Breeding Habitat Analysis and Management Recommendations for the Endangered Ohlone Tiger Beetle, *Cicindela ohlone* (Coleoptera: Cicindelidae)

Photograph by: Richard A. Arnold

Breeding Habitat Analysis

and Management Recommendations

for the Endangered Ohlone Tiger Beetle,

Cicindela ohlone (Coleoptera: Cicindelidae)

US Fish & Wildlife Service Cooperative Agreement #81440AJ314

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The Ohlone Tiger beetle (OTB), *Cicindela ohlone* (Coleoptera: Cicindelidae), was recognized as an endangered species by the U.S. Fish & Wildlife Service (USFWS) in 2001 (USFWS 2001), only eight years after it was described as a new species (Freitag, Kavanaugh, and Morgan 1993). It is endemic to coastal prairie habitat that occurs on former marine terraces characterized by mima mound topography in and near the city of Santa Cruz (Santa Cruz County), California.

During the past 20 years, about one-half of the 17 historical OTB sites (Figure 1) have been extirpated due to urbanization, agriculture, or changes in habitat conditions. Remaining OTB sites are threatened not only by changes in land use practices, but also changing habitat conditions due to colonization by invasive weeds plus non-native annual and perennial grasses, absence of disturbance factors such as wildfires, and successional changes. These factors alter the plant species composition and vegetation structure of the beetle's coastal prairie habitat. These changes include increased plant density, accumulation of thatch, and reduced amount of bare or sparsely-vegetated ground, factors which substantially degrade habitat conditions for the OTB, which prefers more open areas. Unfortunately, these changes in habitat quality can occur very quickly, which can result in the rapid demise of an OTB population.

Thus the purpose of this study is to better understand the OTB's breeding habitat requirements so remaining sites can be managed to improve habitat conditions to favor the beetle and extirpated sites can be restored to again support the beetle. Like many other tiger beetles (Knisley and Schultz 1997; Pearson 1988; and Shelford 1908) OTB eggs and larvae often co-occur in more restricted portions of their prairie habitat than do adults. The larval microhabitat is determined by the adult female in her selection of an oviposition site, which is where not only the egg, but also three larval instars and the pupae of the OTB, will complete their development.

Although bare or sparsely-vegetated Watsonville loam soils are utilized by the OTB, it does not utilize all bare patches at every occupied site. The 17 current or historical OTB sites include approximately 200 ha of grassland habitat, yet within these grasslands oviposition and larval development has consistently been observed in only about 10-15 ha, which represents only 5.0% - 7.5% of the grassland habitat area that has been known to support the beetle. Our Phase 1 study of the OTB (Arnold et al. 2012) examined several vegetation and physical features of currently occupied and unoccupied portions at selected, known OTB sites. Data were collected along transects and our analyses determined that the OTB can occur in habitat patches that exhibit substantial variation in vegetation and bare soil conditions.

Since our Phase 1 study focused on characterizing macro-level habitat features, our Phase 2 study as described in this report, examined micro-habitat level features of the OTB. Specifically, we examined physical and vegetation features at OTB oviposition sites and larval burrows and contrasted them with other portions of the grasslands that lacked oviposition sites or larval burrows. These micro-habitats occupied by the early stages of the OTB can also be referred to as its "breeding habitat". Preliminary habitat management recommendations, based on the findings of our Phase 1 study, are updated to include pertinent findings of our Phase 2

study so land owners and stewards of historical and current OTB locations can manage these sites to benefit the beetle and assist with its conservation and recovery.

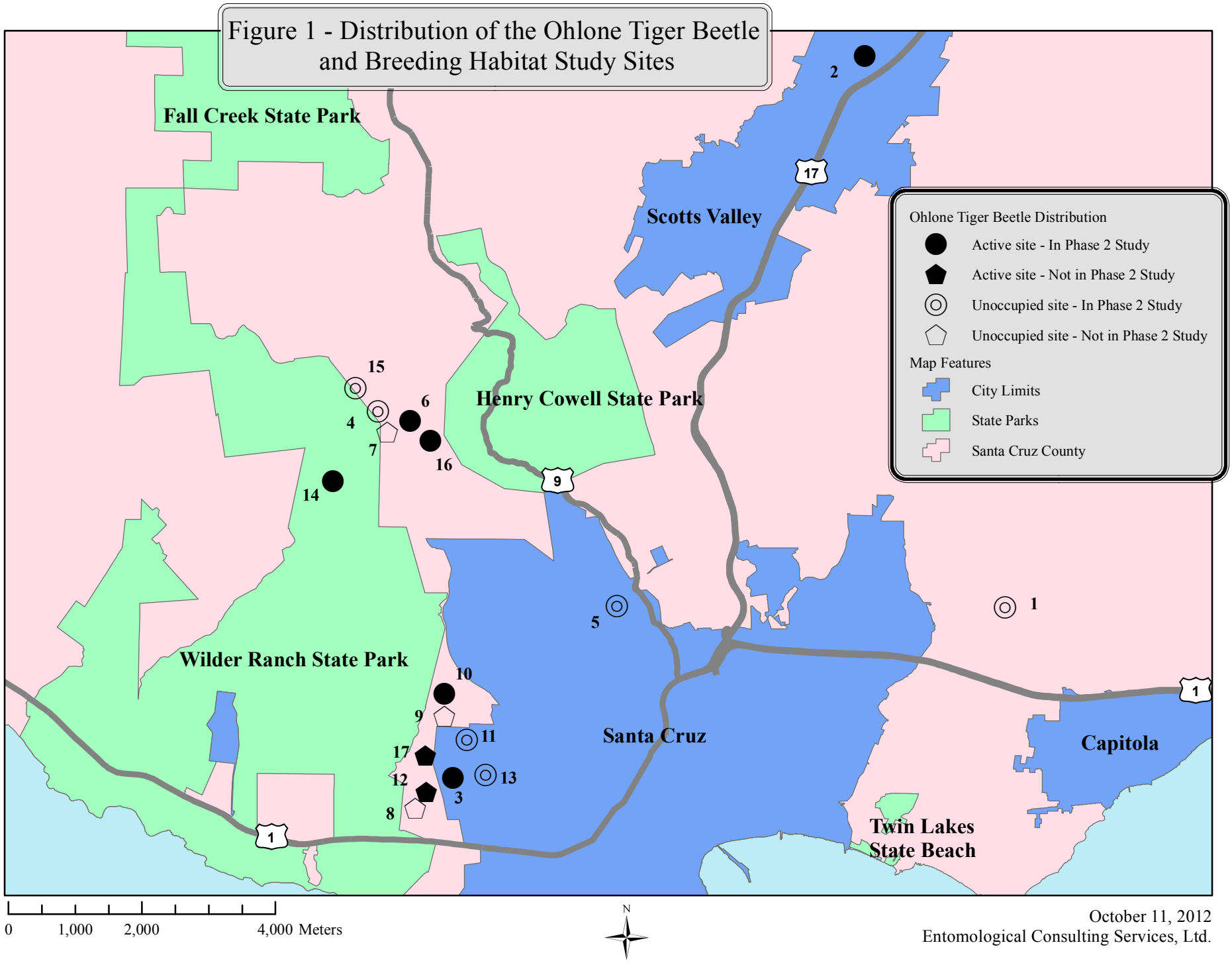


Figure 1 - Distribution of the Ohlone Tiger Beetle and Breeding Habitat Study Sites
Fall Creek State Park
Scotts Valley
Henry Cowell State Park
Wilder Ranch State Park
Santa Cruz
Capitola
Twin Lakes State Beach
17
9
1
2
15
4
6
7
16
14
5
1
10
9
11
17
12
13
3
8
Ohlone Tiger Beetle Distribution
Active site - In Phase 2 Study
Active site - Not in Phase 2 Study
Unoccupied site - In Phase 2 Study
Unoccupied site - Not in Phase 2 Study
Map Features
City Limits
State Parks
Santa Cruz County
0
1,000
2,000
4,000 Meters
N
October 11, 2012
Entomological Consulting Services, Ltd.

BACKGROUND INFORMATION

Information on the OTB's taxonomy, description, historical and current distribution, habitat, and biology was presented in our Phase 1 OTB study (Arnold et al. 2012) and is not repeated herein. The remainder of this section summarizes pertinent findings of our Phase 1 OTB study, along with information on the OTB's ecology and current management of its remaining locations, which are pertinent to our Phase 2 study.

The main breeding habitat zones, where management has improved or maintained habitat suitable for use by OTB for oviposition, establishing larval burrows, as well as larval feeding and growth, can be categorized as follows:

- Dirt trails (horse riding, hiking, biking)
- Dirt roads (driven upon by vehicles)
- Interior grassland bare patches between herbaceous plants (grazed by cattle or horses and bare patches created by decomposed cow manure pats)
- Freshly exposed soil from single-event disturbance, i.e., gopher mounds, feral pig scrapes, vegetation clearing, and construction digging, but not ground squirrels.

Vegetative and soils characteristics of trails, roads, and grasslands that support breeding habitat suitable for use by OTB at locations currently occupied by OTB include:

- Watsonville Loam soil
- Bare or sparsely-vegetated soil patches, especially on the margins of the tread of trails and roads, or between grass plants in grasslands
- Slightly elevated but level to gently sloping topography, apparently associated with better infiltration and drainage
- Sunlight at ground level

Vegetative and soils characteristics of trails, roads, and grasslands that appear to impair habitat quality and use by OTB at locations currently occupied by OTB include:

- Unvegetated soil patches covered by litter, algal mats (i.e., due to saturated soils or standing water), stones, bedrock exposures, loose sand, fresh manure, grass cuttings, accumulations of hay to feed livestock, or decomposed manure "dust"
- Over-hanging cover of herbaceous or woody plants, or woody debris or proximity to tall shrubs or trees that shade adjacent bare patches in the grasssland
- Areas where surface water ponds or flows for extended periods, or where ground water rises to near the surface or above the surface to maintain prolonged periods of saturated soils

Table 1 describes the current management practices of the locations where OTB populations occur at present or were recently extirpated.

Table 1. Current Habitat Management Practices at OTB Locations
(see Figure 1 for site identifiers and locations)

OTB Status	Management				
	Type of Grazing			No Grazing—Human Trails and Roads only	
	Cattle Grazing Operation (with trails and roads)	Horse Boarding and Riding Facility (with trails and roads)	Horse Grazing Operation (with trails and roads)	Moderately High Traffic Bikes and Hiking, Vehicles	No Bikes or Low Traffic Bikes and Hiking, Vehicles
Extant	Relatively extensive grazing units with little pasture subdivision-- *#3*, *#10*, *#12, and #17*	n/a	Relatively large pastures with some pasture sub-division, no structures— *#2*	*#6 and #14*	*#4 and #16*
Recently Extirpated	n/a	Recent shift from extensive horse grazing with no structures or pasture sub-divisions to an operation with small pastures and concentrated uses by "performance" horses—*#8*	n/a	n/a	*#1, #5, #11, #13, and #15*

METHODS

Study Sites.

Habitat features were measured at 10 currently or recently occupied OTB locations as illustrated in Figure 1. These study sites were chosen by Arnold based on his knowledge of current and historical occurrence of OTB and its habitat usage at each location. On-going surveys by Arnold determined that OTBs were currently present at five of these study sites, while OTBs had recently been extirpated or exhibited only limited usage of the other five study sites. Occupied sites included: #2, #3, #14, #10, #4, #6, and #16, but the last three sites were treated as one combined study site. Unoccupied sites included: #1, #5, #11, #13, and #15. We attempted to obtain access to other currently occupied OTB locations, #9, #12, and #17 but were denied access by the property owner. Lastly, we did not attempt to visit #8.

Data Collection.

Habitat features were measured in February 2011 (i.e., prior to peak adult emergence) at all of the OTB study sites except #15 and #11, which were measured in February 2012. Within each OTB study site, measurements of the physical and vegetation site characteristics were taken at subsites on dirt roads or trails and in adjacent off-trail grasslands, which are the two main zones of OTB habitat.

Since adults are more mobile than the egg or larval stages of the OTB, occupied subsites were recognized as locations where oviposition and/or egg and larval burrows had been observed during surveys by Arnold and represent breeding habitat of the OTB. In contrast, unoccupied subsites were locations where no oviposition activity, nor egg and larval burrows had previously been observed.

The following subsite categories were used:
1) trail/road occupied/formerly occupied by OTB (RTO),
2) trail/road unoccupied (RTU),
3) off-trail (in the grassland) occupied/formerly occupied by OTB (GO), and
4) off-trail (grassland) unoccupied (GU).

