Autecology of San Diego thornmint (*Acanthomintha ilicifolia*)

FINAL REPORT

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ABSTRACT

Acanthomintha ilicifolia (San Diego thornmint) is Endangered in the State of California, and is proposed for federal listing as an endangered plant. Only about 30 natural populations survive out of 50 recorded occurrences, and less than half of these are protected. Its range is limited to San Diego County and northern Baja California, Mexico, and within this limited geographic range it is further restricted to isolated patches of clay soil, sometimes derived from gabbroic rocks. Typically, these clay patches occur in gently sloping, open, grassy areas surrounded by chaparral vegetation. Little is known about the basic biology of *Acanthomintha ilicifolia*, so that it is difficult to make important management decisions and prioritize preservation measures. The objectives of this project are to determine under controlled conditions the germination requirements of *Acanthomintha ilicifolia*, to examine the effects of weeds on its survivorship and fecundity in the field, and to observe, identify and collect probable insect pollinators.

A series of experiments indicated that germination of San Diego thornmint was inhibited by warmer temperatures, and that optimum conditions for germination include a long daily period at about 10 degrees C (50 degrees F). Germinability is also clearly related to seed age, with fresh seeds having the lowest germinability and the narrowest range of suitable conditions. With age, the overall percentage of seeds germinating increased and the range of suitable conditions broadened to include higher temperatures. Darkness has an inhibitory effect on germination as well, and its effect is more pronounced in younger seeds and at higher temperatures.

The effect of weeding of field plots appears to be undetectable on survivorship of *Acanthomintha ilicifolia*, but it has a positive impact on fecundity. The survivorship rate of San Diego thornmint plants in the field (1995/1996 rainfall year) was high, exceeding 80 percent for both Sycamore Canyon populations. Weeded plots had an average of 115 seeds/surviving plant, whereas unweeeded plots averaged only 86 seeds per survivor. The seed rain in 1996 was over 5, 000 seeds/m^2 at Site 1 and nearly twice that number at Site 2

Insect visitors to San Diego thornmint plants included checkered beetles (Cleridae), bee flies (Bombyliidae) and various bees. The most common visitors were the bees and to a lesser extent the beetles. Both may be transferring pollen from flower to flower and plant to plant. There do not appear to be any narrowly distributed or specialized insects visiting the plants, but additional work, especially on the bees (Hymenoptera), will be necessary before any conclusions can be made.

Management recommendations include practices that reduce the spread and density of annual weeds in the native habitat and revegetation of highly disturbed areas that may act as reservoirs of weed seeds and unsuitable habitat for pollinators.

CHAPTER 1. INTRODUCTION

1.1. PURPOSE OF THIS STUDY

Acanthomintha ilicifolia (San Diego thornmint) is Endangered in the State of California, and is proposed for federal listing as an endangered plant (CDFG 1997, FWS 1997). Only about 30 natural populations survive out of 50 recorded occurrences, and less than half of these are protected (Bauder, McMillan and Kemp 1994). Its range is limited to San Diego County and northern Baja California, Mexico, and within this limited geographic range it is further restricted to isolated patches of clay soil, sometimes derived from gabbroic rocks (Oberbauer 1993). Typically, these clay patches occur in gently sloping, open, grassy areas surrounded by chaparral vegetation (Bauder et al. 1994).

Little is known about the basic biology of *Acanthomintha ilicifolia*, so that it is difficult to make important management decisions and prioritize preservation measures. Work on another species in the genus, *Acanthomintha duttonii*, has been in progress for over 6 years (Pavlik and Espeland 1991, Pavlik, Espeland and Wittman 1992, Pavlik and Espeland 1993, and Pavlik and Espeland 1994). In these studies survivorship and fecundity of plants were monitored in the field, laboratory seed germination trials were conducted and the plant was reintroduced to an unoccupied site. Steeck (1995) compared the reproductive biology of *A. duttonii* and *A. obovata* ssp. *cordata* in her master's thesis.

The objectives of this project are to determine under controlled conditions the germination requirements of *Acanthomintha ilicifolia* (San Diego thornmint), to examine the effects of weeds on its survivorship and fecundity, and to observe, identify and collect probable insect pollinators.

1.2. BACKGROUND

1.2.1 Habitat

Acanthomintha species all are found in grasslands, often on serpentine or gabbro derived clay soils (Jokerst 1993). Pavlik, Espeland and Wittman (1992) did a comparative analysis of serpentine-derived clay soils supporting *A. duttonii*, non-serpentine soils collected from a Monterey County site with *A. lanceolata* , soil from an unidentified site in San Diego County that supported *A. ilicifolia* and potting soil. As would be expected, the potting soil was highest in NPK. It also was high in Ca and Mg compared to the other soils. The primary difference between the serpentine and non-serpentine native soils was in the Ca/Mg ratio, with a higher ratio in the non-serpentine soils.

Contrary to published floras, *Acanthomintha ilicifolia* is not associated with vernal pools but is usually found on moderate slopes with a slope angle rarely greater than 20° and commonly less than 15° (Bauder, McMillan and Kemp 1994). Clayey soils (sometimes gabbro derived, but probably of various origins) with large, deep fissures during the dry season appear to be an obligate substrate. Sometimes these soils have a very distinct polygonal pattern of cracks. The soils' structure is crumbly, and when moist these soils often feel spongy underfoot, unlike vernal pool soils that are generally very dense and plastic when wet (Greenwood and Abbott 1980). Small pockets of soil with San Diego thornmint plants frequently occur on the uphill side of rocks. There is no evidence that water actually ponds in San Diego thornmint habitat as it does in vernal pools, nor that it is found in close association with Mima mound topography as vernal pools frequently are (Bauder 1989, Cox 1984).

Thriving San Diego thornmint populations generally have limited disturbance and relatively sparse weedy competitors (Bauder, McMillan and Kemp 1994). Native geophytes are especially common in and around *A. ilicifolia* plants. Examples are *Allium* spp., *Bloomeria crocea*, *Calochortus concolor* and *C. splendens*, and *Chlorogalum parviflora*. The native grass, *Nasella pulchra*, and possibly other *Nasella* species, are common associates. Annual herbs frequently found with *Acanthomintha ilicifolia* are *Apiastrum angustifolium*, *Calycadenia tenella*, *Corethrogyne filaginifolia* var. *virgata*, *Chorizanthe fimbriata* var. *fimbriata*, *Hemizonia fasciculata* and *Harpagonella palmeri*. Shrubby species often in association are *Adenostoma fasciculatum*, *Eriogonum fasciculatum*, *Heteromeles arbutifolia*, *Malosma laurina*, *Rhamnus crocea*, *Yucca whipplei*, various *Rhus* species and several *Salvia* species. The difference between the plant community where San Diego thornmint is found and the coastal sage scrub vegetation type is that thornmint habitat is more open and has a greater density of grasses and herbaceous species and a lower density of shrubs, soft-leaved or otherwise.

The exotics that are closely associated with *A. ilicifolia* are the grasses *Avena* (several species), *Bromus hordeaceus* and *B. madritensis* ssp. *rubens*; thistles such as *Centaurea melitensis* and *Cirsium vulgare*; and the annual herbs, *Anagallis arvensis*, *Brassica nigra*, *Hypochaeris glabra* and *Sonchus oleraceus*. The possible negative effect on San Diego thornmint of dense exotic herbs was noted by Taylor and Burkhart (1991, 1993, 1994) in various reports on a mitigation project related to loss of several *Acanthomintha ilicifolia* populations due to development.

1.2.2 The Species

Acanthomintha ilicifolia (San Diego thornmint) is a small herbaceous mint (family Lamiaceae) that is endemic to San Diego County and northwestern Baja California, Mexico. The genus *Acanthomintha* has only four species (five taxa), all of which are found in the California Floristic Province, an area to the west of the Sierra Nevada Mountains and extending from southern Oregon into northern Mexico (Jokerst 1993). Thornmints are all short-stemmed (2-3 dm) annuals with bilabiate white flowers tinged with rose or lavender and subtended by spiny bracts, the origin of the name "thornmint".

Plants vary in size from only a few centimeters tall with just a few branches, to nearly 2 dm tall, several dozen branches and a spread of 5 dm when growing conditions are favorable. Flowers are produced in clusters (called glomerules) at the stem nodes. Fecundity is affected by the number of nodes, the number of flowers per node and the seeds produced per flower. In common with other members of the mint family, each flower produces only four ovules and therefore has a maximum output of four seeds. Seeds are held singly in schizocarps, or fruitlets, derived by separation, upon maturity, of the four one-seeded carpels composing the flower's ovary. The number of flowers produced per node is indeterminate and can vary greatly depending on growing conditions. The number of nodes per plant is correlated with the number of branches and the length of the branches. Spindly plants with little branching will have a lower reproductive output than plants with numerous branches (Pavlik and Espeland 1993).

In common with the other thornmint species, San Diego thornmint is a winter annual which germinates during the winter rainy period, flowers in late spring and sets seed and dies in early summer. When flowering, it may be quite showy because of dense populations of plants with relatively large and numerous flowers. However, Steeck's (1995) work on *A. duttonii* indicated relatively low rates of insect visitation. This thornmint is self-compatible and capable of autogamy. Autogamous seed production equaled that of plants both cross- and hand-pollinated. *A. obovata* sp. *cordata*, on the other hand, appears to be self-compatible but not as likely to self-pollinate as *A. duttonii* . For these two thornmint species, likely pollinators are medium and large-sized bees, with bumble bees the most common visitors (Steeck 1995).

Nothing is known of the breeding system of *Acanthomintha ilicifolia*. Insect visitors were observed and identified in this study (Chapter 4)

CHAPTER 2. GERMINATION EXPERIMENTS

2.1. METHODS

Several hundred plants were harvested from three subpopulations of *A. ilicifolia* from Sycamore Canyon County Open Space Preserve, San Diego County, in September of 1995 (Department of Fish and Game EO #32: sites 1E, 2 and 5 in Bauder, McMillan and Kemp 1994)(Figure 1). Additional plants with seeds were collected from the same populations in 1996 and 1997, as part of the field competition experiment (See Chapter 3). Plants were stored in a laboratory at San Diego State University in paper bags at room temperature. Seeds were carefully removed from the dried flower calyces and stored in glass jars at room temperature. A maximum of 4 seeds (each contained in a fruitlet—also known as a schizocarp or nutlet) can form per flower, and it was observed during the seed removal and cleaning that seed production was generally 3-4 per flower, and that retention in the calyces was extremely high. *A. ilicifolia* apparently retains most of its current seed crop within the dried mother plant until winter rains or other physical disturbances break it down. No evidence of insect herbivory of the seeds was observed. Equal amounts of the seed from each of the subpopulations were pooled for the various germination experiments.

Four growth chambers were set at 10 hours daylight and 14 hours darkness (to simulate winter) and were each given one of the following temperature conditions: 10° C, 20° C, and 25° C—all constant, and alternating day and night temperatures of 22° and 10° C. The seeds were placed in lidded transparent plastic boxes on wetted germination paper. Two replicates of 50 seeds each (for a total of 100 seeds/treatment) were placed in each chamber and exposed to alternating light and darkness (hereafter referred to as the "light" treatment). The germinated seeds were counted every few days and removed. A cumulative tally for each treatment was kept as seeds germinated. In addition, for each of the four temperature conditions, six replicates of 50 seeds each were wrapped in foil and incubated in the dark. These "dark" treatment boxes were opened two at a time at various intervals throughout the course of the experiments to compare germination rates in the dark with those exposed to 10 hours of light per day.

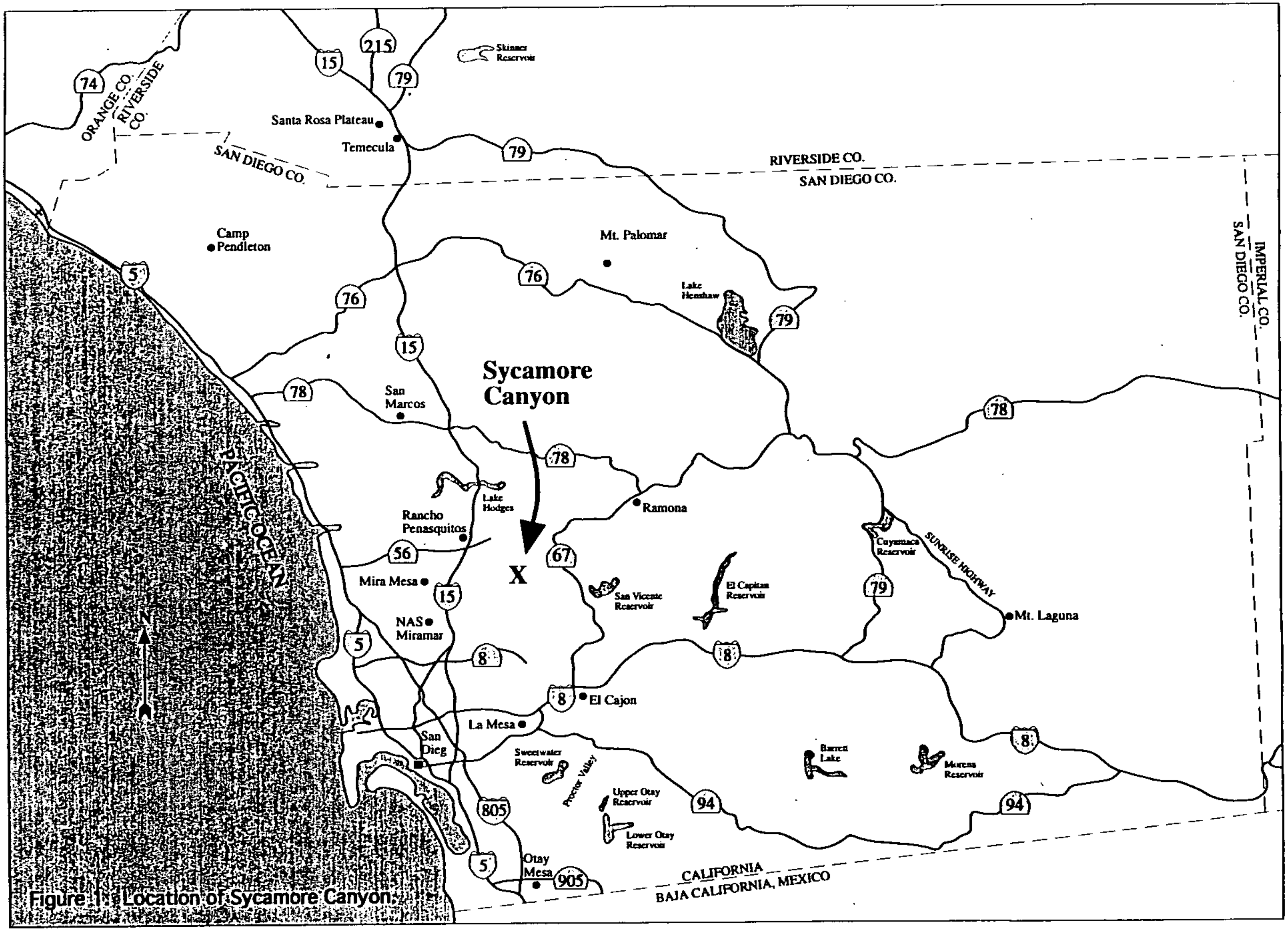

Figure 1. Location of Sycamore Canyon.

