# 2007 Monitoring of Peirson's Milk-vetch
# in the
# Algodones Dunes, Imperial County, California
# Seed Bank Sampling Pilot Study

**Bureau of Land Management**
**California State Office**
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# Contents

Preface....iii

Executive Summary....v

Introduction....1

Methods....1

Results and Discussion....4
- Weather....4
- Seed Population Totals and Densities....7
  - Sampling....7
  - Seed estimates....8
  - Differences between management areas....8
  - Comparison of 2007 seed numbers to 2005 plant numbers....9
  - Seed numbers and densities in areas open and closed to OHV use....9
  - Precision of estimates....10
- Plant Population Totals and Densities....10
- Future Seed Bank Sampling....11

Literature Cited....12

Tables....15

Figures....27

Maps....following page 38
- Map 1 – Management Areas in the Algodones Dunes
- Map 2 – Sampling Areas
- Map 3 – Cells in Planned 2007 Sample
- Map 4 – Cells Sampled in 2007
- Map 5 – Estimated Total Seeds in Cells Sampled in 2007 and in which Seeds were Found
- Map 6 – Number of Surface Seeds in Cells Sampled in 2007 and in which Surface Seeds were Found
- Map 7 – Estimated Buried Seeds in Cells Sampled in 2007 and in which Buried Seeds were Found
- Map 8 – Total Number of Plants in Cells Sampled in 2007 and in which Plants were Found
- Map 9 – Total Number of Seedling and Juvenile Plants in Cells Samples in 2007 and in which Plants in this Category were Found
- Map 10 – Total Number of Adult Plants in Cells Sampled in 2007 and in Which Adult Plants were Found

# Preface

The author of this report is John Willoughby, State Botanist, Bureau of Land Management (BLM), California State Office. BLM began monitoring Peirson's milk-vetch in 1998. Between 1998 and 2002 the monitoring used an abundance-class approach that allowed comparisons to be made to data collected in 1977 from a BLM-contracted study that used a similar approach (WESTEC Services Inc. 1977). The results of the 1998-2002 BLM monitoring and descriptions of the methods used are reported in Willoughby (2000, 2001, and 2004). Recognizing the limitations of the abundance-class approach, BLM decided to use a sampling approach that enabled it to make estimates of the actual density and population size of Peirson's milk-vetch in the Algodones Dunes. A pilot study testing this new approach was conducted in 2003 in two of the seven management areas of the Dunes that support the species (Willoughby 2005a). The study was expanded and refined in 2004 to cover all seven management areas and for the first time allowed density and population estimates to be made for Peirson's milk-vetch over the entire Dunes (Willoughby 2005b). Based on the 2004 results, BLM intensified its sampling in 2005, again sampling over the entire range of Peirson's milk-vetch in the Dunes. Because precipitation in the 2004-2005 growing season was significantly above average, the 2005 data provided the clearest picture yet of the distribution and abundance of Peirson's milk-vetch in the Algodones Dunes (Willoughby 2005; U.S. Fish and Wildlife Service 2007).

The 2006 monitoring was scaled back significantly from the intensive sampling conducted in 2004 and 2005 for two major reasons: (1) by the start of winter 2005 it was clear that the 2005-2006 growing season was likely to be a very poor rainfall year; and (2) some of the money saved by reducing the level of effort expended in the direct on-the-ground monitoring of Peirson's milk-vetch could be used to contract for high resolution aerial photography of the Dunes during Presidents' Day weekend 2006, a period of high off-highway vehicle (OHV) use of the Dunes. Reason 1 was important to BLM's decision because previous monitoring has shown that the number of Peirson's milk-vetch plants is positively correlated with the amount of growing season precipitation. Thus, it did not seem prudent to spend approximately $1 million (the amount spent to monitor the species in 2005) to document the fact that many fewer plants occupied the Dunes in 2006. Because the 2004-2005 growing season was extremely favorable for the growth of Peirson's milk-vetch, the 2005 data were invaluable in terms of determining the spatial distribution and abundance in the areas of the Dunes in which the species occurs. In contrast, the 2006 data would simply show what was already expected: that the very low rainfall of the 2005-2006 growing season would produce a relatively small number of plants. This is not to say that some monitoring of the species was not warranted. The sampling approach used in 2006 still allowed for estimates of Peirson's milk-vetch abundance, albeit at lower levels of precision than 2005. Reason 2 was important because part of BLM's monitoring plan for the Dunes calls for the collection of aerial photography that can be used to determine the level of OHV use in different areas of the Dunes and its relationship to Peirson's milk-vetch abundance. This aerial photography can also be used to determine OHV use patterns in Peirson's milk-vetch habitat. The results of the 2006 monitoring are documented in Willoughby (2006).

Bowers (1996) stated, "It is virtually certain that the hard-seeded *Astragalus magdalenae* var. *peirsonii* has a persistent seed bank…." The BLM studies cited above and studies by Porter et al. (2005), Phillips et al. (2001) and Phillips and Kennedy (2002, 2003, 2004, 2005, and 2006)

demonstrate that Peirson's milk-vetch has a persistent seed bank. Seed banks are crucial in buffering populations of short-lived plants against environmental variability (Doak et al. 2002), and it is likely that they play this role for Peirson's milk-vetch, particularly in light of the findings of Porter et al. (2005) that the species has very high annual mortality and that late germination in some years can result in almost complete recruitment failure. Given the importance of the seed bank, BLM decided to focus its 2007 monitoring on determining the feasibility of estimating the numbers of Peirson's milk-vetch seed in the seed bank. Previous work by Phillips and Kennedy (2002 and 2006) and by Tony McKinney and Jeremy Groom (unpublished data) demonstrated that locating and counting seed was possible, both for buried seeds and seeds on the surface of the sand. Peirson's milk-vetch seeds are large, 4.5-5.5mm long according to Barneby (1964), 4-7mm long according to Bowers (1996), and are larger than the seeds of any other North American *Astragalus* (Barneby 1964). This, along with the sparseness of the dune vegetation, the small number of seeds of other species in soil cores, and the fact that the seeds of other species are not at all similar, made seed sampling appear to be a realistic endeavor. Figures 1 and 2 show the seedpods and seeds of Peirson's milk-vetch and the size and distinctness of the seeds.

Sampling in 2007 was confined to five sampling areas in three management areas (MAs), the Gecko MA, the Adaptive MA, and the Ogilby MA. The five westernmost sampling areas in these management areas were sampled: both of the Gecko MA's two sampling areas, the two westernmost of the Adaptive MA's four sampling areas, and the westernmost of the Ogilby MA's two sampling areas (sampling areas 3, 4, 7, 18, and 19 as shown on Map 2). These sampling areas contained higher numbers and densities of Peirson's milk-vetch plants in 2005 than the other 11 sampling areas in the Dunes. Sampling took place within a stratified random sample of 25m x 25m cells. In addition to collecting information on the number of seeds, the study also collected information on the number of Peirson's milk-vetch seedlings and adult plants in the cells sampled.

The study was designed by Tony McKinney and Jeremy Groom[1] of the U. S. Fish and Wildlife Service and John Willoughby and Erin Dreyfuss of BLM. Tony McKinney provided GIS support for the study and assisted Erin Dreyfuss in training the field crews in the sampling methodology. The study was carried out by SWCA Environmental Consultants under a BLM contract administered by Erin Dreyfuss. Following are the SWCA personnel who performed the sampling and data input:

Eleanor Gladding, project manager and lead biologist
Taya Cummins, field biologist
Andrew Trouette, field biologist and crew leader
Matt Villaneva, field biologist
Lauren Seckel, field biologist
Thomas Staudt, field biologist
Tom Silvia, data entry
Andrew Gannick, field biologist
Jack Tyner, field biologist

All photographs used in this report were taken by Taya Cummins, who has graciously given her permission to use them.

[1] Jeremy Groom is now working for the State of Oregon.

# Executive Summary

In late winter and spring 2007, the Bureau of Land Management (BLM), with technical assistance from the U.S. Fish and Wildlife Service, implemented a pilot study to determine the feasibility of sampling the seed bank of Peirson's milk-vetch (*Astragalus magdalenae* var. *peirsonii*) in the Algodones Dunes (also called Imperial Sand Dunes), located in southeastern Imperial County, California. Peirson's milk-vetch is a Federally-listed threatened species and a State-listed endangered species.

The pilot study was restricted to three of the seven management areas in which Peirson's milk-vetch occurs and to five of the 16 sampling areas that were established in 2005 to monitor above-ground plants of the species. The five sampling areas chosen for the pilot study were those with the highest numbers and densities of Peirson's milk-vetch plants in the 2005 monitoring study. The 2007 sampling took place in the Gecko, Adaptive, and Ogilby management areas. Sampling and data entry were carried out under a contract with the consulting firm, SWCA.

A simple random sample of 25m x 25m cells was selected, stratified by management area and further stratified by areas open and closed to off-highway vehicles (OHVs). Although the study design targeted 900 cells for sampling (300 per management area), the contractors were able to sample 735 cells before the onset of hot weather, 253 cells in the Gecko Management Area, 215 cells in the Adaptive Management Area, and 267 cells in the Ogilby Management Area. Sampling in each of the cells consisted of counting seeds on the surface of the ground in a 20m x 20m area centered in each of the 25m x 25m cells. Buried seeds were sampled by means of a systematic sample of 49 soil cores within each 20m x 20m area. Separate tallies were made for seeds outside and seeds inside of pods. Counts of Peirson's milk-vetch plants were also made in each of the 20m x 20m surveyed areas; separate tallies were made for seedling and juvenile plants and for adult plants.

There were an estimated 53,200,000 seeds in the 2007 sampled area, corresponding to a density of 6,356 seeds/hectare. Most of the seeds counted during monitoring were outside of pods, but this varied depending on whether the seed was found on the surface of the sampled cells or buried and found using soil cores. Over the entire area sampled, 30% of the seed found on the surface was still contained in pods, while only 3% of buried seed was still in pods.

Seed density was highest in the Adaptive Management Area, next highest in the Ogilby Management Area, and lowest in the Gecko Management Area. Differences in seed densities were not statistically significant between the Adaptive and Ogilby management areas, but seed density for the Gecko Management Area was significantly lower than the densities of the other two management areas. The estimated total number of seeds in the Adaptive Management Area was considerably higher than the estimates for both the Gecko and Ogilby management areas. The seed total for the Adaptive Management Area was higher than the Ogilby Management Area because the sampled area of the Adaptive Management Area was much larger than the sampled area of the Ogilby Management Area.

Seed numbers and densities were significantly higher in the areas closed to OHV use than in the areas open to OHV use. Seed density was particularly high in the closed part of the Ogilby

Management Area, where the estimated density was 35,882 seeds/hectare, almost 6 times higher than the estimated density for the entire sampled area and more than 14 times higher than the estimated density for the open part of the Ogilby Management Area. Despite the fact that the closed part of the Ogilby Management Area is only 269 hectares, compared to 1,429 hectares in the Ogilby open area, the total estimated number of seeds in the closed part of the Ogilby Management Area was significantly higher than the number in the open part of that management area. The reasons for these differences between the open and closed areas may or may not be related to recent or past OHV use, but regardless of the cause of the differences, it is clear that the closed areas sampled as part of this study are very important to Peirson's milk-vetch productivity.

Seed banks are notoriously difficult to sample because their distribution underground is usually very clustered and using relatively small cores to sample the seed bank results in a large number of cores with no seeds of the target species and a small number of cores with many seeds. This results in high coefficients of variation. The 2007 Peirson's milk-vetch data set is no exception to this rule. Coefficients of variation were very high for each of the management areas and for all three management areas combined. Despite this, however, the precision of the estimate was reasonable for the entire sampled area (35%) and for the Ogilby Management Area (39%), largely as a result of relatively large sample sizes. Precision was poorer for the Adaptive (57%) and Gecko (70%) management areas.

This study has demonstrated that it is possible to sample the seed bank with reasonable levels of precision given large enough sample sizes. More cells would have to be sampled in the Gecko and Adaptive MAs to achieve reasonable (e.g., < 40%) precisions in those management areas. Seed bank sampling is possible for Peirson's milk-vetch because of its large seed size, the sparseness of the dune vegetation, the small number of seeds of other species in soil cores, the fact that the seeds of other species are not at all similar, and the Dune sand is easy to core and sift (as long as the sand is dry). This combination of factors makes it reasonable to sample a relatively large number of cells, something that would not be possible for most other plant species. One caveat is that if the sand is wet, the sifting process is slowed down considerably.

There were an estimated 293,102 plants in the entire area sampled in 2007, corresponding to an estimated density of 35 plants/hectare. Most (83%) of the plants were seedlings and juvenile plants. Unlike the situation in 2005, the Gecko MA had a higher plant density (24 plants/hectare) than the Adaptive MA (8.7 plants/hectare). The highest plant numbers and densities, however, were found in the Ogilby MA, with an estimated 177,192 plants, 60% of the total for the entire area sampled, and an estimated density of 106 plants/hectare. Almost 92% of the estimated plants in the Ogilby MA were seedlings and juvenile plants. This could be the result of a localized rainfall event that was not reflected in the precipitation records for the Buttercup RAWS, the closest station to the Ogilby MA. Precisions of the 2007 plant estimates were universally poor, the result of a poor rainfall year, the relatively small number of plants, and spatial variability.

Although this study demonstrates that seed bank sampling is feasible, its routine use in a monitoring program would be expensive if applied to the entire habitat of ASMAP in the Dunes.

Such an effort would be cost prohibitive on an annual basis, but might be possible every 5 years or so.

The 2007 sampling took place just two years following the highly productive 2005 spring. It is unknown whether most of the seed found in 2007 was produced in 2005 or in earlier seasons (little was produced in 2006 because of poor rainfall). Seed bank sampling in a good rainfall year – following germination but before seed set – would answer questions relative to seed bank depletion and give some insight into the age of the seed bank. Such sampling could be directed at the same 5 sampling areas that were sampled in 2007.

# Introduction

In late winter and spring 2007, the Bureau of Land Management (BLM) implemented a monitoring program to estimate the number of seeds of Peirson's milk-vetch (*Astragalus magdalenae* var. *peirsonii*, hereafter referred to as ASMAP) in three of the management areas of the Algodones Dunes (also called Imperial Sand Dunes), located in southeastern Imperial County, California. ASMAP is a Federally-listed threatened species and a State-listed endangered species. Though the survey began in late winter 2007, it will be referred to simply as the spring 2007 survey hereafter.

The Imperial Sand Dunes Recreation Area Management Plan (ISDRAMP), approved by the BLM California State Director in 2005, established eight management areas (Map 1).[2] Seven of these management areas support populations of ASMAP. Monitoring in 2005 and 2006 was conducted in 16 sampling areas distributed throughout the areas of the seven management areas that support ASMAP. Map 2 shows these sampling areas and their relationship to the management areas.

The spring 2007 survey was intended to serve as a pilot study to determine the feasibility of estimating the number of ASMAP seeds in the seed bank. Consequently, the survey did not cover all of the areas of the Dunes in which ASMAP occurs, but was confined to five sampling areas in three management areas (MAs), the Gecko MA, the Adaptive MA, and the Ogilby MA. Monitoring in 2005 showed that the ASMAP plant densities in these three MAs were higher than any of the other MAs and that within the Adaptive MA and Ogilby MA densities were highest in the westernmost sampling areas. This led to the conclusion that seed densities would also be highest in these areas. If seed sampling was going to be practical at all, it would be most practical in the areas containing the most seed. Therefore, the 2007 sampling was confined to sampling areas 3 and 4 in the Gecko MA, sampling areas 7 and 18 in the Adaptive MA, and sampling area 19 in the Ogilby MA (see Map 2). Sampling took place within a stratified random sample of 25m x 25m cells. In addition to collecting information on the number of seeds, the study also collected information on the number of Peirson's milk-vetch seedlings and adult plants in the cells sampled.

# Methods

The 2007 sampling used a stratified random sample of 25m x 25m cells from an original very large sample of cells sampled in 2005. Thus, the 2005 and 2006 sampling is described briefly here before discussing the 2007 sampling design.

In 2005 a total of 510 belt transects, ranging in length from 2.35 to 7.75 kilometers, were positioned systematically with a random start within 16 sampling areas located within the seven

[2] The ISDRAMP has not been implemented because of ongoing litigation, as a result of which it appears likely that BLM will prepare a new ISDRAMP. It is not yet known whether the new plan will retain these same management areas, but they are used here for continuity with previous monitoring.

management areas. Sampling areas were positioned to incorporate as much Peirson's milk-vetch habitat as practical. Transects were 25m wide, and counts were recorded in 25m segments along each of the transects (these 25m x 25m segments are referred to as "cells" in this document). Counts were made of the number of plants in each of six categories: (1) seedlings and young, nonflowering plants, (2) flowering plants, (3) total number of plants (this is the total of categories 1 and 2), (4) number of plants greater than 1-year old, (5) number of plants showing damage from off-highway vehicles (OHVs), and (6) number of plants showing damage from sources other than OHVs. See Willoughby (2005c) for more information on the design of the 2005 monitoring study.