During 2011, we measured the physical site and vegetation characteristics on 0.25 m^2 quadrats arranged along either a transect for roads and trails or in a cluster for grasslands. Each of the four subsite categories was replicated, creating eight sample units for each of the 8 OTB study sites, or a total of 64 sample units. At five quadrats within each sample unit, we measured the vegetation characteristics (5 quadrats x 8 sample units = 40 quadrats per study site). We also took one soil sample per sample unit (1 soil sample x 8 sample units = 8 soil samples per study site x 8 study sites = 64 soil samples total). Due to the results of our soils analyses, soil samples were not taken at the two properties measured in 2012. Soil samples were only taken once during the study because soil characteristics were not expected to change within the time frame of the study. For the dirt road or trails segments, a quadrat was placed on top of the center point identified by Arnold and two quadrats were placed along (not across) the road or trail on either side of the center quadrat. All quadrats were adjacent to each other. The quadrats were placed at the edge of the trail tread with 10 cm overlapping the adjacent surface beyond the trail tread's edge. For the grassland sample units, a quadrat was placed on top of the center point

identified by Arnold and two quadrats on either side of the center quadrat (from west to east). One soil sample was taken from each transect at the center quadrat. During our Phase 2 study, we tested the same soil variables as we did in our Phase 1 study, except for the addition to two new features, sulfate (SO_4) and bulk density.

The location of every quadrat was mapped with a GPS and photographed to illustrate habitat conditions. All photos are presented in the appendix to this report. Data measurements were taken during early winter after the first rains and herbaceous green-up, but before the peak of adult OTB emergence. Table 2 is the Phase II data form we developed for this study.

We measured the following physical and vegetation features at each subsite:

1) Soil samples (one sample taken with a soil hammer; rocks, bushes, and OTB burrows were avoided); these samples were delivered to the Bartolome lab at UC Berkeley, where pH and bulk density were measured. Samples were subsequently mailed to the UC Davis Agronomy Lab for analysis of all remaining soil variables:
    a. pH, which is a measure of hydrogen ion activity in the soil;
    b. Phosphorus (P), a major element in organic matter of soil;
    c. Sulfate (SO_4), an ion important for plant growth;
    d. Carbon (C), an element important for plant growth;
    e. Nitrogen (N), an element important for plant growth;
    f. The ratio of Carbon to Nitrogen, [C:N];
    g. texture, derived from sand, silt, and clay proportions; and
    h. bulk density, an indirect measure of the relative volume of solids and voids in a soil.
2) Percent cover not vegetated at surface (% not covered by vegetation—total 100% minus % cover combined herbaceous phytomass and minus litter, manure, and other):
    a. Soil
    b. Loose Sand
    c. Stones
    d. Bedrock
    e. Disturbance (burrowing mammal [except not ground squirrels], construction digging, etc.).
3) Degree and type of road/trail use:
    a. Causes (vehicle track, bike track, foot prints, manure); and
    b. Frequency of traffic.
4) Percent cover vegetated at crown (total 100% minus % cover of combined bare soil, loose sand, stones, bedrock, and bare disturbance):
    a. standing herbaceous matter (live or dead foliage, standing or bent-over, but not detached);

Table 2. Data Form for Phase 2 OTB Habitat Study.

Data Form for Current Physical and Vegetation Characteristics of Known Oviposition/Burrow and Unoccupied OTB Habitat Sites. (Updated 2/16/2011 by DR)

Date _____ Property Owner _____ Property Name_____
Zone_____ Field Name _____ Recorders _____ Orientation of Transect_____

Degree of Use (cause, frequency):

Transect Photos #s

Quadrat #	Waypoint #	Quadrat Photo #	Physical Characteristics: % Cover at Surface: *Total Non-Vegetated*	Soil	Loose Sand	Stones	Bedrock	Disturbance: Mam. Burrow (not gr. squirrel)	Human Digging	Other	Vegetation Characteristics: % Cover at Surface or Crown: Functional Groups: *Total Stand Herb. Matter*	Ann. Grass	Peren. Grass	Legumes	Other Forb	Litter	Manure	Other	Herbaceous Mass Height (Inches)	Combined Herbaceous Mass (lbs/acre)
1																				
2																				
3*																				
4																				
5																				

Date _____ Property Owner _____ Property Name_____
Zone Field Name Recorders Orientation of Transect

Degree of Use (cause, frequency):

Transect Photos #s

Quadrat #	Waypoint #	Quadrat Photo #	Physical Characteristics: % Cover at Surface: *Total Non-Vegetated*	Soil	Loose Sand	Stones	Bedrock	Disturbance: Mam. Burrow (not gr. squirrel)	Human Digging	Other	Vegetation Characteristics: % Cover at Surface or Crown: Functional Groups: *Total Stand Herb. Matter*	Ann. Grass	Peren. Grass	Legumes	Other Forb	Litter	Manure	Other	Herbaceous Mass Height (Inches)	Combined Herbaceous Mass (lbs/acre)
1																				
2																				
3*																				
4																				
5																				

Zone Codes: Trail Occupied—TO; Trail Unoccupied—TU; Trail Formerly Occupied–TFO; Trail Formerly Unoccupied–TFU; Grassland Occupied—GO; Grassland Unoccupied—GU; Grassland Formerly Occupied–GFO; Grassland Formerly Unoccupied–GFU

*Quadrat #3 is where soil the sample was taken and is the center point identified by the GPS coordinate and on the maps.
*Total Non-Vegetated" equals the sum of all Physical Characteristics.
*Total Stand Herb. Matter" equals the sum of Ann. Grass, Peren. Grass, Legumes, and Other Forb.
and Other Forb.

b. functional plant groups (legume, annual grass, perennial grass, or other forb); we added non-native perennial grass as a functional plant group on February 23, after having completed measurements at 2 properties;
c. litter (detached from current or prior year's growth [includes grass/forb stems, decomposing hay/manure, other herbaceous material] not yet incorporated into the soil);
d. manure (cattle, horse, other); and
e. other (woody root, trash, etc.).

5) Herbaceous mass height (Ford's "obstruction height" method—inches).
6) Combined herbaceous mass (0.96 square foot frame; use x 100 conversion factor--lbs/acre).

Based on the analyses of our habitat data collected in 2011, we simplified sampling for the two sites added in 2012 by excluding soil samples and restricting vegetative and soil measures to percent bare soil and percent cover of non-native perennial grasses. As discussed in more detail in subsequent sections of this report, these two habitat features were primary determinants of suitable OTB breeding habitat.

Data Analyses.

Detrended Correspondence Analysis (DCA), a multivariate, statistical ordination technique (Hill and Gauch 1980), was used to analyze the data set of 18 OTB habitat features. It has frequently been used to examine gradients in ecological data sets and species responses. PC-Ord version 5 (MJM Software), was used to analyze our data.

In this study DCA was utilized to determine if the 2011 data set transects could be quantitatively classified into groupings based on vegetation, environmental factors, land use management, soil characteristics, or presence or absence of OTB. The DCA ordination procedure simplifies complex multivariate data sets into graphs that can help in evaluating patterns in the data. Axes in ordination space can often be interpreted as environmental gradients. DCA grouped the transects along the axes based on overall similarity of the habitat features, i.e., transects with more similar features plotted closer together and transects that are more different plotted farther apart. DCA is commonly used for classification of complex ecological data and is best thought of as a quantitative descriptive method valuable for generating hypotheses (for further study) rather than a rigorous inferential test of hypotheses.

For DCA analysis we removed variables that were either too infrequent (did not occur on more than one site) or were highly correlated with other variables. We used all of the soil characteristics from the cores; physical surface characteristics of bare soil, stones, and mammal burrows; and the vegetation characteristics of abundance by functional plant group; but none of the estimates of degree of use. The plant measures of standing herbaceous matter, litter, and herbaceous mass height were all highly negatively correlated with bare soil, so were omitted from DCA.

We used DCA to group similar samples and to examine the relationships among physical site, vegetation, and management variables and between those variables and occupancy by OTB at 64 transects on the 10 study sites. We present details on breeding habitat variables that had significant correlation with one or more of the three DCA axes. For a sample size of 64 transects

"r" values greater than 0.4 can be considered indication that there is $p < .01$ that the relationship between the variable of interest and the ordination axis is simply due to chance (Table 2). The data from the 2012 samples were used to test qualitative predictions about characteristics of occupied and unoccupied OTB transects, so were not included in the DCA. Instead these data are discussed and incorporated into Figure 8.

RESULTS

DCA produced good results with the modified 2011 data set, revealing some well-defined environmental gradients in the three axes, and three important groupings of samples. Axes 1, 2, and 3 explained approximately 0.197, 0.256, and 0.149 of the total variation, respectively, with a total of approximately 60% of the variance explained. This is a good result for these kinds of data.

DCA places the transects into three major groupings along axes one and two (Figure 2a). Several variables are significantly correlated with axis one (Table 3). The first axis primarily reflects a gradient from low vegetation cover and high mounts of bare soil on the left to higher amounts of vegetation on the right (Figures 2a and 3). Higher levels of vegetation cover are accompanied by additional small mammal burrows, greater cover of annual grasses and other forbs, and lower soil bulk density (Figures 4a, 4b, 4c, and 4d). The transects with higher levels of plant cover are also either currently unoccupied or formerly occupied sites. The small group in the upper right (Group 1 in Figure 2a) are all unoccupied or formerly occupied, one from former OTB site #5, the rest from #13, and contain high percentages of non-native perennial grass cover, a reflection of axis 2 (Figure 4). The group in the lower right (Group 2 in Figure 2a), with only two exceptions, are all unoccupied or formerly occupied OTB sites, and strongly affected by presence of annual grasses (Figure 4b) and absence of non-native perennial grasses (Figure 5), which are habitat features important components of axis 2. The group on the left with the least vegetation cover and most bare soil (Group 3 in Figure 2a) contains nearly all of the occupied OTB transects, plus many unoccupied and formerly occupied transects.

DCA axis 3 also explains an important variance component (Table 2 and Figure 6a) and primarily reflects an effect on the individual samples of perennial grasses (Figure 7a) and legumes (Figure 7b), as well as the soil characteristics Carbon (Figure 7c) and total Nitrogen (Figure 7d). These factors did not appear to have any direct effect on OTB occupancy (Figure 6b).

The six categories of samples and OTB occupancy (Grass Occupied, Trail/Road Occupied, Grass Unoccupied, Trail/Road Unoccupied, Grass Formerly Occupied, and Trail/Road Formerly Occupied) in 2011 are strongly affected by axes 1 and 2. This reflects the gradient from less to more vegetation and its strong negative correlation with percent bare soil and percent non-vegetated on axis 1, coupled to the negatively correlated vegetative measures of perennial grasses and annual grasses of axis 2 (Figures 2a and 2b).

Grassland transects from 2011 have lower average percentage non-vegetated than trail/road transects (Figure 8). Occupied trail/road transects had about the same vegetative cover as unoccupied trail/road transects in 2011, while the unoccupied grass transects have very low percentage of non-vegetated/bare soil (Figure 8). The 14 transects sampled in 2012 included four in unoccupied grassland averaging only 1.25% non-vegetated, two in occupied grassland averaging 16% non-vegetated, which is what would have been predicted from the 2011 transects. As in 2011, the highest percent non-vegetated was on the two occupied trails, but in contrast to the 2011 data set the four unoccupied trails varied greatly in percent non-vegetated (range 13-90%) and averaged much higher non-vegetated at 64.5%. The two formerly occupied trail/road

transects averaged 54.5%, much higher than the 2011 average. No formerly occupied transect sites were available in the 2012 locations. Non-native perennial grasses, the other characteristic sampled in 2012, were abundant only on unoccupied grassland transects, occurring at 80% frequency and detected only in a single additional quadrat in occupied grassland.

Table 3. Pearson and Kendall Correlations of 18 Habitat Variables with Three Ordination Axes (Note: r values greater than 0.4 or -0.4 reflect a correlation significant at approximately $p < 0.01$).

