Measuring the sustainability of Artichoke Thistle (*Cynara cardunculus*) control efforts following suspension of control activities in historic southern California rangeland

Final Report to the
Nature Reserve of Orange County (NROC)

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Overview. Artichoke Thistle (*Cynara cardunculus*; CYCA), a deep-rooted perennial thistle, is an extremely problematic invader of disturbed grasslands in southern California. It has invaded large areas (over 4,000 acres) of the Nature Reserve of Orange County (NROC). The NROC, working with The Nature Conservancy (TNC), established a control program for CYCA involving direct application of herbicide to individual plants. Thousands of acres have been treated annually since 1994. We had two objectives of this project. First, we resurveyed areas initially surveyed in 1998 to assess the changes in areas that have been part of the control program. We particularly focused on changes in CYCA cover, and what was replacing CYCA in areas where it was controlled. Secondly, we initiated a long-term monitoring program to assess how treated areas responded to the cessation of control. We detail the results of both of these efforts in this report, and include data collected as part of the accompanying CD.

Summary of Results. We resurveyed 116 areas in the NROC where treatment to control artichoke thistle invasion had occurred for at least 3 years. These areas encompassed the variation in soil type and past invasion intensity representative of the coastal areas of the reserve. Our major findings are as follows:

- Control efforts have been successful in reducing the invasion of artichoke thistle, and were particularly effective in heavily infested sites.

- Both the exotic mustard and native species (likely needlegrass, *Nassella*) have increased in response to the reduction of thistle in the reserve. It appears that a portion of mustard increase is unrelated to the thistle control program and instead related to yearly rainfall variability or release from grazing. The increase in native cover closely tracks the reduction in thistle and, particularly for needlegrass, likely indicates a positive long-term trend.

- Weather conditions were unusually dry in 2007. This may have caused an underestimation of the cover of several species. An assessment in non-drought year is needed.

- To assess how reserve areas will respond after the control program ends, we established and collected baseline data on 26 30m x 30m plots where control (herbicide application) will be excluded starting in 2008.

METHODOLOGY

I. Resurvey. During April and May 2007, we resurveyed 116 areas initially surveyed in 1998. We used the same polygon delimitation as the initial survey, and tried to make our sampling methods as comparable as possible with the previous effort. We use the terms "polygon" to describe the unit area of sampling, "TNC survey" to refer to the initial survey conducted in 1998, and the "UCI survey" to refer to the 2007 survey. We also refer to species with abbreviations comprised of the first two letters of the genus and first two of the species scientific name (e.g., CYCA for *Cynara cardunculus*).

We collected data in areas delineated by the TNC Weed Mapping survey. TNC polygons were coded by numbers (Example: 1.1.002). The first number corresponds to a "unit," or geographic region (e.g. Unit 1 = Central sites, Unit 2= Coastal sites). The second number corresponds to "subunit" of the area. Subunits are based on ownership, watershed, or geographic boundaries. The third number indicates the individual polygon located within a subunit. We continue the use of this nomenclature.

It is critical to interpret these data in light of the fact that 2007 was an extremely dry year, with approximately 2 inches of rainfall or less than a fifth of average annual precipitation. Many species did not emerge due to these drought conditions, and we particularly expect our estimates of native richness to be underestimates.

Polygons range in shape and size. They were originally determined based on a combination of factors: the presence or absence of CYCA, the generally heterogeneity of the dominant vegetation, and geographic boundaries surrounding grasslands. These polygons were determined in the field by surveyors. To determine the extent of the polygons for the current survey, we used a combination of aerial maps superimposed with the polygon boundaries, GPS coordinates, ground-level photos taken by TNC during the initial survey, and their field notes. We are fairly confident that we were able to correctly identify the polygon boundaries to within several meters in most cases. In cases were it was unclear, we consulted Trish Smith, who was the lead on the original survey and had an excellent memory of the site delimitation.

The original TNC survey identified 917 polygons. We restricted the set of polygons we could potentially resample according to the following criteria: 1) that they had been treated at least two years for CYCA control during the last decade; 2) that they were not on "marginal" or unusual soil types (so we could stratify by the generalized sand-clay gradient in the reserve); and 3) that they hadn't been subjected to intense active restoration (burning, frequent mowing, seeding; this occurred mostly in Crystal Cove State Park). In total, our criteria resulted in 136 possible polygons to resurvey, and we surveyed 116 of these.

Survey method. In each polygon, 2-4 people conducted walk-through ocular estimates of polygons. In each walk-through, surveyors estimated percent cover (using cover classes) of CYCA, annual grasses, Nassella pulchra (NAPU), other native species, and other exotic species. The top species (over 10%) were recorded and their cover estimated separately. A list of all native species present in the site was also recorded.

Because this season was unusually dry, we modified some of our measurement to account for this year's low growth. The percent of this year's vegetative cover was estimated based on green growth. Two cover class estimates were taken for *Brassica nigra* (BRNI) and annual grasses, present vegetation and last year's vegetation, as last year/present year vegetation was easily distinguished. This distinction did not seem to be important with perennials such as CYCA and NAPU; although we did record two values for all species groups. It is also important to note that, due to this dry year, our results are biased in favor of some types of species (NAPU seemed to do fairly well) and missed the dynamics of other (very few geophyte bulbs emerged, for instance).

We also used soil maps to identify soil type for each of the polygons. When there were multiple soil types, we characterized the soil type with the greatest coverage in the polygon. We also calculated average slope and aspect and the area for each polygon. We also calculated the number of years treated for each polygon; when some portions of the polygon were treated more often that other portions, we used the maximum years treated.

All data were compiled, quality-checked, and archived in a MS Access database. All data collected, with corresponding metadata, accompanies this report.