A total of 123,488 cells were surveyed in 2005, 26,116 of which contained one or more ASMAP plants. In 2006 a stratified simple random sample of 735 of the occupied cells was surveyed for ASMAP plants. The strata were 15 of the 16 sampling areas (because Sampling Area 12 in the Buttercup MA had so few occupied cells in 2005 it was not sampled in 2006; consequently, density and population estimates for the Buttercup MA in 2006 are based only on the cells sampled in Buttercup Sampling Area 11). The sample of 735 cells was allocated to the sampling areas in proportion to the sampling effort afforded them in 2005. Counts were made of the number of plants in each of the same six categories as described above for the 2005 monitoring. Refer to Willoughby (2006) for more details on the 2006 study.

For the 2007 study, a stratified simple random sample of 900 cells was selected from the collection of cells sampled in the 2005 monitoring effort for the Gecko, Adaptive, and Ogilby MAs, 300 cells per MA. The three MAs were the principal strata, but the samples within the management areas were further stratified by areas opened or closed to OHVs. Both the Gecko and Ogilby MAs contain areas that are open to OHVs and areas that have been closed to OHVs since 2000 as part of a lawsuit settlement in which administrative closures were put into place until a new Imperial Sand Dunes Recreation Area Management Plan (ISDRAMP) is approved by the California BLM State Director.[3] The entire area within the Adaptive MA has been closed to OHV use since 2000. In the Gecko MA sample cells were allocated in proportion to the amount of area closed and open to OHVs (47% and 53%, respectively). Because only about 16% of the Ogilby MA is currently closed to OHV use, an allocation of cells in proportion to area open or closed would have resulted in too small a sample size for precise estimates in the closed part of the Ogilby MA. Consequently, 100 cells were allocated to the closed area of the Ogilby MA and the remaining 200 cells were allocated to the open area of the Ogilby MA. All of the cells in the planned sample in the Adaptive MA are in areas closed to OHVs. Table 1 shows the number of targeted cells by management area and sampling area. Map 3 shows the physical location of the targeted cells.

In case the monitors were unable to sample all 900 cells because of environmental conditions during the sampling (e.g., high temperatures, rain making the sifting of sand more difficult), the

[3] Although a new ISDRAMP was approved by the State Director in 2005, that ISDRAMP has not been implemented because of a U.S. District Court decision that found against both the U.S. Fish and Wildlife Service's critical habitat designation for ASMAP and BLM's ISDRAMP with respect to ASMAP and other issues. Following a new final critical habitat rulemaking by the U.S. Fish and Wildlife Service that is expected in February 2008, BLM will develop a new IDSRAMP. Until that is accomplished, the administrative closures will remain in place.

sample for each management area was divided into six "bouts" of 50 cells each. This was accomplished by drawing a separate random sample of 50 cells for bout 1, another for bout 2, and so on. Sampling was without replacement, so if a cell was selected for a bout that was already represented in a previous bout, it was rejected and replaced by another cell. Monitors were to sample all of the cells in bout 1 for each management area before moving on to bout 2, all of the cells in bout 2 before moving on to bout 3, and so on. The purpose of sampling by bouts was to preserve the random selection of cells and ensure good interspersion of sampling throughout the management areas in case it was not possible to sample all 900 cells.

Cells were sampled in the following manner. Monitors were equipped with Global Positioning System (GPS) units into which the coordinates of points identifying the southeastern corner of each of the randomly selected cells. A 20m x 20m area centered within each 25m x 25m cell was sampled. Sampling consisted of counting all of the seeds on the surface of the 20m x 20m area and recording these counts as seeds still within fruits (pods) or seeds separate from fruits and then sampling underground to a depth of 10cm with 10.16cm diameter soil cores (made from 4 inch PVC pipe). Counts were also made of living ASMAP plants; separate counts were made of (1) seedling and juvenile plants, and (2) adult flowering or post-flowering plants. The aspect (in degrees east of true north) and slope (in degrees) of the center of each sampled cell was also recorded.

A total of 49 soil cores were sampled systematically within an 18m x 18m area centered within the 20m x 20m area. Cores were spaced 3m apart. Figure 3 shows how the soil cores were positioned in each cell.

The sand in the soil cores was sifted through a 2-mm sieve and ASMAP seeds counted. Counts were recorded separately for seeds found within fruits and those found outside of fruits. Seeds on the surface of each core were not included in the counts for those found buried. Once the seeds had been counted they were returned to the substrate. Figures 2 and 3 illustrate the soil core sampling.

Estimates for total numbers of seeds and total numbers of plants were obtained using the survey module of Stata release 9.2 (StataCorp 2006). The data were analyzed as a stratified random sample. The plant estimates consist of a one-stage sample: all of the plants present in each cell were counted ("cell" here is the 20m x 20m area centered in each 25m x 25m cell). The seed estimates consist of both one-stage and two-stage samples. The estimates of seed on the surface come from complete counts of the seeds on the surface of the cell, which makes this a one-stage sample. The estimates of below-ground seed come from a systematic random sample of 49 soil cores within each cell. Thus, below-ground estimates comprise a two-stage sample, with cells functioning as the primary sampling units and cores as the secondary sampling units. Seed counts in the secondary sample of core were converted to cell estimates as follows. The area actually sampled by the soil cores was calculated by multiplying the area of each core (0.008107 $m^2$) by the 49 cores to obtain the product 0.397259 $m^2$, which was divided into the total area of the 20m x 20m cell (400 $m^2$) to obtain the value 1006.901. The value 1006.901 was then used as the multiplier to convert the number of seeds found in the collection of 49 cores to an estimated number of seeds for the entire cell. This estimated number of underground seeds for the cell was

then added to the estimated number of aboveground seeds to obtain an estimate of the total number of seeds for each cell.

Stata 9.2 does not incorporate variance estimates beyond the first stage. Rather, it ignores the variance of second and lower stages and calculates only the variance associated with the first stage. This is a perfectly acceptable practice as long as the variance estimate does not incorporate a finite population correction (Cochran 1977:279), and Stata 9.2 indeed does not use the finite population correction in its calculations. A newer version of Stata, release 10 (StataCorp 2007), became available after the analysis described above was completed. Stata 10 does have the ability to incorporate variance estimates of the second and lower stages into an estimate of the overall variance. To see whether this made any difference in the variance estimation of underground seeds in this study, the data were analyzed as a two-stage stratified sample in Stata 10. The estimates were nearly exactly the same as those obtained from the Stata 9.2 study. This is likely because the area within both the first and second stage samples were very small compared to the total area sampled. Thus, the estimated variance did not benefit from application of the finite population correction at either stage.

Seed and plant densities per management area were calculated by dividing the estimates of the totals by the area sampled. Pairwise permutation tests, implemented in Stata release 10 (StataCorp 2007), were used to compare total seed density estimates between management areas.[4] Permutation tests were used instead of parametric tests (e.g., t tests) because of the large numbers of zeroes in the data set: permutation tests do not require either the assumption of normality or homogeneity of variance. Precipitation data were obtained from two remote area weather stations (RAWS), one located in the northern half of the dunes at the Cahuilla Ranger Station near State Highway 78 on the western edge of the dunes and the other at Buttercup in the southern part of the dunes south of Interstate 8. These data were compared to long-term average precipitation obtained from the Western Regional Climate Center (WRCC) for weather stations in the vicinity of the Dunes. The locations of the RAWS and WRCC weather stations are shown in Willoughby (2004).

Precipitation graphs were constructed using Microsoft Excel 2003 (Figure 6) and SYSTAT version 10.2 (SYSTAT 2002; Figure 7). Graphs of ASMAP seed numbers and density were constructed using SYSTAT 10.2.

# Results and Discussion

## Weather

Until the 2006 report (Willoughby 2006), previous BLM monitoring reports (Willoughby 2005b, 2005c) defined the growing season as the period between September 1 and June 30,

[4] No corrections (such as the Bonferroni correction) were applied to the *P* values from these tests to control for multiple testing because these were planned comparisons and because recent researchers have shown these corrections to be counterproductive (see, for example, Cabin and Mitchell 2000, Moran 2003, Nakagawa 2004, and Perneger 1998).

corresponding to the definition used by Sneva and Hyder (1962) in the Intermountain West (they term this period the "crop-year"). The months of July and August were excluded due to the fact that rain falling in those months as a result of tropical storms from the Gulf of California likely does not promote germination and growth of ASMAP because of the intense heat during those months. Romspert and Burk (1978) demonstrated that germination of ASMAP seed was suppressed at temperatures above 27° C (81° F). Long-term average maximum temperatures at Gold Rock Ranch, the weather station closest to the Dunes (period of record 1964-1996) are 107.0° F and 105.6° F for July and August, respectively. Long-term average minimum temperatures for that same station are 79.6° F and 79.4° F for July and August, respectively.

Phillips and Kennedy (2006) define the growing season for ASMAP as the period between October and April. Based on the data collected by those two authors and BLM's experience monitoring ASMAP since 1998, the October-April period seems more reasonable than the September-June period formerly considered by BLM to represent the growing season. Elimination of the months May and June from the calculation of total growing season precipitation has little effect on long-term average precipitation values because the long-term average precipitation values for May and June are only 0.03 and 0.01 inches, respectively. Thus, September-June values are essentially equivalent to September-April values. Because the long-term average precipitation for September is 0.33 inches, elimination of September from the calculation of total growing season precipitation has more of an effect on the resulting precipitation value. September is no longer considered to be part of the growing season for ASMAP because of the high temperatures in that month. Long-term average maximum and minimum temperatures at the Gold Rock Ranch weather station are 100.4° F and 73.5° F, respectively. Only in October do the average maximum temperatures drop below 90° F (long-term average 89.9° F).

For the reasons given above, the ASMAP growing season is defined in this report to be the period between October 1 and April 30. Growing season average precipitation values are used to compare growing seasons to each other and to long-term averages collected from the seven WRCC weather stations in the vicinity of the Dunes.

Table 2 shows the total growing season precipitation recorded by the two RAWS for growing seasons 2002-2003, 2003-2004, 2004-2005, 2005-2006, and 2006-2007 and compares the average precipitation for the two RAWS to the long-term average of the WRCC weather stations in the vicinity of the Dunes. Figure 6 shows the monthly precipitation totals recorded by each of the stations for these growing seasons.

Data from BLM's monitoring and from studies conducted by others (Phillips and Kennedy, 2003, 2004, 2005, and 2006; Porter et al. 2005) indicate that ASMAP plants germinating early in the growing season (e.g., October and November) flower and set seed during the following spring, whereas individuals that germinate later in the growing season (e.g., February and March) do not flower and set seed until the next growing season. Less clear are the fates of plants that germinate in either December or January. Porter et al. (2005) observed that plants flowered about 3 months from germination. This suggests that plants germinating in December may flower in March and plants germinating in January may flower in April. March temperatures are still relatively mild on the Dunes (average maximum temperature is 78.0° F),

while April temperatures are warmer (average maximum temperature 86° F). Thus, a December cohort would probably have sufficient time to set seed before desiccation took much of a toll, at least in average years. On the other hand, a January cohort, particularly a cohort germinating late in the month, may not have time to set seed before hot weather in late April and May either killed individual plants or triggered dormancy.

Figure 7 shows total precipitation in the Dunes between growing seasons 1964-1965 and 2005-2007, and the amount of precipitation that fell between October-December and January-March in each of those growing seasons. This assumes that plants germinating in the period October-December would flower and set seed in the same growing season, while plants germinating in the period January-March would not set seed until the following growing season.[5]

As Figure 7 shows, the total rainfall for 24 of the last 43 growing seasons was less than the long-term average, 2 of these 24 seasons had less than half but more than one-quarter of the long-term average (poor rainfall years), and 8 of these 24 seasons had less than one-quarter of the long-term average (very poor rainfall years). Three times during the period since 1964, a series of two consecutive very poor rainfall years occurred (growing seasons 1970-1971 and 1971-1972; 1995-1996 and 1996-1997; and 1998-1999 and 1999-2000). The longest series of consecutive below-average rainfall years was 4, which occurred from growing seasons 1973-1974 to 1976-1977. There were 14 growing seasons in which most or all precipitation occurred in the January-March period. Five of these growing seasons (1989-1990, 1995-1996, 1996-1997, 1999-2000, and 2005-2006) had precipitation totals that were so low they likely did not trigger much if any germination of ASMAP. The remaining 9 of these growing seasons probably resulted in germination only or at least principally in the January-March time period. Given the findings of Phillips and Kennedy (2003, 2004, and 2006) and Porter et al. (2005) for the 2002-2003 and 2003-2004 growing seasons, it is likely that few of the seedlings that germinated in these growing seasons survived to reproduce.[6] This late-germination pattern occurred during 3 consecutive growing seasons between 1979-1980 and 1981-1982 and during two consecutive growing seasons in 2002-2003 and 2003-2004. Given this inter- and intra-annual variability in precipitation, it is reasonable to assume that the ASMAP seed bank is very important to the species' long-term viability.

As Table 2 shows, rainfall for the 2006-2007 growing season was 32 percent of the long-term average. The 32 percent figure is an average of the two RAWS in the Dunes, and the rainfall was not distributed evenly through the Dunes. Rainfall at the Cahuilla RAWS in the northern part of the Dunes was 1.11 inches, or about 53% of the long-term average, while rainfall at the Buttercup RAWS in the southern part of the Dunes was only 0.22 inches, or 10% of the long-

[5] As more information is collected concerning the fates of plants germinating in January, it may be necessary to modify this graph to include January in the first part of the growing season. The month of April was not included in the graph because of the observations of Phillips and Kennedy (2005) that no plants germinated following an early April rainfall in 2004.

[6] This assumes that a cohort resulting from January precipitation does not reproduce in the same growing season. If further study reveals that January cohorts do in fact reproduce in the same growing season, the number of years in which most germinants likely senesced prior to reproduction would be smaller, as January precipitation was a significant part of the January-March precipitation in several of the 9 years in which January-March precipitation was the principal contributor to the total growing season precipitation.

term average. Thus, rainfall in the southern part of the Dunes was similar to the very low Dune-wide rainfall experienced in the 2005-2006 growing season, which was also 10% of the long-term average.

Most of the 2006-2007 rainfall resulted from a single rainfall event on October 24, 2006, during which 0.75 inches and 0.16 inches were recorded at the Cahuilla and Buttercup RAWS, respectively.

**Seed Population Totals and Densities**

**Sampling.** Sampling began February 12, 2007, and ended on May 4, 2007, with the onset of high temperatures. A total of 735 cells were sampled out of the planned sample of 900 cells. Apparently due to a misunderstanding of the sampling protocol the contracted observers did not sample in order of bouts 1 to 6, but apparently scheduled sampling in accordance with logistical considerations. As a consequence, management areas were not evenly sampled, as illustrated in Table 3, which compares the number of cells actually sampled to the number in the planned sample for each management area and the closed and open areas within each management areas. The biggest difference in sampling intensity is between the Adaptive MA (all of which is closed to OHVs), where only 72% of the cells in the planned sample were actually sampled, and the closed part of the Ogilby MA, where 100% of the cells in the planned sample were actually sampled. For management areas as a whole, the sampling intensity ranged from 72% for the Adaptive MA to 84% for the Gecko MA, to 89% for the Ogilby MA.

This differential sampling intensity is illustrated graphically in Maps 3 and 4, showing the locations of the planned sample of cells and the actual sample of cells, respectively. Note the heavier intensity of actual sampling in the Ogilby MA (Map 4). This is partly a function of sampling a higher percentage of the planned sample there than in the other two management areas, but it is also the result of a more intensive planned sample in the Ogilby MA. The allocation of 300 cells to each management area in the planned sample results in more intensive sampling in the Ogilby MA, simply because the area sampled in Ogilby (Sampling Area 19 on Map 2) is smaller than the area sampled in the other two management areas (Table 4). As Table 4 illustrates, each cell in the planned sample for the Gecko MA represents 12.6 hectares, each cell in the planned sample for the Adaptive MA represents 9.6 hectares, and each cell in the planned sample for the Ogilby MA represents 5.7 hectares. Thus, the planned sampling intensity for the Ogilby MA is more than twice that of the Gecko MA. The actual sample resulted in relatively similar sampling intensities for the Gecko and Adaptive MAs (with each cell representing 14.9 and 13.4 hectares, respectively) and a sampling intensity for Ogilby that is more than twice that of the other two MAs (Table 4).