The basic experiment, as outlined above, was repeated with seeds of different ages originating from two seed crops (1995 and 1996, as indicated above)(Table 1) to explore the effect of these two factors, in addition to illumination and temperature, on seed germinability. In one experiment (March 1996), ungerminated seeds incubated at high temperatures were moved to cooler temperatures to determine if they were dormant or dead.

Analysis of variance was conducted on transformed data (the arc sine of the square root). Significant interaction terms are discussed where appropriate.

2.2. RESULTS

2.2.1. March 1996 experiment

Cool temperature, for at least part of the daily cycle, was the most important factor for germination of 7-mo old seeds collected in 1995 (ANOVA p= <0.0001). All two-way comparisons were significant, with the exception of the 10 degree treatment vs. the 22/10 degree treatment. There appears to be a threshold between 10 degrees C and 20 degrees C, with germination significantly lower above 10 degrees C or 10 degrees alternating with 22 degrees C (Figure 2). The rate of germination in the "light" treatment was most rapid in the two coolest temperatures, with most seeds germinated after 15 days (Figure 3). At warmer temperatures, germination proceeded more slowly and leveled off by day 10. Seeds which failed to germinate after 22 days at either 20 or 25 degrees C, remained viable and germinated within 21 days after they were moved to a chamber set at alternating 22/10 degrees C (Figure 4).

Darkness was a significant inhibitor of germination, with the final percent of seed germinated lower in the "dark" treatment in three of the four temperature treatments, and only slightly higher at the 10 degrees C treatment (ANOVA p= <0.0001)(Figure 2). The interaction between illumination and temperature was non-significant (p= 0.0931).

Experiment date	1995	1996
March 1996	7	——
July 1996	12	0
October 1996	15	2
January 1997	19	6
August 1997	25	13

Table 1. Year of seed crops and seed ages used in germination experiments (in months).

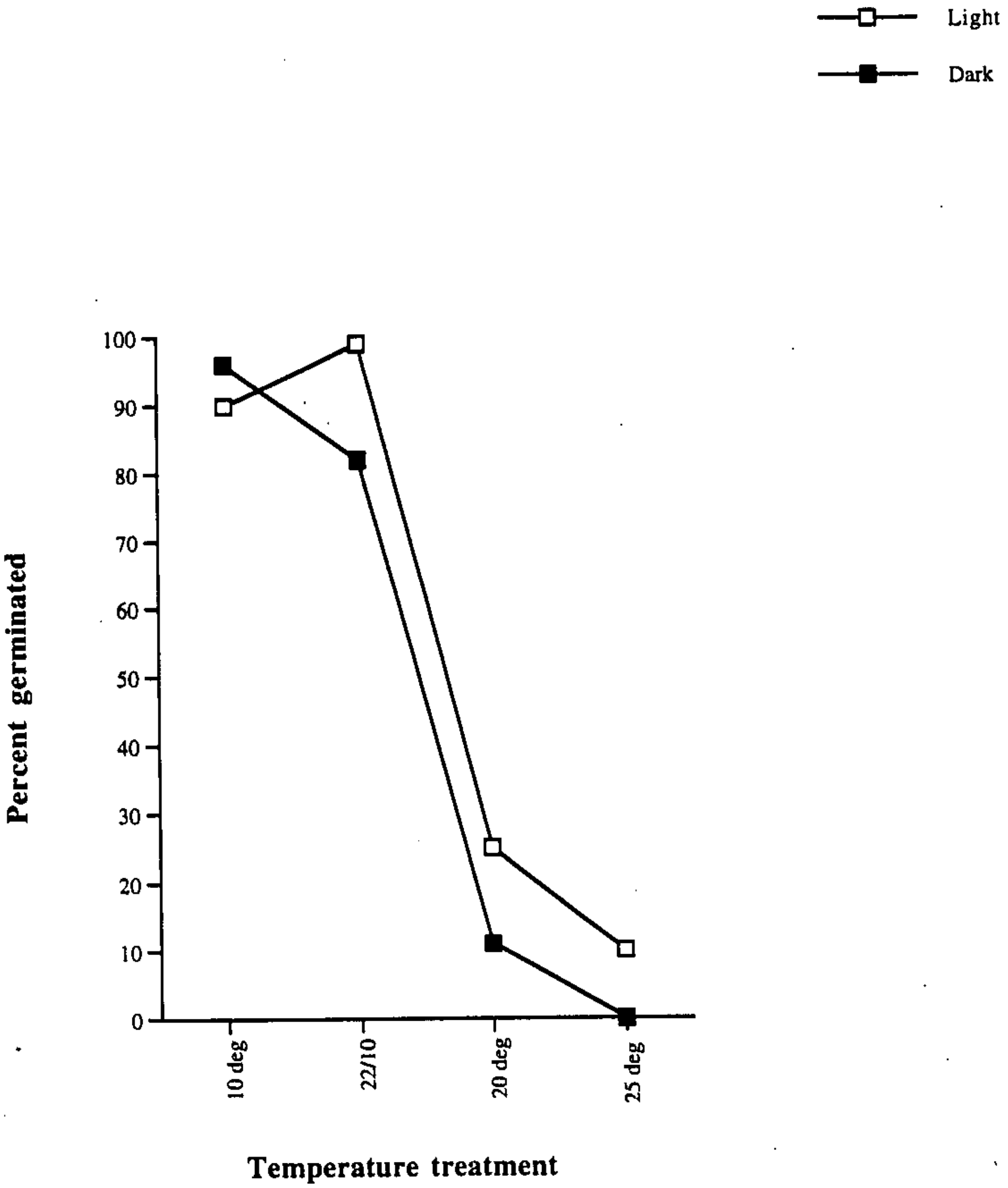

Figure 2. Total percent germinated (mean of two replicates).

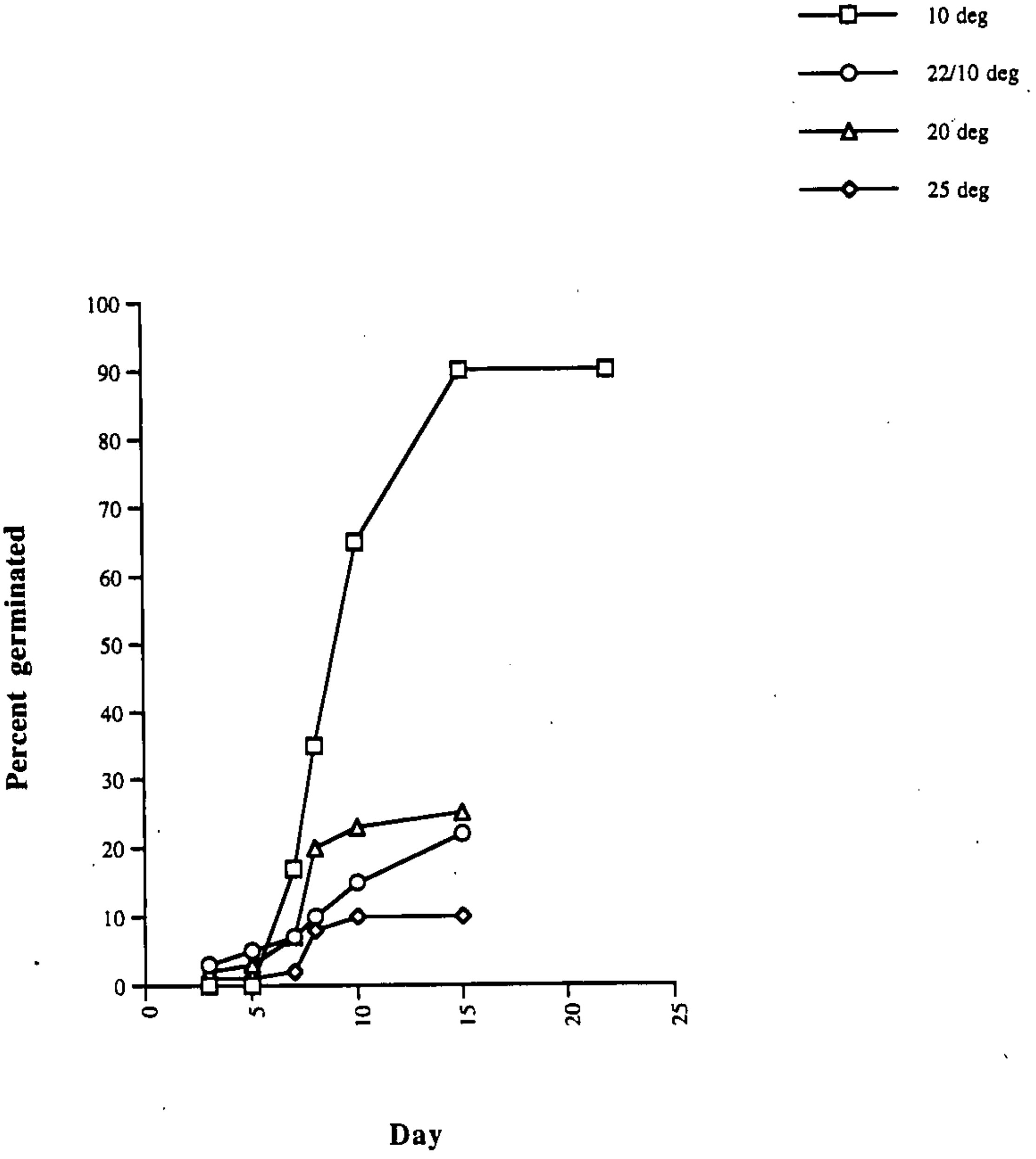

Figure 3. Cumulative percent germinated in the "light" treatment (mean of two replicates).

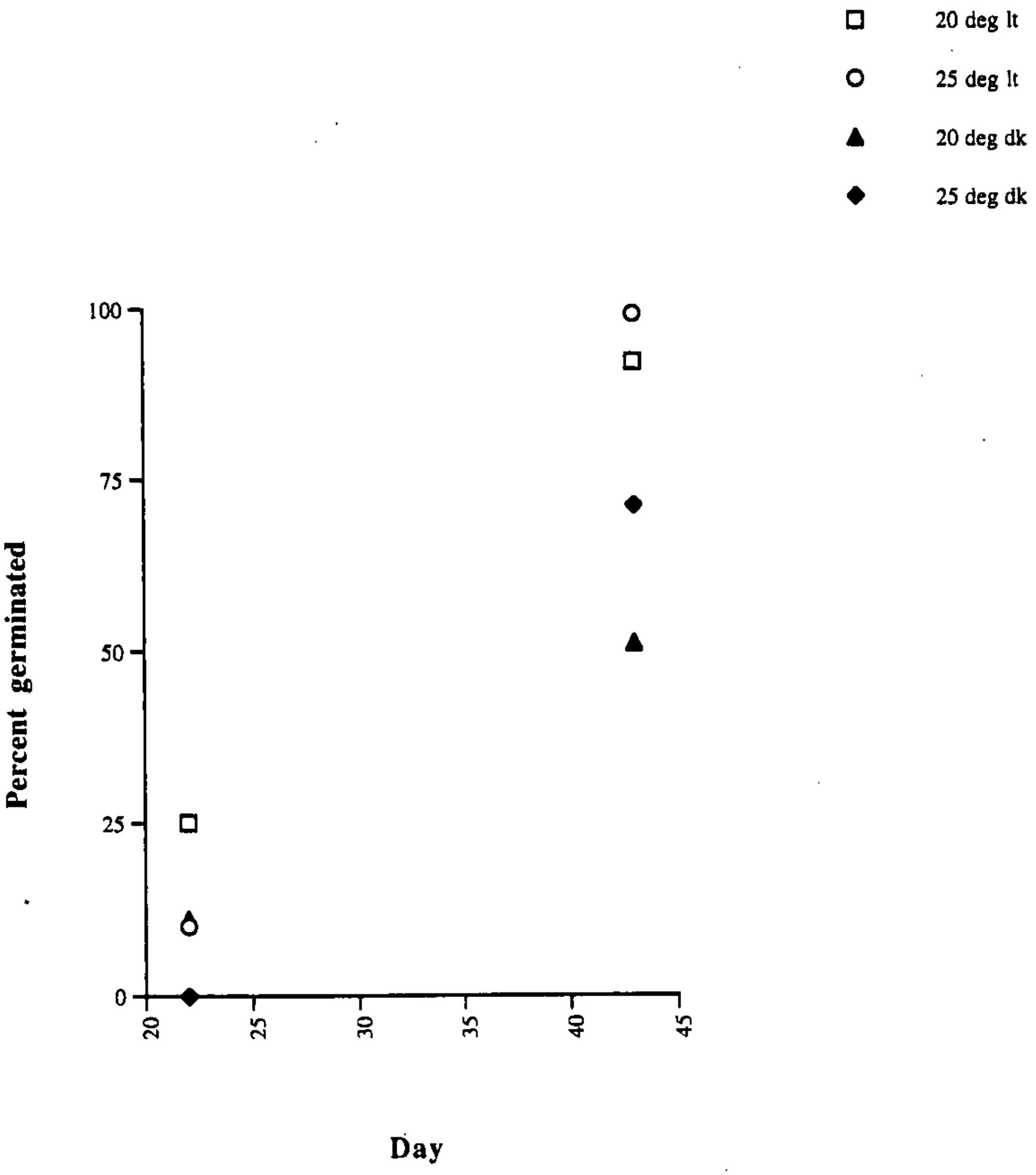

Figure 4. Seeds moved to 22/10 degree C treatment after 22 days. (Mean of two replicates).

2.2.2. July 1996 experiment

2.2.2.1. *1995 seed crop*

The 1 year old seeds (1995 seed crop) retained a high degree of viability with >70 percent germination at all temperatures in both the "light" and "dark" treatments, with the exception of the seeds incubated at 25 degrees C in the "light" treatment (Figure 5). This interaction between light and temperature resulted in a significant interaction term (ANOVA p= 0.0025). As with the 7 month old seeds tested in March 1996, germination was both more rapid and substantial at the cooler temperatures, with a slower germination rate at 25 degrees C which leveled off after about 10 days (Figure 6).

Seeds of the 1995 crop tested at two ages (7 months and 1 year) germinated well at cooler temperatures but behaved differently at higher temperatures (Figure 7). The most dramatic change in the response of the seeds to the two treatment variables was the increased germination of older seeds at the two higher temperatures when kept in the dark , although there was a substantial increase as well in total percent germinated of older seeds kept at 20 degrees C with the "light" treatment (Figure 7). The lessened sensitivity of the older seeds to light resulted in a higher proportion of seeds germinating, compared to younger seeds, when all treatment combinations are combined.

