr. Ömer Gülkal of Authority for the Protection of Special Areas (ASPA) has developed a master plan for both conservation of species sustainable use of the area for educational purposes for the SDO site. Implementation of the plan would be a most promising progress for the conservation of the species (Ö. Gülkal, pers.comm.). The DOB site should also be preserved by legal protection, but it should be decided whether leaving the sites untouched ensures the species' survival or any action like ploughing the area with regular intervals will be needed.

Because expropriation of privately-owned lands in Gölbaşı is not a credible option, it is very difficult to prevent construction work or cereal farming. Therefore, different strategies for the conservation of rare weeds should be developed like it happened in European countries. Ensuring protective zones for threatened weeds in field edges without herbicides application, the establishment of field flora reserves, seed multiplication in botanic gardens and storage in gene banks were some of the protection programs initiated and adapted in several European countries. But management restrictions for the sake of species conservation are only accepted when high levels of compensation is paid and effectiveness is regularly controlled. Conservation of arable weeds could be possible by integrating conservation and sustainable management systems (Albrecht and Mattheis, 1998). Ecologically friendly cultivation methods over intensive systems, long-term population viability and cost-efficiency research should be carried out before formulating recipes for conservation. One option is the promotion of winter rye cultivation which can be considered 'Yanardöner'-friendly. Another is to find ways to decrease herbicide applications in cereal plantations.

Cooperation with residents of Gölbaşı by increasing their public awareness is a progress in species conservation that should be continued till every resident will learn the name of their neighbour 'yanardöner'.

Further reserach is needed to address several questions that remains unanswered. These studies should be on population genetics, seed bank dynamics on natural populations and relationships with other plants and insects.

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APPENDIX A

ANNUAL METEOROLOGICAL FACTORS OF ANKARA

METEOROLOGICAL FACTORS	ANNUAL VALUES	METEOROLOGICAL OBSERVATION (YEAR)
Average temperature	10	20
Average maximum temperature	15.7	20
Average minimum temperature	4.4	20
Maximum temperature	38.3	20
Minimum temperature	-19	20
Average relative humidity	73	20
Minimum relative humidity	12	20
Average cloud cover (0-10)	3.4	20
Average precipitation	408.5	18
Maximum daily precipitation	39.7	18
Average number of snowy days	24.1	19
Average wind velocity (Beufort Scale)	2.4	20
The speed of fastest wind (Beufort Scale)	8	20
Average number of days with storm (wind speed ≥ 8Beufort Scale)	0.4	10
Average number of days with strong wind (wind speed 6-7 Beufort Scale)	19.2	10
Direction of fastest wind	S	20

Table A.4.1 Annual meteorological factors of Ankara (Boşgelmez, 2005)

APPENDIX B

Table B.1 SOIL PROPERTIES OF THE SITES THAT *Centaurea tchihatcheffii* GROWS

Parameters		**Site 1**	**Site 2**	**Site 3**	**Site 4**	**Site 5**	**Site 6**	**Site 7**	**Site 8**
Saturation with water, %		105	81	103	87	132	102	110	108
pH of soil solution *		8,63**	8,56	8,49	8,03	8,86	8,61	8,88	8,23
Salinity,%		0,Q7	0,04	0,05	0,03	0,07	0,04	1,18	0,04
Bioavailability of P_2Os, kg^{-1}		2,29*	4,12	2,75	2,58	1,61	2,58	5,88	5,19
Bioavailability of K_2O, kg^{-1}		200	179	142	116	95	116	181	119
Organic matter %		0,86	1,14	1,09	0,69	1,23	0,92	0,78	0,59
Lime, %		12.9	12	1500	32.63	1125	1611	13,47	1083
Bioavailability of Fe, ppm		5,43	6,24	4,20	3,60	7,50	3,90	7,50	3,80
Bioavailability of Cu, ppm		0,73	0,65	0,97	0,46	1,26	0,68	1,28	1,42
Bioavailability of Zn, ppm		0,31	0,22	0,33	0,29	0,25	0,25	0,30	0,30
Bioavailability of Mn, ppm		5,64	6,06	6,08	3,80	6,30	4,92	8,67	9,69
Total nitrogen, %		0,056	0,059	0,057	0,04	0,07	0,05	0,060	0,08
Soil texture	Clay(C), %	43	45	56	48	64	60	60	70
	Silt (Si), %	34	38	32	27	22	18	22	18
	Sand(S), %	23	17	12	25	14	22	18	12
Field capacity %		34,9	32,0	34,7	32,5	37,7	33,8	34,1	32,6
Pemanent wilting point%		21,2	19,2	22,0	20,1	22,6	21,3	20,6	20,4
Volume mass ($g.cm^{-3}$)		1,26	1,21	1,24	1,23	1,18	1,23	1,25	1,22

(Özcan *et al*., 2005) Sites: (1)Bzim Çatı resort, (2)SDO, (3) SDO, (4) Close to Karaoğlan village, (5) Close to Karaoğlan village, (6) Arable land near Aquapark, (7) Salty soils close to Aquapark, (8) DOB

Table B.1 SOIL PROPERTIES OF THE SITES THAT *Centaurea tchihatcheffii* GROWS (cont.)