The closed area of the Ogilby MA is sampled more intensively than any of the other closed and open areas (Maps 3 and 4) both because 100% of the cells in the planned sample for that area were actually sampled and because one third of the total cells in the planned sample for the Ogilby MA were allocated to the closed part of the MA despite the fact that the closed area only comprises about one sixth of the total area in the MA. Reasons for this differential allocation of cells were given in the methods section. Each sampled cell in both the planned and actual sample for the Ogilby closed area represents 2.69 hectares.

This differential sampling intensity should not affect the estimates for the numbers of seeds and plants in the management areas and the entire sampled area, other than narrowing the confidence intervals for the areas sampled more intensively. It may, however, affect the interpretation of Maps 5-10. Those maps plot the cells that were occupied by seeds or plants and color code the plotted cells in 5 abundance classes. These maps show a higher concentration of occupied cells in the Ogilby closed area, but this may partly be a function of the higher sampling intensity there (although the density of seeds and plants in this area is also much higher than any other area of the Dunes).

Both the open and closed areas were sampled in the Gecko and Ogilby MAs. Table 3 shows the number of hectares and cells sampled in these open and closed areas. All of the sampling in the Adaptive MA is within areas closed to OHVs, because all ASMAP habitat within that MA is closed.

**Seed estimates.** Seed estimates and 95% confidence intervals are given in Table 5. Estimates are given for the number of seeds found on the surface (including seeds still contained within pods that have broken off parent plants and those outside of fruits--see Figure 1), buried seeds, and the total number of seeds (surface + buried). There was an estimated 53,200,000 seeds in the entire area sampled in 2007. This corresponds to a density of 6,356 seeds/hectare.

Maps 5-7 show the distribution and abundance of ASMAP seeds in the occupied cells for estimated total seeds, number of surface seeds, and estimated buried seeds, respectively.

Most of the seed counted during monitoring was outside of pods, but this varied depending on whether the seed was found on the surface of the sampled cells or buried and found using soil cores. Over the entire area sampled, 30% of the seed found on the surface was still contained in pods found on the ground, while only 3% of buried seed was still in pods. This may be because seed is more easily buried than pods. The pods found on the surface are likely to be blown about by wind giving the seeds within them a greater chance of falling out over time.

*Differences between management areas.* Figure 8 illustrates the differences in seed numbers and densities between management areas. Seed density was highest in the Adaptive MA, next highest in the Ogilby MA, and lowest in the Gecko MA (Figure 8B). Differences in seed densities were not statistically significant between the Adaptive and Ogilby MAs ($P = 0.757$). Seed density for the Gecko MA was significantly lower than the densities of both the Adaptive and Ogilby management areas ($P = 0.024$ and $P = 0.021$, respectively). The estimated total number of seeds in the Adaptive MA was considerably higher than the estimates for both the Gecko and Ogilby MAs (Figure 8A). The Adaptive MA seed total is higher than the Gecko MA total because the seed density of the former is significantly higher than the latter. The seed total for the Adaptive MA is higher than that for the Ogilby MA because the sampled area of the Adaptive MA (2,891 hectares) is much larger than the sampled area of the Ogilby MA (1,698 hectares). Seed totals are similar between the Gecko and Ogilby MAs because the area sampled in the Ogilby MA (1,698 hectares) is less than half that of the Gecko MA (3,781 hectares), compensating for the lower seed density of the Gecko MA.

***Comparison of 2007 seed numbers to 2005 plant numbers.*** Figure 9 plots the $\log_{10}$ of the estimated total number of plants in 2005, the last good rainfall year, and the $\log_{10}$ of the estimated total number of seeds in 2007 for the area sampled in 2007 (both sampling areas in the Gecko MA, sampling areas 7 and 18 in the Adaptive MA, and sampling area 19 in the Ogilby MA – see Map2). Actual plant and seed estimates were log transformed for scaling purposes. The large difference between the estimated total number of 2005 plants (1,350,817) and the estimated total number of 2007 seeds (53,200,000) would have resulted in an unreadable graph. As Figure 9 shows, the number of seeds per management area in 2007 largely tracks with the number of plants in 2005.

***Seed numbers and densities in areas open and closed to OHV use.*** Seed numbers and densities were significantly higher in the areas closed to OHV use than in the areas open to OHV use (Figure 10). This was true in both management areas (Gecko and Ogilby) in which open and closed areas occur (Figure 11). Seed density was particularly high in the closed part of the Ogilby MA, where the estimated density was 35,882 seeds/hectare, almost 6 times higher than the estimated density for the entire sampled area and more than 14 times higher than the estimated density for the open part of the Ogilby MA (Figure 11B and Table 5). The closed part of the Ogilby MA is only 269 hectares, compared to 1,429 hectares in the Ogilby open area. Despite this difference in area, the total estimated number of seeds in the closed part of the Ogilby MA was significantly higher than the number in the open part of the Ogilby MA (Figure 11A).

The reason for the significantly higher seed numbers and densities in the closed areas compared to the open areas is not clear. Groom et al. (2007) reporting on a 2005 study of ASMAP plants in open and closed areas in the Gecko MA found similar differences in the densities of plants between open and closed areas there and concluded that OHV use was the reason for the lower density of plants in the open area (the density in the open area were 4-5 times lower than the density in the closed area). They also suggested that periodic closures of occupied habitat during years with above-average rainfall might increase ASMAP productivity over the productivity that would occur in the absence of such closures. Both of these conclusions, however, rely upon the assumption that the open and closed areas supported similar numbers of plants at the time the administrative closures were implemented in November 2000. There is no evidence that this was the case. In fact, the boundaries of the administrative closures were determined through court settlement discussions between BLM and the plaintiffs (the Center for Biological Diversity and others) based on the likelihood that significant numbers of ASMAP plants were known or suspected to be within the closures. BLM's 1998 monitoring data set was used as the basis for this determination (Willoughby, personal knowledge). Thus, ASMAP plant numbers (and, by extension, seed numbers) between open and closed areas may have been just as different in 2000 as at present. These differences *may* be the result of OHV use, but whether they result from OHV use subsequent to 2000 or long before 2000 is difficult to infer from the data collected to date. Nevertheless, it is accurate to conclude that—regardless of the reason—the closed areas of the Gecko and Ogilby MAs have larger seed banks than the open areas of those MAs. The Adaptive MA, where ASMAP habitat has been entirely closed to OHVs since 2000 is also clearly important to the species, supporting an estimated 25.5 million seeds, almost half of the number estimated for the entire area sampled in 2007.

***Precision of estimates*.** Seed banks are notoriously difficult to monitor because their distribution underground is usually very clustered and using relatively small cores to sample the seed bank results in a large number of cores with no seeds of the target species and a small number of cores with many seeds (Elzinga et al. 1998, 2001). This leads to high coefficients of variation. This is certainly the case with the 2007 ASMAP seed data set. Table 6 shows the coefficients of variation (standard deviations divided by means) for each management area and for all three management areas combined. These are extremely high, ranging from 3.22 for the Ogilby MA to 5.70 for the Gecko MA.

Table 7 shows the precisions achieved for the estimates of total seeds for each management area and for all three management areas combined. Despite the high coefficients of variation, precisions were reasonable for all management areas combined (35%) and for the Ogilby MA (39%), largely as a function of a large sample size (735 cells) for the entire sampled area and a relatively large sample size (267 cells) and a smaller coefficient of variation for the Ogilby MA. Precisions for the Adaptive MA (57%) and Gecko MA (70%) were poorer because sample sizes there were not large enough to compensate for the larger coefficients of variation there.

This study has demonstrated that it is possible to sample the seed bank with reasonable levels of precision with large enough sample sizes. More cells would have to be sampled in the Gecko and Adaptive MAs to achieve reasonable (e.g., < 40%) precisions in those management areas. This study focused on the 5 sampling areas with the highest densities of ASMAP plants in 2005. It is therefore reasonable to assume these 5 sampling areas also have the highest densities of seeds. If this is true, the other sampling areas in the Dunes (including Sampling Areas 8 and 17 in the Adaptive MA and Sampling Area 20 in the Ogilby MA—see Map 2) would have to be sampled even more intensively than the 5 sampling areas that were part of this study.

Seed bank sampling is possible for ASMAP because of its large seed size, the sparseness of the dune vegetation, the small number of seeds of other species in soil cores, the fact that the seeds of other species are not at all similar, and the Dune sand is easy to core and sift (as long as the sand is dry). This combination of factors makes it reasonable to sample a relatively large number of cells, something that would not be possible for most other plant species. One caveat is that if the sand is wet, the sifting process is slowed down considerably. This would result in a smaller number of cells sampled with the same number of observers. Obtaining large enough samples would likely require more teams of observers.

## Plant Population Totals and Densities

Although seed bank estimation was the principal objective of this study, data were also collected on numbers of ASMAP plants. ASMAP plant estimates and 95% confidence intervals are given in Table 5. Estimates are given for: (1) seedlings and juvenile plants, (2) adult plants, and (3) total number of plants (1+2). There were an estimated 293,102 plants in the entire area sampled in 2007, corresponding to an estimated density of 35 plants/hectare. Most (83%) of the plants were seedlings and juvenile plants.

Maps 8-10 show the distribution and abundance of ASMAP plants in the occupied cells for total number of plants, number of seedling and juvenile plants, and number of adult plants, respectively.

Unlike the situation in 2005, the Gecko MA had a higher plant density (24 plants/hectare) than the Adaptive MA (8.7 plants/hectare). The highest plant numbers and densities, however, were found in the Ogilby MA, with an estimated 177,192 plants, 60% of the total for the entire area sampled, and an estimated density of 106 plants/hectare. Almost 92% of the estimated plants in the Ogilby MA were seedlings and juvenile plants. This could be the result of a localized rainfall event that was not reflected in the precipitation records for the Buttercup RAWS, the closest station to the Ogilby MA. Most of the cells occupied by plants, and especially those with higher plant numbers, are located in the northern part of the Ogilby MA, which is farther away from the Buttercup RAWS from the rest of the Ogilby MA.

All of the ASMAP plant estimates have poor precision. Precisions for the estimates of the total number of plants are 62% for the entire area sampled, 92% for the Gecko MA, 95% for the Adaptive MA, and 91% for the Ogilby MA. This is not surprising given the poor rainfall year, the relatively small number of plants, and the spatial variability shown in Map 8.

Figure 12 shows the estimated total number of plants for 2004, 2005, 2006, and 2007. Values for 2005, 2006, and 2007 are for the 5 sampling areas sampled in 2007. Values for 2004 are for the entire ASMAP habitat area of Gecko, Adaptive, and Ogilby MAs, because the sampling areas used in 2004 were not the same as those used in subsequent years. Note the wide confidence interval for 2007 compared to the other years.

**Future Seed Bank Sampling**

Although this study demonstrates that seed bank sampling is feasible, its routine use in a monitoring program would be expensive if applied to the entire habitat of ASMAP in the Dunes. Field work and data entry for this study of 5 sampling areas cost about $120,000. Analysis, interpretation, and report preparation added another $30,000, bringing the total cost for the 2007 monitoring to $150,000. Expanding the effort to all 16 sampling areas and sampling at an intensity that would result in precisions of 40% or better would cost several hundred thousand dollars. This makes such an effort cost prohibitive on an annual basis. Perhaps such an effort could be mounted every 5 years.

The 2007 sampling took place just two years following the highly productive 2005 spring. It is unknown whether most of the seed found in 2007 was produced in 2005 or in earlier seasons (little was produced in 2006 because of poor rainfall). Seed bank sampling in a good rainfall year – following germination but before seed set – would answer questions relative to seed bank depletion and give some insight into the age of the seed bank. Such sampling could be directed at the same 5 sampling areas that were sampled in 2007.

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**Table 1.** Number of cells in target sample by management area and sampling area.

| Management Area | Sampling Area | Number of Cells |
|---|---|---|
| Gecko | 3 | 143 |
| | 4 | 157 |
| Adaptive | 7 | 122 |
| | 18 | 178 |
| Ogilby | 19 | 300 |
| Total | | 900 |

**Table 2.** Growing season (October-April) precipitation from the two remote area weather stations (RAWS) in the Algodones Dunes. The long-term growing season average of the WRCC stations in the vicinity of the dunes is given for comparison. All units are in inches.

| Growing Season | Cahuilla RAWS | Buttercup RAWS | Average of the two RAWS | Long-term average of all WRCC Stations | Percent of long-term average (Col. 4/Col 5 * 100) |
|---|---|---|---|---|---|
| 2002-2003 | 2.68 | 1.15 | 1.92 | 2.11 | 65% |
| 2003-2004 | 2.2 | 2.46 | 2.33 | 2.11 | 110% |
| 2004-2005 | 4.87 | 4.68 | 4.78 | 2.11 | 226% |
| 2005-2006 | 0.26 | 0.17 | 0.22 | 2.11 | 10% |
| 2006-2007 | 1.11 | 0.22 | 0.67 | 2.11 | 32% |

**Table 3.** Number of cells sampled by management area and closed status compared to the number of cells in the planned sample.

| Management Area | Closed Status | Area (hectares) | Number Cells Sampled | Number Cells in Planned Sample | % of Planned |
|---|---|---|---|---|---|
| Gecko | Y | 1,761 | 113 | 139 | 81% |
| Gecko | N | 2,020 | 140 | 161 | 87% |
| **Gecko Total** | | **3,781** | **253** | **300** | **84%** |
| Adaptive | Y | 2,891 | 215 | 300 | 72% |
| Adaptive | N | 0 | 0 | 0 | N/A |
| **Adaptive Total** | | **2,891** | **215** | **300** | **72%** |
| Ogilby | Y | 269 | 100 | 100 | 100% |
| Ogilby | N | 1,429 | 167 | 200 | 84% |
| **Ogilby Total** | | **1,698** | **267** | **300** | **89%** |
| **Grand Total** | | **8,370** | **735** | **900** | **82%** |

**Table 4.** Sampling intensity by management area in planned and actual samples.

| Management Area | Area (hectares) | Hectares Represented by each Cell in Planned Sample | Hectares Represented by each Cell in Actual Sample |
|---|---|---|---|
| Gecko | 3,780 | 12.60 | 14.94 |
| Adaptive | 2,891 | 9.64 | 13.44 |
| Ogilby | 1,698 | 5.66 | 6.36 |
| Total | 8,369 | 9.30 | 11.39 |

**Table 5.** Spring 2007 population and density estimates for ASMAP seeds and plants in the Gecko, Adaptive, and Ogilby management areas of the Algodones Dunes. Estimates are provided for the entire sampled population, each management area, the closed and open areas of each management area (none of the Adaptive Management Area is open), and for the closed and open areas of the entire sampled population.

**Entire Sampled Population**

| Category | Population Estimate | 95% Confidence Limits Lower | 95% Confidence Limits Upper | Density Estimate (plants/ha) | 95% Confidence Limits Lower | 95% Confidence Limits Upper | Precision (+/- percent of estimate) |
|---|---|---|---|---|---|---|---|
| Seedlings and juvenile plants | 242,311 | 79,770 | 404,853 | 28.95 | 9.53 | 48.37 | 67% |
| Adult plants | 50,791 | 191 | 107,630 | 6.07 | 0.02 | 12.86 | 112% |
| Total number of plants | 293,102 | 110,189 | 476,015 | 35.02 | 13.16 | 56.87 | 62% |
| Total seeds on surface | 6,737,889 | 1,220,208 | 12,300,000 | 805.00 | 145.78 | 1,469.53 | 83% |
| Total buried seeds | 46,500,000 | 30,700,000 | 62,200,000 | 5,555.56 | 3,667.86 | 7,431.30 | 34% |
| Total number of seeds | 53,200,000 | 34,700,000 | 71,700,000 | 6,356.03 | 4,145.76 | 8,566.31 | 35% |

**Gecko Management Area**

| Category | Population Estimate | 95% Confidence Limits Lower | 95% Confidence Limits Upper | Density Estimate (plants/ha) | 95% Confidence Limits Lower | 95% Confidence Limits Upper | Precision (+/- percent of estimate) |
|---|---|---|---|---|---|---|---|
| Seedlings and juvenile plants | 57,754 | 17,922 | 97,586 | 15.27 | 4.74 | 25.81 | 69% |
| Adult plants | 33,007 | 92 | 86,832 | 8.73 | 0.02 | 22.97 | 163% |
| Total number of plants | 90,761 | 7,476 | 174,045 | 24.00 | 1.98 | 46.03 | 92% |
| Total seeds on surface | 939,328 | 401,315 | 1,477,341 | 248.43 | 106.14 | 390.73 | 57% |
| Total buried seeds | 13,600,000 | 3,530,532 | 23,600,000 | 3,596.93 | 933.76 | 6,241.73 | 74% |
| Total number of seeds | 14,500,000 | 4,287,659 | 24,700,000 | 3,834.96 | 1,134.00 | 6,532.66 | 70% |

**Table 5.** Spring 2007 population and density estimates for ASMAP seeds and plants in the Gecko, Adaptive, and Ogilby management areas of the Algodones Dunes. Estimates are provided for the entire sampled population, each management area, the closed and open areas of each management area (none of the Adaptive Management Area is open), and for the closed and open areas of the entire sampled population.