2.2.2.2. *1996 seed crop*

Germination of freshly collected seeds produced in 1996 was low in all treatments, regardless of illumination (Figure 8). Only at the lowest temperature was total percent germination comparable to the germination rates observed for the 1995 seeds in the more favorable treatments (See Figures 5-7). The negative effect of higher temperatures was more pronounced in the dark. The rate of germination was quite rapid at the two lower temperatures, with most germination occurring in the first 8-10 days (Figure 9).

2.2.3. October 1996 experiment

2.2.3.1. *1995 seed crop*

The 1995 seeds were at this point 14 months old. Seed germination rates remained high at all temperatures in the "light" treatment (>90 percent at the three coolest

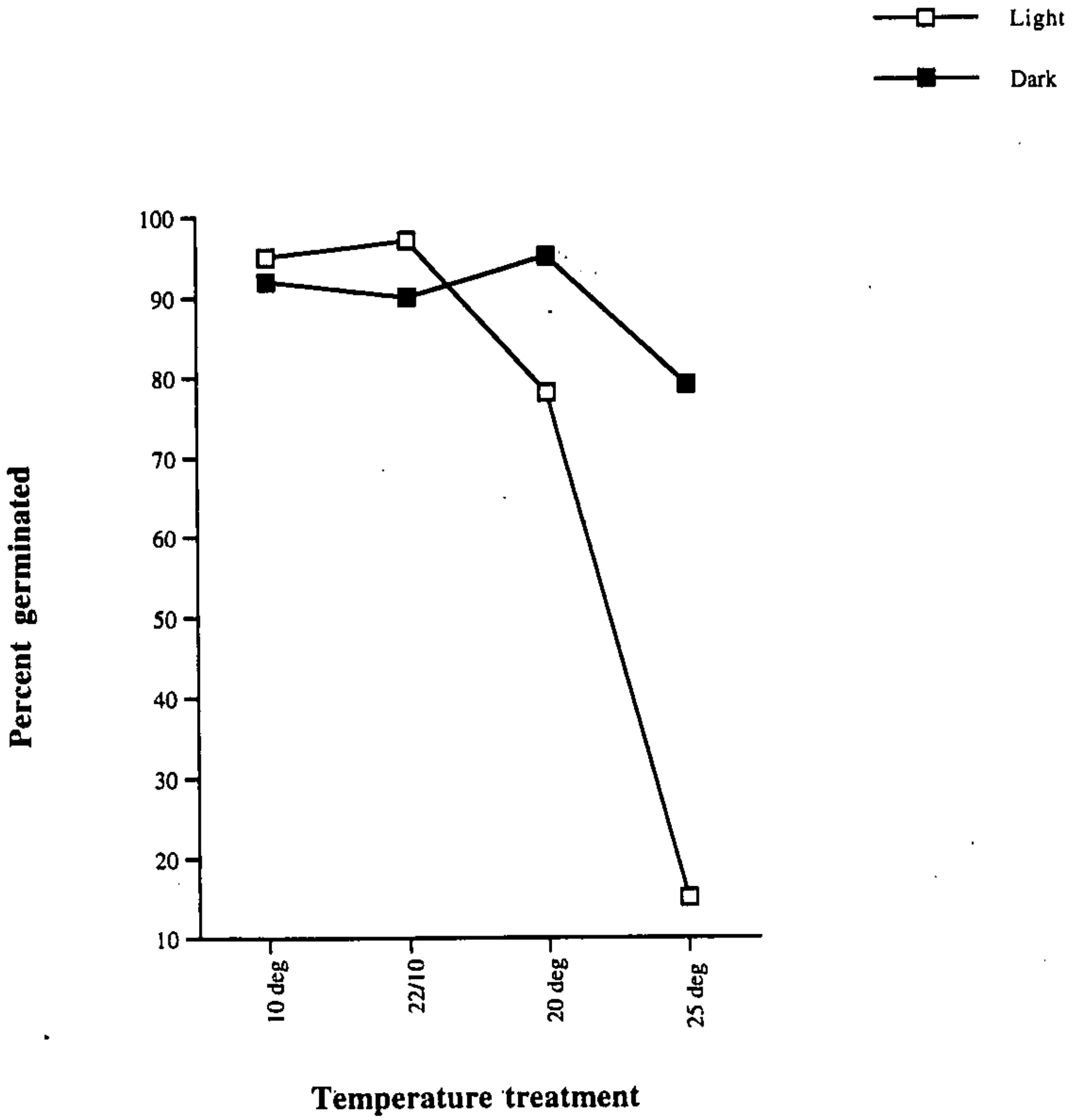

Figure 5. Total percent germinated (1995 seeds in July 1996, mean of two replicates per treatment).

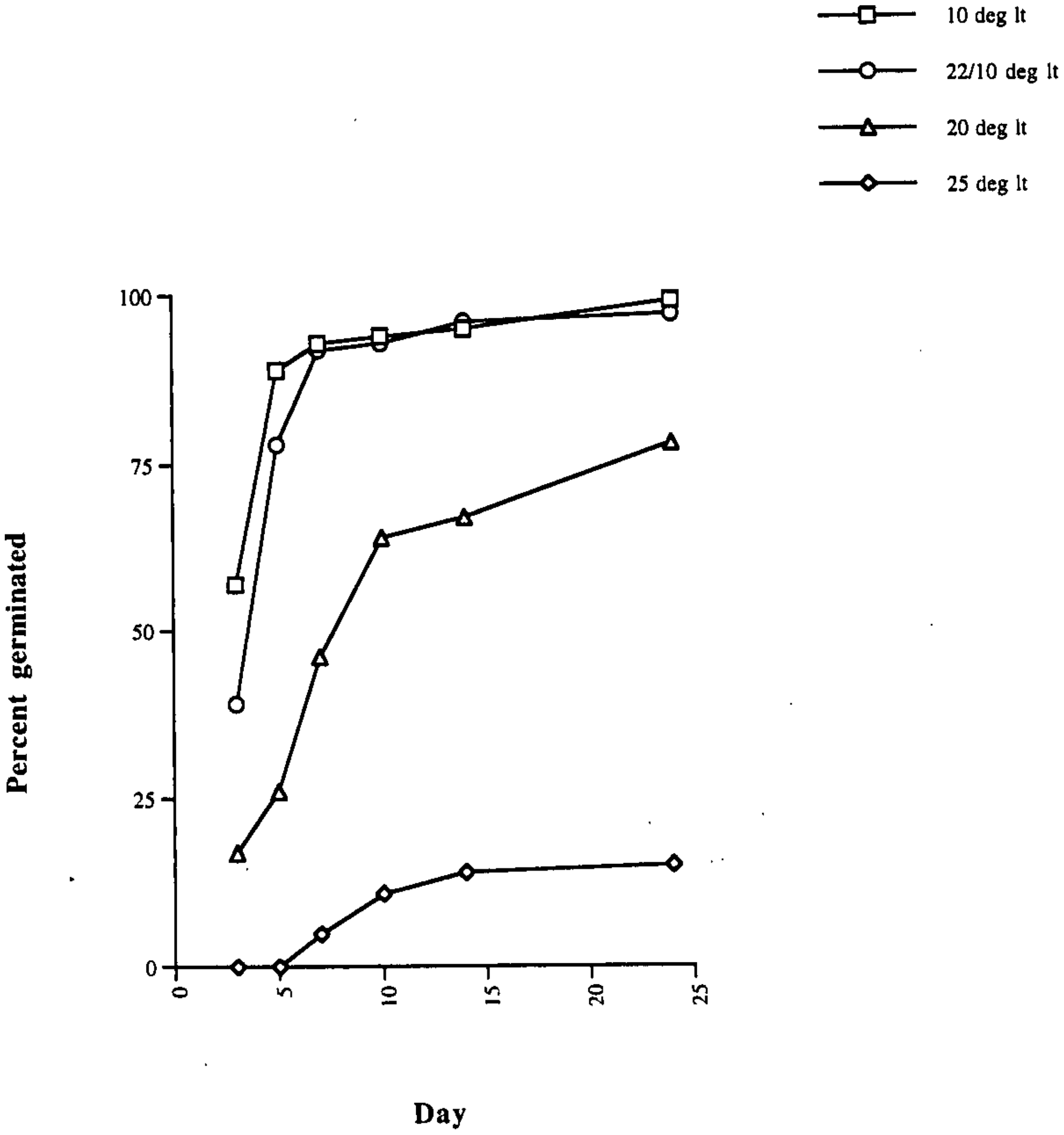

Figure 6. Cumulative percent germinated (1995 seeds in July 1996, mean of two replicates).

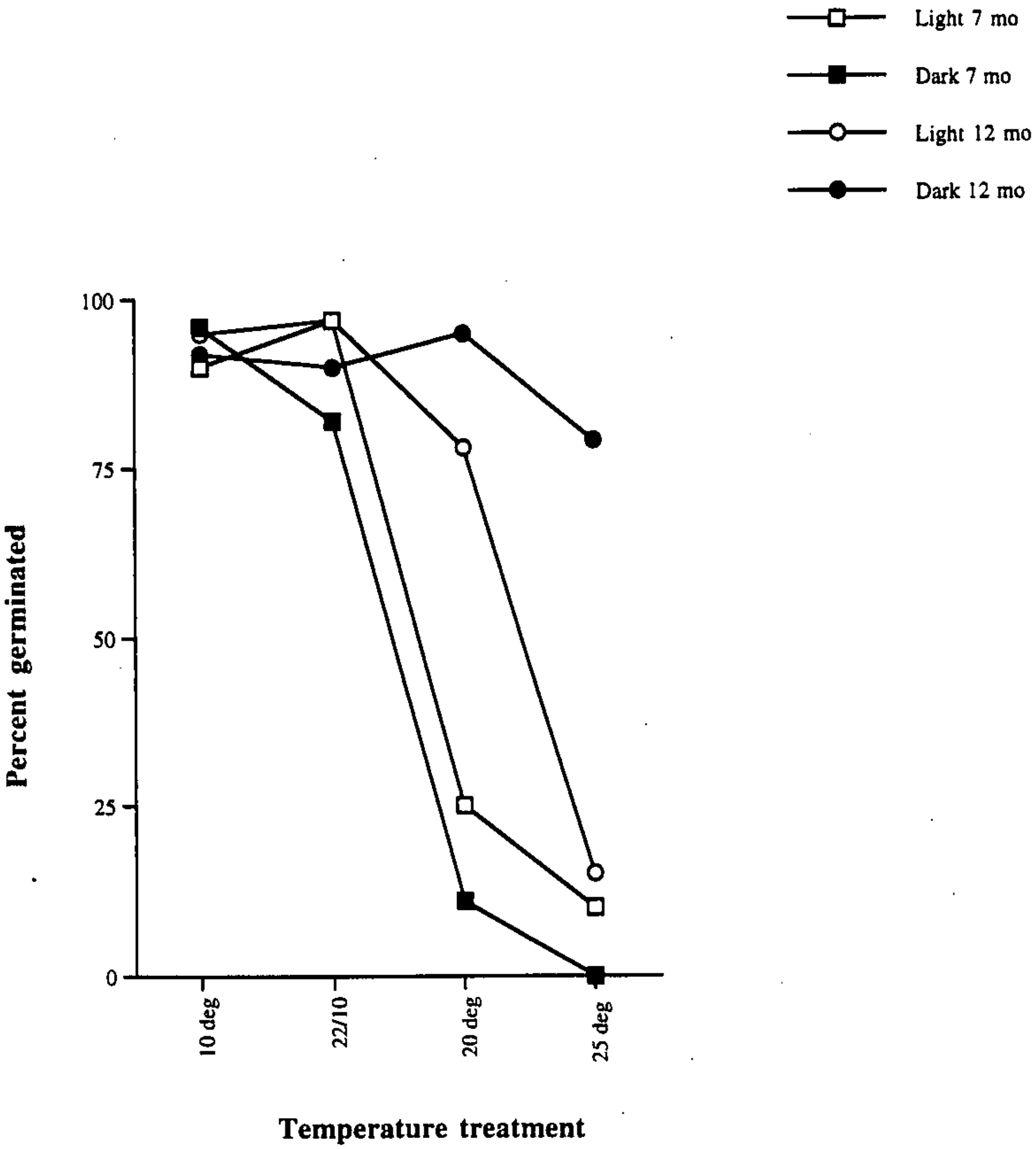

Figure 7. Total percent germinated (1995 seeds of two ages, mean of two replicates).

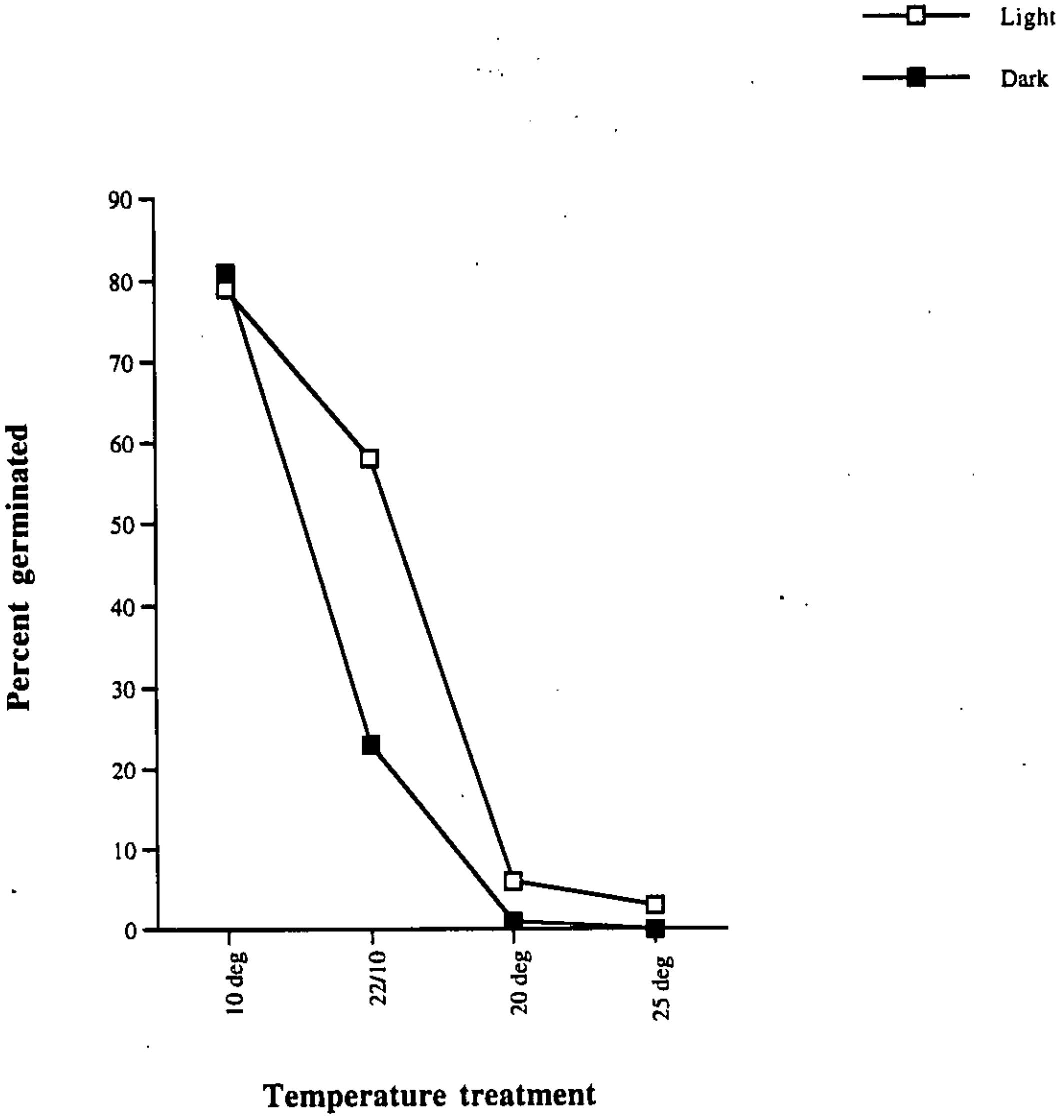

Figure 8. Total percent germinated (1996 seeds in July 1996, mean of two replicates).