Data comparison with TNC survey. We have worked to standardize our survey with the TNC survey, reconciling some inconsistent values and notations. The TNC survey focused on problematic exotic weeds, and so did not explicitly record cover of particular native species (i.e., NAPU, *Artemisia*) or annual grasses as we did in our survey. Thus, we can not follow the change in specific native species or annual grass cover through time. In addition, the TNC survey estimated the cover of the four most abundant exotics, and so if they did not record the cover of one of the focal exotics (i.e., CYCA, BRNI), we assumed that its cover had to have been less than the cover of the exotics recorded. We had to make these estimations in 30% of the polygons for BRNI cover and 16% of the polygons for CYCA cover.

Data analyses. Statistical analyses were preformed in SYSTAT. Change in cover of the focal groups were calculated as the difference in cover classes rather than the differences in the mean cover of each cover class to ensure normality in the dataset. Because cover classes are more narrow at low abundances, this also preserves the natural abundance distribution (where most species are at low abundances and very few reach high abundances. We focused on foru response variables: change in CYCA cover, change in BRNI cover, change in native cover, and change in native species richness. For all response variables, we followed the same analysis procedure. First, simple paired t-tests were used to test changes in cover across the entire dataset. Then multiple regressions were run with the following predictor variables: soil type (sand or clay), years treated, most recent year treated, and Nassella cover (2007). For species other than CYCA, the models also included change in CYCA cover. The best regression model was selected using AIC criteria. Lastly, data were graphed spatially using GIS. These maps are included in the appendices of this report.

II. Experimental Control Plots (ECP). We have also initiated work to address the question: what is the response of the treated areas after cessation of intensive control efforts? In 2007, we laid out plots to designate areas where we will ask the herbicide crew not to herbicide CYCA in the future so we can assess recovery. We have initiated vegetation monitoring in 26 plots within the Nature Reserve of Orange County. The 30m x 30m ECPs span the 2007 UCI surveyed areas in the NROC. The plots are delineated by flagged green t-posts on each corner, and are set up in locations which represent the predominant soil and vegetation types, as well as varying herbicide treatment history. A GPS coordinate has been recoded for each plot.

Transects. Three 30 meter transects were laid out in the ECP. Transects were set 5 meters from each t-post, inside the ECP, and were spaced 10 meters apart evenly. A ½ x ½ meter frame was placed every 5 meters, on alternating sides of the transect, beginning 2 meters within the edge of the ECP.

Data Collection. In 2007, we collected baseline data to allow us to follow species composition, and particularly NAPU and CYCA over time. In each plot, we recorded cover of the following groups: annual grasses, native grasses, other native species and other exotic plant species, as well as liter and percentage live vegetation. Counts of all *Nassella pulchra* and CYCA were also noted for each plot, as well as any plants species not accounted for in the transect data were noted. Lastly, we collected soil samples in each plot to assess the composition of the seed bank via germination trials in the UCI greenhouse this fall.

RESULTS

I. Dynamics over time: Resurvey results.

Since 1998, CYCA cover has decreased across the surveyed polygons (Fig. 1a; Fig. 2). Most notably, in areas that were heavily invaded in 1998, control has successful reduced cover to less than 10% in all but 9% of the surveyed areas. CYCA cover remained highest on sites high in clay content. While there was no relationship in the change in CYCA cover and number of years treated, CYCA cover was lower in areas that were more recently treated.

Our main question was focused on whether passive restoration of native perennial grasses (e.g., NAPU) was occurring or if other problematic exotics (such as BRNI) were replacing CYCA. Over this period, BRNI cover increased (Fig. 2). The majority of this change was due to the spread of mustard into 33 polygons that previously had no mustard present (Fig. 1b). There were no areas surveyed in 2007 that did not contain at least low levels of BRNI (Fig 1b). While the current (2007) cover of BRNI was relatively constant across all treated areas (Fig. 3a), BRNI increased the most in areas where CYCA reductions were greatest (Fig. 4a). However, BRNI also increased in areas where CYCA cover remained low or even increased and the response of BRNI was not related to CYCA treatment history. CYCA cover in 1998 and CYCA cover reduction were the best predictors of changes in BRNI cover; soil type did not influence its response. Taken together, these results suggest that BRNI cover is responding to some factor in addition to CYCA control. One possibility is that it could have been generally high across the reserve in 2006/2007 due to weather patterns. Alternatively, the cover increase in BRNI could be due to recovery following grazing. These would be important avenues to pursue in the future.

While the increase in BRNI cover was not consistent with passive restoration predictions, the survey also suggested that native cover increased over the last decade (Fig. 1c, Fig. 2). Most notably, areas with over 30% cover of natives were fairly infrequent (a tenth of all areas) in the surveyed area in 1998 and substantially increased in frequency in 2007 (over a third of the areas had >30% cover in 2007). Native cover increased in the areas where CYCA was reduced but also increased in areas where control kept CYCA cover constant (Fig. 4b). Native cover change was not influenced by years treated, most recent year treated, or soil type.