Axis	1			2			3		
Habitat Variable	Correlations			Correlations			Correlations		
	R	r^2	tau	r	r^2	tau	r	r^2	tau
Soil	-0.762	0.581	-0.669	0.291	0.085	0.374	-0.383	0.146	-0.317
Stones	-0.305	0.093	0.255	0.091	0.008	0.115	-0.208	0.043	-0.206
Small Mammal Burrows	0.431	0.186	0.361	-0.343	0.117	-0.318	0.119	0.014	0.162
Annual Grasses	0.809	0.655	0.694	-0.848	0.720	-0.750	0.249	0.062	0.250
Perennial Grasses	-0.294	0.086	-0.272	-0.011	0.000	0.034	-0.697	0.486	-0.580
Legumes	-0.212	0.045	-0.178	0.017	0.000	0.003	0.610	0.372	0.204
Other Forbs	-0.451	0.204	-0.401	0.369	0.136	0.378	0.124	0.015	-0.037
Non-native Perennial Grasses	0.367	0.135	0.378	0.633	0.401	0.144	0.222	0.049	0.312
Manure	0.111	0.012	0.104	-0.173	0.030	-0.187	0.200	0.040	0.207
Total Nitrogen	0.320	0.102	0.217	0.050	0.003	0.033	0.414	0.171	0.355
Total Carbon	0.212	0.450	0.154	0.024	0.001	0.059	0.533	0.285	0.286
Bray Phosphorous	-0.051	0.003	0.106	0.147	0.022	0.069	0.204	0.041	0.275
Sulfates	0.037	0.001	-0.049	-0.003	0.000	0.125	0.136	0.019	0.111
Sand	-0.184	0.340	-0.106	0.065	0.004	0.063	0.299	0.090	0.159
Silt	0.242	0.059	0.167	-0.069	0.005	-0.036	-0.185	0.034	-0.073
Clay	-0.003	0.000	-0.038	-0.027	0.001	0.007	-0.346	0.119	-0.206
Bulk Density	-0.509	0.259	-0.372	0.165	0.027	0.154	-0.160	0.026	-0.186
pH	-0.120	0.014	-0.058	0.019	0.000	-0.010	0.222	0.049	-0.114

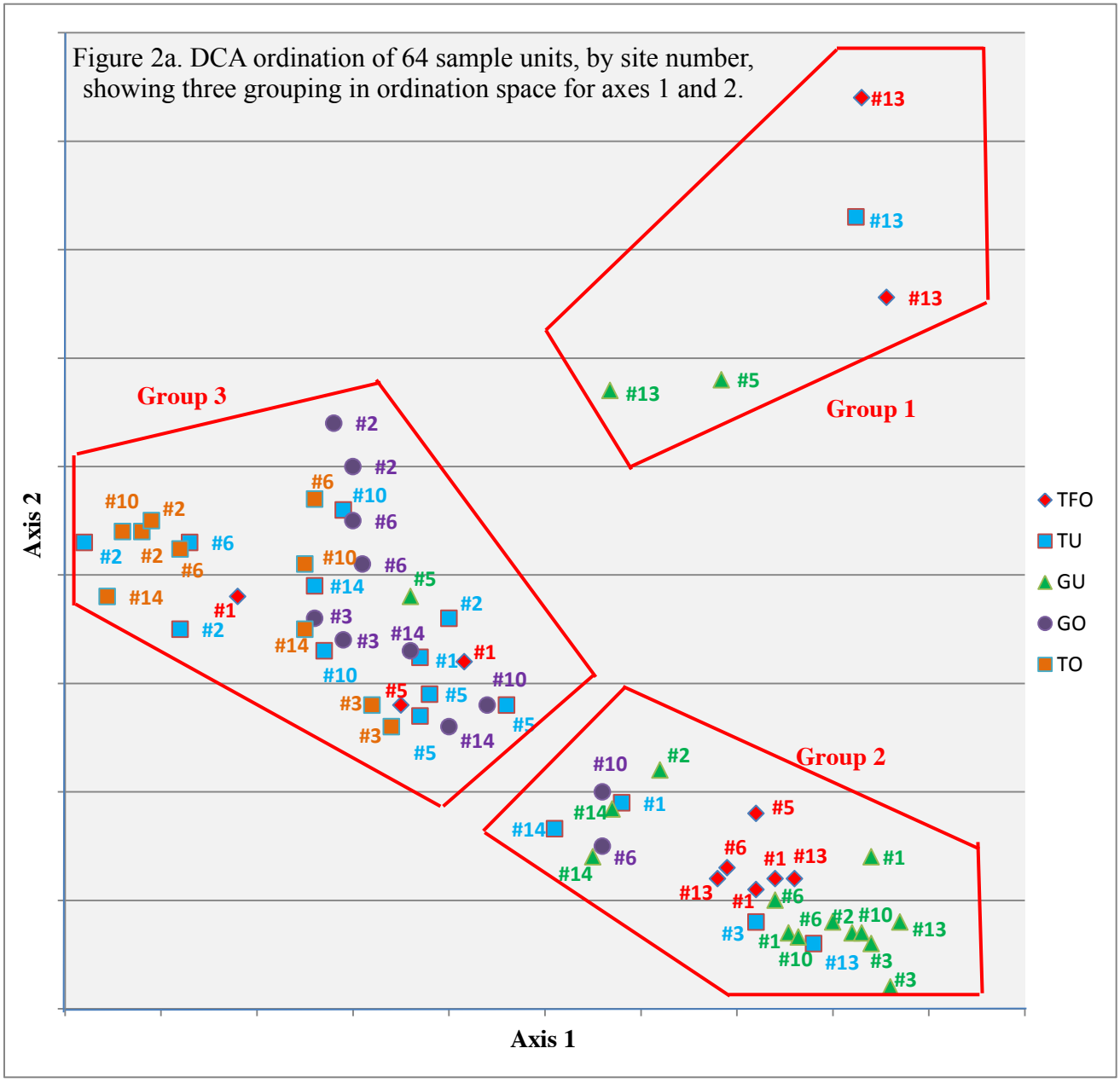
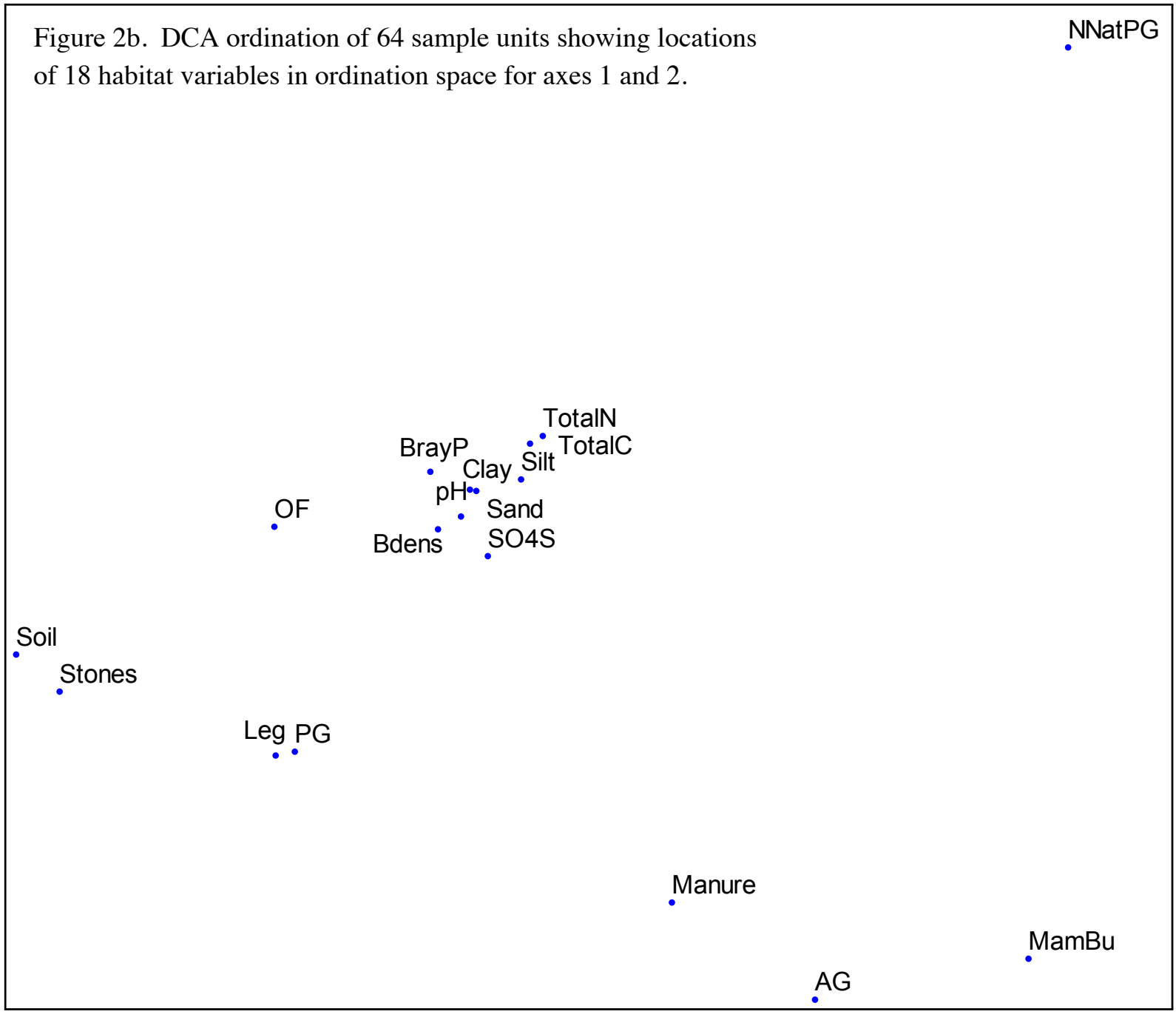


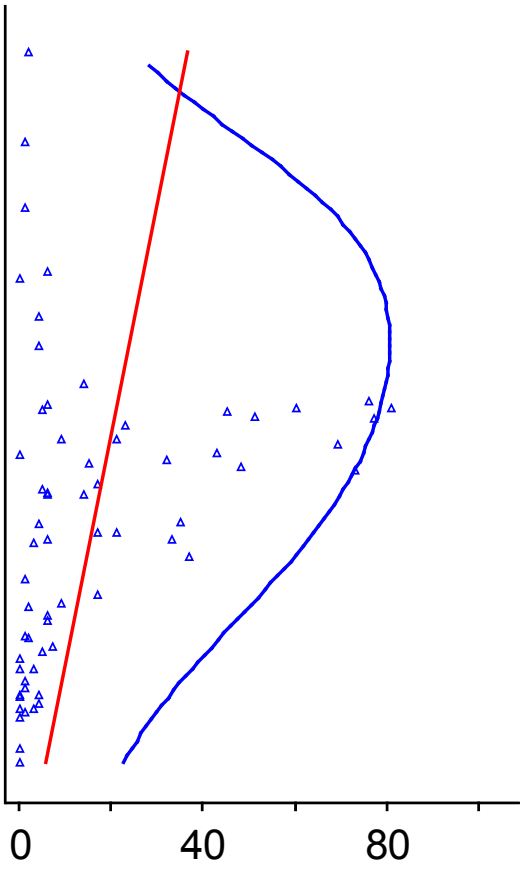
Figure 2a. DCA ordination of 64 sample units, by site number, showing three grouping in ordination space for axes 1 and 2.
Group 1
Group 2
Group 3
Axis 1
Axis 2
TFO
TU
GU
GO
TO

OTB DCA 2011

Figure 2b. DCA ordination of 64 sample units showing locations of 18 habitat variables in ordination space for axes 1 and 2.