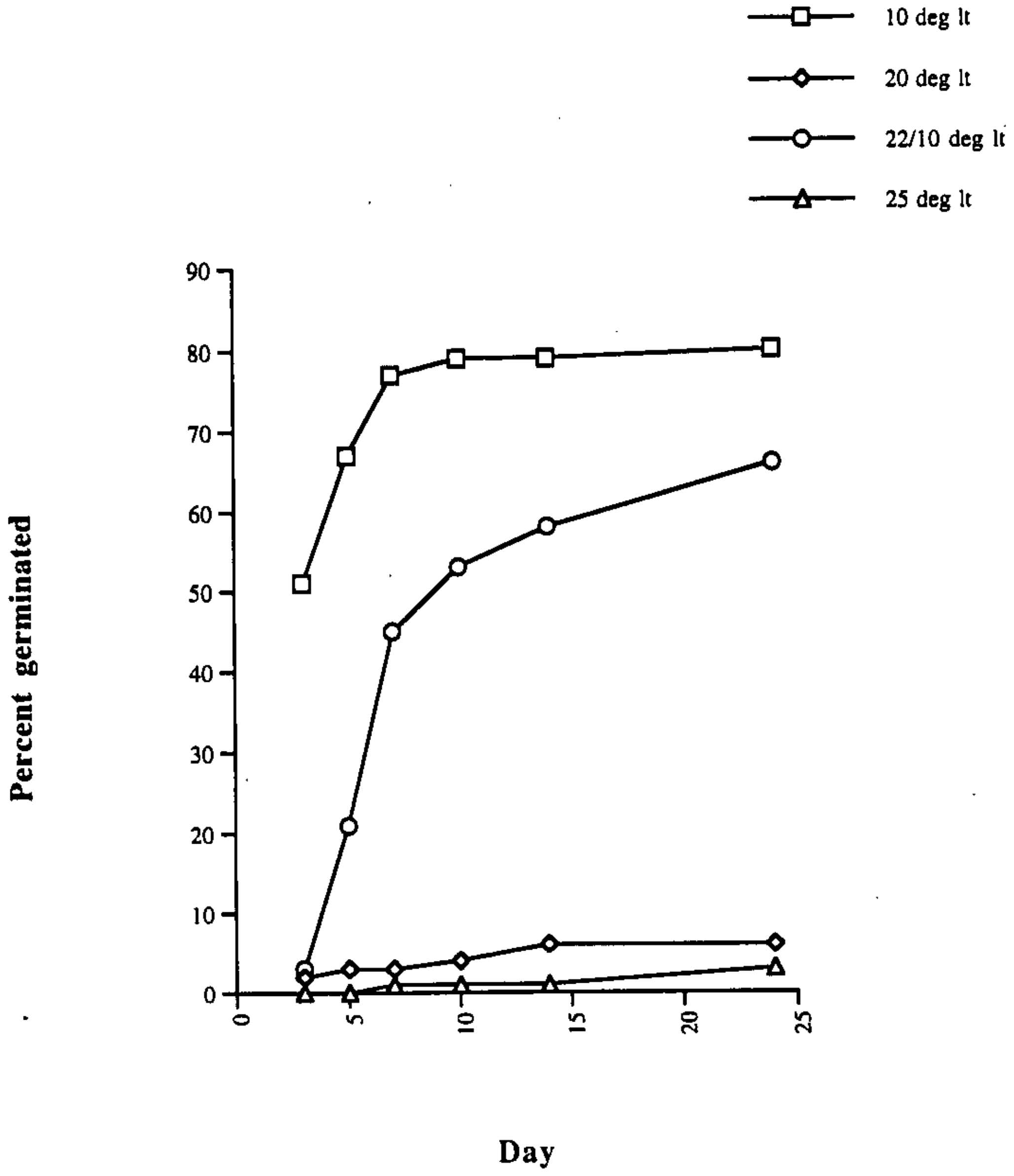

Figure 9. Cumulative percent germinated (1996 seeds in July 1996, mean of two replicates).

temperatures), were generally lower in the dark, and less than 40 percent in the dark at the highest temperature (Figure 10). The rate of germination was rapid, with most seeds germinating in 10 days or less (Figure 11). When germination response of seeds of three ages (7, 12 and 14 mo) from the 1995 seed crop are compared, the oldest seeds were less affected by temperature in the light than was evident for the younger seeds and the oldest seeds germinated well in the dark, with the exception of the high temperature treatment (Figures 12 and 13). The sharp breakpoint at 20 or 25 degrees C was more evident in the two sets of younger seeds than the oldest seeds.

2.2.3.2. *1996 seed crop*

Germination of 2-month old versus fresh seed, was equal or better in all illumination and temperature treatments (Figures 14). Older seeds germinated more readily at the two highest temperatures, especially in the "light" treatment. Germination rate of the 2-month old seeds in the "light" treatment was somewhat slower than observed in earlier experiments (Figures 9 and 11), with germination beginning in less than a week but not tapering off until after nearly 2 weeks (Figure 15).

2.2.4. <u>January 1997 experiment</u>

2.2.4.1. *1995 seed crop*

The seeds from the 1995 seed crop tested in this experiment were 19 months old. Germination in the "light"was substantial, ranging from a low of 77 percent at 25 degrees C to over 90 percent at the other three temperatures (Figure 16). Germination in the "dark" was high at the coolest temperature, but low at higher temperatures (Figure 16). Data for the highest temperature in the dark have been omitted because of the high variability among replicates, suggesting the possibility of light entering some boxes. The rate of germination in the "light" treatment was again more rapid in the cooler temperatures, and leveled off after 10 days (Figure 17). In the warmest temperature, germination leveled off after 20 days.

When germination response of seeds of four ages, all from the 1995 seed crop, is compared, it is apparent that the range of suitable conditions widens with age to include the two warmer incubation temperatures (Figure 18). In the "dark" treatment at the coolest temperature, germination ranged from 86 percent of 19 month old seeds (the oldest seeds) to 70- 96 percent of seeds 7 months or younger (Figure 19).

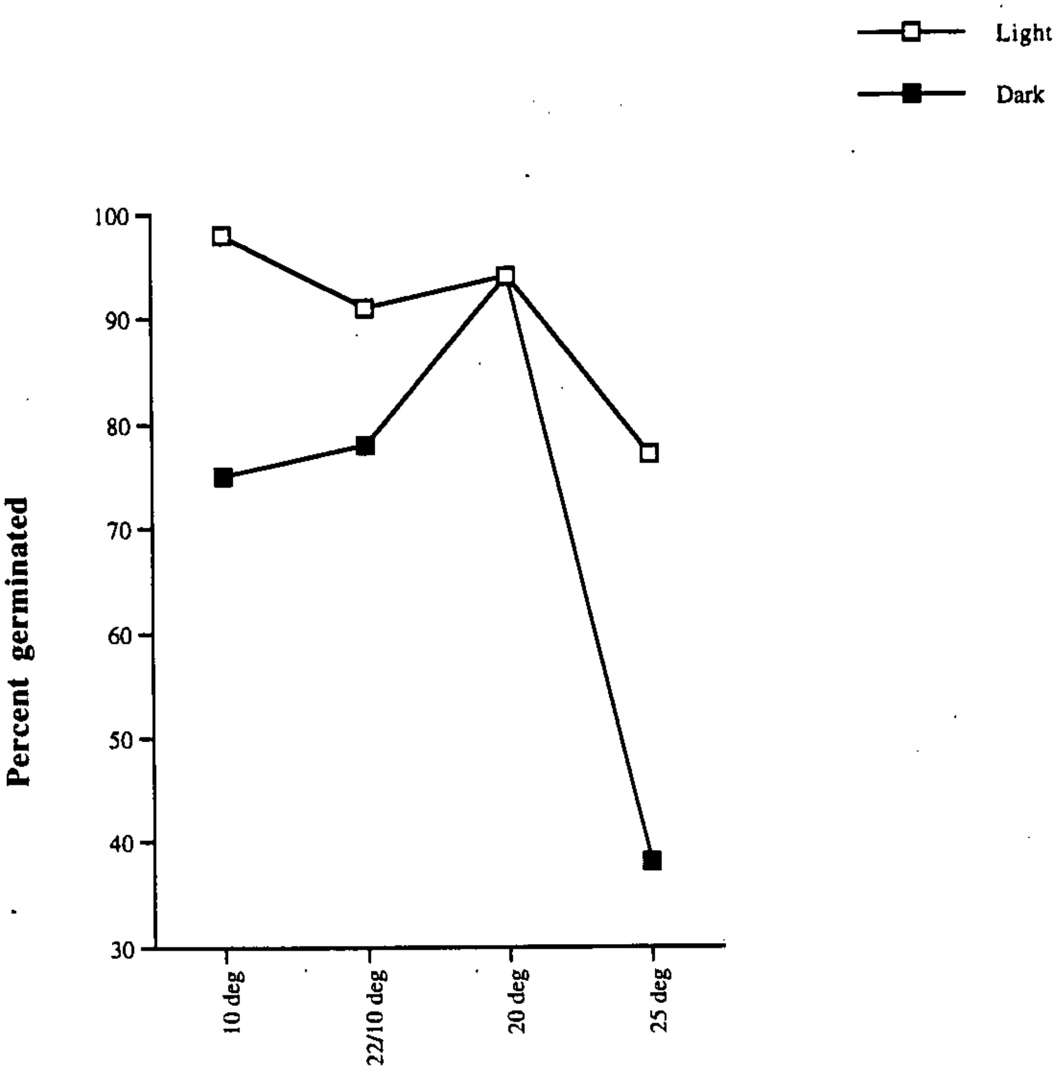

Figure 10. Total percent germinated (1995 seeds in October 1996, mean of two replicates).

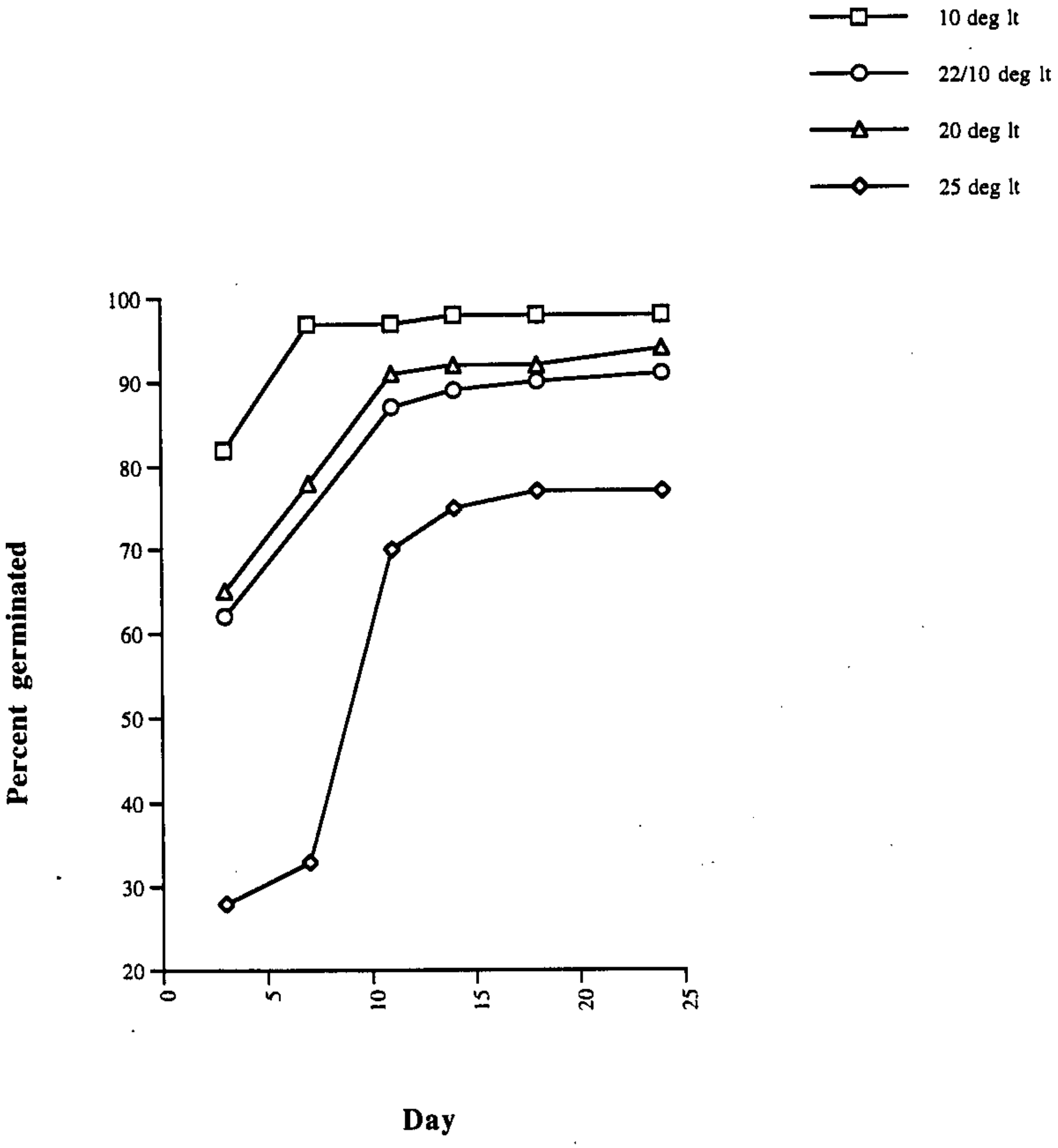

Figure 11. Cumulative percent germinated (1995 seeds in October 1996, mean of two replicates).