**Adaptive Management Area**

| Category | Population Estimate | 95% Confidence Limits Lower | 95% Confidence Limits Upper | Density Estimate (plants/ha) | 95% Confidence Limits Lower | 95% Confidence Limits Upper | Precision (+/- percent of estimate) |
|---|---|---|---|---|---|---|---|
| Seedlings and juvenile plants | 22,052 | 1,213 | 42,890 | 7.63 | 0.42 | 14.84 | 94% |
| Adult plants | 3,098 | 7 | 7,059 | 1.07 | 0.00 | 2.44 | 128% |
| Total number of plants | 25,149 | 1,280 | 49,019 | 8.70 | 0.44 | 16.96 | 95% |
| Total seeds on surface | 4,310,148 | 15,464 | 9,775,842 | 1,490.88 | 5.35 | 3,381.47 | 127% |
| Total buried seeds | 21,200,000 | 9,835,489 | 32,500,000 | 7,333.10 | 3,402.11 | 11,241.78 | 53% |
| Total number of seeds | 25,500,000 | 10,900,000 | 40,100,000 | 8,820.48 | 3,770.32 | 13,870.63 | 57% |

**Ogilby Management Area**

| Category | Population Estimate | 95% Confidence Limits Lower | 95% Confidence Limits Upper | Density Estimate (plants/ha) | 95% Confidence Limits Lower | 95% Confidence Limits Upper | Precision (+/- percent of estimate) |
|---|---|---|---|---|---|---|---|
| Seedlings and juvenile plants | 162,506 | 5,805 | 319,207 | 95.70 | 3.42 | 187.99 | 96% |
| Adult plants | 14,686 | 92 | 33,081 | 8.65 | 0.05 | 19.48 | 125% |
| Total number of plants | 177,192 | 15,477 | 338,907 | 104.35 | 9.11 | 199.59 | 91% |
| Total seeds on surface | 1,488,414 | 763,731 | 2,213,096 | 876.57 | 449.78 | 1,303.35 | 49% |
| Total buried seeds | 11,700,000 | 7,150,060 | 16,300,000 | 6,890.46 | 4,210.87 | 9,599.53 | 39% |
| Total number of seeds | 13,200,000 | 8,093,022 | 18,400,000 | 7,773.85 | 4,766.21 | 10,836.28 | 39% |

**Table 5.** Spring 2007 population and density estimates for ASMAP seeds and plants in the Gecko, Adaptive, and Ogilby management areas of the Algodones Dunes. Estimates are provided for the entire sampled population, each management area, the closed and open areas of each management area (none of the Adaptive Management Area is open), and for the closed and open areas of the entire sampled population.

**Closed Areas, Entire Sampled Population**

| Category | Population Estimate | 95% Confidence Limits Lower | 95% Confidence Limits Upper | Density Estimate (plants/ha) | 95% Confidence Limits Lower | 95% Confidence Limits Upper | Precision (+/- percent of estimate) |
|---|---|---|---|---|---|---|---|
| Seedlings and juvenile plants | 237,203 | 76,020 | 398,386 | 48.20 | 15.45 | 80.96 | 68% |
| Adult plants | 50,791 | 191 | 107,624 | 10.32 | 0.04 | 21.87 | 112% |
| Total number of plants | 287,994 | 106,711 | 469,277 | 58.52 | 21.68 | 95.36 | 63% |
| Total seeds on surface | 6,308,022 | 789,747 | 11,800,000 | 1,281.86 | 160.49 | 2,397.89 | 87% |
| Total buried seeds | 40,800,000 | 25,400,000 | 56,100,000 | 8,291.00 | 5,161.55 | 11,400.12 | 38% |
| Total number of seeds | 47,100,000 | 29,000,000 | 65,200,000 | 9,571.23 | 5,893.11 | 13,249.34 | 38% |

**Open Areas, Entire Sampled Population**

| Category | Population Estimate | 95% Confidence Limits Lower | 95% Confidence Limits Upper | Density Estimate (plants/ha) | 95% Confidence Limits Lower | 95% Confidence Limits Upper | Precision (+/- percent of estimate) |
|---|---|---|---|---|---|---|---|
| Seedlings and juvenile plants | 5,108 | 1,050 | 9,166 | 1.48 | 0.30 | 2.66 | 79% |
| Adult plants | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0% |
| Total number of plants | 5,108 | 1,050 | 9,166 | 1.48 | 0.30 | 2.66 | 79% |
| Total seeds on surface | 429,867 | 249,599 | 610,134 | 124.64 | 72.37 | 176.90 | 42% |
| Total buried seeds | 5,703,295 | 2,730,421 | 8,676,168 | 1,653.61 | 791.66 | 2,515.56 | 52% |
| Total number of seeds | 6,133,161 | 3,082,277 | 9,184,045 | 1,778.24 | 893.67 | 2,662.81 | 50% |

**Table 5.** Spring 2007 population and density estimates for ASMAP seeds and plants in the Gecko, Adaptive, and Ogilby management areas of the Algodones Dunes. Estimates are provided for the entire sampled population, each management area, the closed and open areas of each management area (none of the Adaptive Management Area is open), and for the closed and open areas of the entire sampled population.

**Closed Areas, Gecko Mangement Area**

| Category | Population Estimate | 95% Confidence Limits Lower | 95% Confidence Limits Upper | Density Estimate (plants/ha) | 95% Confidence Limits Lower | 95% Confidence Limits Upper | Precision (+/- percent of estimate) |
|---|---|---|---|---|---|---|---|
| Seedlings and juvenile plants | 57,754 | 18,367 | 97,140 | 32.80 | 10.43 | 55.16 | 68% |
| Adult plants | 33,007 | 92 | 87,112 | 18.74 | 0.05 | 49.47 | 164% |
| Total number of plants | 90,761 | 7,680 | 173,841 | 51.54 | 4.36 | 98.72 | 92% |
| Total seeds on surface | 703,893 | 189,712 | 1,218,074 | 399.71 | 107.73 | 691.69 | 73% |
| Total buried seeds | 11,200,000 | 1,597,837 | 20,900,000 | 6,360.02 | 907.35 | 11,868.26 | 87% |
| Total number of seeds | 11,900,000 | 2,137,488 | 21,800,000 | 6,757.52 | 1,213.79 | 12,379.33 | 83% |

**Open Areas, Gecko Management Area**

| Category | Population Estimate | 95% Confidence Limits Lower | 95% Confidence Limits Upper | Density Estimate (plants/ha) | 95% Confidence Limits Lower | 95% Confidence Limits Upper | Precision (+/- percent of estimate) |
|---|---|---|---|---|---|---|---|
| Seedlings and juvenile plants | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 |
| Adult plants | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 |
| Total number of plants | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 |
| Total seeds on surface | 235,434 | 77,284 | 393,585 | 116.55 | 38.26 | 194.84 | 67% |
| Total buried seeds | 2,327,879 | 178,670 | 4,477,087 | 1,152.42 | 88.45 | 2,216.38 | 92% |
| Total number of seeds | 2,563,313 | 360,253 | 4,766,373 | 1,268.97 | 178.34 | 2,359.59 | 86% |

**Table 5.** Spring 2007 population and density estimates for ASMAP seeds and plants in the Gecko, Adaptive, and Ogilby management areas of the Algodones Dunes. Estimates are provided for the entire sampled population, each management area, the closed and open areas of each management area (none of the Adaptive Management Area is open), and for the closed and open areas of the entire sampled population.

**Closed Areas, Adaptive Management Area**

| Category | Population Estimate | 95% Confidence Limits Lower | 95% Confidence Limits Upper | Density Estimate (plants/ha) | 95% Confidence Limits Lower | 95% Confidence Limits Upper | Precision (+/- percent of estimate) |
|---|---|---|---|---|---|---|---|
| Seedlings and juvenile plants | 22,052 | 1,213 | 42,890 | 7.63 | 0.42 | 14.84 | 94% |
| Adult plants | 3,098 | 7 | 7,059 | 1.07 | 0.00 | 2.44 | 128% |
| Total number of plants | 25,149 | 1,280 | 49,019 | 8.70 | 0.44 | 16.96 | 95% |
| Total seeds on surface | 4,310,148 | 15,464 | 9,775,842 | 1,490.88 | 5.35 | 3,381.47 | 127% |
| Total buried seeds | 21,200,000 | 9,835,489 | 32,500,000 | 7,333.10 | 3,402.11 | 11,241.78 | 53% |
| Total number of seeds | 25,500,000 | 10,900,000 | 40,100,000 | 8,820.48 | 3,770.32 | 13,870.63 | 57% |

**Closed Areas, Ogilby Management Area**

| Category | Population Estimate | 95% Confidence Limits Lower | 95% Confidence Limits Upper | Density Estimate (plants/ha) | 95% Confidence Limits Lower | 95% Confidence Limits Upper | Precision (+/- percent of estimate) |
|---|---|---|---|---|---|---|---|
| Seedlings and juvenile plants | 157,398 | 986 | 313,876 | 585.12 | 3.67 | 1,166.82 | 99% |
| Adult plants | 14,686 | 92 | 33,138 | 54.60 | 0.34 | 123.19 | 126% |
| Total number of plants | 172,084 | 10,846 | 333,322 | 639.72 | 40.32 | 1,239.12 | 94% |
| Total seeds on surface | 1,293,981 | 591,167 | 1,996,796 | 4,810.34 | 2,197.65 | 7,423.03 | 54% |
| Total buried seeds | 8,358,172 | 4,345,139 | 12,400,000 | 31,071.27 | 16,152.93 | 46,096.65 | 48% |
| Total number of seeds | 9,652,154 | 5,084,393 | 14,200,000 | 35,881.61 | 18,901.09 | 52,788.10 | 47% |

**Table 5.** Spring 2007 population and density estimates for ASMAP seeds and plants in the Gecko, Adaptive, and Ogilby management areas of the Algodones Dunes. Estimates are provided for the entire sampled population, each management area, the closed and open areas of each management area (none of the Adaptive Management Area is open), and for the closed and open areas of the entire sampled population.

**Open Areas, Ogilby Management Area**

| Category | Population Estimate | 95% Confidence Limits Lower | 95% Confidence Limits Upper | Density Estimate (plants/ha) | 95% Confidence Limits Lower | 95% Confidence Limits Upper | Precision (+/- percent of estimate) |
|---|---|---|---|---|---|---|---|
| Seedlings and juvenile plants | 5,108 | 1,037 | 9,180 | 3.57 | 0.73 | 6.42 | 80% |
| Adult plants | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0 |
| Total number of plants | 5,108 | 1,037 | 9,180 | 3.57 | 0.73 | 6.42 | 80% |
| Total seeds on surface | 194,432 | 106,250 | 282,615 | 136.06 | 74.35 | 197.77 | 45% |
| Total buried seeds | 3,375,416 | 1,303,785 | 5,447,046 | 2,362.08 | 912.38 | 3,811.79 | 61% |
| Total number of seeds | 3,569,848 | 1,441,227 | 5,698,469 | 2,498.14 | 1,008.56 | 3,987.73 | 60% |

**Table 6.** Coefficients of variation for 2007 estimates of the total number of ASMAP seed in each of the management areas sampled and in all three management areas combined.

| Management Area | Coefficient of Variation |
|---|---|
| Gecko | 5.70 |
| Adaptive | 4.26 |
| Ogilby | 3.22 |
| All | 4.80 |

**Table 7.** Precisions attained for 2007 estimates of the total number of ASMAP seeds and plants in each of the management areas sampled and in all three management areas combined.

| Management Area | Precision (+/- percent of the population estimate) | |
|---|---|---|
| | Total Number of Seeds | Total Number of Plants |
| Gecko | 70% | 92% |
| Adaptive | 57% | 72% |
| Ogilby | 39% | 91% |
| All | 35% | 62% |

**Figure 1.** Seedpods and seeds of Peirson's milk-vetch.

**Figure 2.** Seeds of Peirson's milk-vetch.

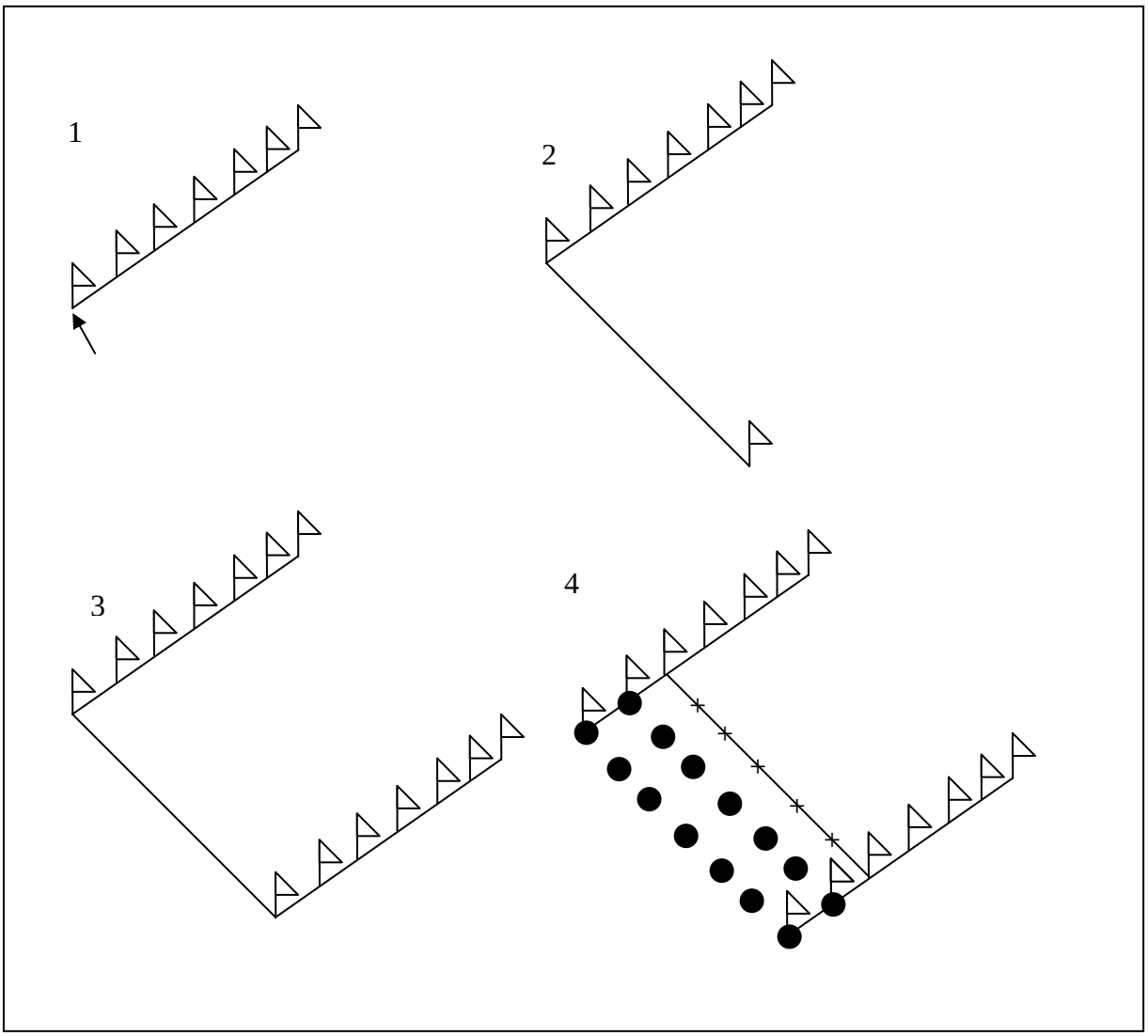
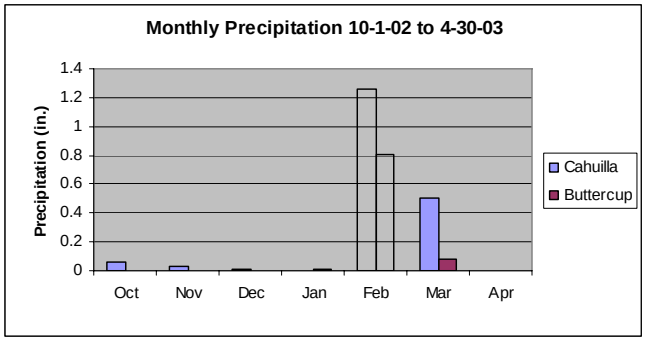
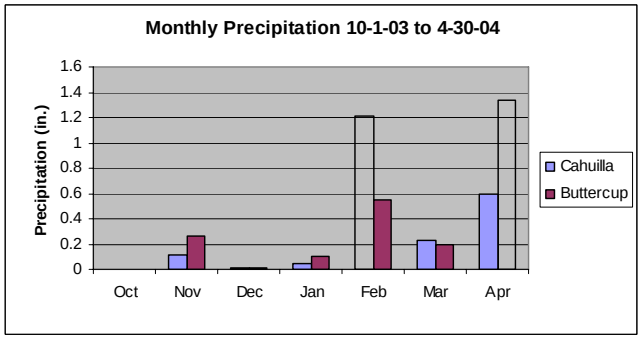


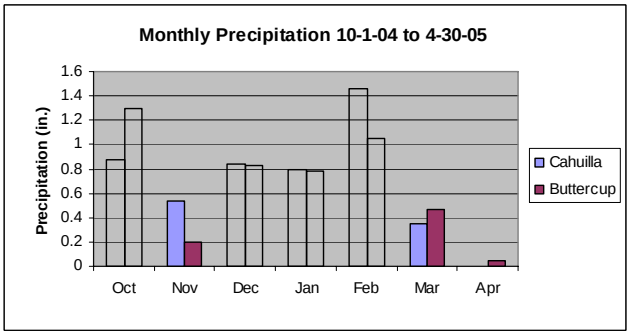

**Figure 3.** Progression of seed-bank sampling plot layout. 1) At a cell, a pin flag is first placed according to GPS waypoint information. Then a string is laid out on the ground with evenly-spaced markings at seven locations at a predetermined orientation. Pin flags are placed at each mark. 2) The same string is then laid out at 90 degrees to the row of flags, and a pin flag placed at the terminal string marking. 3) A third row of pin flags is set up at the same orientation as in step 1. 4) Between corresponding sets of pin flags the marked string is once again laid down. Soil core sampling occurs at every mark, including the first and last mark. Forty-nine cores total are taken per cell.