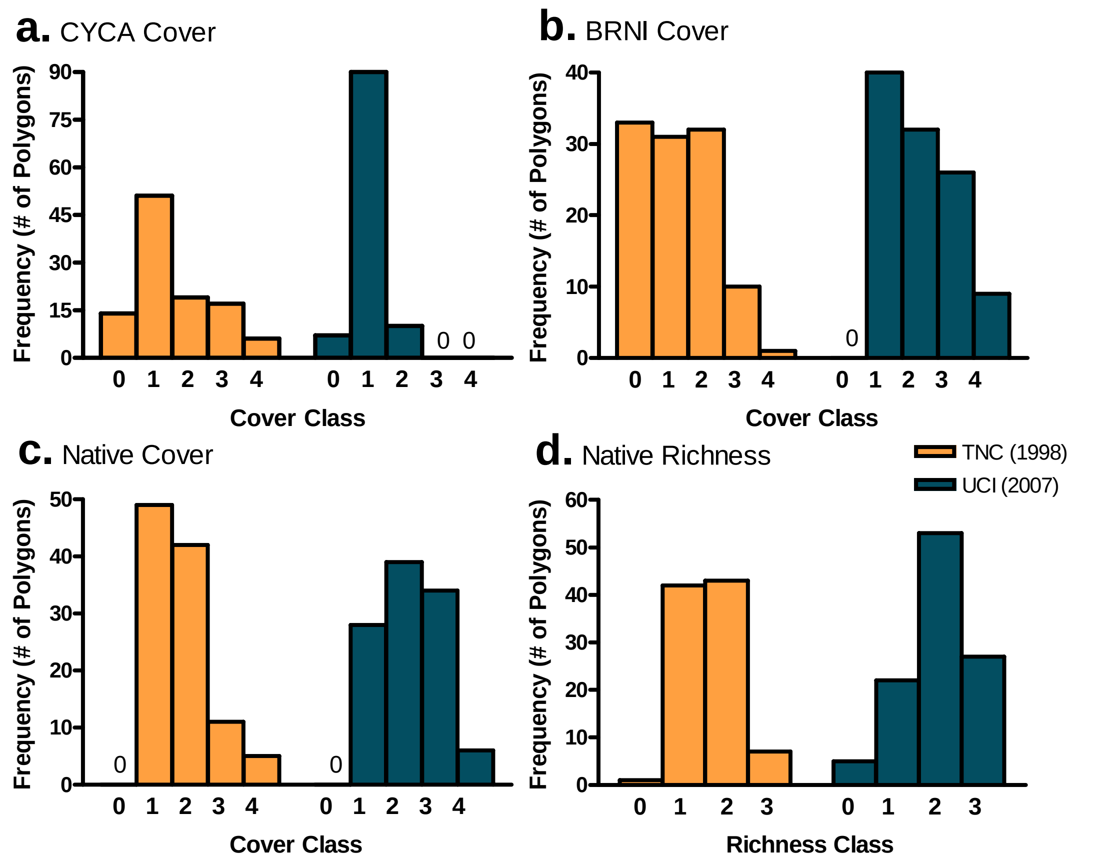


Fig. 1. Changes in the cover distribution of CYCA (a), BRNI (b), and native plant species (c) and changes in native richness (number of species)(d). Polygons are grouped according to cover class (0, not present; 1, 1-10%; 2, 11-30%; 3, 31-50%, and 4, >50%) or richness range (0, none present; 1, 1-3 species; 2, 3-10 species; 3, >11 species). Native richness was not estimated in 14 Polygons in the TNC survey.

Unfortunately, we can not determine changes in *Nassella* cover over time because the TNC survey did not record specifically record *Nassella* cover. Because 2007 was a severe drought year and many natives were absent due to the drought, the native cover estimates predominantly consisted of *Nassella* and coastal sage scrub species. *Nassella* cover in 2007 was high in areas where native cover substantially increased (Fig. 5b), suggesting that an increase in *Nassella* could be responsible for the increase in native cover in these areas. Interestingly, BRNI also increased the most in areas that had high Nassella cover in 2007 (Fig. 5a). Thus, it appears that in areas where CYCA has been reduced, both BRNI and Nassella are increasing.

We also assessed changes in native species richness between the 1998 and 2007 survey. We expect these data to be particularly affected by the unusual weather conditions in 2007. Overall, native species richness did not increase, and it was also not related to reduction in CYCA cover (Fig.4c). It did, however, significantly increase with the number of years treated (Fig. 6c). If this pattern persists in more typical precipitation years, this later result may indicate that repeated control measures are allowing native diversity to increase.

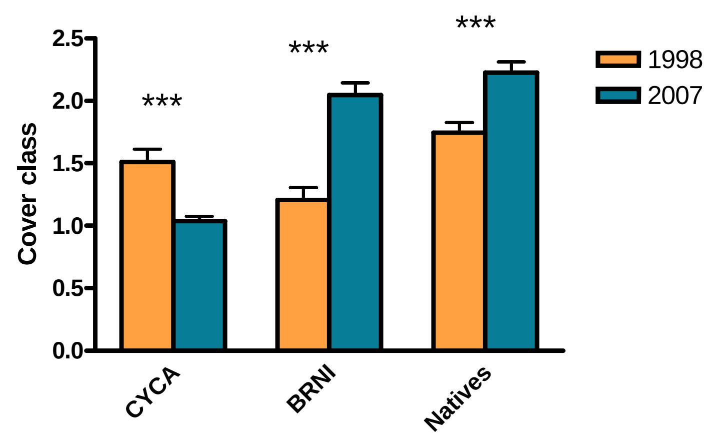


Fig. 2. Average change in cover of the three focal groups: CYCA, BRNI, and Natives. Shown are means across all polygons +/-1 std error. Asterisks indicate significant differences (P<0.001) between surveys. Cover class values range from 0 to 4 (0, not present; 1, 1-10%; 2, 11-30%; 3, 31-50%, and 4, >50%). There was no difference in native richness between surveys (not shown).

II. Sustainability of control efforts: experimental control plots.
We initiated this second project in the spring of 2007. Site locations are given in Figure 7. Baseline data are included in CD as part of this report.

CONCLUSIONS AND FINAL RECOMMENDATIONS

There is strong evidence that control efforts have substantially reduced CYCA over the past nine years. The majority of all areas had less than 10% cover of the thistle and artichoke thistle only increased in cover in less than 15% of the areas sampled. Control efforts appear to be most successful in reducing the highly infested sites (>30% cover) to more manageable levels of invasion (1-5%). Artichoke invasion was associated with clay soils, but control efforts were effective in all soil types and so soil type did not emerge as an important management consideration.