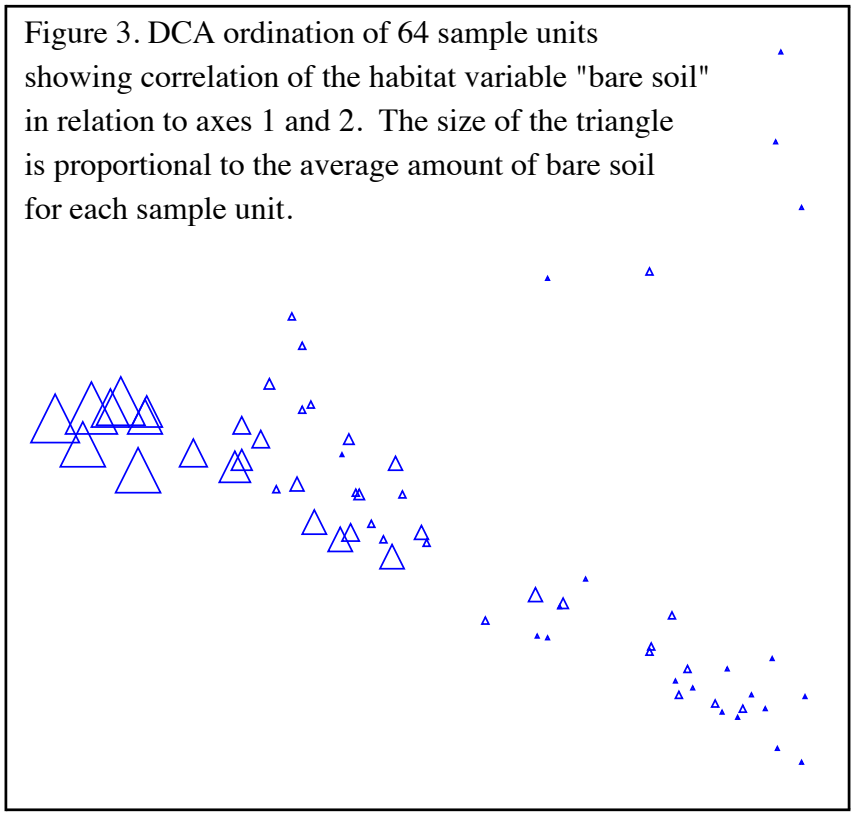


OTB DCA 2011



Axis 2

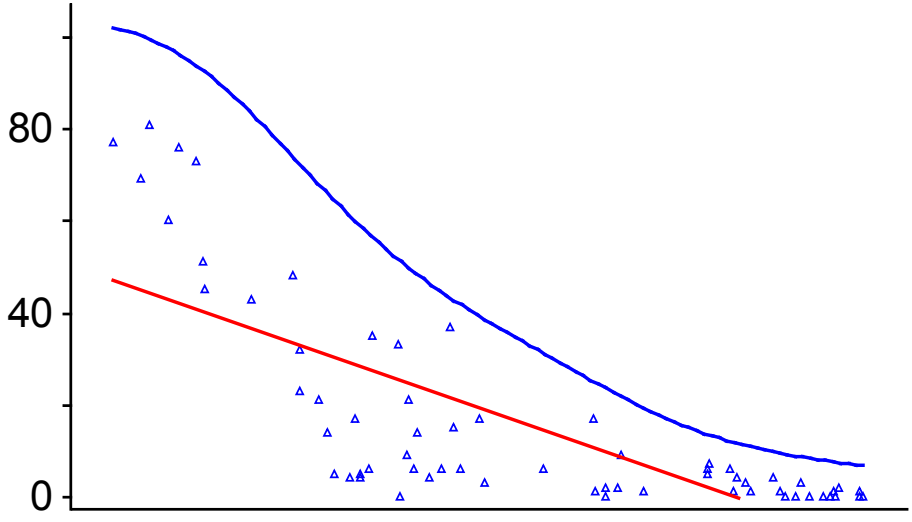
Figure 3. DCA ordination of 64 sample units showing correlation of the habitat variable "bare soil" in relation to axes 1 and 2. The size of the triangle is proportional to the average amount of bare soil for each sample unit.



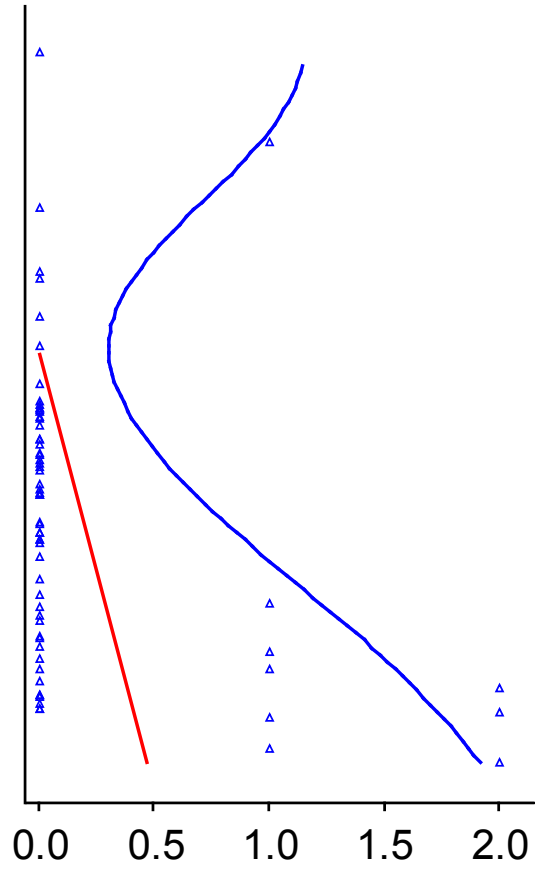
Axis 1

Soil

Axis 1
r = -.762 tau = -.669
Axis 2
r = .291 tau = .374



OTB DCA 2011

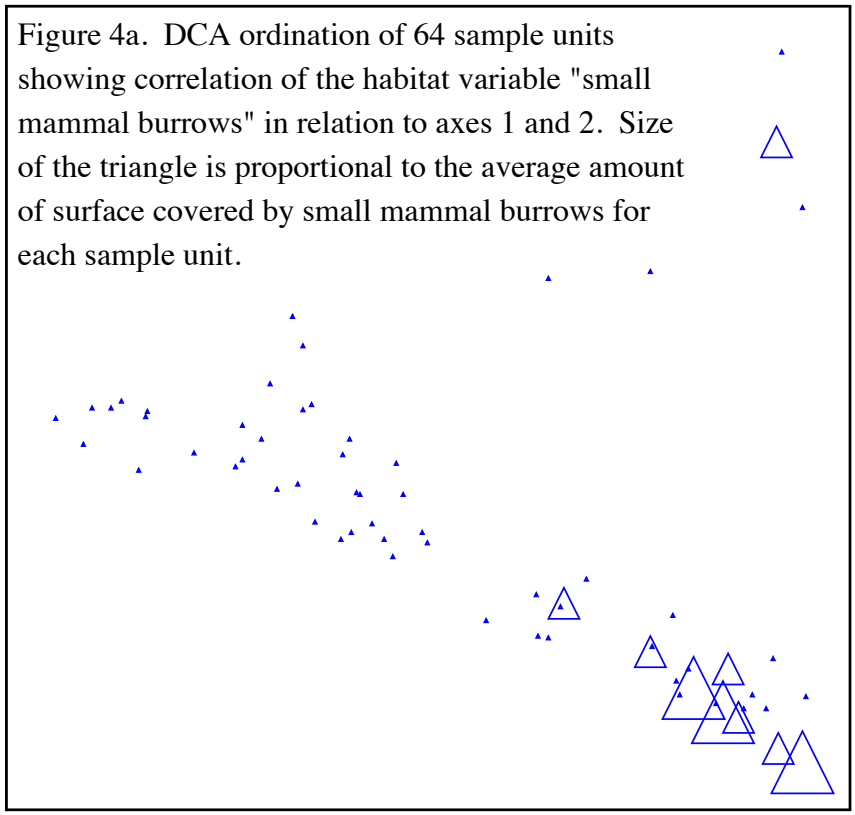


MamBu

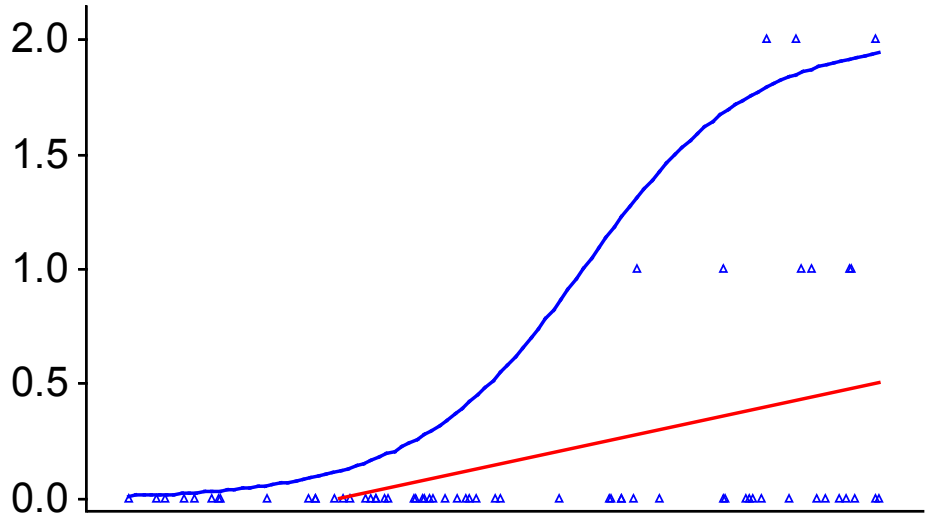
Axis 1
r = .431 tau = .361
Axis 2
r = -.343 tau = -.318

Figure 4a. DCA ordination of 64 sample units showing correlation of the habitat variable "small mammal burrows" in relation to axes 1 and 2. Size of the triangle is proportional to the average amount of surface covered by small mammal burrows for each sample unit.

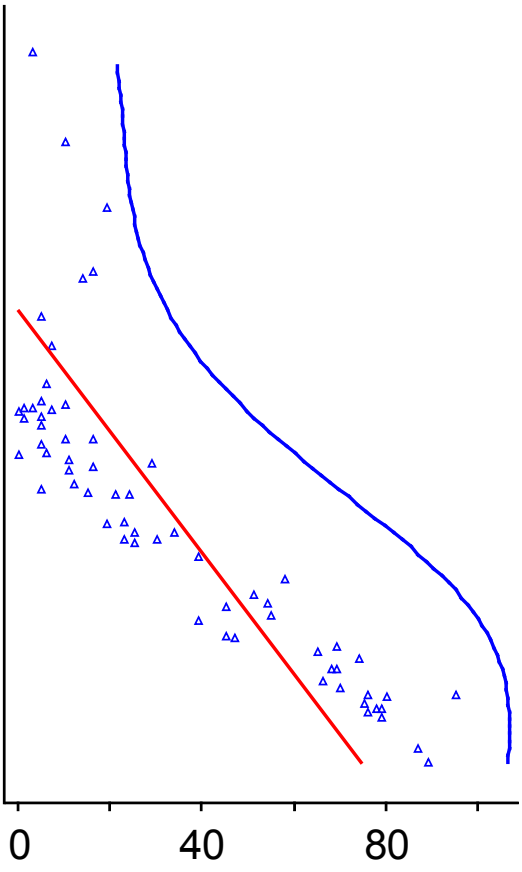
Axis 2



Axis 1

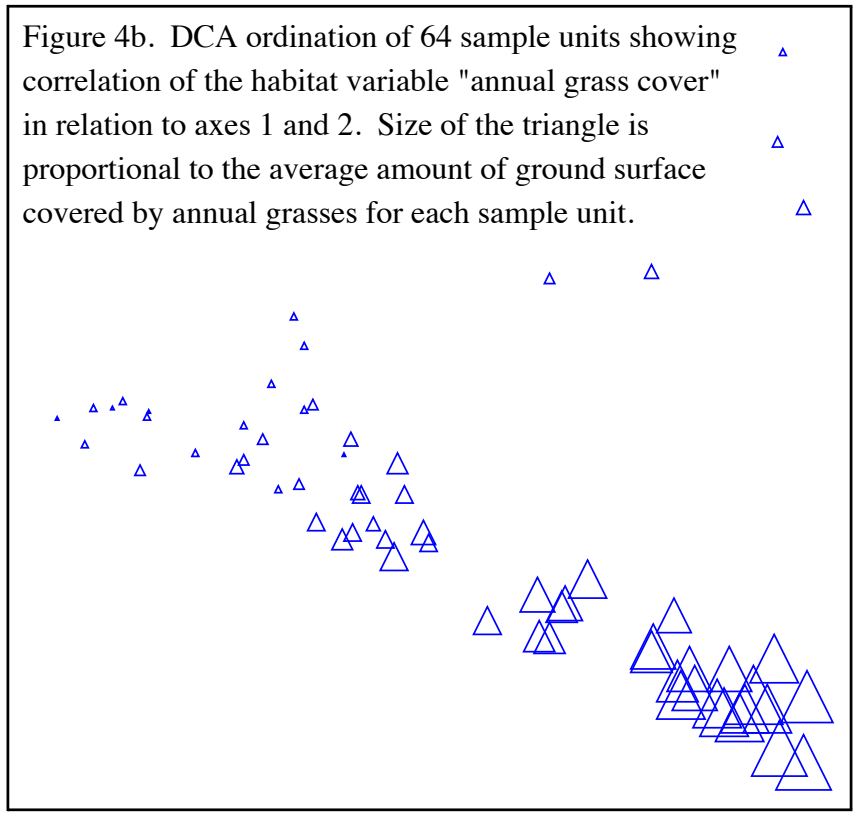


OTB DCA 2011



Axis 2

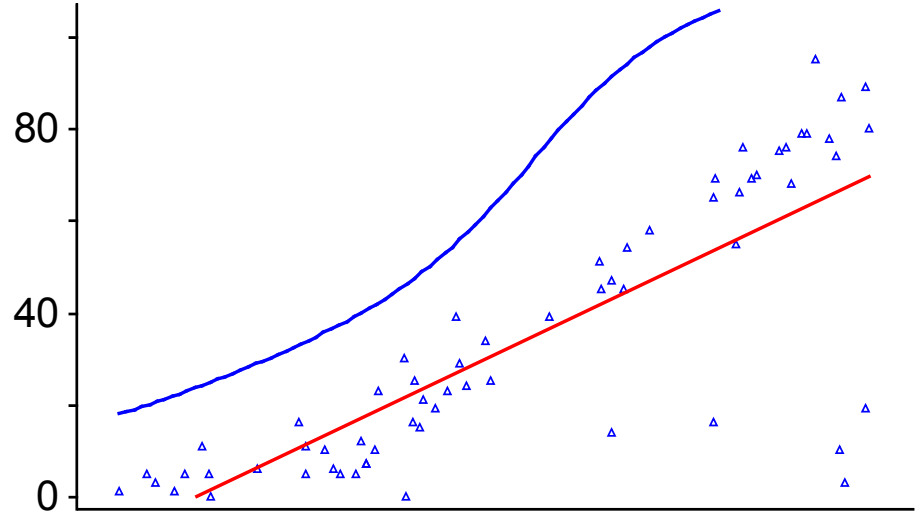
Figure 4b. DCA ordination of 64 sample units showing correlation of the habitat variable "annual grass cover" in relation to axes 1 and 2. Size of the triangle is proportional to the average amount of ground surface covered by annual grasses for each sample unit.