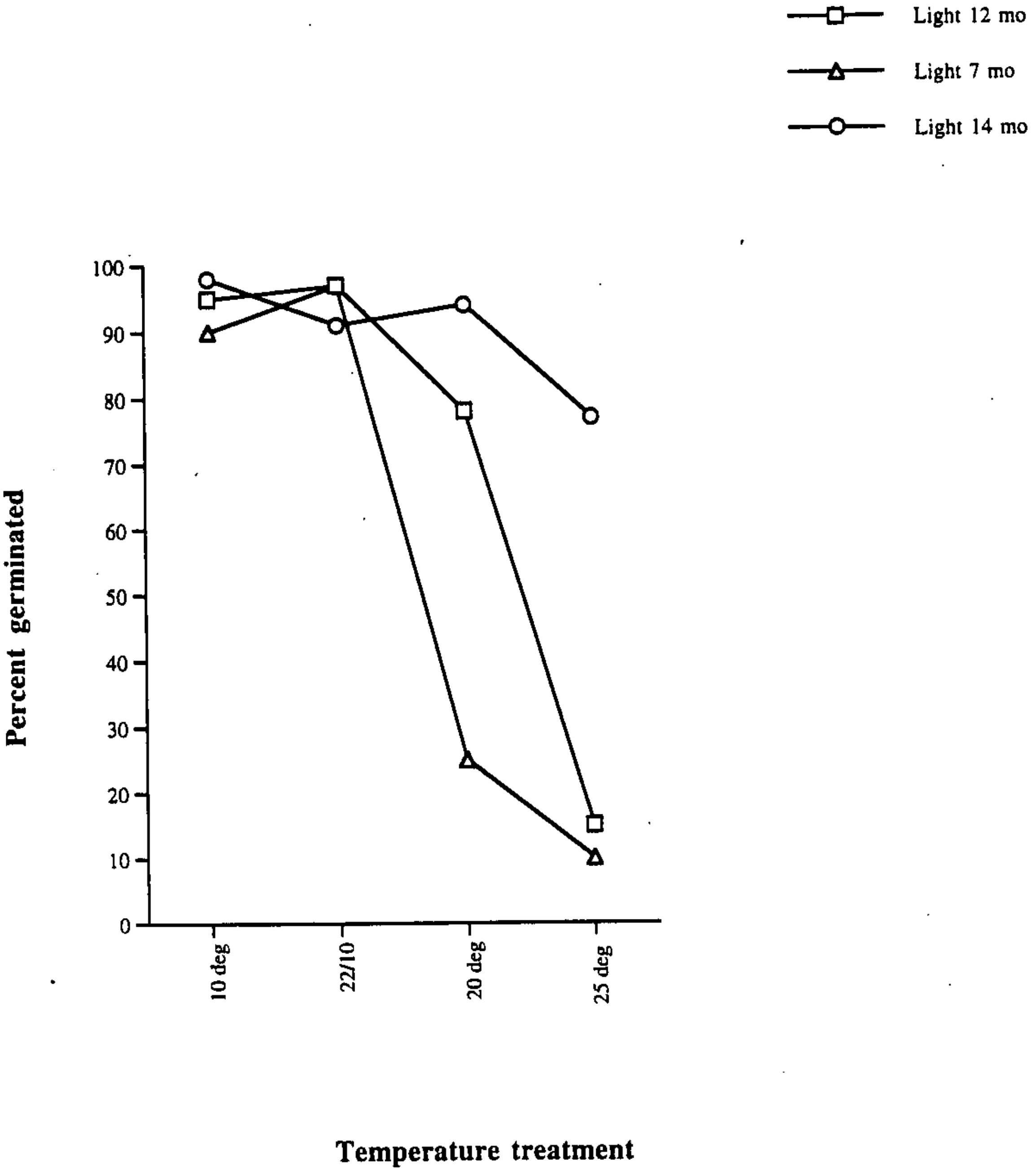

Figure 12. Total percent germinated (Seeds of 3 ages from the 1995 seed crop, mean of two replicates).

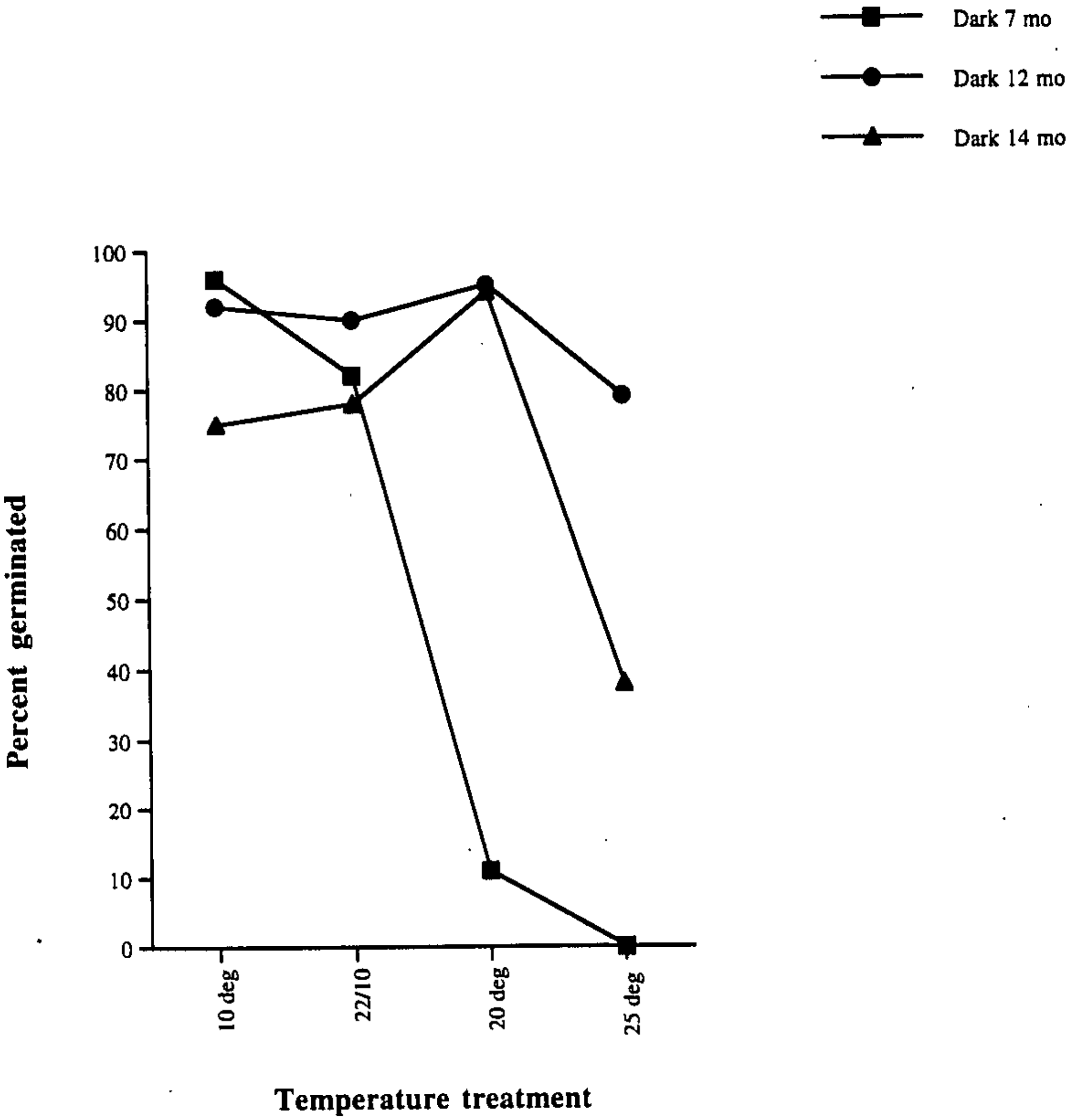

Figure 13. Total percent germinated in the dark of 1995 seeds of 3 ages (mean of two replicates).

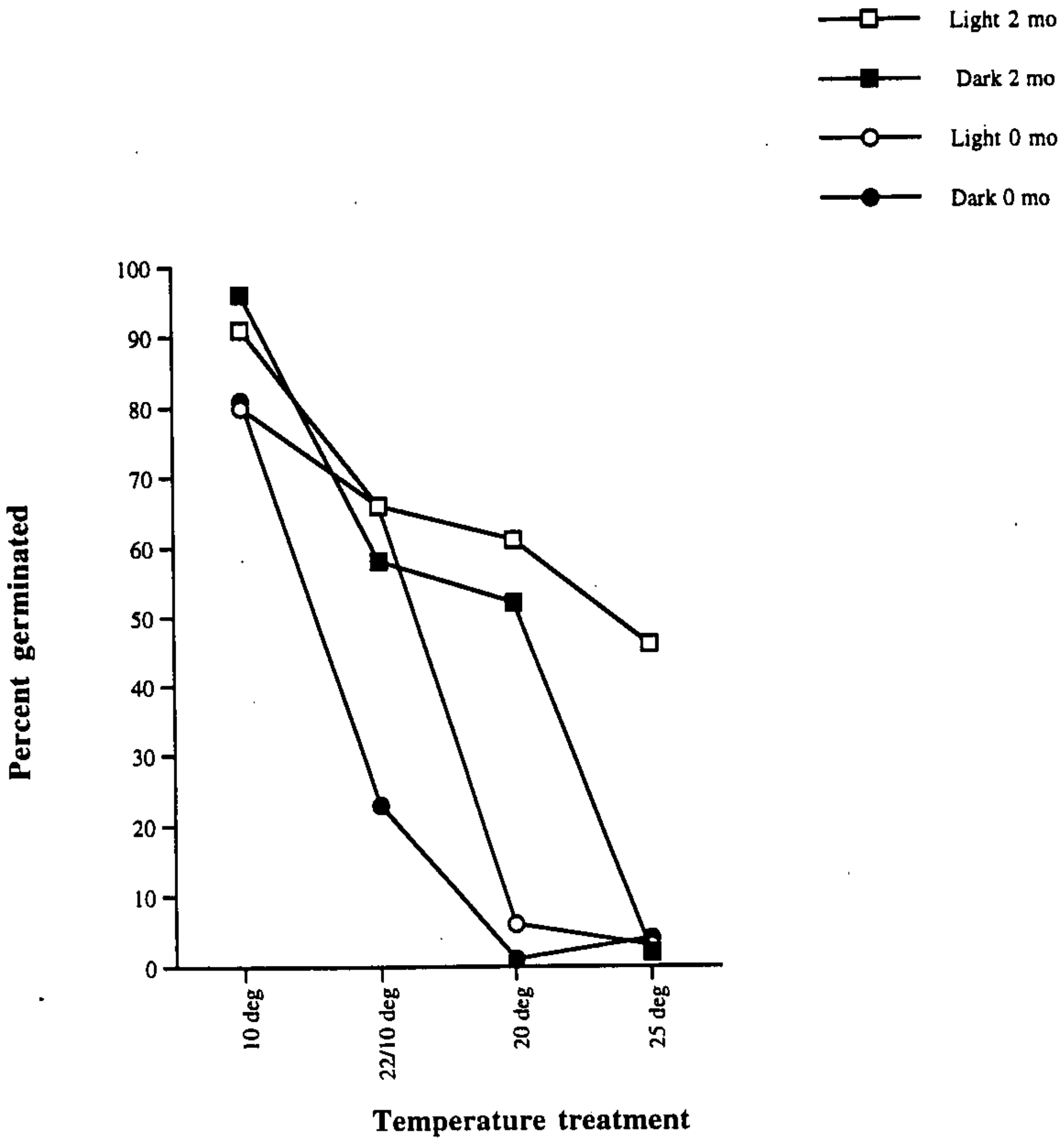

Figure 14. Total percent germinated of 1996 seeds of 2 ages (mean of two replicates).

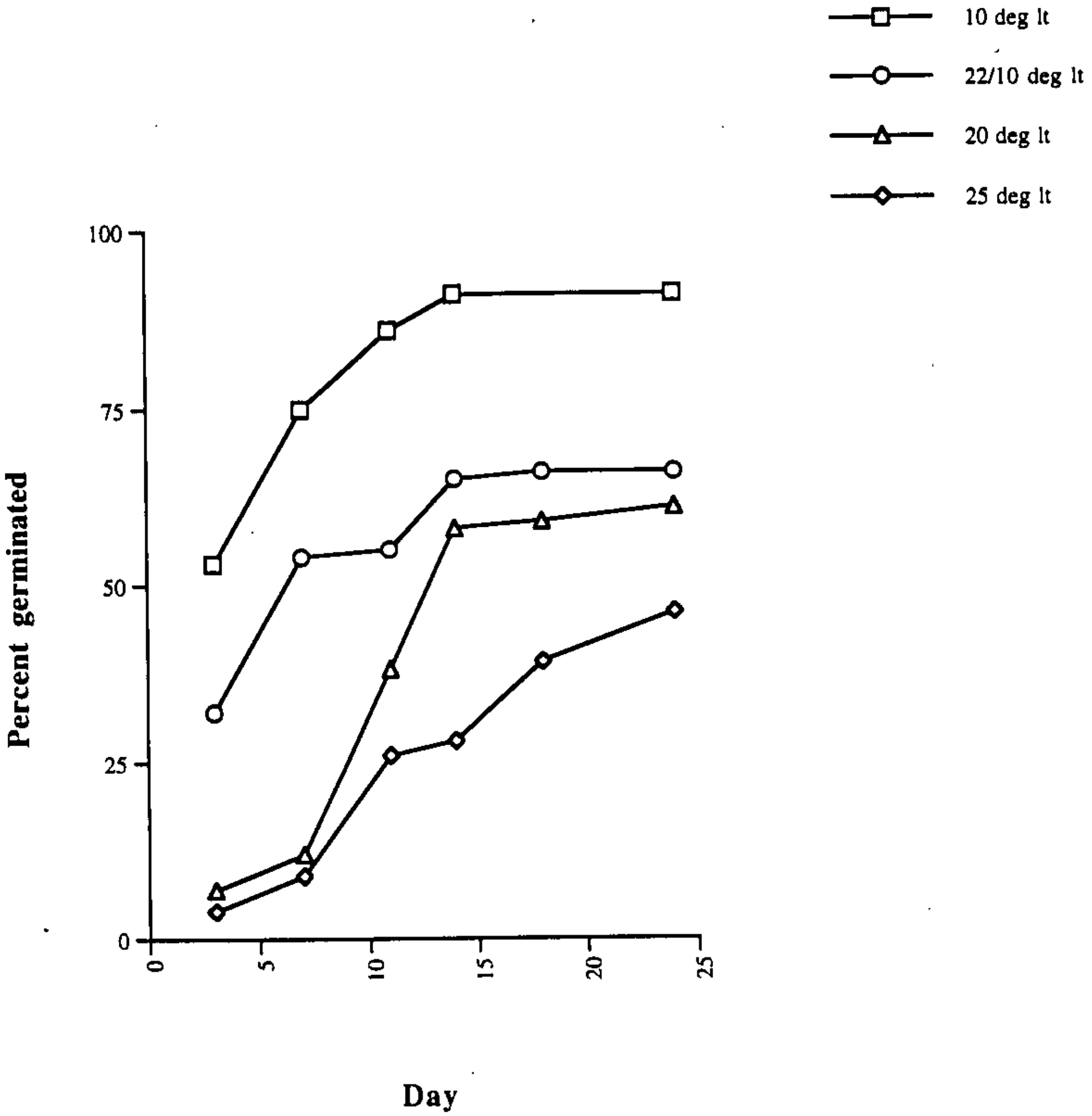

Figure 15. Cumulative percent germinated (1996 seeds in October 1996, mean of two replicates).