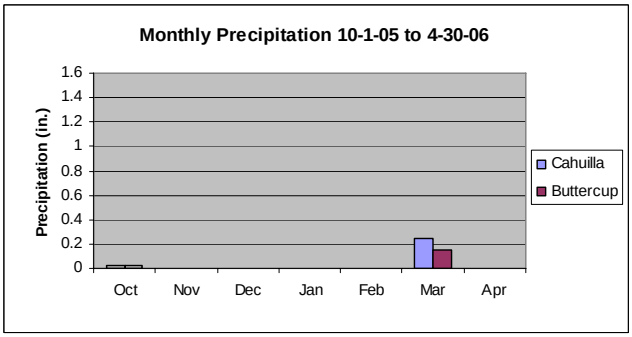
**Figure 4.** Soil core sampling.

**Figure 5.** ASMAP seeds in sieve following sifting.



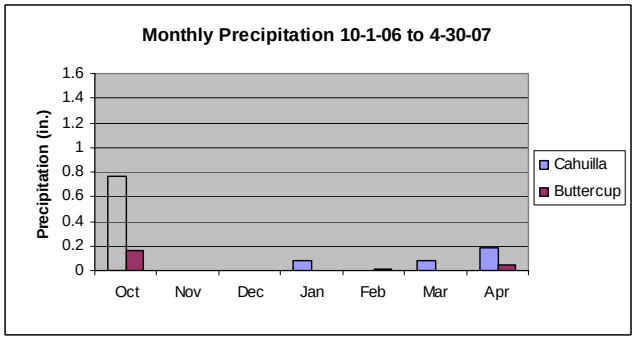




**Figure 6.** Monthly total precipitation at the two Rmote Area Weather Stations in the Algodones Dunes for growing seasons 2002-2003, 2003-2004, 2004-2005, 2005-2006, and 2006-2007.

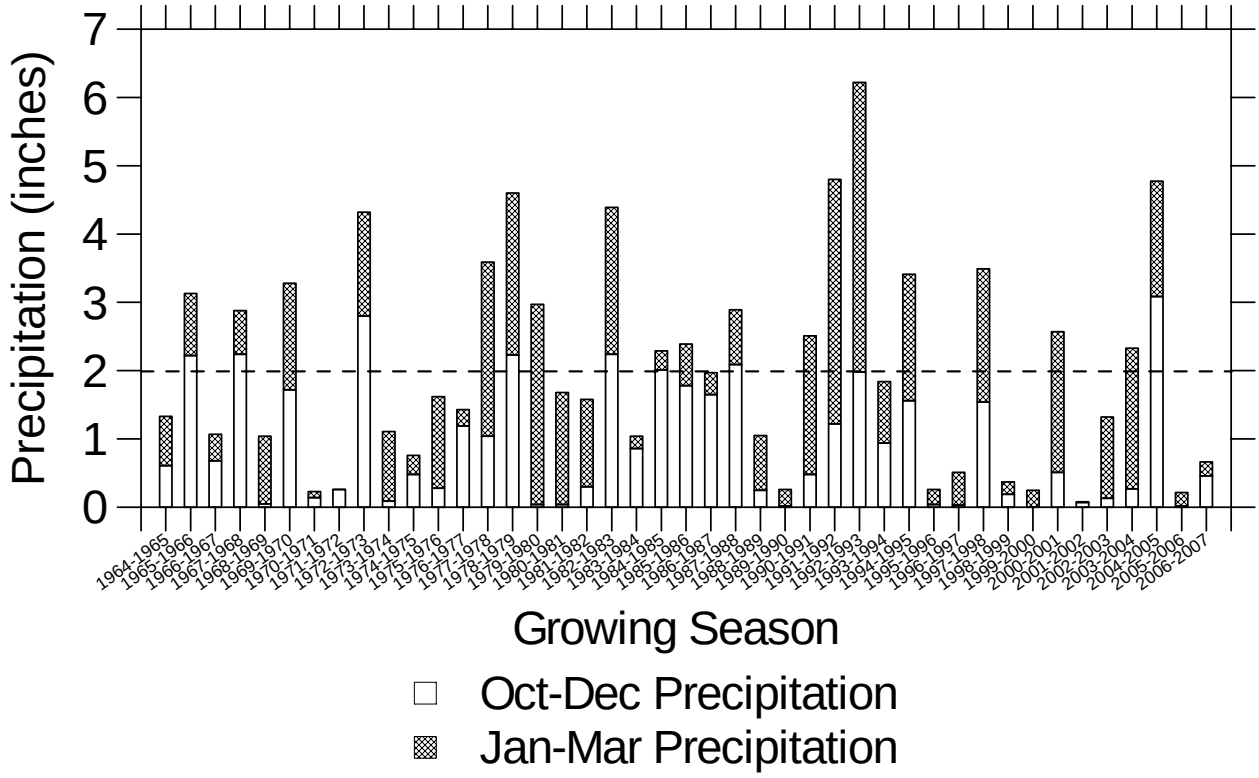



**Figure 7.** Total growing season (October to March) precipitation for growing seasons 1964-1965 to 2006-2007. The bottom part of each bar is the October-December precipitation. The top part of each bar is the January-March precipitation. Precipitation values for growing seasons 1964-1965 to 1999-2000 are the averages of 7 WRCC weather stations in the vicinity of the Algodones Dunes. The value for October-December 2000 is from the same source. The values for January-March 2001 and for all subsequent growing seasons are the averages of the precipitation recorded for the two Remote Area Weather Stations in the Algodones Dunes. The dashed line is the average growing season precipitation of the 7 WRCC weather stations.

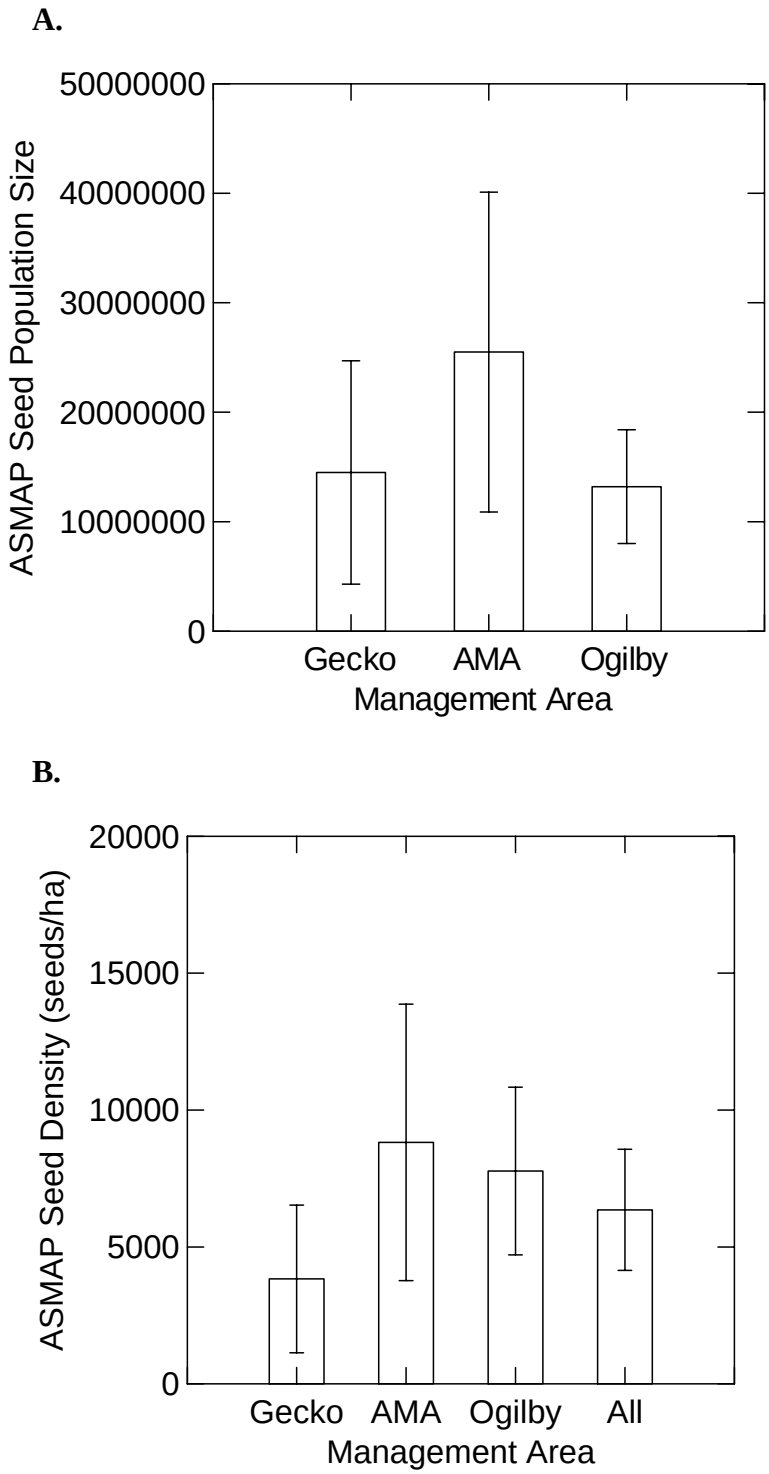



**Figure 8.** ASMAP seed population size (A) for the three management areas sampled in 2007 and seed density (B) for the three management areas and the entire sampled area ("All"). Error bars are 95% confidence intervals.

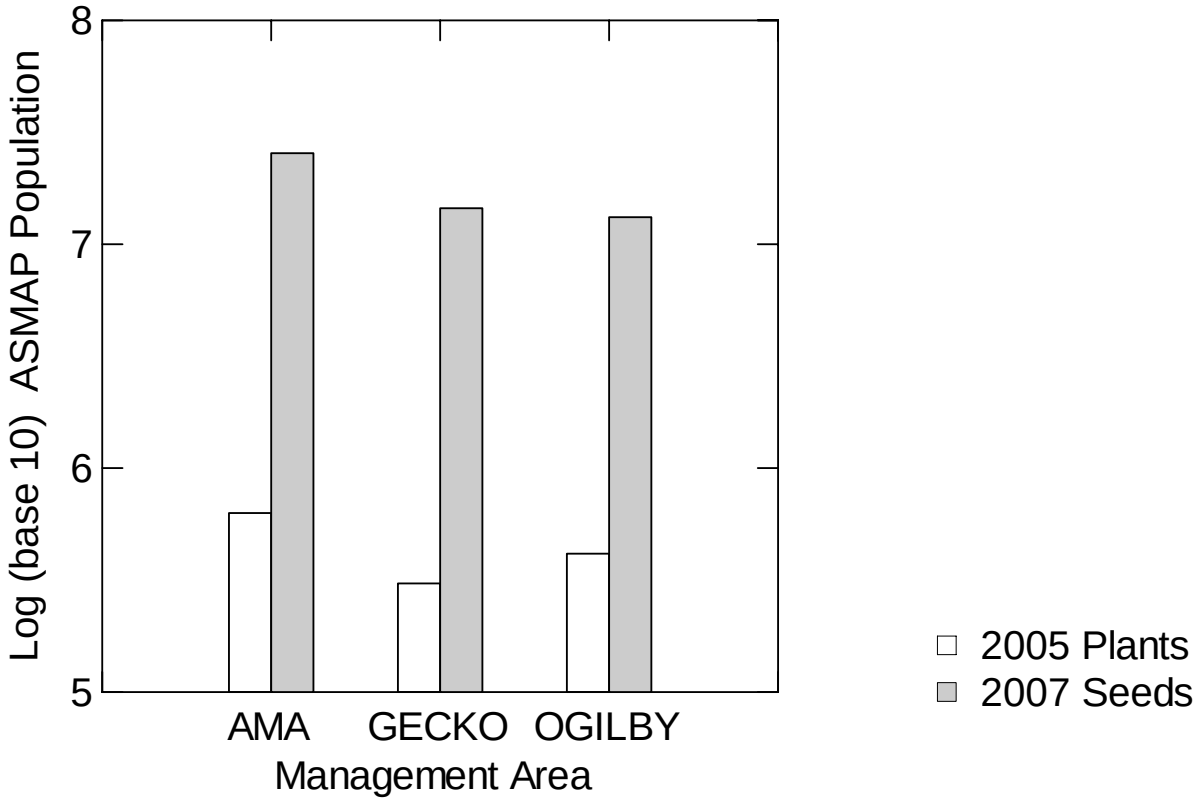
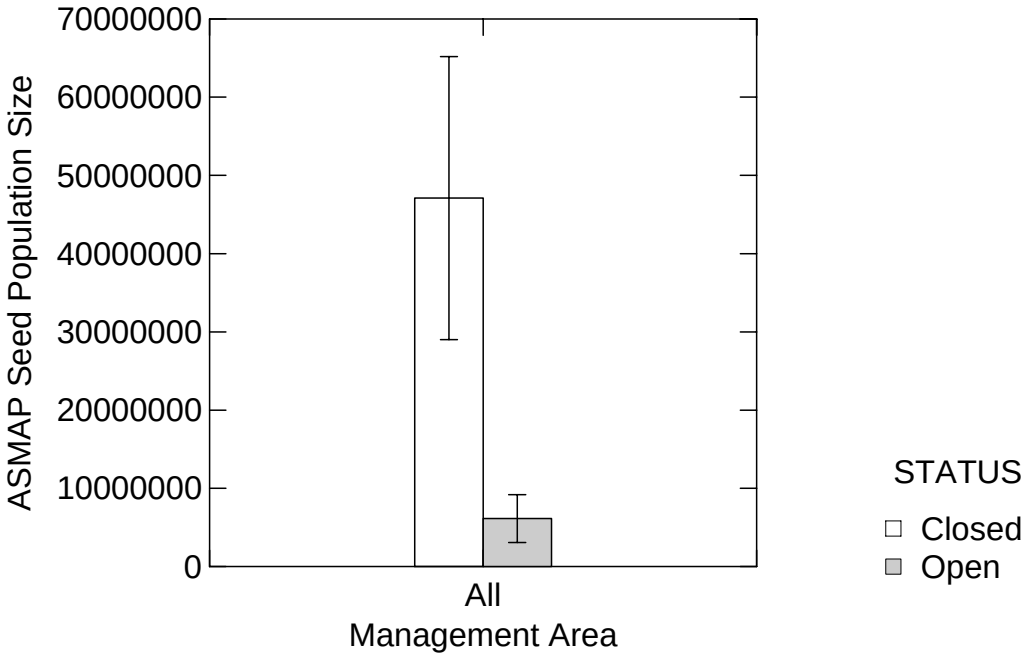



**Figure 9.** Relationship of number of ASMAP plants in 2005 to number of seeds in 2007. Logs (base 10) were taken of the values for scaling purposes.