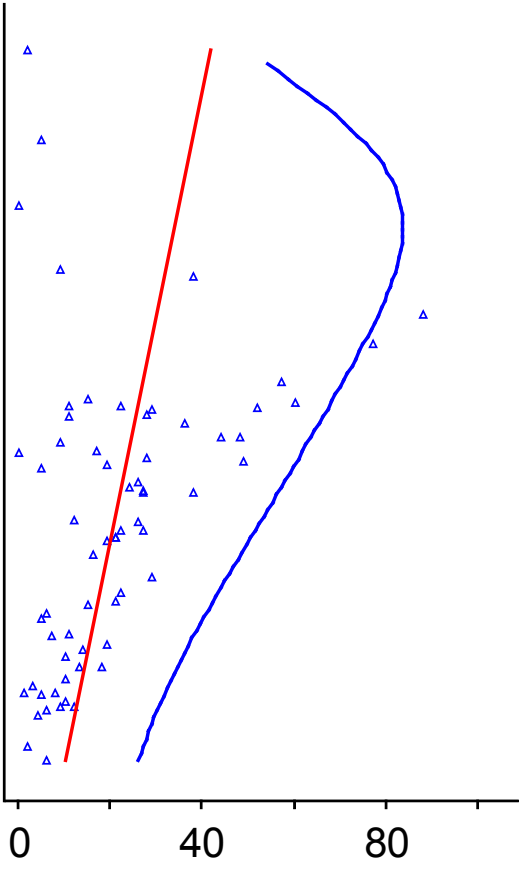
Axis 1

AG

Axis 1
r = .809 tau = .694
Axis 2
r = -.848 tau = -.750

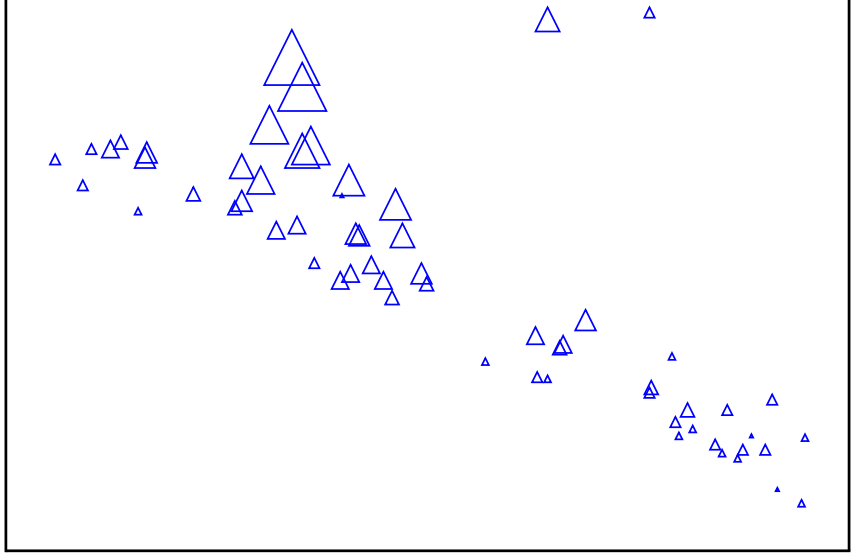


OTB DCA 2011



Axis 2

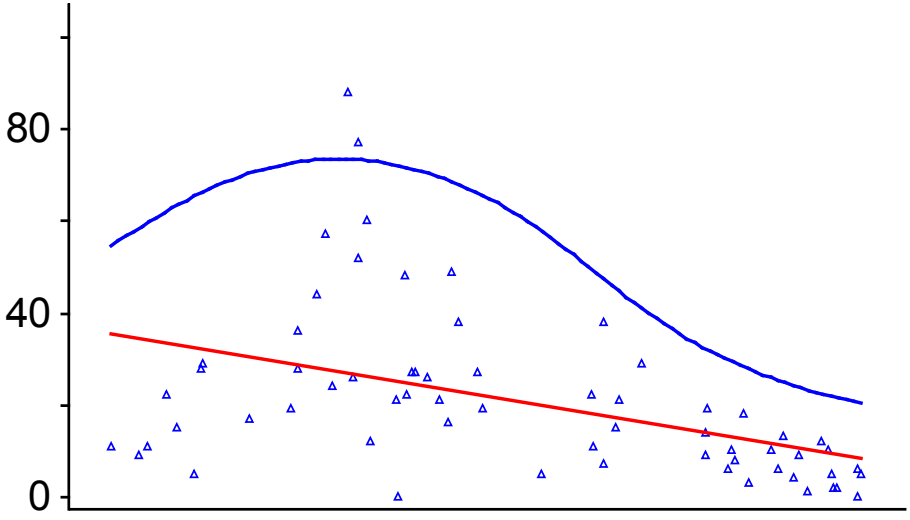
Figure 4c. DCA ordination of 64 sample units showing correlation of the habitat variable "other forbs" in relation to axes 1 and 2. Size of the triangle is proportional to the average amount of the ground surface covered by other forbs for each sample unit.



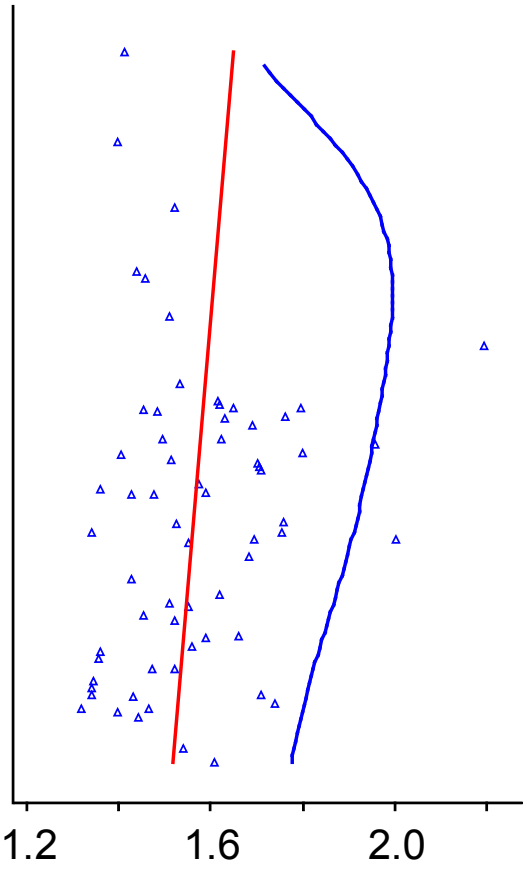
OF

Axis 1
r = -.451 tau = -.401
Axis 2
r = .369 tau = .378

Axis 1

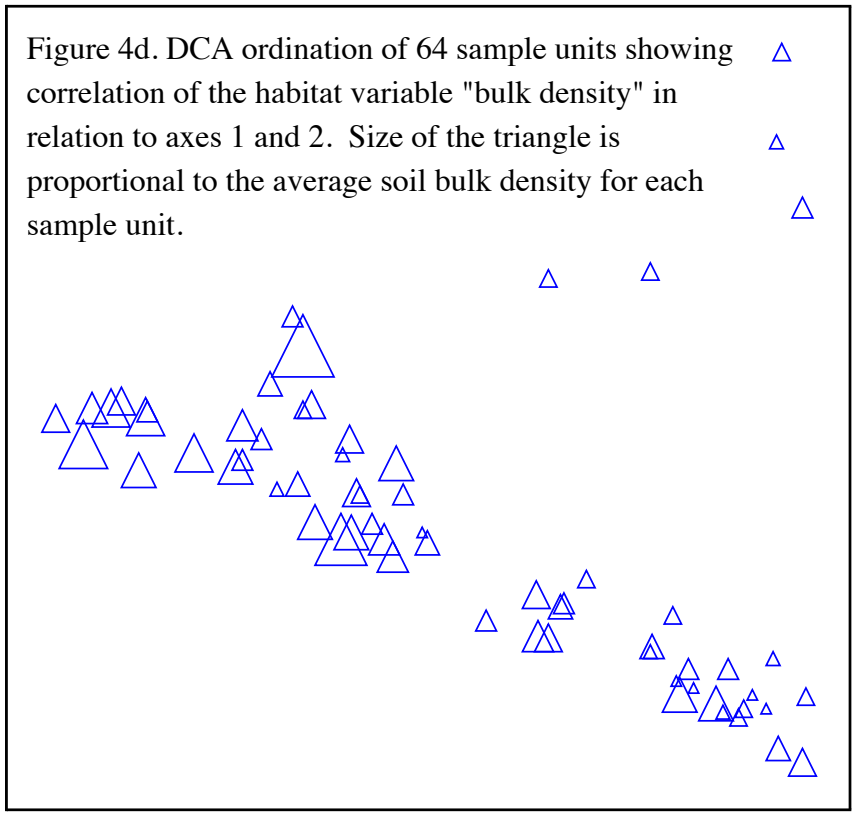


OTB DCA 2011



Axis 2

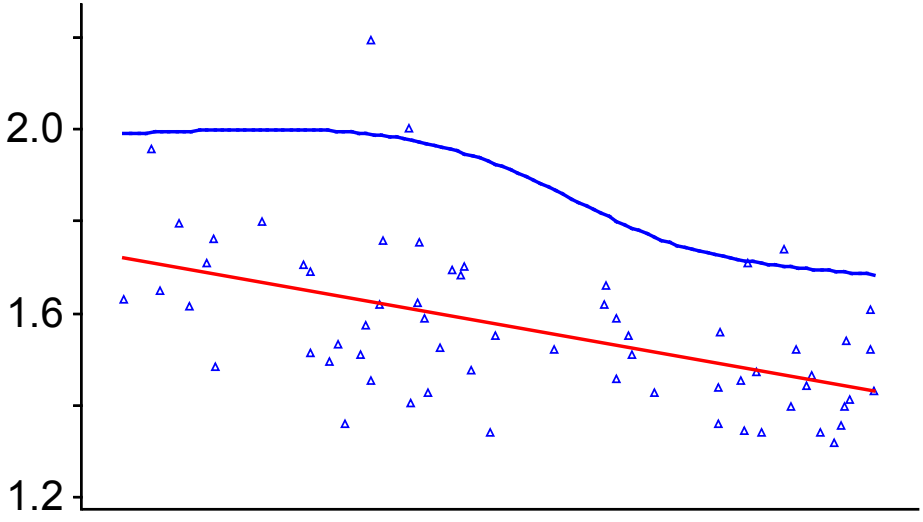
Figure 4d. DCA ordination of 64 sample units showing correlation of the habitat variable "bulk density" in relation to axes 1 and 2. Size of the triangle is proportional to the average soil bulk density for each sample unit.