Thistle cover was most reduced in areas most recently treated. The length of treatment was not associated with the degree of thistle cover reduction, but the longer the area was treated, the greater the increase in native species richness. These dynamics need to be followed closely as treatment history lengthens to determine if longer treatment history is needed to slow CYCA re-invasion from surrounding areas and whether the increase in native diversity represents a invasion-resistant recovery trajectory in these areas.

It appears that both BRNI and native species (likely *Nassella*) have increased in response to the reduction of thistle in the reserve. We expect the increase of *Nassella* to be sustainable, as the plant is long-lived and competitive once established. The question whether the increase in BRNI is transient or persistent is an important one that requires a longer time frame to answer.

The unusually dry weather conditions in 2007 likely caused us to underestimate current cover and diversity of native species (many of which never emerged due to the lack of rainfall). An assessment in non-drought year is needed, as many of the differences between the surveys could be due to the differences in the weather in the two years.

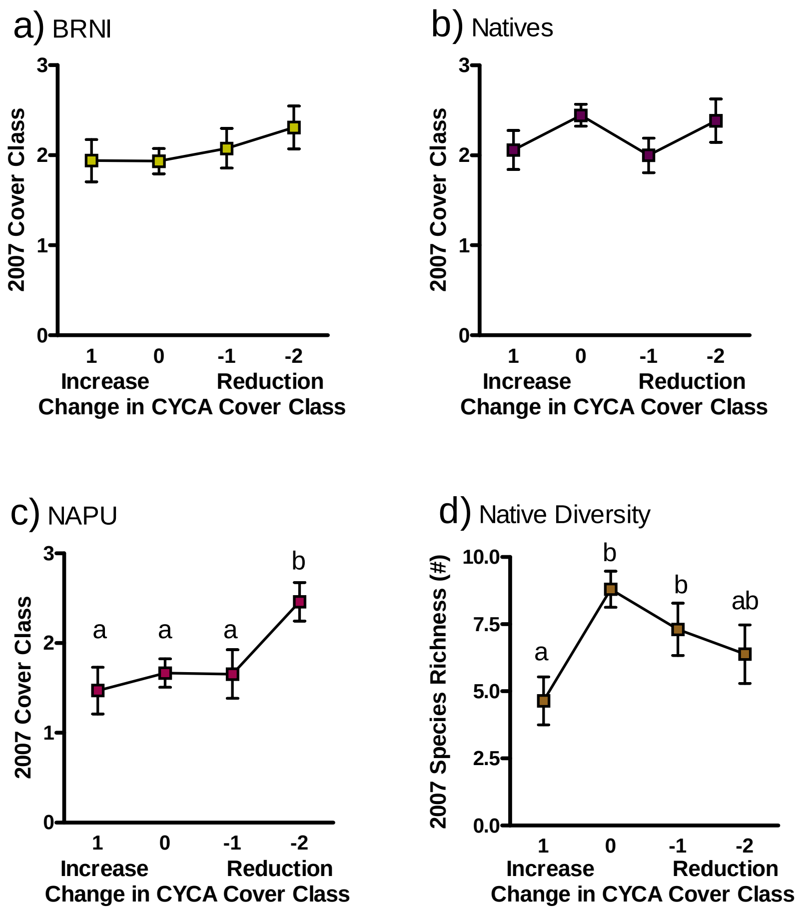


Fig. 3. The influence of CYCA reduction on current (2007) cover of BRNI (a), Natives (b), Nassella (c) and Native diversity (d). Cover class values range from 0 to 4 (0, not present; 1, 1-10%; 2, 11-30%; 3, 31-50%, and 4, >50%). Native diversity is actual richness counts of native species present in polygons in 2007. Different letters indicate significant differences; there were no differences between any reduction category for BRNI and Natives.

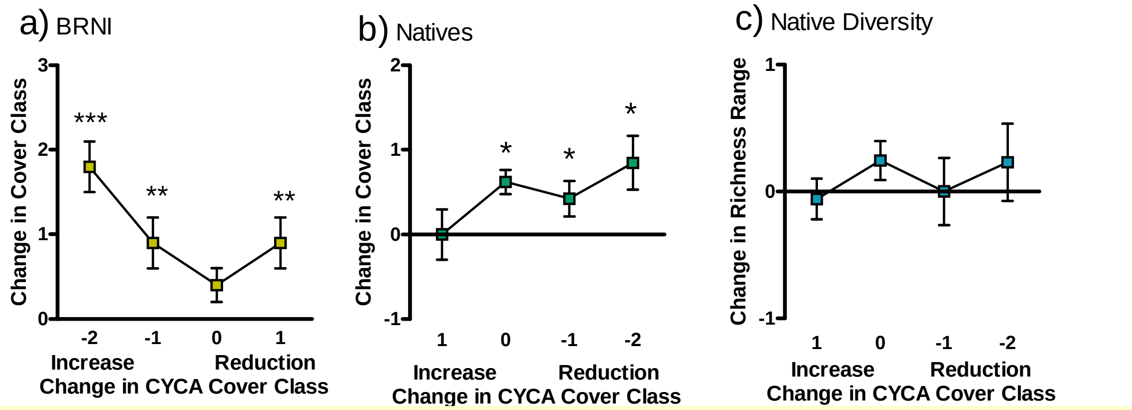


Fig. 4. The influence of CYCA reduction on the change in cover of BRNI (a), Natives (b), and Native diversity (c). Change in cover class is the difference between the cover in 1998 and cover in 2007; a positive value indicates an increase between the survey years. Asterisks indicate significant increased in cover (* P<0.05; ** P<0.01; ***P<0.005).