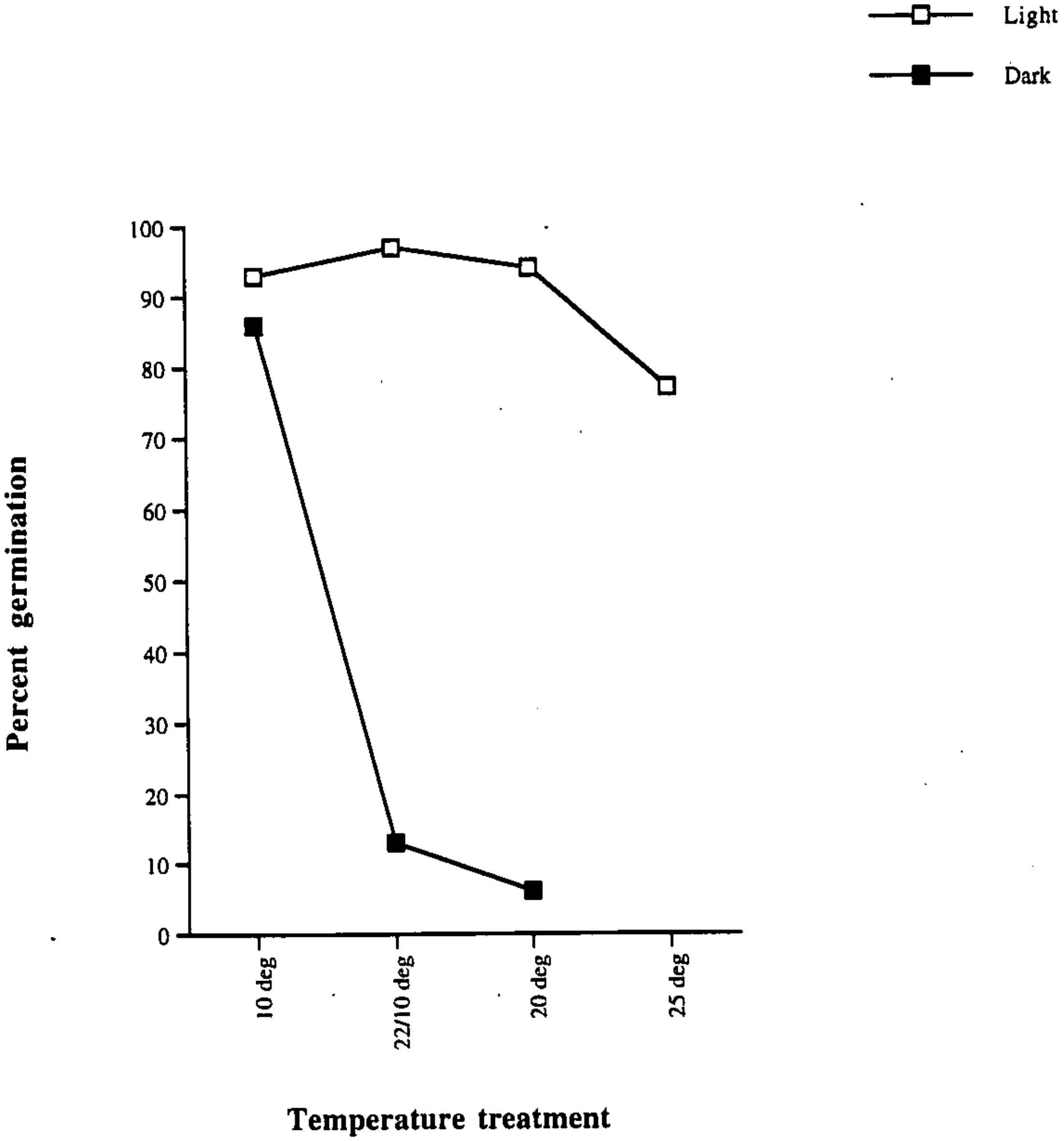

Figure 16. Total percent germinated (1995 seeds in January 1997, mean of two replicates).

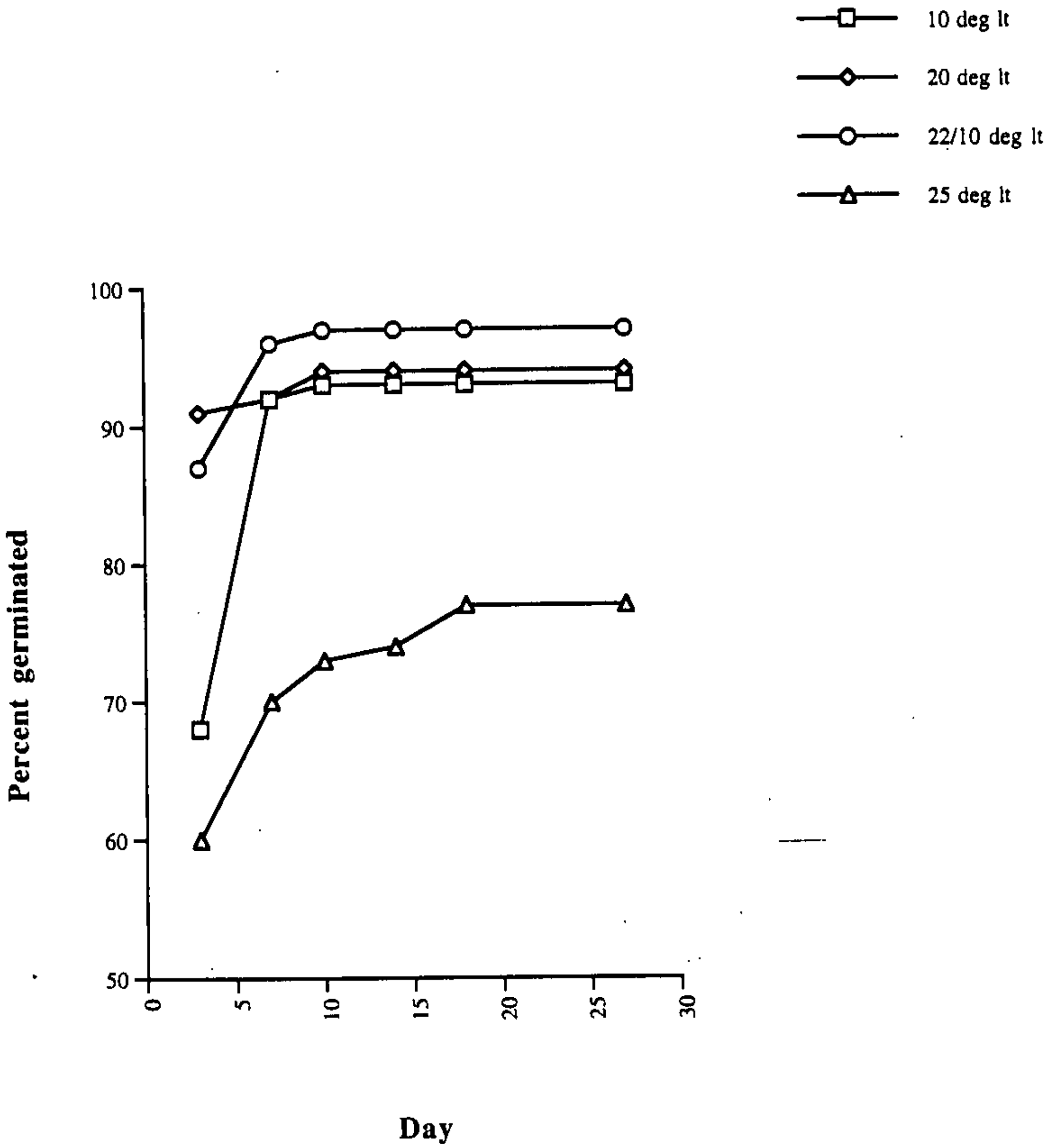

Figure 17. Cumulative percent germinated (1995 seeds in January 1997, mean of two replicates).

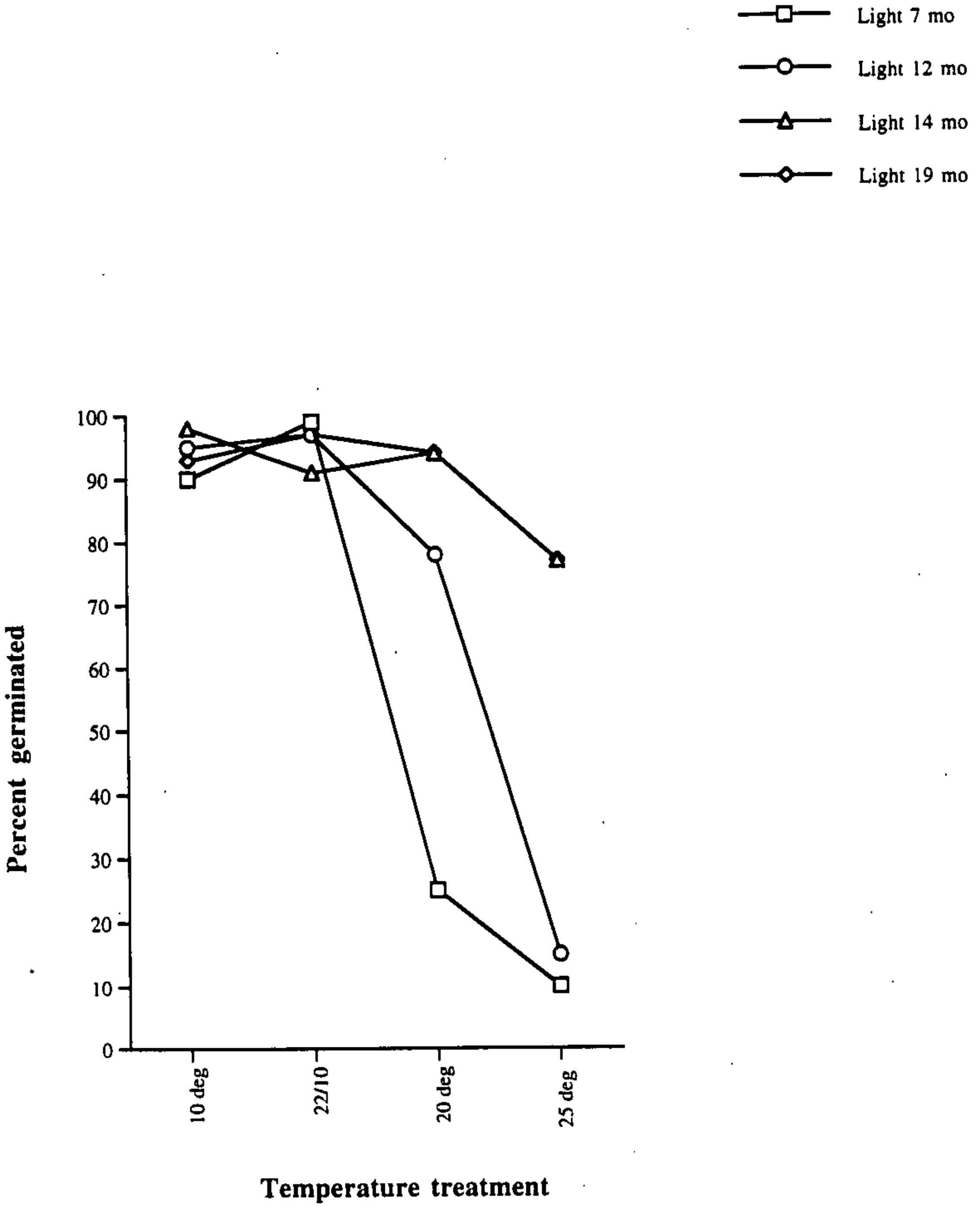

Figure 18. Total percent germinated of 1995 seed crop with seeds of 4 ages, mean of two replicates.

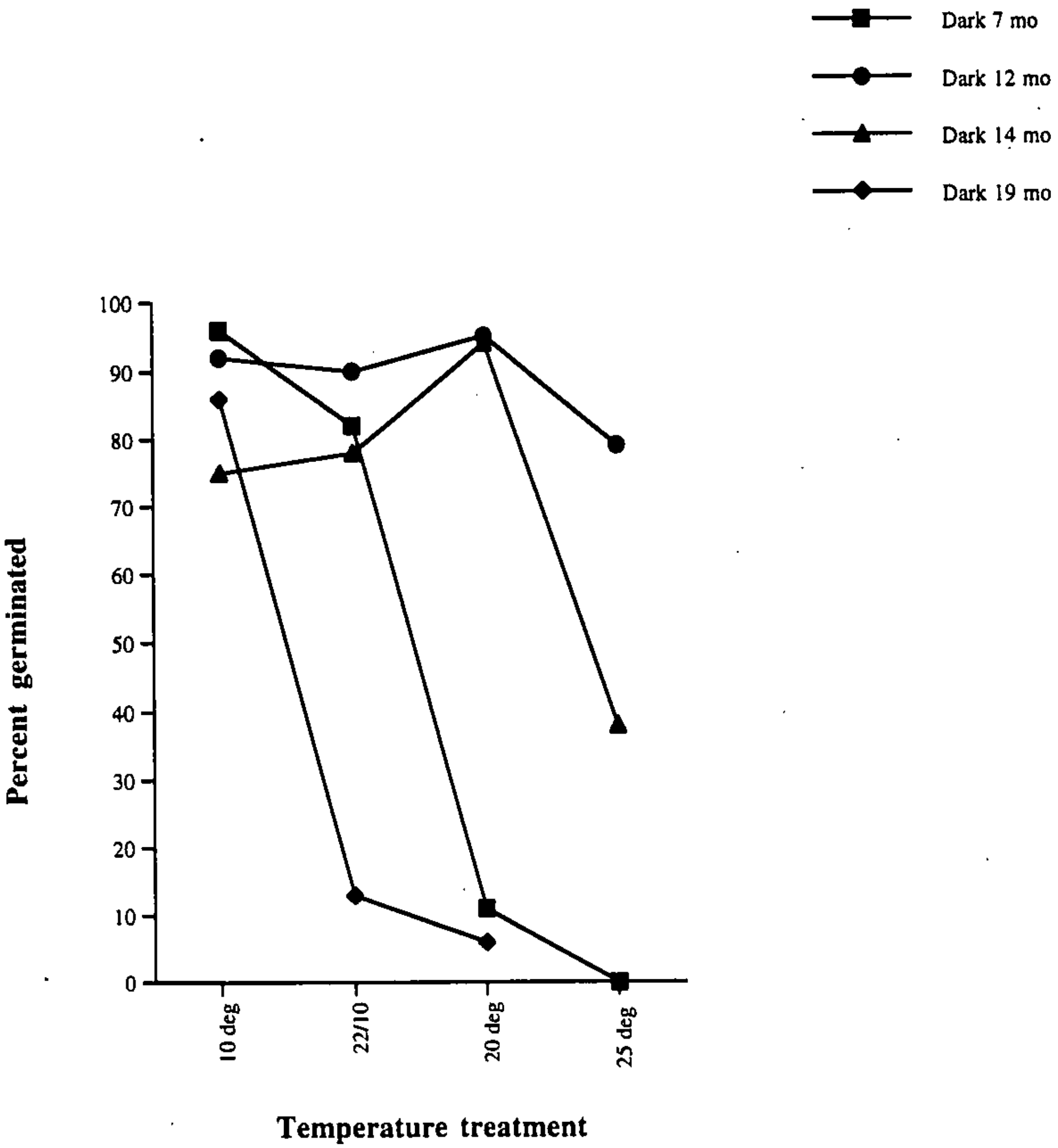

Figure 19. Total percent germinated in the dark of 1995 seeds of 4 ages, mean of two replicates.