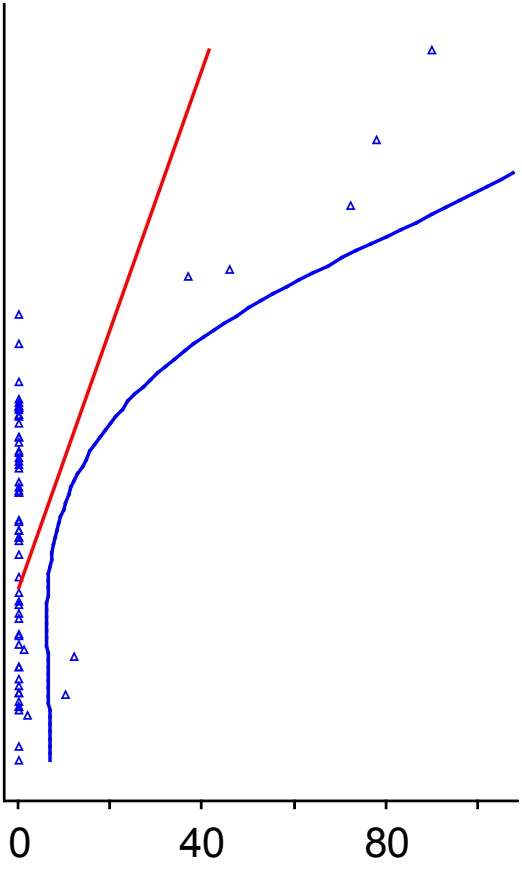
Bdens

Axis 1
r = -.509 tau = -.372
Axis 2
r = .165 tau = .154

Axis 1

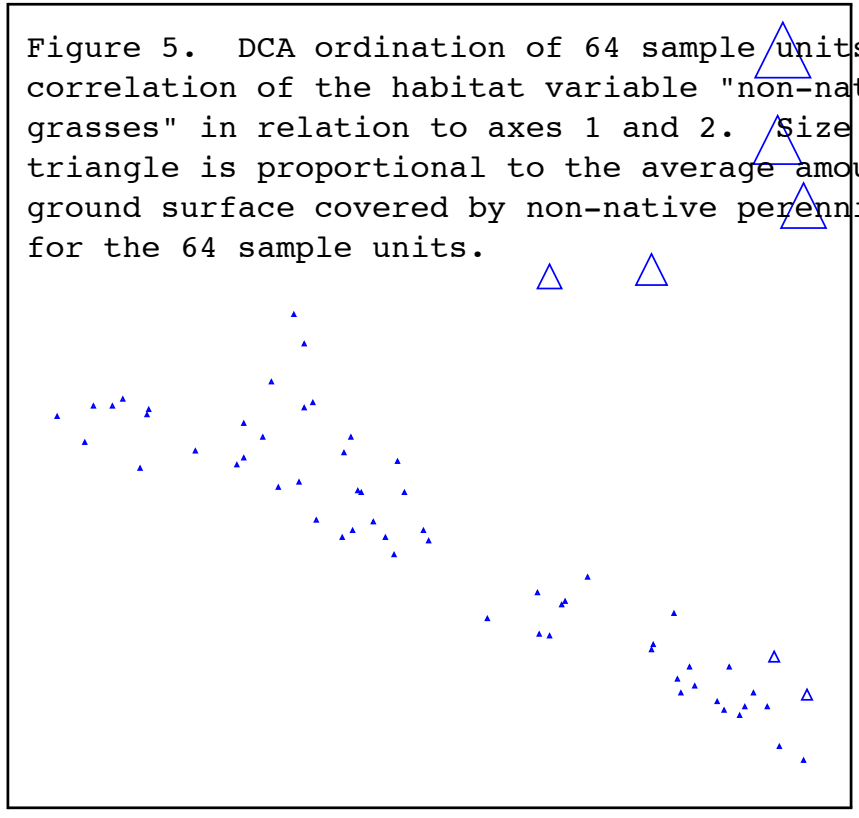


OTB DCA 2011



Axis 2

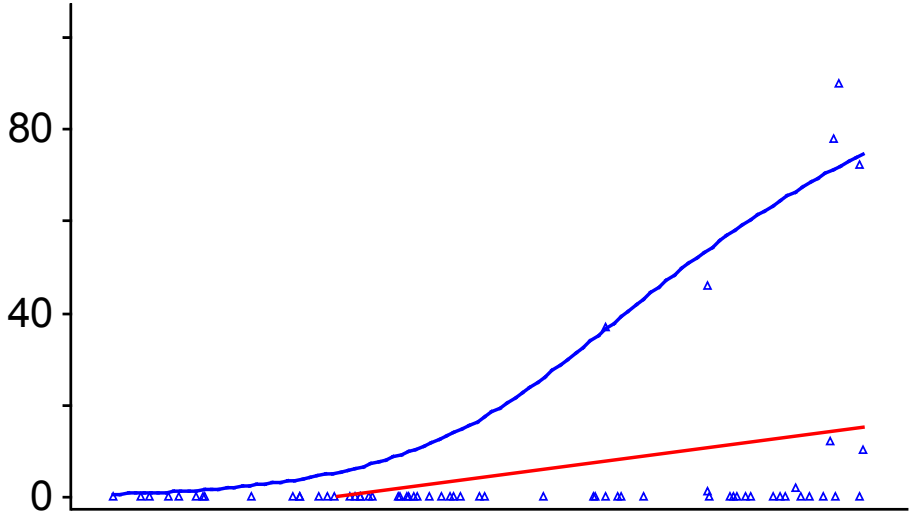
Figure 5. DCA ordination of 64 sample units
correlation of the habitat variable "non-nat
grasses" in relation to axes 1 and 2. Size
triangle is proportional to the average amou
ground surface covered by non-native perenni
for the 64 sample units.



NNatPG

Axis 1
r = .367 tau = .378
Axis 2
r = .633 tau = .144

Axis 1



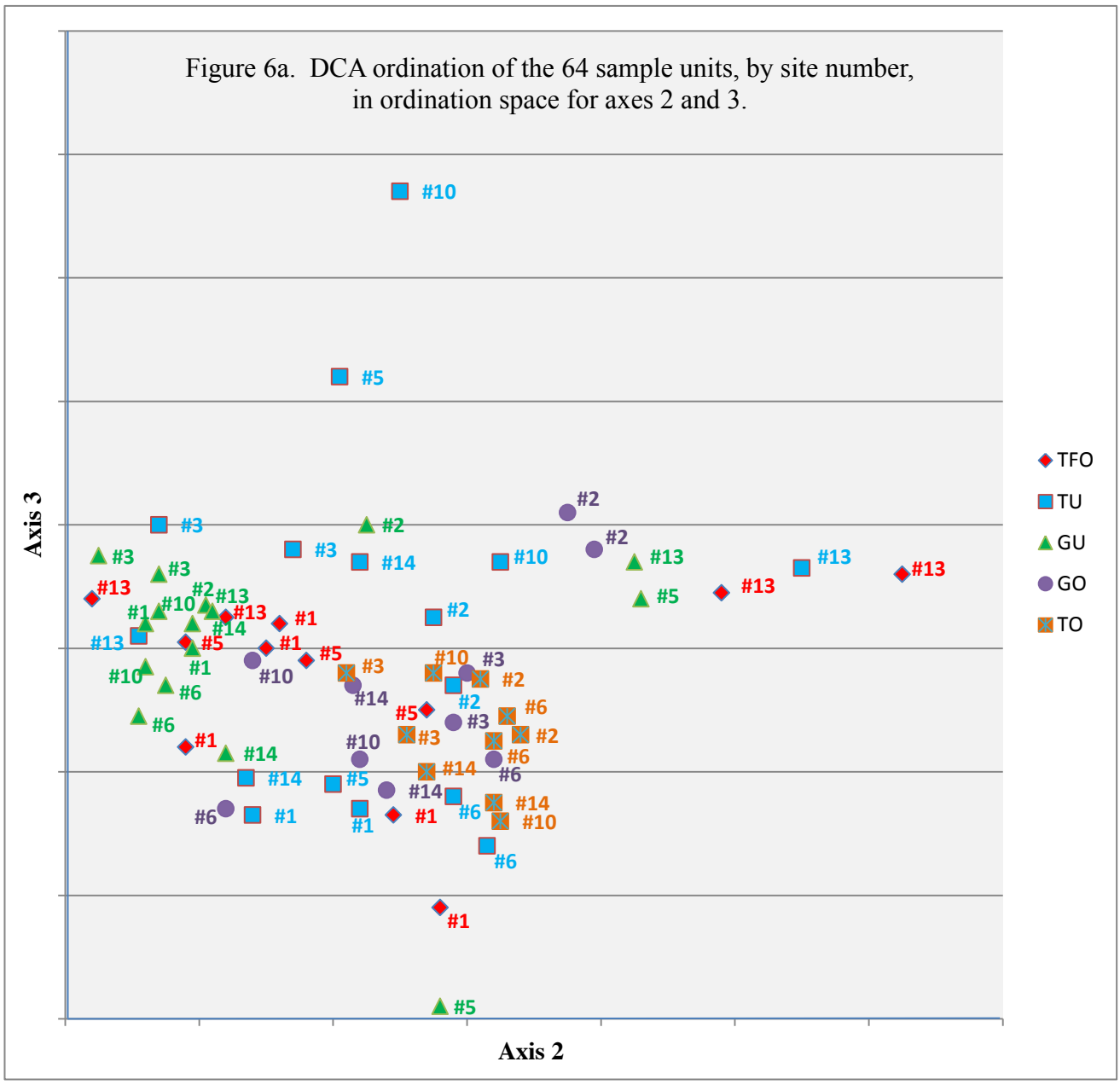


Figure 6a. DCA ordination of the 64 sample units, by site number, in ordination space for axes 2 and 3.
Axis 3
Axis 2
TFO
TU
GU
GO
TO

OTB DCA 2011

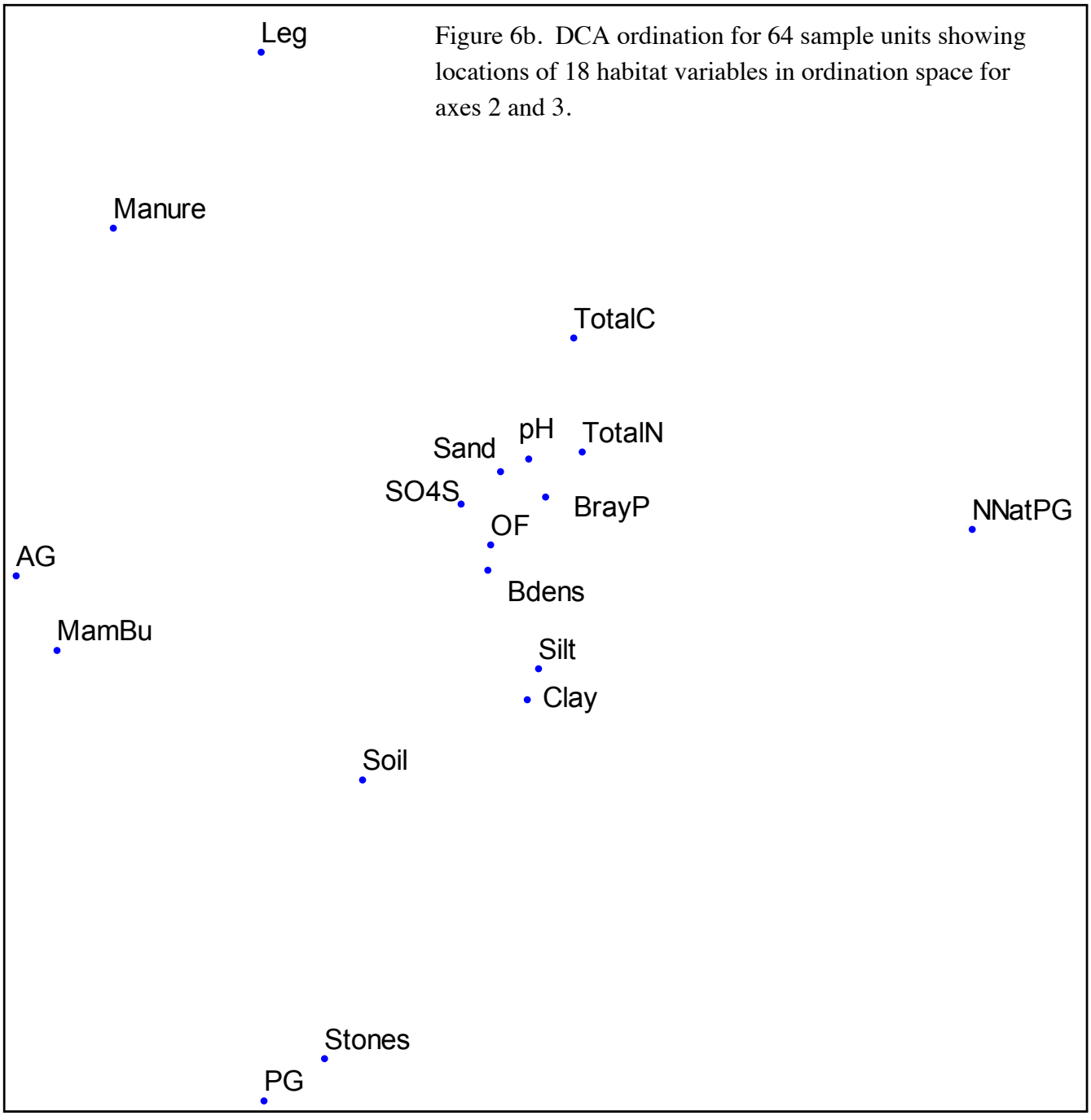
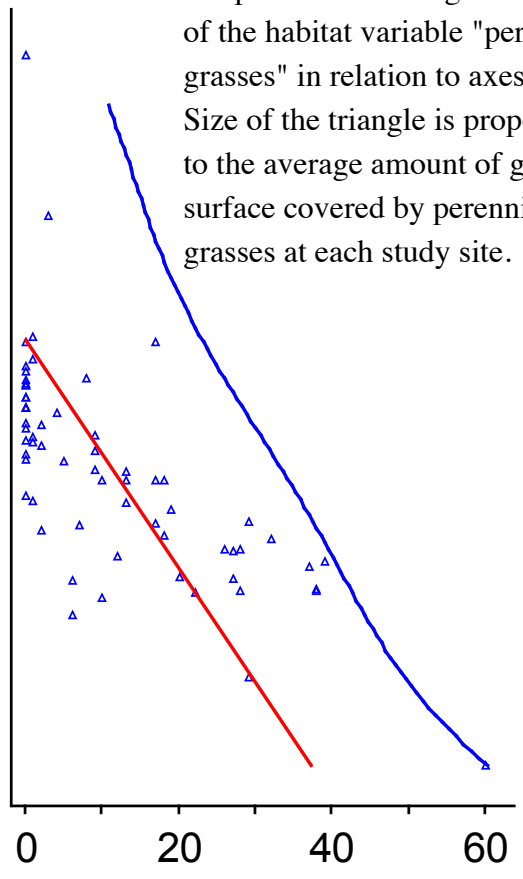