Parameters		**Site 1**	**Site2**	**Site 3**	**Site 4**	**Site 5**	**Site 6**	**Site 7**	**Site 8**
	Na+	10.98	589	659	2,55	11 55	654	**81.74**	6,35
Soluble cations (me.L^{-1})	K+	5	4	0,03	0,08	0,03	3	**0,25**	0,02
	Ca+2	1,00	1,30	1,60	188	1,44	110	**24,75**	0,88
	Mg+2	0,63	0,70	0,20	0,30	0,71	0,30	**7,91**	0,41
	Total	12,66	7,93	8,42	4,81	13,73	7,97	**114,6**	7,66
Soluble anions (me.L^{-1})	CO_3^-	159	120	180	0	201	163	**1.18**	0
	HCO_3^-	6,31	5,62	5,72	2,85	4,13	5,31	3,24	5,51
	Cl^-	70	32	65	186	683	248	**43,48**	186
	SO_4^{-2}	4,06	0,79	0,25	0,10	0,76	0,18	**66,72**	0,29
	Total	12,66	7,93	8,42	4,81	13,73	7,97	**114,6**	7,66
Extcractable Na,me 100g^{-1}		1981	988	1251	126	13.04	63	**36,4**	11 30
Cation exchange capacity me.100g^{-1}		4045	3972	3658	32,60	40,49	4201	4356	5585
Exchangable Na, me.100g-1		18,32	9,37	4,82	1,04	11,52	5,65	16,39	6,89
Exhangable Na percent, %		**45,28**	**23,59**	12,36	3,18	**28,44**	13,44	**37,60**	12,34
Boron, ppm		**9,18**	**6,31**	2,39	1,02	**27,37**	2,28	**6,92**	1,56

Sites: (1)Bizim Çatı resort, (2)SDO, (3) SDO, (4) Close to Karaoğlan village, (5) Close to Karaoğlan village, (6) Arable land near Aquapark, (7) Salty soils close to Aquapark, (8) DOB

APPENDIX C

PHOTOGRAPHS SHOWING PLANTS, MATERIALS AND SETUPS

Photo C.1 Density estimation quadrat for 2004 and 2005

Photo C.2 Marks on rosettes in a quadrat

Photo C.3 A budding individual

Photo C.4 Flowering individuals

Photo C.4 Dried individuals after seed

Photo C.5 Seeds

APPENDIX C
Photographs showing the plant.

Photo C.6 A flowerhead with marginal flowers (ray) flowers and central (disc) flowers

Photo C.7 Flowerhead with outermost disc fertile and innermosts aborted

Photo C.8 Different flowerhead colors

Photo C.10 Flowerhead, bract and seed

Photo C.11 Newly flowering plant (Gamze)

APPENDIX D

Photographs showing pollinating vectors and organisms interacting with *C.tchihatcheffii*

Photo D.1,a,b,c: *Epicometis hirta*

Photo D.2,a,b: *Apis mellifera*

Photo D.3,a,b: An ant carrying seeds from seed plate

Photo D.4 Hemipters: seed eaters

Photos by Uğur Zeydanlı and Didem Çakaroğulları

APPENDIX D

Photographs showing organisms interacting with *C.tchihatcheffii*

Photo D.6: *C.depressa* in a quadrat

Photo D.5: Winter rye plantation in DOB in 2003

Photo D.7: Pigeons flying on seed dispersing plants in DOB in 2005

APPENDIX E

PHOTOGRAPHS SHOWING DISTRIBUTION PATCHES IN DIFFERENT PERIODS


Photo E.1 a,b SDO in 2003


Photo E.2 a,b Individuals growing on aerated soils tree plantations and in arable land 2003

Photo E.3 Patch nearby 'Bizim Çatı' Resort 2004

Photo E.4 A patch on Hacılar village 2004

APPENDIX E

PHOTOGRAPHS SHOWING DISTRIBUTION PATCHES IN DIFFERENT PERIODS

Photo E.5 a,b Arable land in second site 2003

Photo E.6 Ploughed arable land of 2nd site **Photo E.7** Wheat plantation in arable 2004
2004

Photo E.8 a,b DOB 2004

APPENDIX E

PHOTOGRAPHS SHOWING DISTRIBUTION PATCHES IN DIFFERENT PERIODS

Photo E.9 SDO 2005

Photo E.10 DOB 2005