**A.**




**B.**

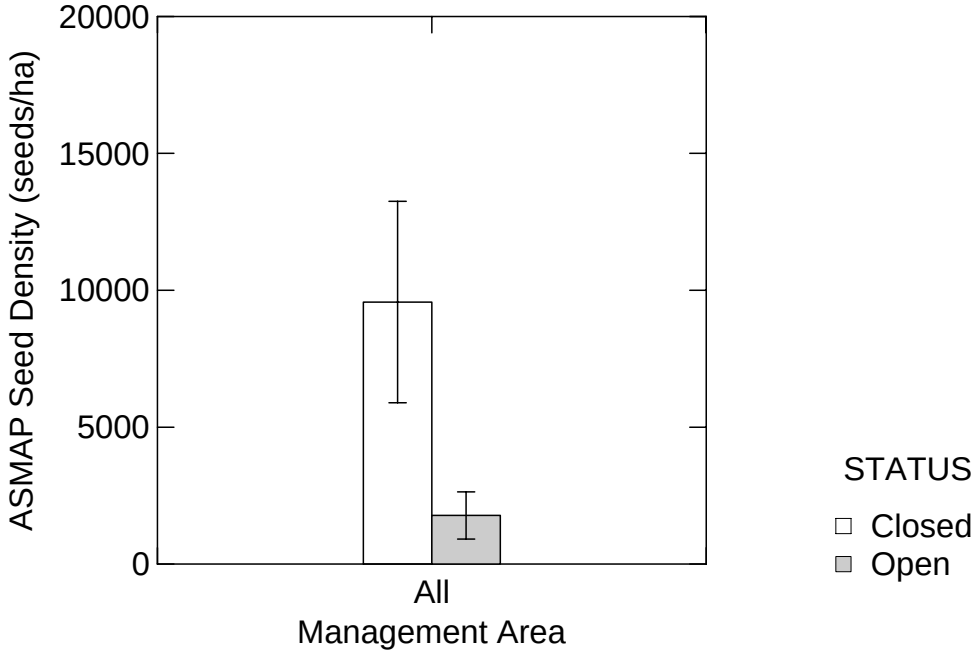



**Figure 10.** ASMAP seed population size (A) and seed density (B) for the closed and open parts of the entire area sampled in 2007. Error bars are 95% confidence intervals.

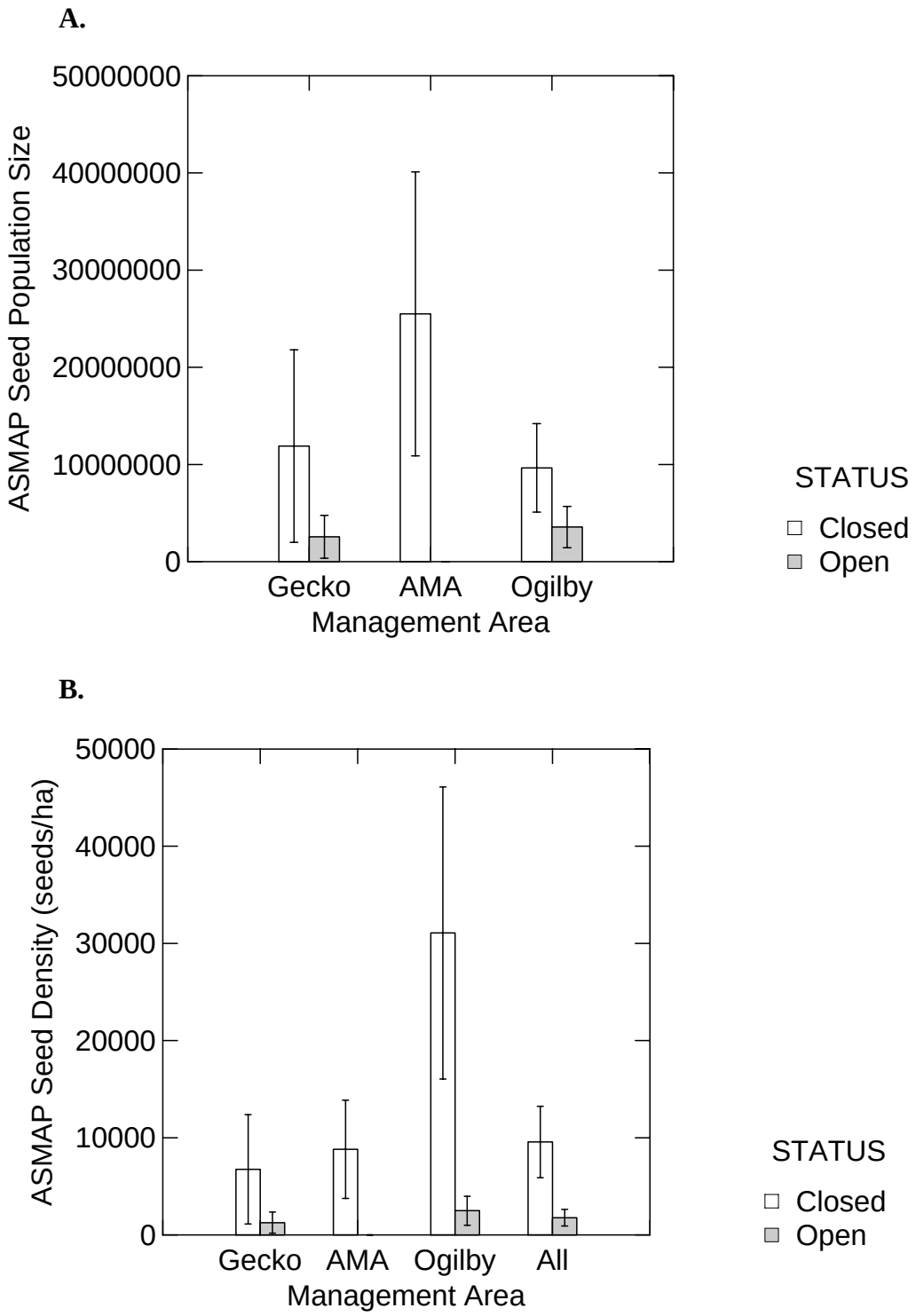



**Figure 11.** ASMAP seed population size (A) for the closed and open parts of the three management areas sampled in 2007 and seed density (B) for the closed and open parts of the three management areas and the entire sampled area ("All"). Error bars are 95% confidence intervals. The AMA has no open area values because the entire ASMAP habitat there is closed to OHVs.

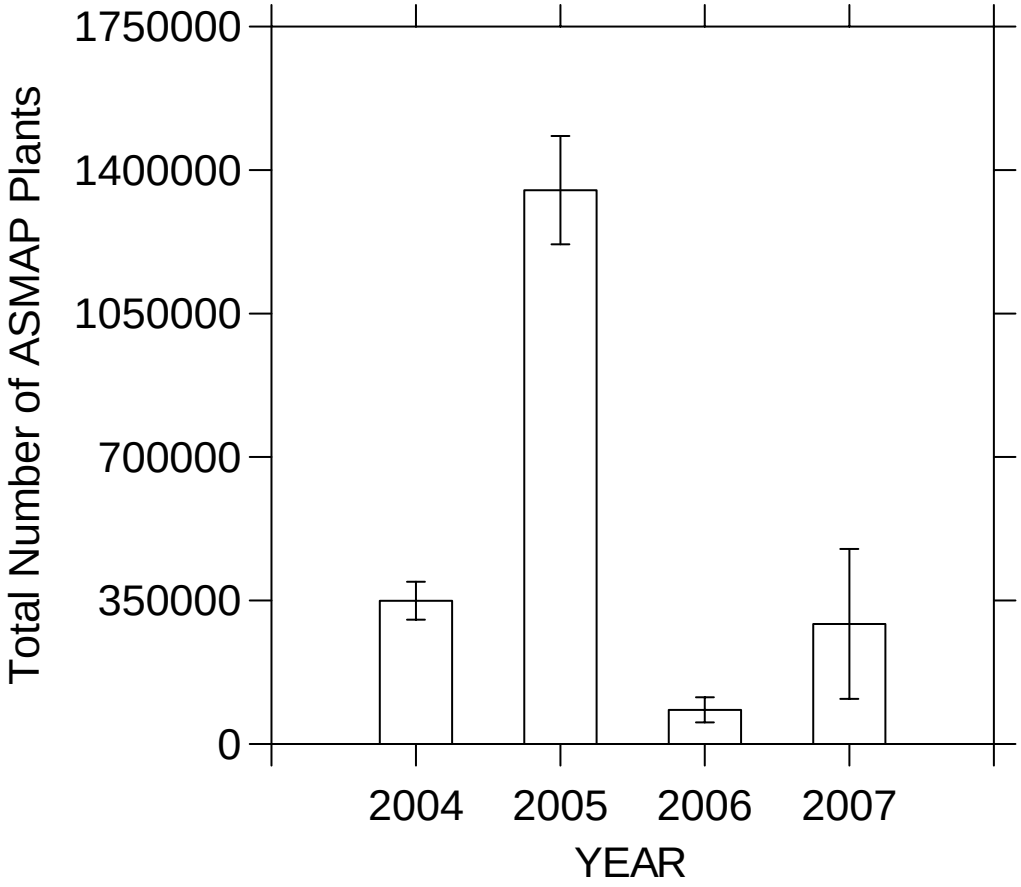
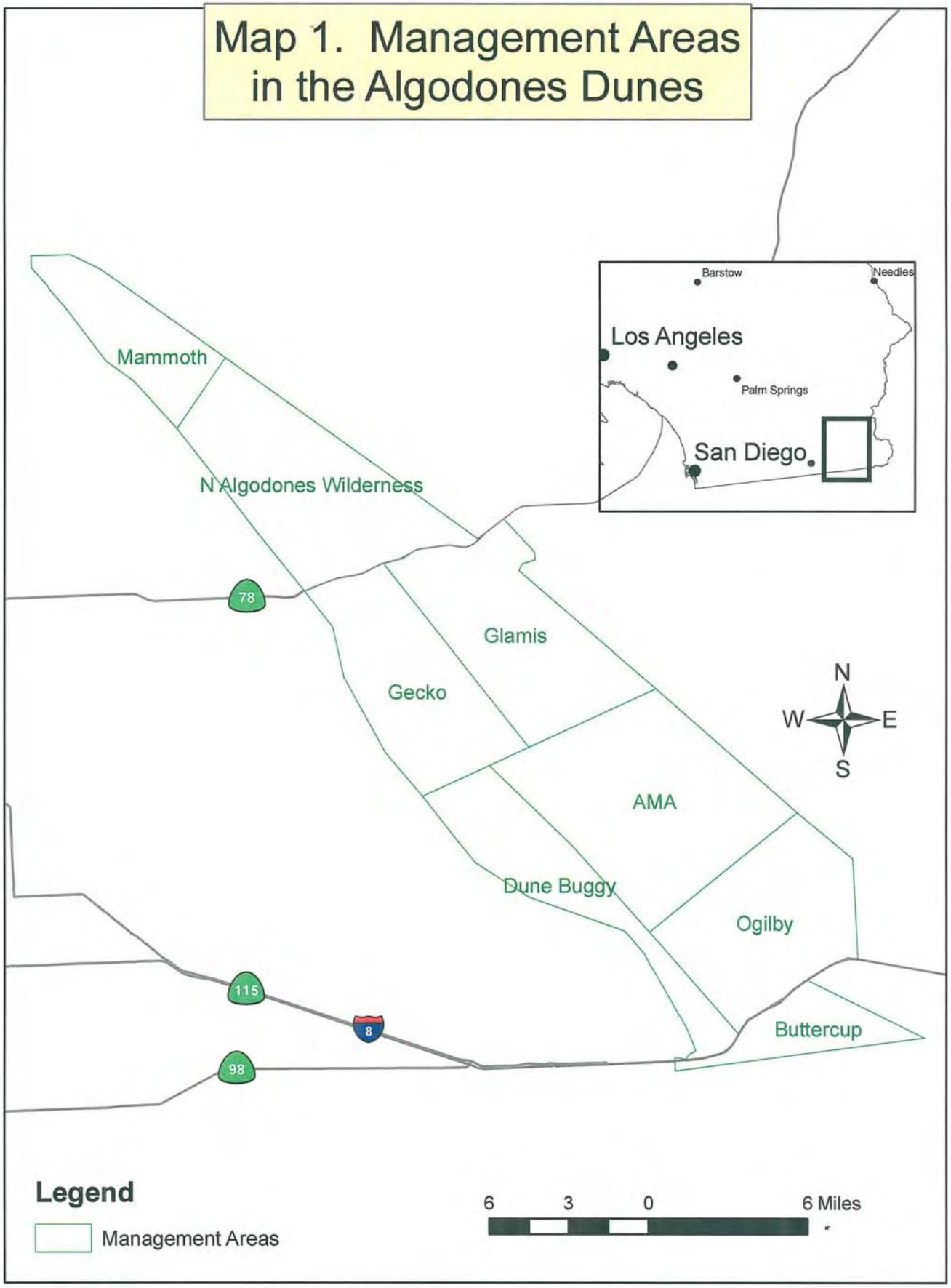
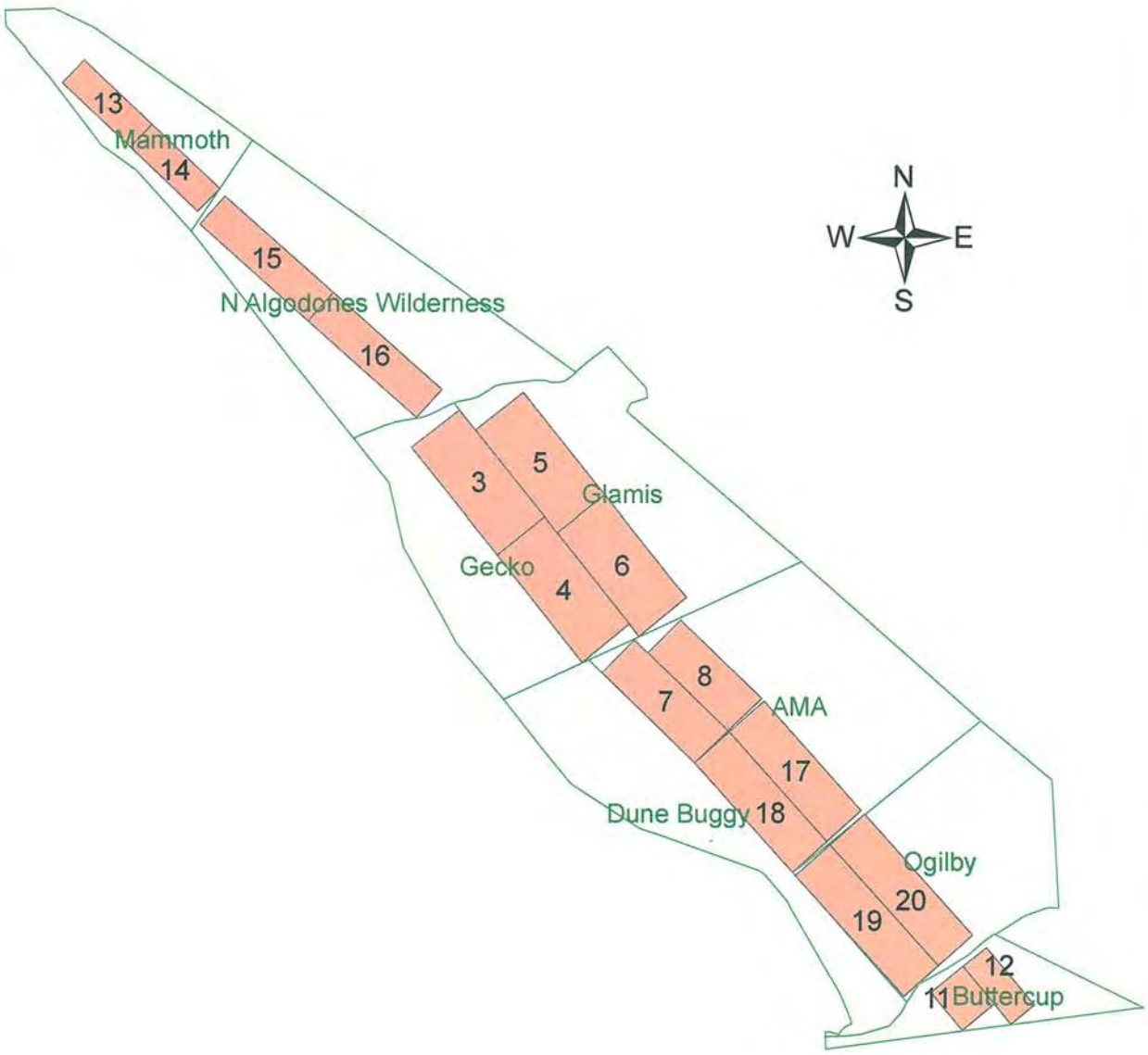



**Figure 12.** Total number of ASMAP plants by year in the total area sampled in 2007. Estimates for 2005, 2006, and 2007 are for the 5 sampling areas sampled in 2007 (both sampling areas in the Gecko MA, 2 out of the 4 in the Adaptive MA, and 1 of the 2 in the Ogilby MA). Estimates for 2004 are based on sampling in the entire Gecko, Adaptive, and Ogilby MAs (because sampling areas for the Adaptive and Ogilby MAs were not the same in 2004 as in subsequent years). See text for further discussion. Error bars are 95% confidence intervals.