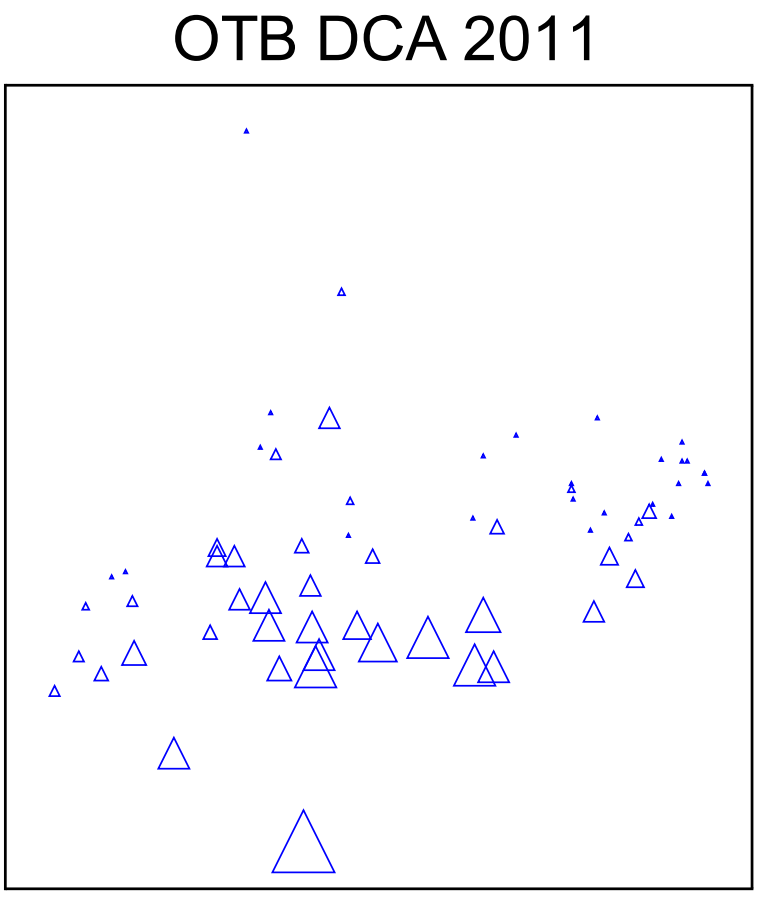
Figure 6b. DCA ordination for 64 sample units showing locations of 18 habitat variables in ordination space for axes 2 and 3.

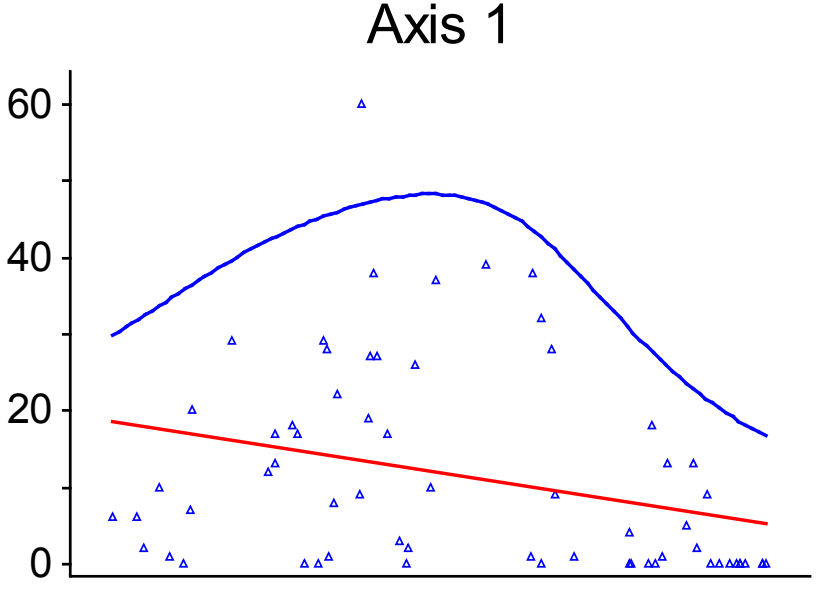
Figure 7a. DCA ordination of 64 sample units showing correlation of the habitat variable "perennial grasses" in relation to axes 1 and 3. Size of the triangle is proportional to the average amount of ground surface covered by perennial grasses at each study site.



PG

Axis 1
r = -.294 tau = -.272
Axis 3
r = -.697 tau = -.580





OTB DCA 2011

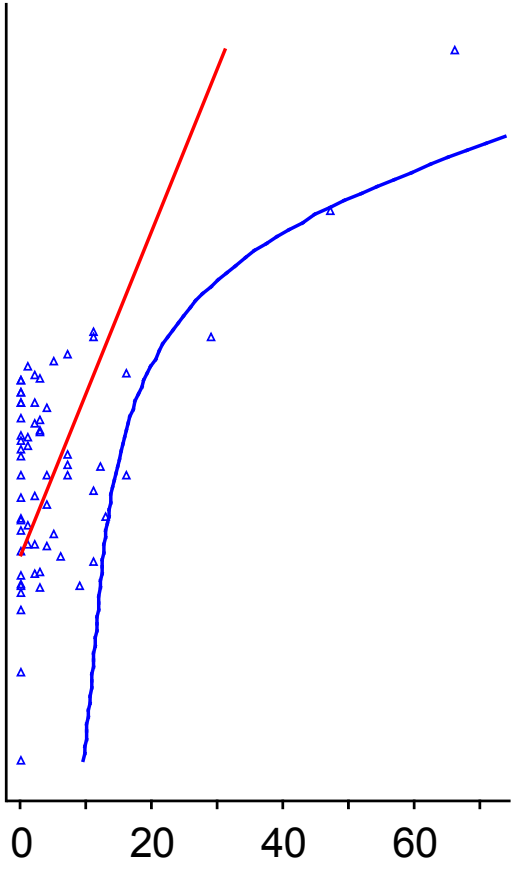


Figure 7b. DCA ordination of 64 sample units showing correlation of the habitat variable "legumes" in relation to axes 1 and 3. Size of the triangle is proportional to the average amount of ground surface covered by legumes.

Axis 3

Axis 1

Leg

Axis 1
r = -.212 tau = -.178
Axis 3
r = .610 tau = .204

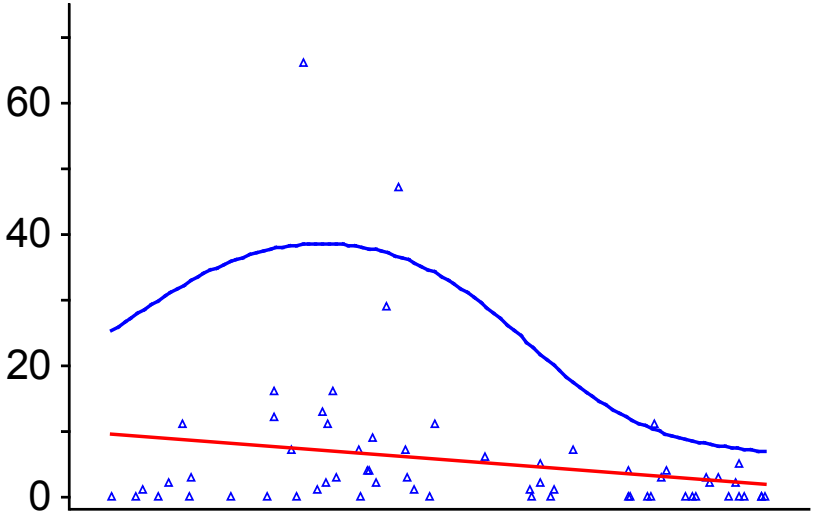
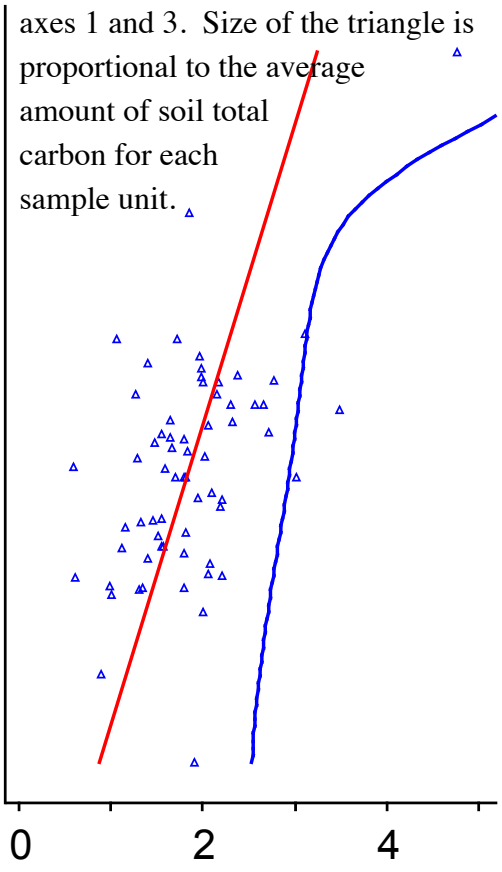
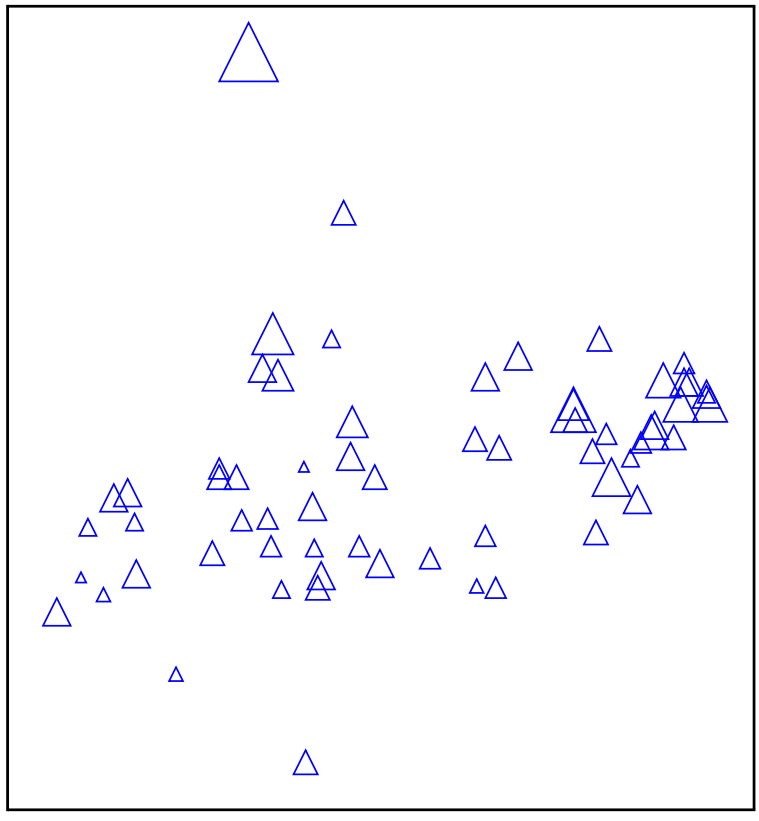


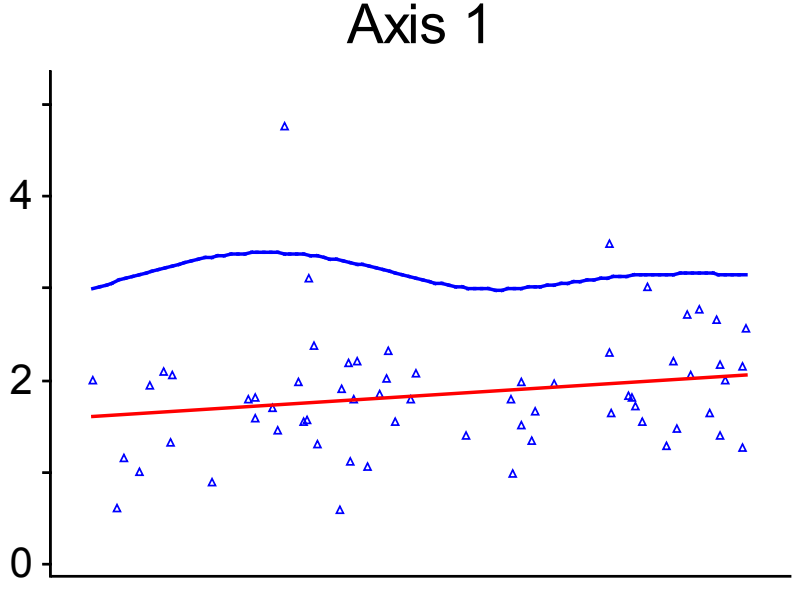
Figure 7c. DCA ordination of 64 sample units showing correlation of the variable "Total Carbon" in relation to axes 1 and 3. Size of the triangle is proportional to the average amount of soil total carbon for each sample unit.