2.2.4.2. *1996 seed crop*

Seeds 6 months of age were germinated. In the "light" treatment, there was a decline in total percent germinated with increasing temperature, with a sharp drop at 20 degrees C (Figure 20). With seeds in the "dark", the decline was not as smooth, but the pattern was the same. When seeds of three ages from the 1996 seed crop are compared in their germination responses, the pattern of a widening range of suitable temperatures, observed in the 1995 seed crop, occurs again (Figures 21 and 22). Seeds germinate less well in the dark compared to the "light" treatment regardless of age, with the exception of the coolest temperature where germination is comparable between "light" and "dark" treatments.

2.3. CONCLUSIONS AND DISCUSSION

Cool temperatures, at least at night, are optimum for the germination of *Acanthomintha ilicifolia* (San Diego thornmint) and lack of exposure to light inhibits germination. The effect of darkness is generally intensified at higher temperatures. With exposure to 10 hours of light ("light" treatment), the total percent of seeds germinated (mean of two replications) at 10 degrees C was 90 percent or greater in all but two of the seven experiments. In those two experiments, the mean was 79-80 percent. The results were similar when seeds were incubated in the dark ("dark" treatment) at 10 degrees C. When cool nights were alternated with warm days (22 degree/10 degree treatment), the percent germinated in the "light" was even higher than at the 10 degrees C constant temperature, with the exception of the two sets of fresh seeds which were 0 months and 2 months old. Only 66 percent of these seeds germinated in the "light" with alternating day/night temperatures. Darkness reduced the percentage of seed germinating in the alternating temperature regime, with no clear pattern of response, although the highest percentages germinated were with seeds about 1 year old.

At constant temperatures of 20 degrees C , germination in the "light" was poor (6-63 percent), with the exception of seeds 1 year or older which had 78-94 percent germinate. In the "dark", seeds incubated at 20 degrees C did very poorly (4-7 percent germinated) if they were less or more than one year old. The highest percent germination was in seeds approximately 1 year old (12 and 14 months old with 95 and 94 percent germinated). When seeds were kept at 25 degrees C constant temperature and in the "light" treatment, germination declined for seeds of all ages, compared to the cooler temperature treatments. Again, older seeds generally did better than fresher seeds (77 percent

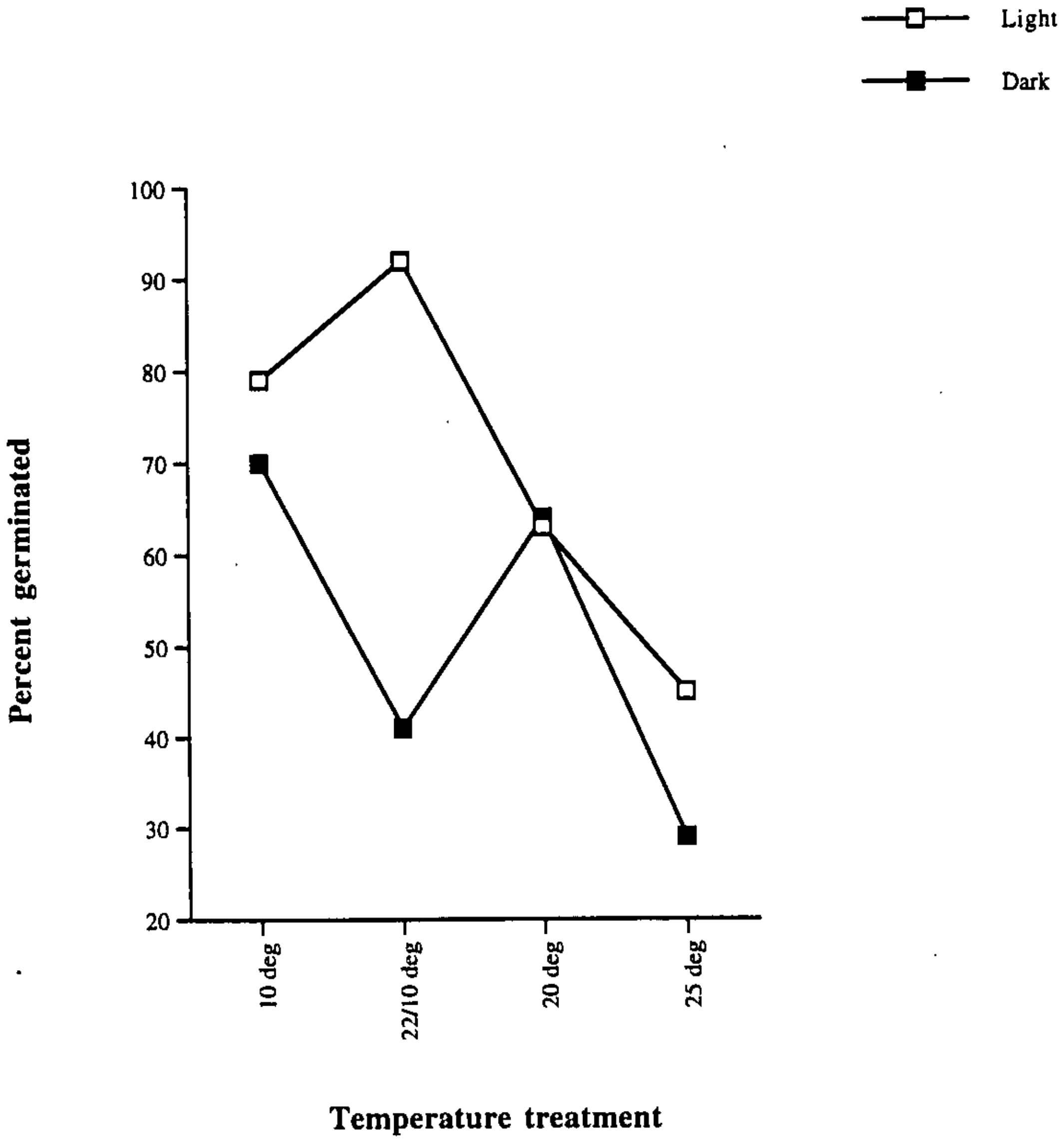

Figure 20. Total percent germinated (1996 seeds in January 1997, mean of two replicates).

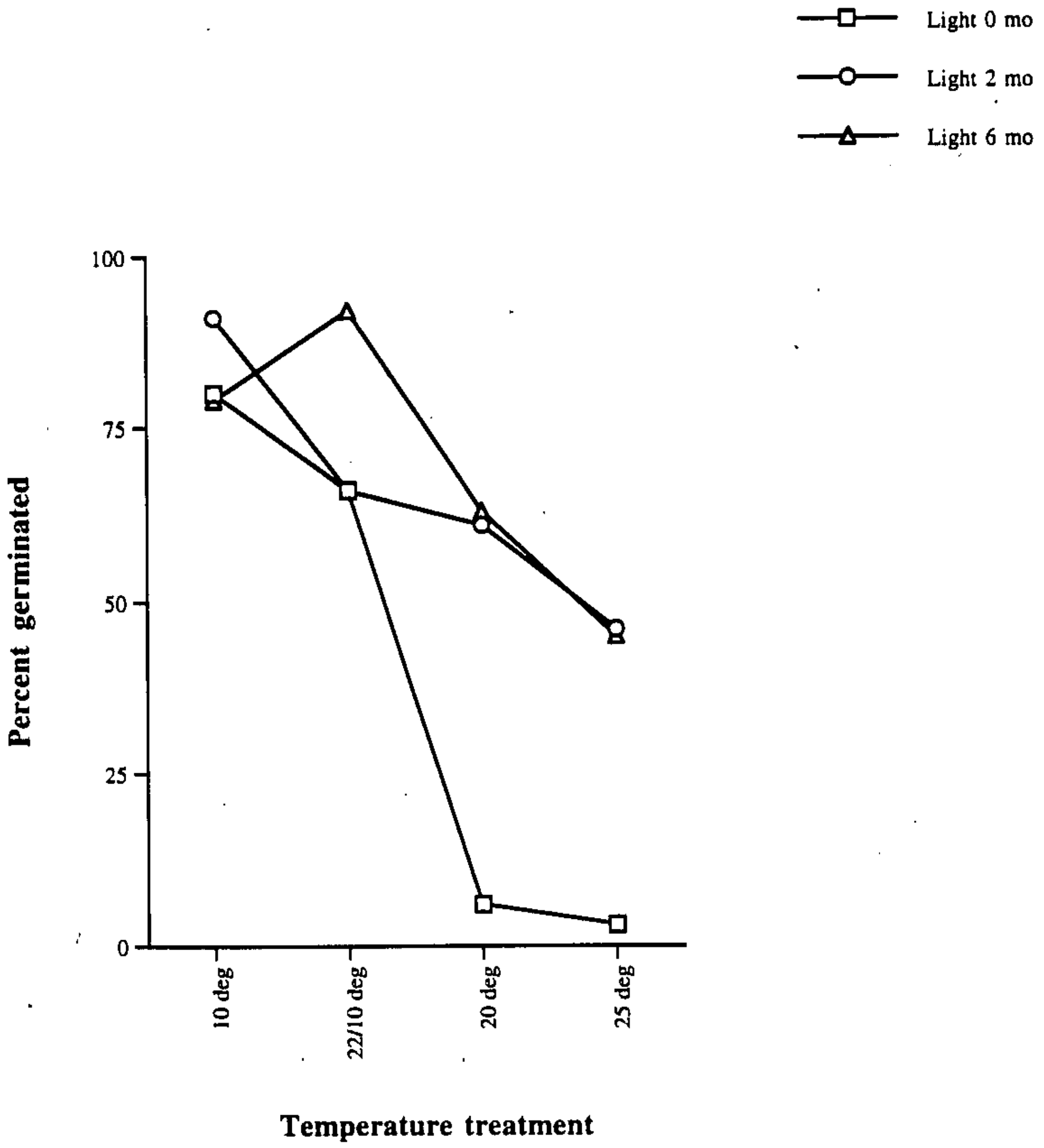

Figure 21. Total percent germinated of 1996 seeds of 3 ages (mean of two replicates).

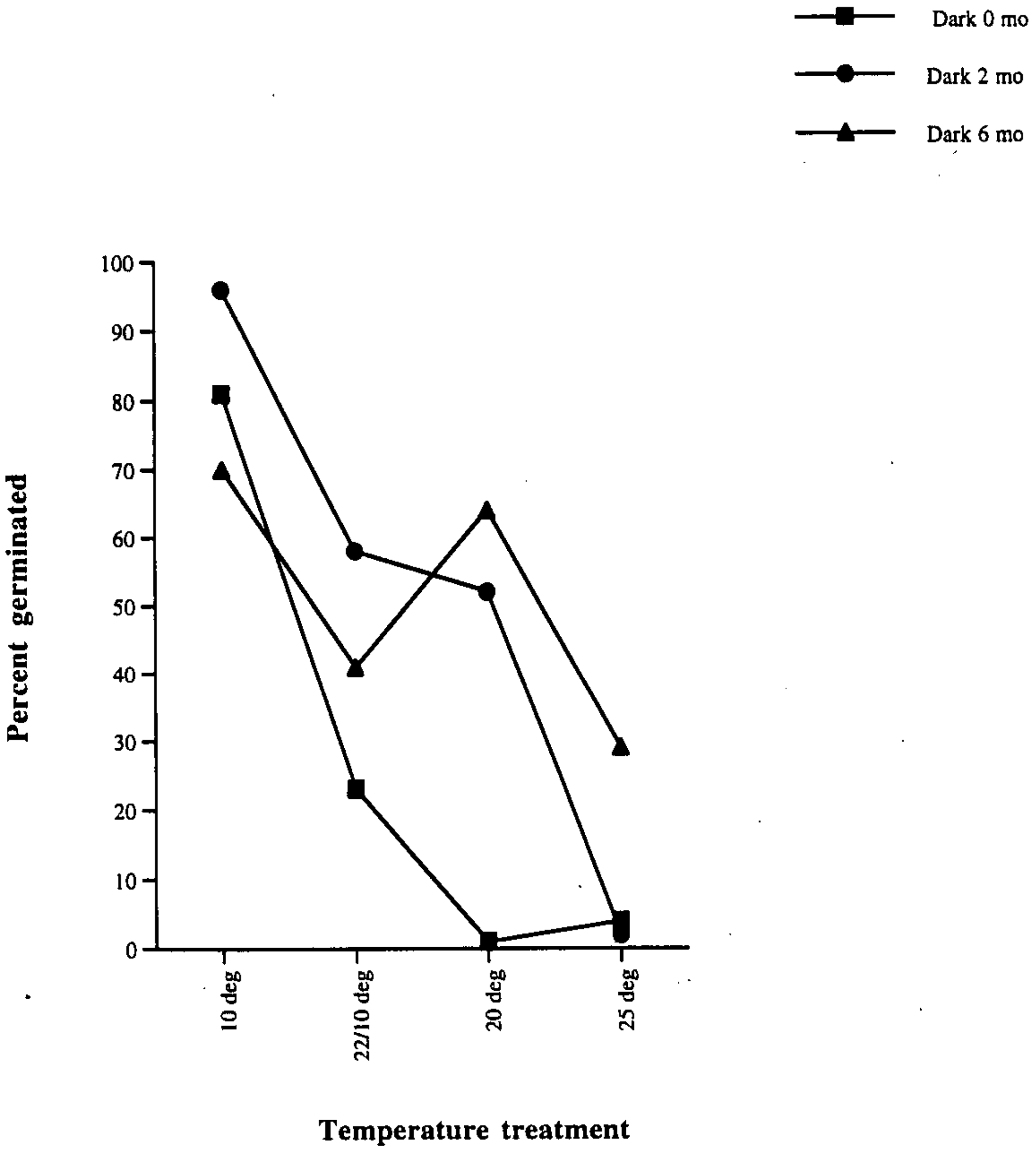

Figure 22. Total percent germinated in the dark of 1996 seeds of 3 ages (mean of two replicates).

germinated vs. 3-46 percent germinated). In the "dark" treatment at 25 degrees C, germination was generally very poor, but the results were ambiguous, with high variability among the three sets of boxes per seed age (2 boxes per set). These were kept in the dark and sets were opened at 2-week intervals. The poorest germination at high temperatures was with the youngest seeds. Widening of the suitable temperature range to higher temperatures occurs as seeds age. This was apparent with both the 1995 and 1996 seed crops.