# Map 1. Management Areas in the Algodones Dunes



# Map 2. Sampling Areas in the Algodones Dunes

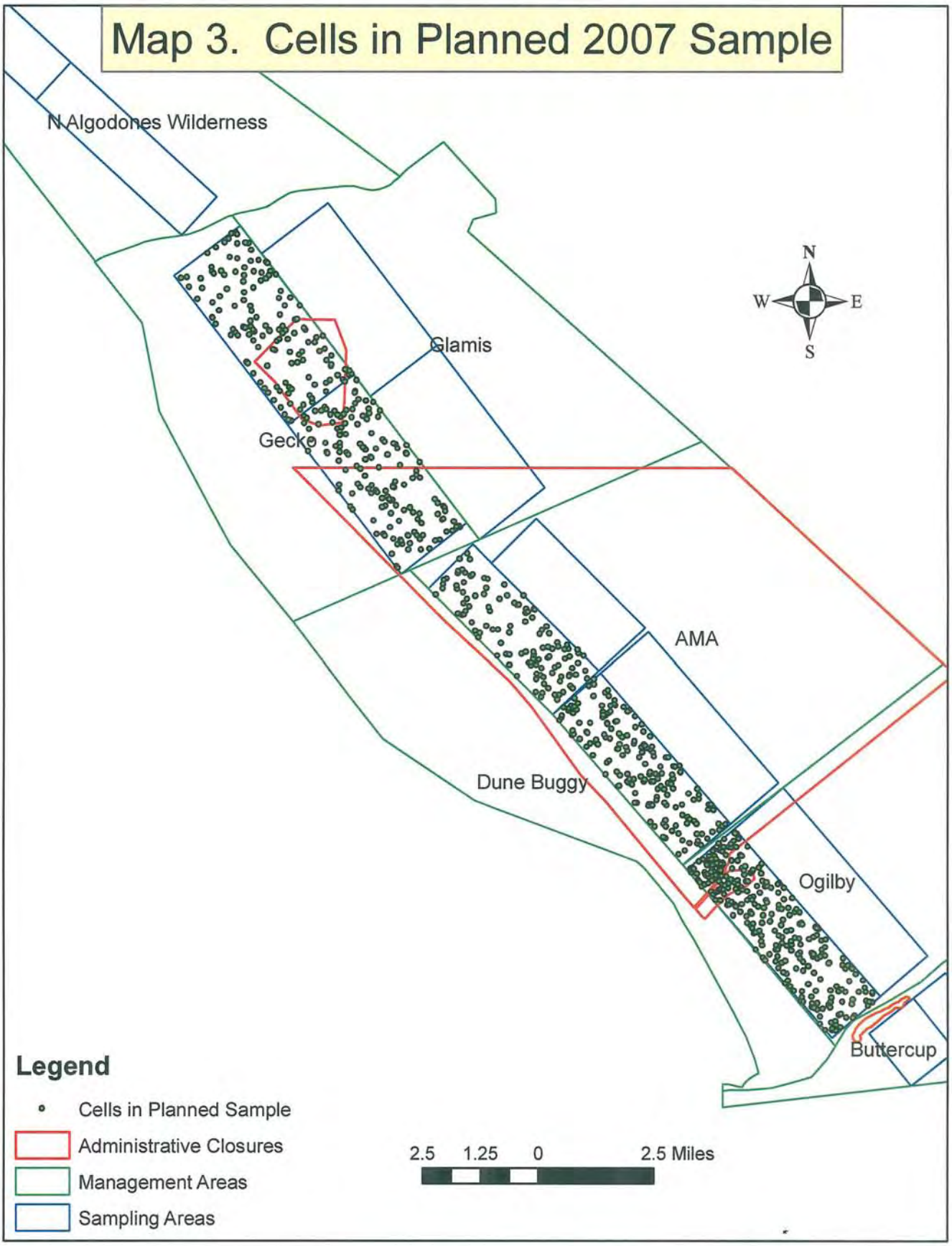


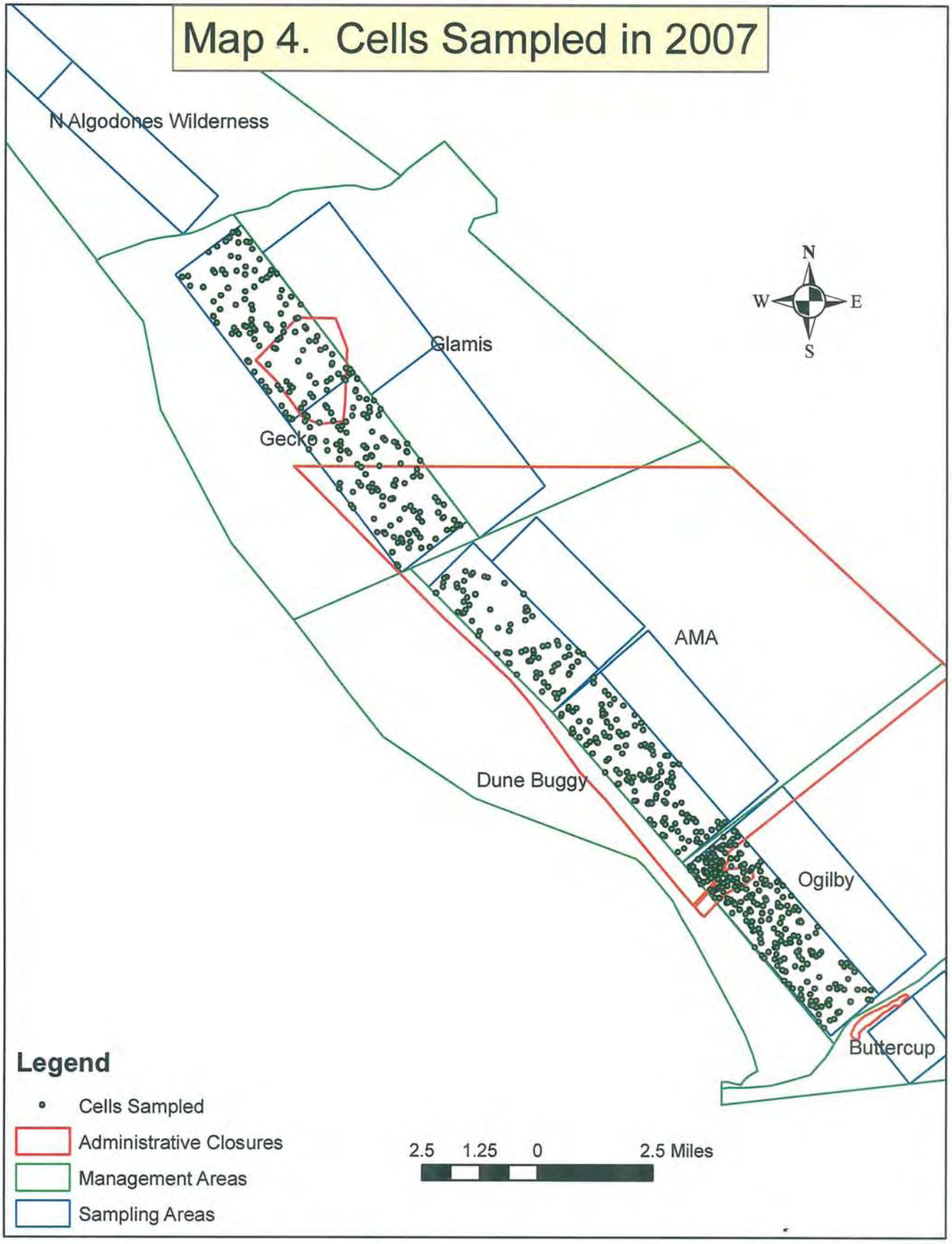

**Legend**

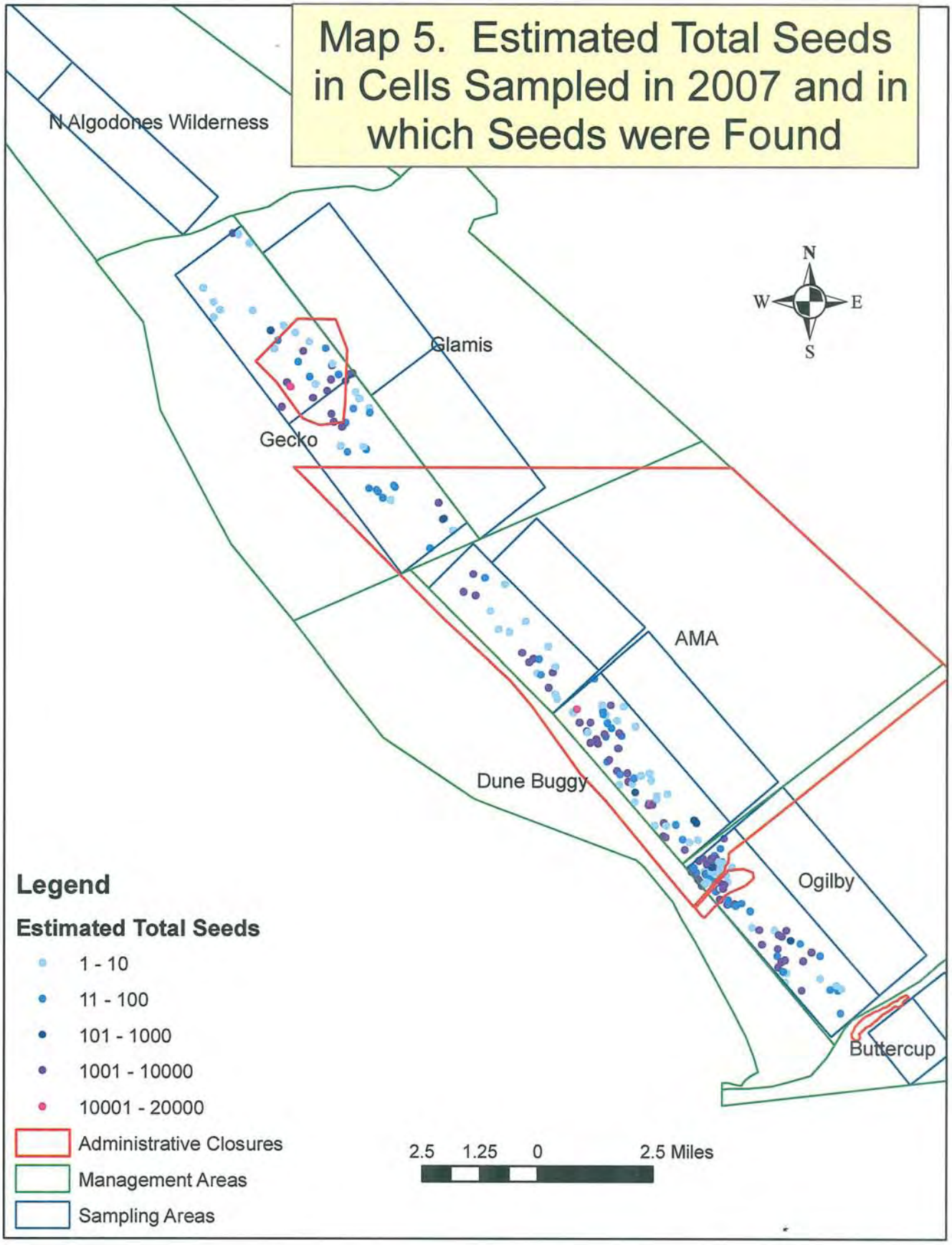
Sampling Areas

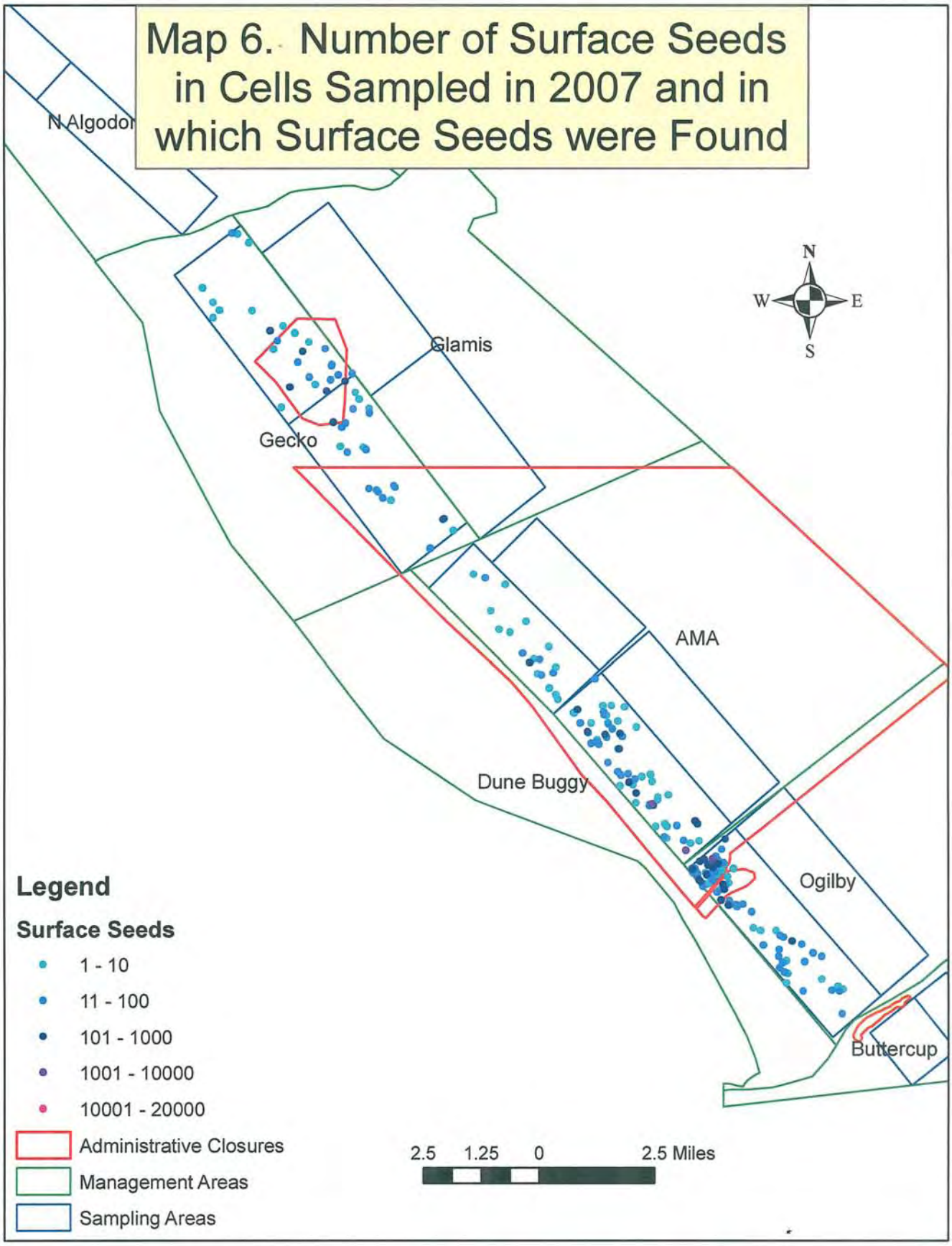
Management Areas

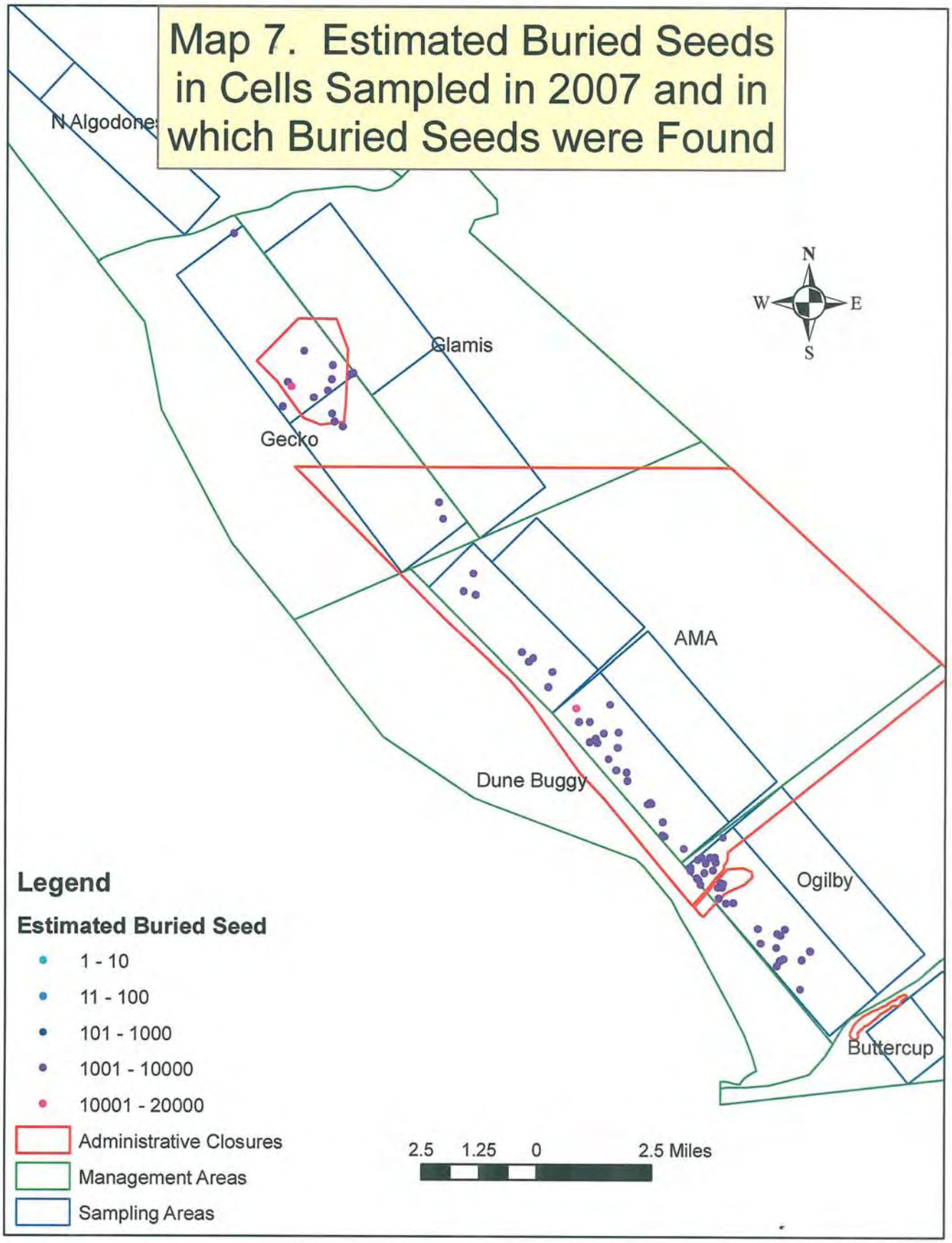
6 3 0 6 Miles

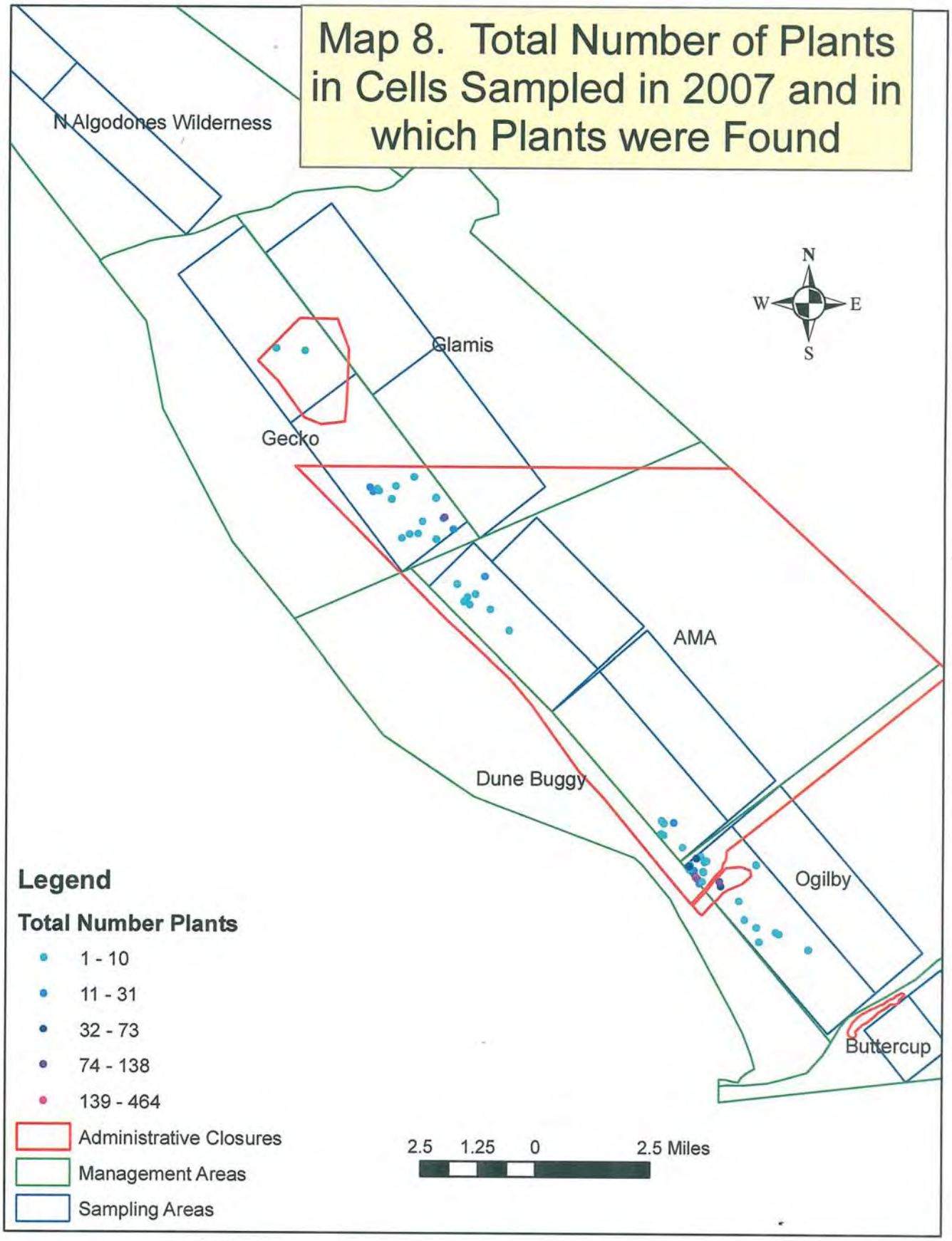

Map 3. Cells in Planned 2007 Sample
N Algodones Wilderness
Glamis
Gecko
AMA
Dune Buggy
Ogilby
Buttercup
N
W
E
S
Legend
Cells in Planned Sample
Administrative Closures
Management Areas
Sampling Areas
2.5 1.25 0 2.5 Miles


Map 4. Cells Sampled in 2007
N Algodones Wilderness
Glamis
Gecko
AMA
Dune Buggy
Ogilby
Buttercup
N
W
E
S
Legend
Cells Sampled
Administrative Closures
Management Areas
Sampling Areas
2.5 1.25 0 2.5 Miles

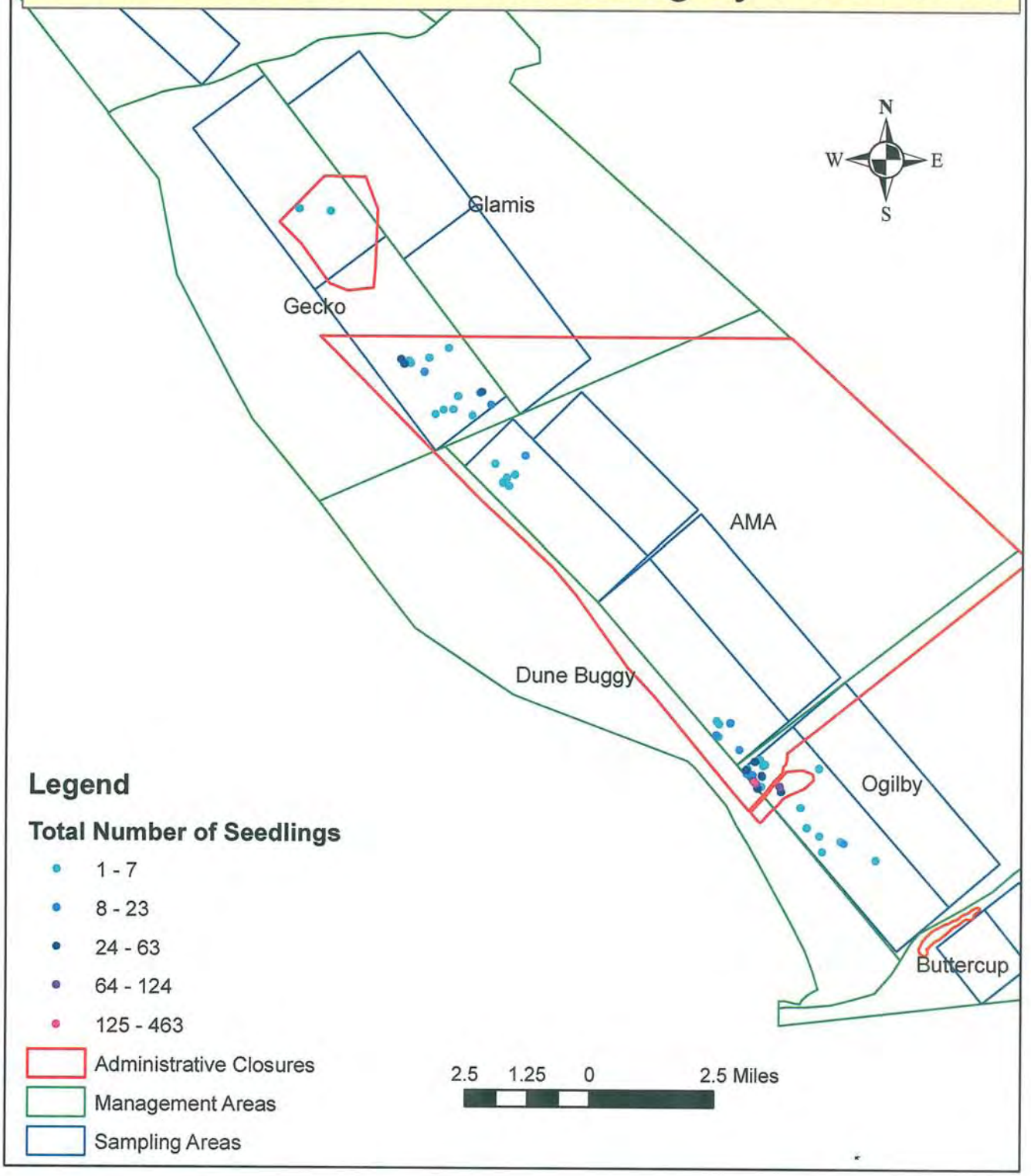

Map 5. Estimated Total Seeds in Cells Sampled in 2007 and in which Seeds were Found
N Algodones Wilderness
Glamis
Gecko
AMA
Dune Buggy
Ogilby
Buttercup
N
W
E
S
Legend
Estimated Total Seeds
1 - 10
11 - 100
101 - 1000
1001 - 10000
10001 - 20000
Administrative Closures
Management Areas
Sampling Areas
2.5 1.25 0 2.5 Miles

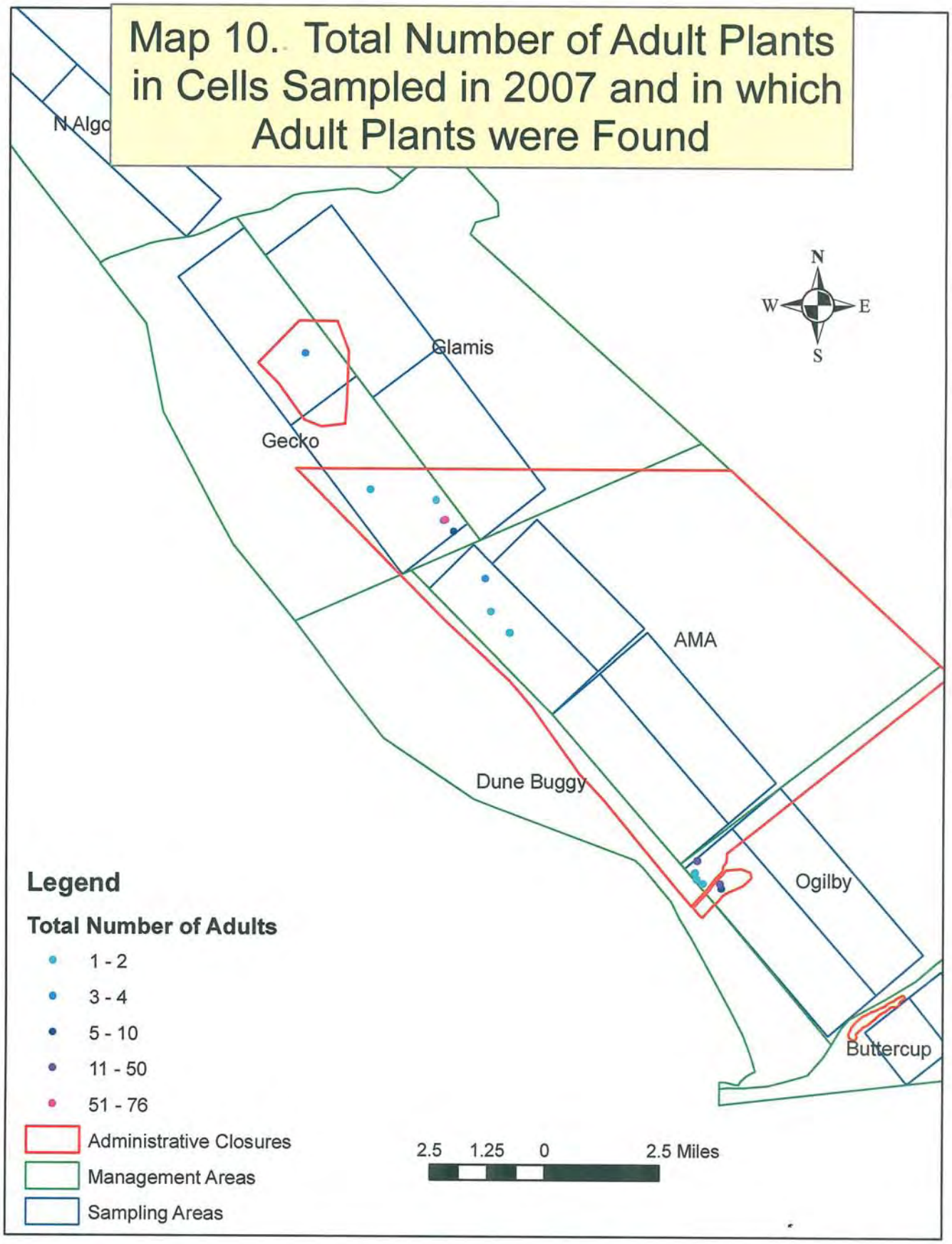

Map 6. Number of Surface Seeds in Cells Sampled in 2007 and in which Surface Seeds were Found