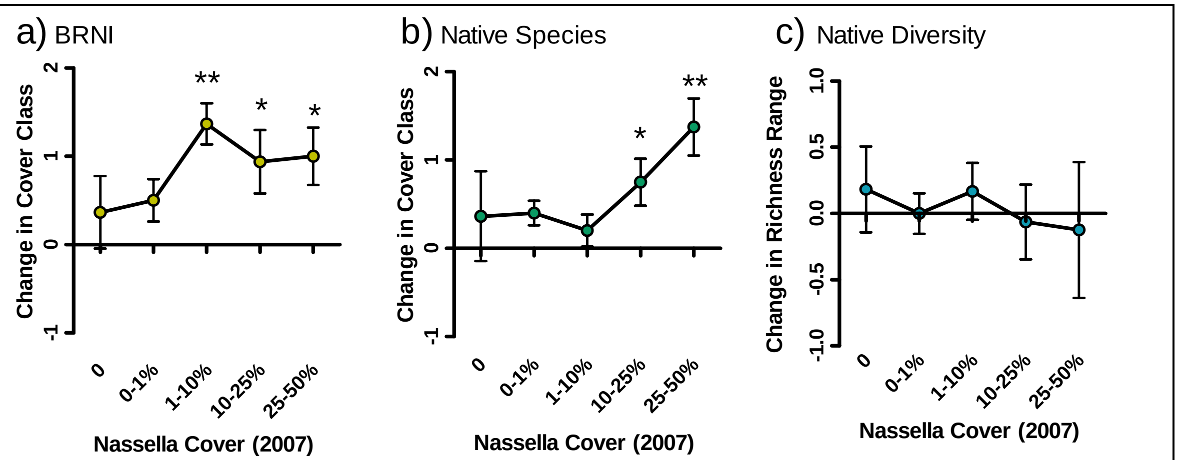


Fig. 5. The relationship between current (2007) *Nassella* cover and the change in cover of BRNI (a) and Natives (b), and the change in richness of natives (c). Asterisks indicate significant increased in cover (* P<0.05; ** P<0.01).

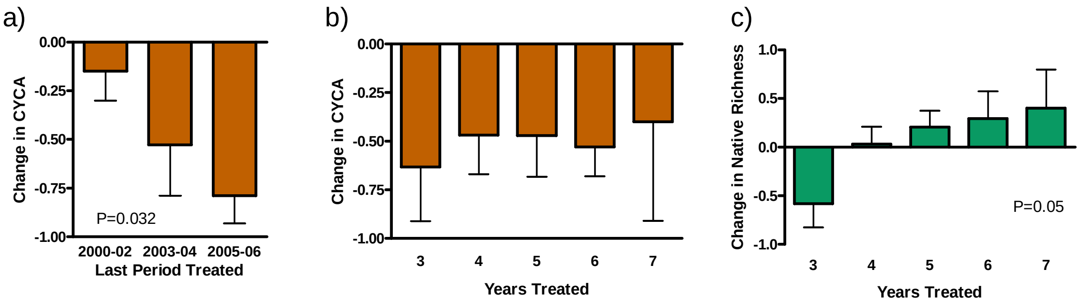


Fig. 6. The effect of treatment history on change in CYCA cover (a,b) and change in native richness (b). CYCA cover was reduced more in areas more recently treated (a) but was not affected by number of years treated. However, native richness increase was greatest in areas with long treatment histories.