The importance of cool temperatures to the germination of this species makes ecological sense because plants normally germinate in the late winter/early spring when nights in this region are very cool even when daytime temperatures may be warm. Cool nights also coincide with the rainy season. As with *Downingia concolor* ssp. *brevior*, seeds unable to germinate at warm temperatures remain viable and germinate when temperatures are reduced (Bauder 1992). The inhibition on germination by warmer temperatures prevents the seeds from germinating too late in the spring, when seedlings would face summer drought or in the summer/early fall after a rare thunderstorm or hurricane. Germinability is clearly related to seed age, with fresh seeds having the lowest rates of germinability and the narrowest range of suitable conditions. With age, the overall percentage of seeds germinating increases and the range of suitable conditions broadens to include higher temperatures. Darkness has an inhibitory effect on germination which is more pronounced in younger seeds and at higher temperatures. This may be advantageous to the species by preventing the germination of seeds which are too deeply buried to emerge.

By germinating at cooler temperatures, *Acanthomintha ilicifolia* would be well adapted to growth at a time of year when reproductive success is likely, but it would put this species at a substantial disadvantage in competing with annual exotics which germinate at warmer temperatures in both the light and dark. These exotics can thus begin growth earlier in the season, preempt space from San Diego thornmint seedlings, utilize soil water and shade them as they grow. Our work on seeds of various exotics, including *Centaurea melitensis*, indicates that they germinate at nearly 100 percent regardless of temperature or illumination conditions (Bauder and Swanekamp unpublished data).

CHAPTER 3. RESPONSES TO NEIGHBORS

3.1. Methods

Two sites in Sycamore Canyon, sites #1-E and #2 (Figure 1), were chosen to test the impacts of non-native herbaceous plants on San Diego thornmint (*Acanthomintha ilicifolia*). Sycamore Canyon is part of the Sycamore Canyon Ecological Reserve which is jointly managed by the County of San Diego Department of Parks and Recreation and the California Department of Fish and Game. The proposed research sites at McGinty Mountain were not included in the study because access to the mountain was too time-consuming to allow us to complete the tasks at both sites during the very limited times of the year when San Diego thornmint seedlings can be monitored, weeds can be removed and insects can be observed. The Sycamore Canyon populations were selected on the basis of the overall size and topography of the sites and the abundance of *A. ilicifolia.* Three transects were laid out across the site #1-E and two at site #2 (Bauder, McMillan and Kemp 1994). Sampling quadrats were 0.5 m by 0.25 m, divided into two 0.25-m^2 plots, one on each side (north and south) of the transect line. A total of 130 quadrats (260 plots) were delineated on the five transects combined. All *A. ilicifolia* seedlings in each plot (or one-half quadrat) were counted. Half of the quadrats, chosen at random, were weeded of all exotics. Natives were not removed. *Avena* (several species) and other exotic grasses were by far the most common plants in the quadrats, aside from San Diego thornmint. Other exotics removed included *Anagallis arvensis, Brassica nigra, Bromus hordeaceus, B. madritensis* ssp. *rubens, Centaurea melitensis,* and *Sonchus sp.*. Weeding was completed in March 1996 and again in March 1997.

In June of 1996 and 1997, when the *A. ilicifolia* had set seed and dried, the surviving plants in each plot were counted and collected in paper bags, 1 bag for each plot. Originally, we had hoped to collect each plant separately in its own bag, but this proved to be unrealistic considering the large number of surviving plants, their brittleness and intertwined branches. The collected survivors were stored in their paper bags in sealed containers kept at room temperature, and the number of seeds in each bag was counted for the 1996 harvest. Seeds were placed in labeled envelopes by plot and will be replaced into those plots at the conclusion of our work on this species.

3.2. Results

Survivorship overall in 1996 was greater than 80% for both sites, combining weeded and unweeded quadrats (Table 2). Weeding appeared to have only a slight impact, if any, on survivorship in 1996 and may even have been slightly deleterious in 1997. A preliminary analysis indicates that weeding increased the fecundity of the 1996 survivors. Weeded plots had 115 seeds/survivor whereas unweeded plots averaged only 86 seeds/survivor. The seed rain in 1996 was over 5,000 seeds/m^2 at Site 1 and nearly twice that number at Site 2 (Table 3). In 1997, compared to 1996, seedling density and survivor density were greater at both sites (Table 3).

When the two sites are considered separately, some differences emerge. Seedling density and survivorship density were higher at Site 2 both years. Despite a 1996 seedling density that was nearly two times greater at Site 2 compared to Site 1, survivorship was higher (87.2 % versus 80.2 %). In 1997, the two sites were more similar, but Site 2 seedling density was still 1.2 times that of Site 1. Survivorship at both sites was nearly identical (Site 1= 78.9 %; Site 2= 79.7 %). In 1996, the high seedling density and survivorship at Site 2 apparently were not great enough to adversely affect fecundity. Mean seeds per survivor was 84.6 at Site 1, but 122.6 at Site 2.

3.3. Conclusions

The affect of weeding appears to be undetectable on survivorship but probably has a significant positive effect on fecundity.

The survivorship rate was far above our expectations, especially since the rainfall year (July 1995-July 1996) was the 12th driest on record with only 5.1 inches of rain (measured at Lindbergh Field, San Diego, CA), about half of the yearly average (US Weather Service). In the 1996/1997 rainfall year, there were 7.1 inches of rain (still below the average), but most of this occurred during the cooler winter months and the spring growing season was unusually dry. The favorable conditions for germination resulted in a high number of seedlings, and apparently soil moisture was sufficient for a high proportion to survive, although the survivorship was somewhat lower. We have not analyzed the seed set for 1997, but our observation at the time of harvest was that the plants were much smaller than in 1996. We therefore expect reduced fecundity.

Percent survival

	1996		1997	
	Not weeded	Weeded	Not weeded	Weeded
SITE 1:	77	79	83	75
SITE 2:	85	87	88	79
Both combined:	82	84	86	77
SITE 1:				
Neither side weeded	62	78	81	56
One side weeded	80	81	81	84
Both sides weeded	77	83	90	94
SITE 2:				
Neither side weeded	82	91	72	87
One side weeded	88	87	92	75
Both sides weeded	84	79	87	67
BOTH SITES COMBINED				
Neither side weeded	71	87	78	76
One side weeded	82	83	86	80
Both sides weeded	83	80	87	74

Table 2. Summary of survivorship in two different years with various treatments.

	SEEDLING DENSITY (m^2)	SURVIVOR DENSITY (m^2)	SEEDS (m^2)
1996			
Site 1	85.12	68.32	5008.64
Site 2	161.84	141.04	9705.12
1997			
Site 1	163.76	129.2	
Site 2	198.40	158.24	

Table 3. *Acanthomintha ilicifolia* seedling density, survivor density and seeds, all per square meter at two different Sycamore Canyon sites in two different years.

Taylor and Burkhart (1994) found that the Sycamore Canyon sites they were monitoring (DFG EO#32, Sites 1 A and B) had average thornmint densities/m^2 ranging from 18.7 plants in the 1990/91 season to 145/m^2 in the 1992/93 season. The 1990/91 and 1991/92 growing seasons had slightly greater than average precipitation, but 1992/93 was nearly double the average (US Weather Service). They found that the number of branches per plant had a twofold increase in the wetter year (1992/93) compared to the two drier ones (1990/91 and 1991/92). The seed rain at the Sycamore Canyon monitoring plots was estimated by Taylor and Burkhart (1993) to be 7,079/m^2 in 1991/92, compared to our 5009m^2 and 9705m^2 counted in 1995/96 at two nearby study sites. They estimated seed production per plant to be 261 seeds in 1991/92 and 115 seeds in 1992/93 (Taylor and Burkhart 1994) and we calculated 74 seeds per plant and 69 seeds per plant in 1995/96. Again, the lower seed production could be attributed to the less-than-average precipitation in 1995/96. Our comparable plant densities from drier-than-average years but lower seed production per plant reinforces our conclusion that *Acanthomintha ilicifolia*'s plastic responses to environmental variation is primarily in plant size and fecundity rather than survivorship.

CHAPTER 4. POLLINATORS

4.1. METHODS

Population 1E (Bauder, McMillan and Kemp 1994) was surveyed in late spring of 1996. On April 27 and May 4, Becky Watts and Andrea Peirce visited the site to observe insect visitors to *Acanthomintha ilicifolia* plants. At this time, the plants were in full flower. Possible pollinators were defined as insects that were seen crawling, alighting or feeding on the open flowers. Samples of possible pollinators were collected for identification. Specimens were identified to family. Insects were collected by hand or insect net, and time, date, and behavior observed at that time were recorded.

4.2. RESULTS

Insects visitors of *Acanthomintha ilicifolia* blooms were members of the orders Coleoptera, Diptera and Hymenoptera. Many specimens of one species in the family Cleridae (checkered beetles)(Coleoptera) were seen on thornmint plants crawling from flower to flower on a single plant. These beetles appeared to be feeding on the pollen. Diptera were represented by a species of bee fly (Bombyliidae) and a hover fly (Syrphidae). The bee flies hovered above the plants and probed the flowers with their proboscises. Each fly touched the blooms with its proboscis and front feet. They moved from flower to flower and from plant to plant. The hover flies landed on blooms and moved from plant to plant.

Hymenoptera were represented by four families: Anthophoridae, Halictidae, Andrenidae and Apidae. Three distinct species of Anthophorid bees were observed. One species alighted on the thornmint blooms for a few seconds while curling its abdomen under the lower lip of the flower. A second species (small, with a striped abdomen) was also collected. A species of the Andrenidae family was observed visiting widely spaced flowers. These Hymenoptera moved from flower to flower, spending several seconds at each flower. The Halictid was collected when it visited a flower, but this family of bees was less common. A species of bumble bee (Apidae; *Bombus*) was seen moving from flower to flower and from plant to plant.

4.3. CONCLUSIONS

Most of the insects seen during the two observation days visiting *Acanthomintha ilicifolia* flowers appeared to be commonly occurring pollinators. Many of these possible Acanthomintha pollinators moved from plant to plant, suggesting that there may be cross pollination of San Diego thornmint plants. The checkered beetles (Cleridae) were observed moving in and out of flower parts, usually staying on one plant. They traveled from flower to flower on each plant by walking, not flying. Pollen clinging to their bodies may be transferred from flower to flower.

Although bee flies were seen visiting thornmint blooms, they may not be transferring pollen from flower to flower. This is because they were never seen alighting on a plant. The bee flies hovered above a flower while inserting their proboscis into the flower. No other body parts touched the flower. This suggests that they were obtaining nectar, but not coming into contact with pollen.

The bees appeared to be the most prolific insect visitors of San Diego thornmint. There were more bee species seen than any other insect group during the two observation days, and they appeared to move more quickly from flower to flower than other insects. Most bees collected had pollen attached to their legs. Bees were seen visiting widely spaced flowers within the site, suggesting a vehicle for cross pollination.

Although several possible pollinators of *Acanthomintha ilicifolia* were identified during the 2-day observation period, a more comprehensive study needs to be carried out to determine the relationships of insects to San Diego thornmint. The hymenopteran species seen visiting the plants do not appear to be unique to the flower species and therefore can be considered opportunistic pollinators. A hymenopterist would need to collect bee specimens for more definitive identifications. There may be a closer relationship between the checkered beetles and San Diego thornmint.

CHAPTER 5. OVERALL CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

Our work on the germination ecology and effects of competitors on *Acanthomintha ilicifolia* suggests that in areas where weeds are at high density, San Diego thornmint may be at a disadvantage. Because it germinates at cooler temperatures than many of the herbaceous exotics, they may become established earlier in the season and preempt space. Their rapid growth can also shade *Acanthomintha ilicifolia* seedlings. So far, our results suggest that this does not have a substantial effect on survivorship of San Diego thornmint, but does change its morphology and flower production. Overall biomass is reduced as well. The consequence of these growth changes is reduced fecundity.

We placed our field transects to be certain of passing through patches with dense San Diego thornmint. At both transect sites there were dense weed patches with few or any thornmint plants that had the same clay soils supporting *Acanthomintha ilicifolia*. It is possible that San Diego thornmint has already been eliminated or reduced in these areas.

Some of the remaining *Acanthomintha ilicifolia* populations may be small enough that hand weeding will be effective in reducing the density of exotics and maintaining San Diego thornmint populations. This is a very labor intensive solution and would require great care so as not to damage any existing plants. Spraying of large thistle species such as *Cyanara cardunculus* is strongly recommended, with dead plant material subsequently removed. This could be done without damaging sensitive natives. Other thistles like *Centaurea melitensis* and grasses like *Avena* spp. could be cut before they go to seed. In general, they are taller than *Acanthomintha ilicifolia* plants. Brome grasses often are tall enough that they might also be cut. Sometimes they are comparable in size to San Diego thornmint, and then cutting would not, obviously, be advisable. Cutting would need to be done a number of years in a row to have any effect.

Because *Acanthomintha ilicifolia* grows on patches of clay soil embedded in a matrix of shrubby vegetation, one of the best ways to protect the San Diego thornmint populations is to maintain the proper shrubby vegetation so that it can act as a screen to protect the habitat from dispersion of weed seeds. Restoration to native shrubs or herbaceous species is strongly recommended for the large areas at Sycamore Canyon Ecological Reserve that were tilled prior to its becoming a preserve. These fields provide massive reservoirs of non-native seeds, especially various species of grasses and thistles.

Disturbances such as trails should be routed around the clay patches to minimize the dispersal of weed seeds and the creation of favorable growing conditions for introduced species that are commonly adapted to successful establishment in disturbed soil and vegetation. The clay soils are erodible, and disturbances could move soil, cause deep gullies and bury seeds. Grazing could also have an adverse effect, primarily because it would favor the spread and maintenance of introduced species. Pollinators may be dependent on the native shrubby vegetation as well as other co-occurring herbaceous species. The array of herbs frequently associated with San Diego thornmint (Bauder, McMillan and Kemp 1994) may support a diverse insect fauna. Many of these plant species are also of limited distribution.

Small, isolated *Acanthomintha ilicifolia* populations could be affected by overhanging shrubbery or nearby trees that might cause shade or produce debris that could bury plants and seeds or cover the soil surface. Cultivated plants could compete for pollinators as well. Out-of-season moisture would adversely affect San Diego thornmint populations by sustaining weedy species and shrubbery, neither of which are as tied to the naturally occurring seasonal changes in temperature and moisture as is *Acanthomintha ilicifolia*.

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