N Algodon
Glamis
Gecko
AMA
Dune Buggy
Ogilby
Buttercup
N
W
E
S
Legend
Surface Seeds
1 - 10
11 - 100
101 - 1000
1001 - 10000
10001 - 20000
Administrative Closures
Management Areas
Sampling Areas
2.5 1.25 0 2.5 Miles


Map 7. Estimated Buried Seeds in Cells Sampled in 2007 and in which Buried Seeds were Found
N Algodones
Glamis
Gecko
AMA
Dune Buggy
Ogilby
Buttercup
N
W
E
S
Legend
Estimated Buried Seed
1 - 10
11 - 100
101 - 1000
1001 - 10000
10001 - 20000
Administrative Closures
Management Areas
Sampling Areas
2.5 1.25 0 2.5 Miles


Map 8. Total Number of Plants in Cells Sampled in 2007 and in which Plants were Found
N Algodones Wilderness
Glamis
Gecko
AMA
Dune Buggy
Ogilby
Buttercup
N
W
E
S
Legend
Total Number Plants
1 - 10
11 - 31
32 - 73
74 - 138
139 - 464
Administrative Closures
Management Areas
Sampling Areas
2.5 1.25 0 2.5 Miles

# Map 9. Total Number of Seedling and Juvenile Plants in Cells Sampled in 2007 and in which Plants in this Category were Found




Map 10. Total Number of Adult Plants in Cells Sampled in 2007 and in which Adult Plants were Found
N Algo
Glamis
Gecko
AMA
Dune Buggy
Ogilby
Buttercup
N
W
E
S
Legend
Total Number of Adults
1 - 2
3 - 4
5 - 10
11 - 50
51 - 76
Administrative Closures
Management Areas
Sampling Areas
2.5 1.25 0 2.5 Miles