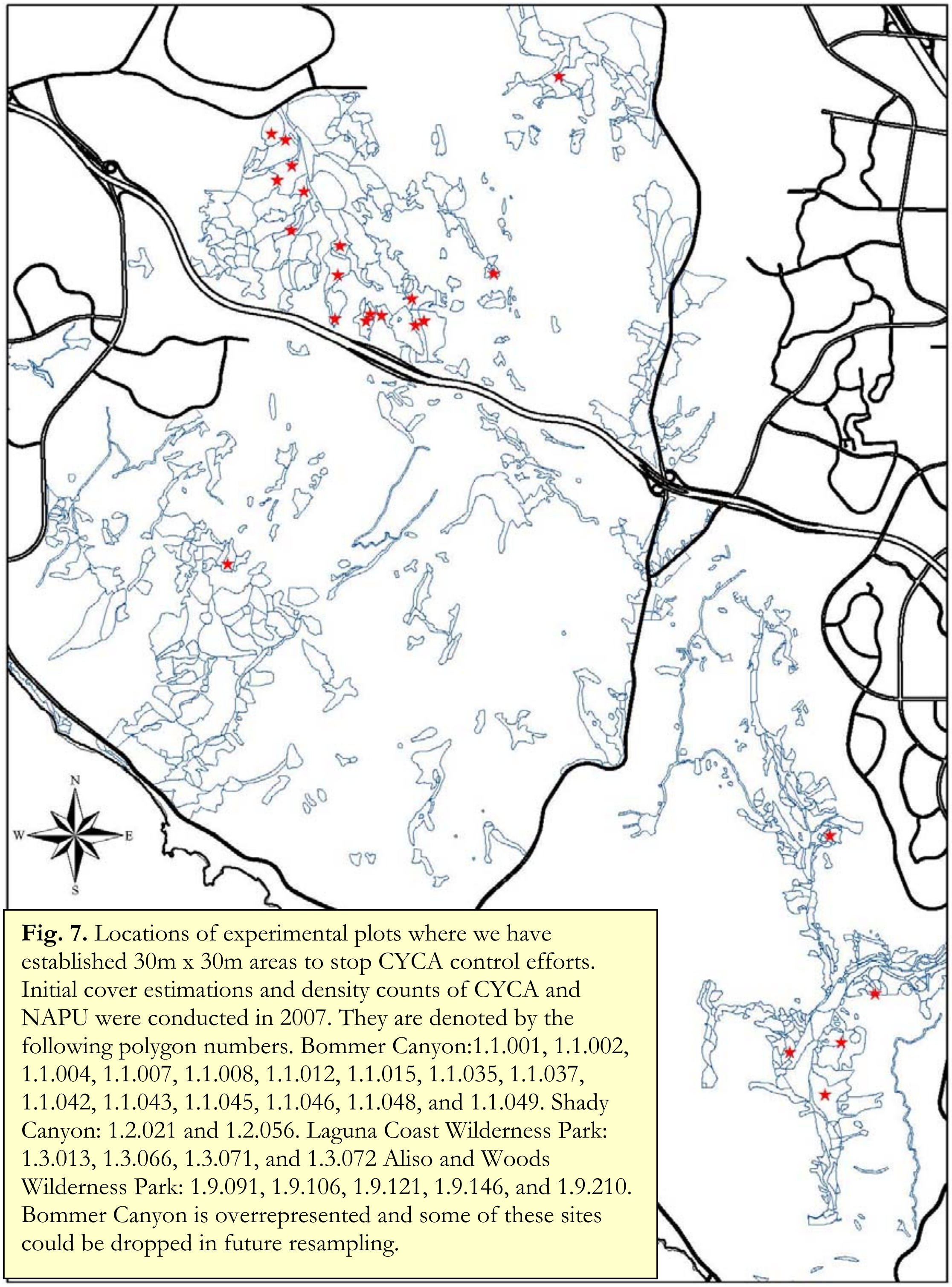
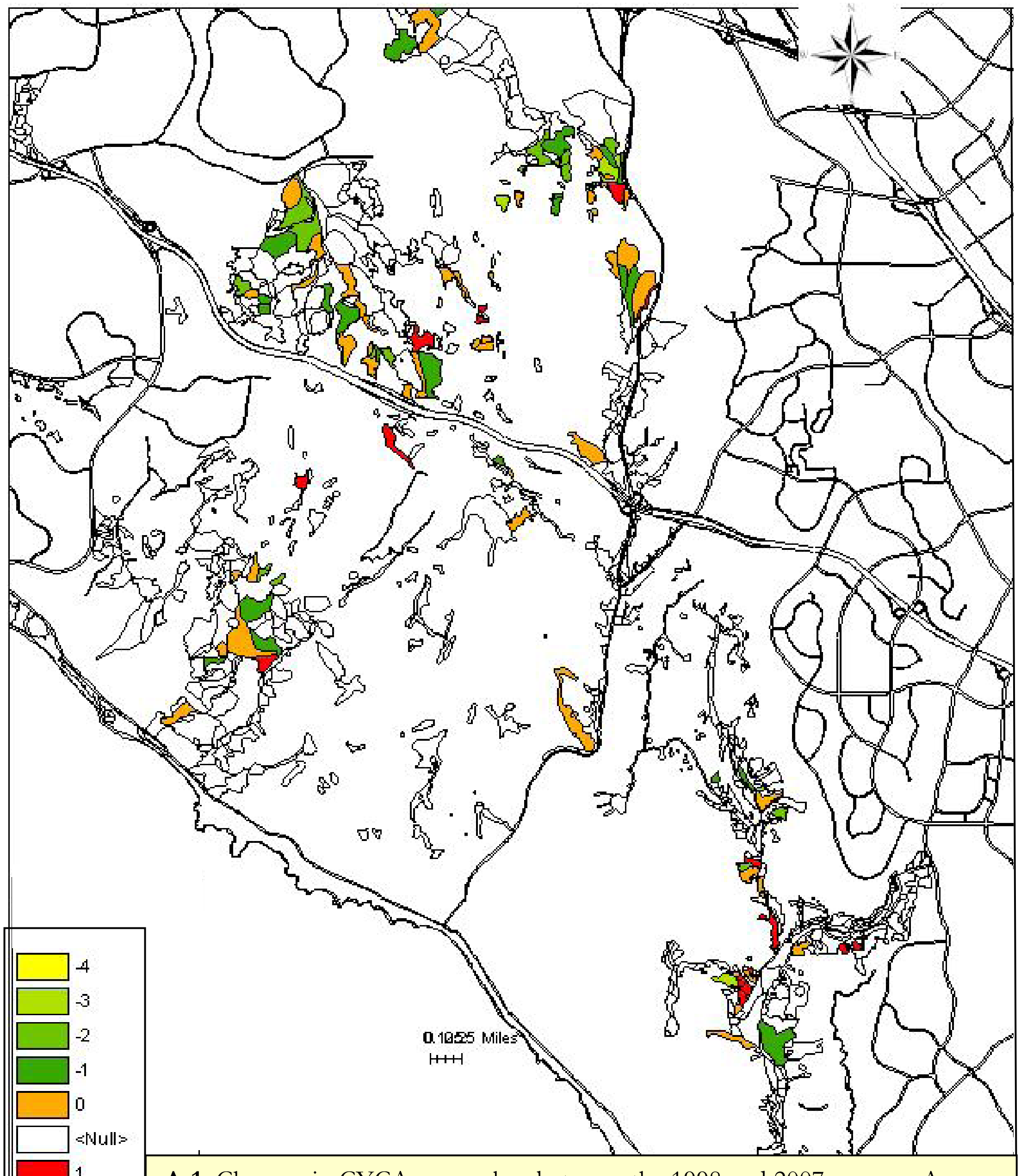


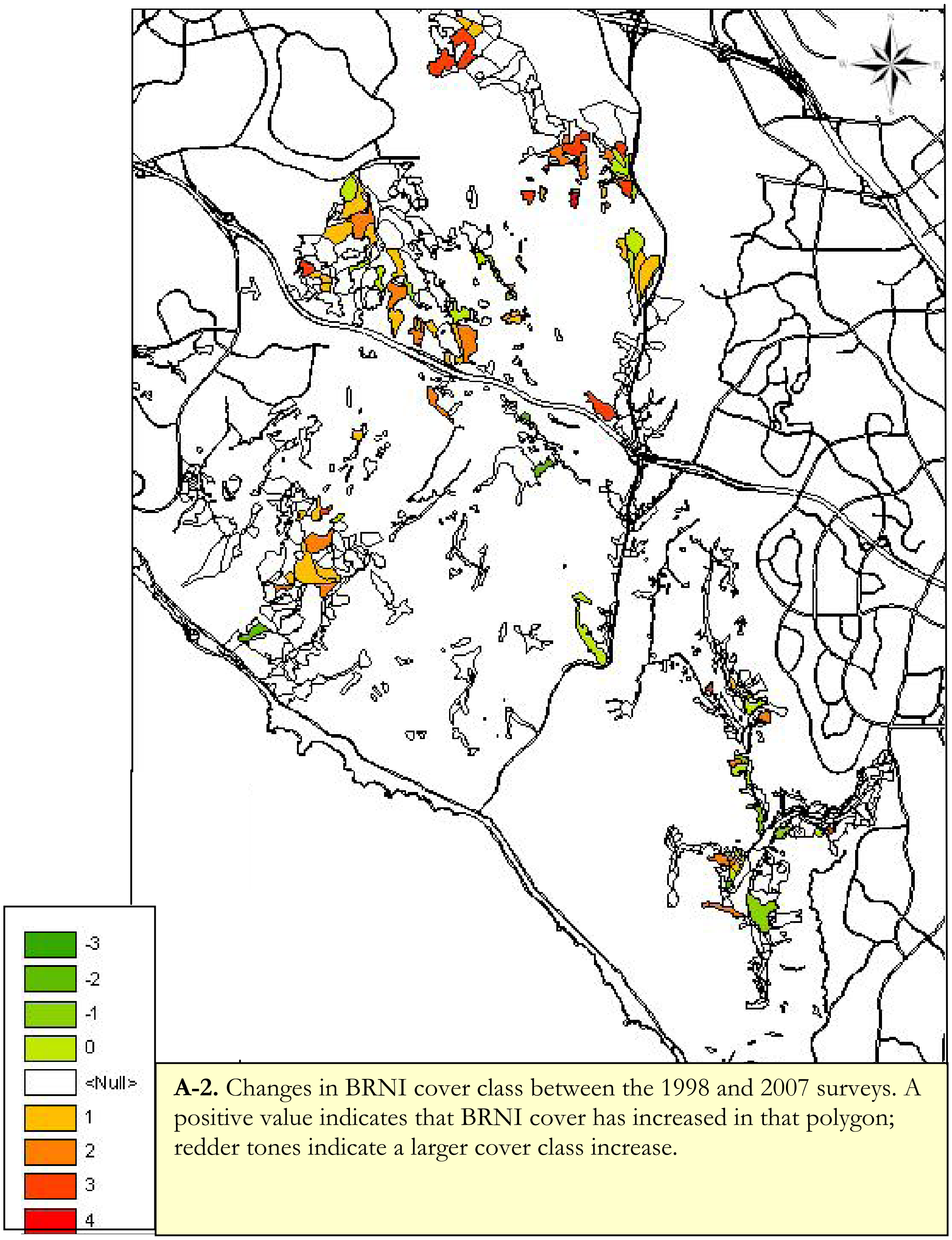
Fig. 7. Locations of experimental plots where we have established 30m x 30m areas to stop CYCA control efforts. Initial cover estimations and density counts of CYCA and NAPU were conducted in 2007. They are denoted by the following polygon numbers. Bommer Canyon:1.1.001, 1.1.002, 1.1.004, 1.1.007, 1.1.008, 1.1.012, 1.1.015, 1.1.035, 1.1.037, 1.1.042, 1.1.043, 1.1.045, 1.1.046, 1.1.048, and 1.1.049. Shady Canyon: 1.2.021 and 1.2.056. Laguna Coast Wilderness Park: 1.3.013, 1.3.066, 1.3.071, and 1.3.072 Aliso and Woods Wilderness Park: 1.9.091, 1.9.106, 1.9.121, 1.9.146, and 1.9.210. Bommer Canyon is overrepresented and some of these sites could be dropped in future resampling.

APPENDIX

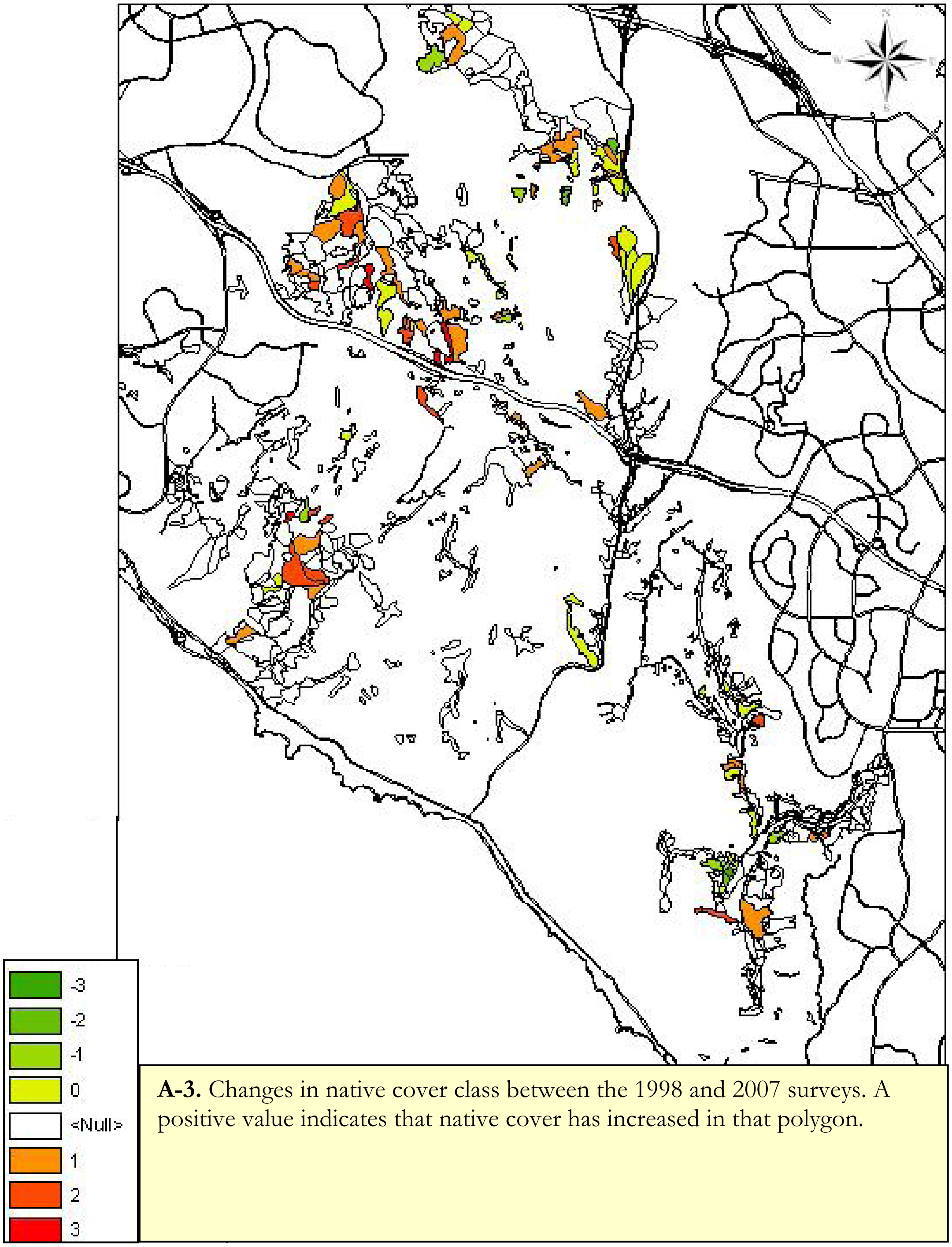
A-1. Change in CYCA cover class in the 116 polygons surveyed.
A-2. Change in BRNI cover.
A-3. Change in Native Cover.
A-4. *Nassella pulchra* cover in 2007.



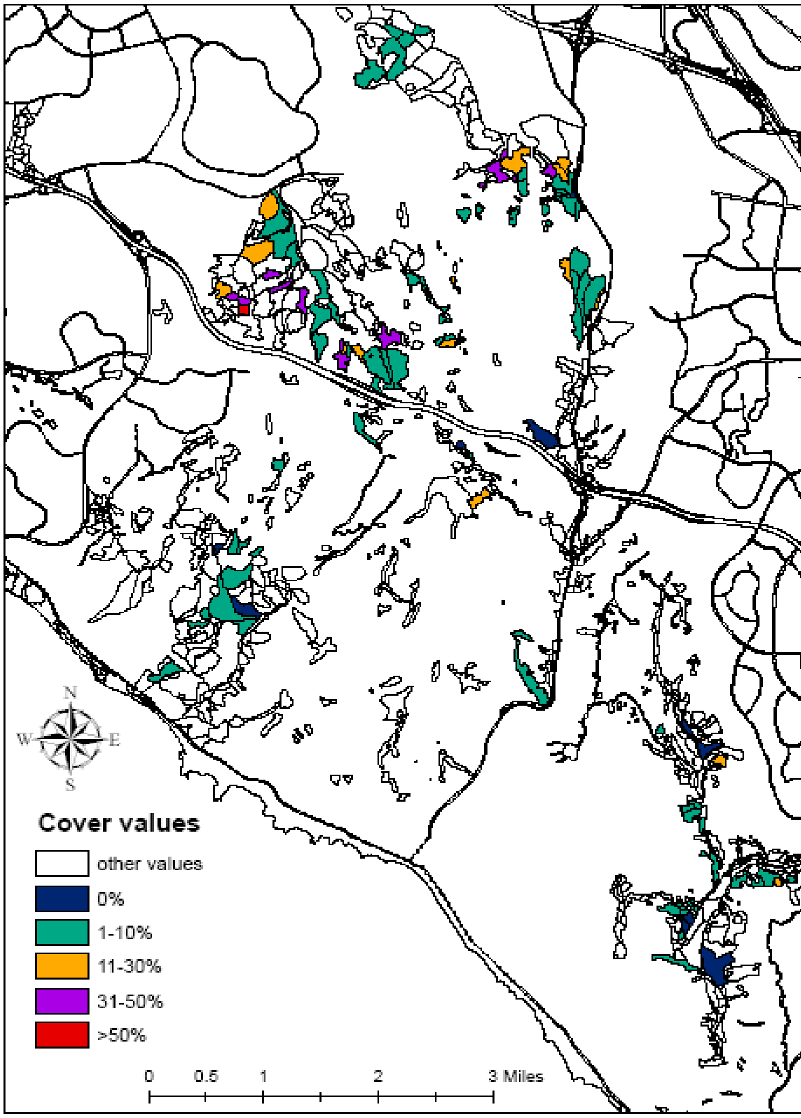
A-1. Changes in CYCA cover class between the 1998 and 2007 surveys. A positive value indicates that CYCA cover has increased; zero (orange) indicates no change in cover class; and negative values (green tones) indicate that CYCA cover has decreased.



A-2. Changes in BRNI cover class between the 1998 and 2007 surveys. A positive value indicates that BRNI cover has increased in that polygon; redder tones indicate a larger cover class increase.



A-3. Changes in native cover class between the 1998 and 2007 surveys. A positive value indicates that native cover has increased in that polygon.



A-4. Cover classes of NAPU across the 116 sampled polygons in 2007. In six polygons NAPU