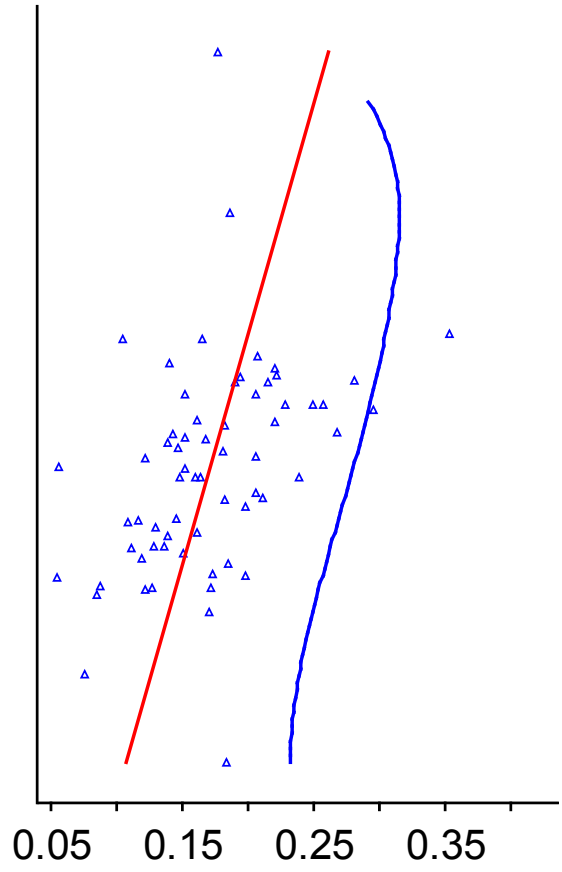


TotalC

Axis 1
r = .212 tau = .154
Axis 3
r = .533 tau = .286



OTB DCA 2011



Axis 3

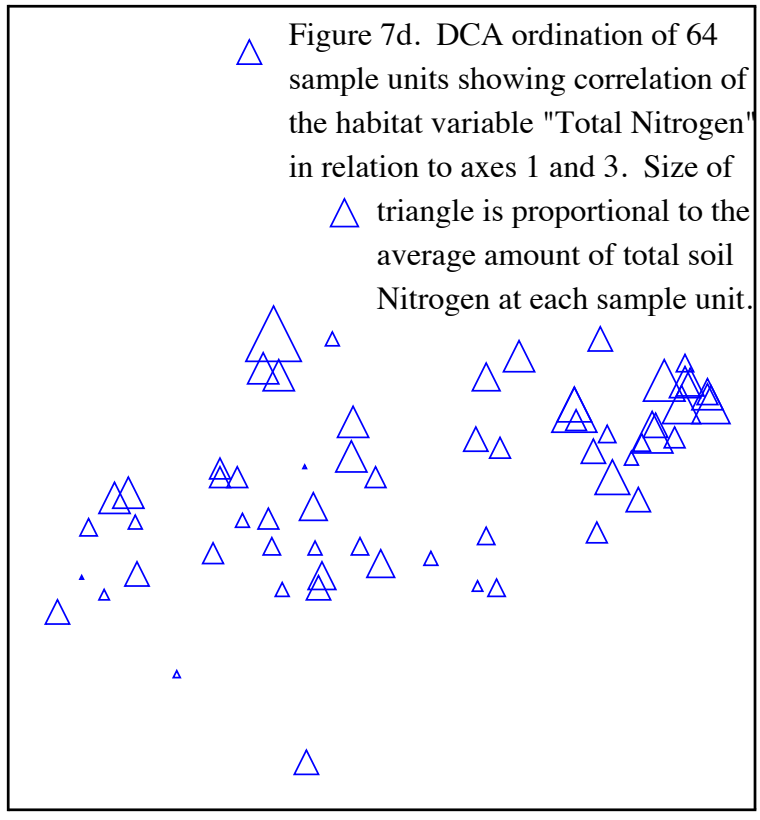
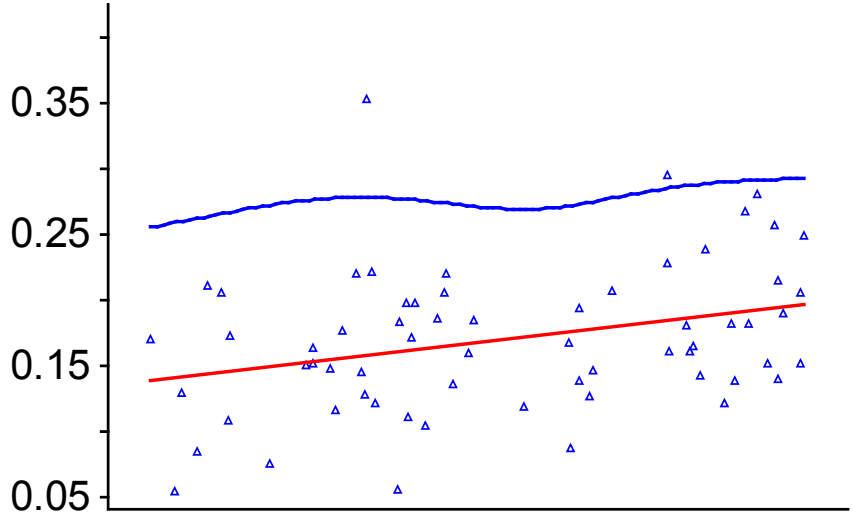


Figure 7d. DCA ordination of 64 sample units showing correlation of the habitat variable "Total Nitrogen" in relation to axes 1 and 3. Size of triangle is proportional to the average amount of total soil Nitrogen at each sample unit.

TotalN

Axis 1
r = .320 tau = .217
Axis 3
r = .414 tau = .355

Axis 1



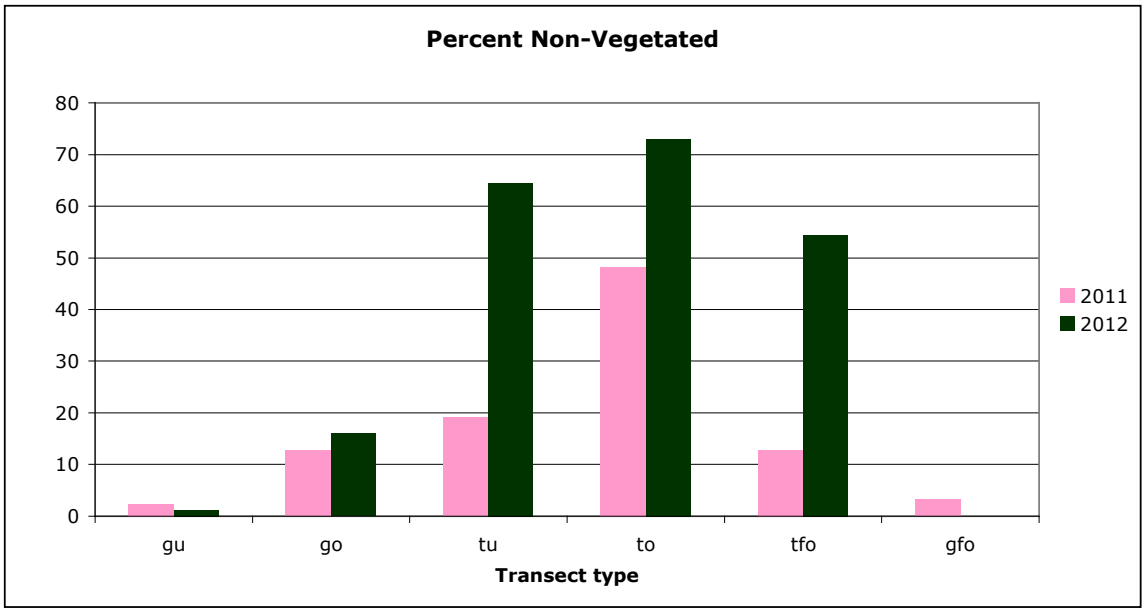


Figure 8. Average percent non-vegetated surface and OTB occupancy status for 64 transects sampled in February 2011 and for 15 transects sampled in February 2012. Transect types are gu=grassland unoccupied, go=grassland occupied, tu=Trail/Road unoccupied, to=Trail/Road occupied, tfo=Trail/Road formerly occupied, gfo=grass formerly occupied.

DISCUSSION

Results from our sampling in February of 2011 distinguished OTB breeding habitat areas from non-breeding habitat areas within the beetle's grassland habitat. This was in contrast to previous years, in which the larger scale of plot size and arrangement made it difficult to come up with good habitat variables correlated with actual OTB occupation. It appears that the 0.25 m^2 quadrats arranged along a 10 meter transect do a good job of describing habitat features. The results of our Phase 2 OTB study are sufficient to formulate directed adaptive management actions to improve and increase the quality of breeding habitat for the beetle, which should reverse the decline in number of viable OTB populations. Our earlier habitat management recommendations (Arnold et al. 2012) are still applicable, but these directed adaptive management actions are refinements.

The three groups of sample transects created by DCA from our 2011 data were based on a variety of habitat features which distinguished the OTB sample sites. Current occupancy by OTB was most closely related to the amount of bare soil and associated differences in vegetation. No sample site averaging less than 5% bare soil was occupied by the OTB. The occupancy of Grass and Trail/Road transects differed considerably in area non-vegetated. Occupied Trail/Road transects averaged nearly 50% non-vegetated, whereas occupied grass transects averaged only about 12% non-vegetated, which is in the range of the unoccupied and formerly occupied Trail/Road transects (Figure 8). Unoccupied Trail/Road transects had about the same percentage non-vegetated and occupied grass samples. These results from 2011 predicted that subsequent sites should show similar relationships.

The additional grassland transects from 2012 did fall within the cover ranges predicted from 2011, with much lower percent non-vegetated than in Trail/Road transects (Figure 8). We found that the 2012 Trail/Road transects had higher percentages non-vegetated, but considerable variability, especially on the unoccupied Trail/Road transects. This could reflect recent loss of suitable openings along trails at OTB site #3.

The 2011 data showed an interesting link to non-native perennial grasses. DCA Group 1 in Figure 2a consists only of five unoccupied or formerly occupied transects, all from OTB site #13 except for one OTB site #5 transect, and all with non-native perennial grasses above 35% (Figure 5). Non-native perennial grasses are the main driver of this grouping. The 2012 transects had significant amounts (80% cover) of non-native perennial grasses on two transects and both were unoccupied. The role of invasive non-native perennial grasses in loss of favorable sites for occupancy needs further investigation and control of these species may be warranted.

The location of the overwhelmingly unoccupied Group 2 (Figure 2a) is primarily the result of lack of bare soil (axis 1), and more annual grasses, and more small mammal burrows (axes 1 and 2). There is evidence in the grassland literature (Bartolome et al 2007) for a link between small mammal activity and the presence of annuals. The lack of non-native perennial grasses separates these transects from Group 1 (Figure 2a). The abundance of plant material on the plot surface separates this group from Group 3 (Figure 2a).

Group 3 (Figure 2a) consists of sample transects, all with the apparent potential for occupancy by OTB, but not all were actually occupied. The conclusion that few areas without vegetative cover exclude OTB but that areas with low level of cover are not always occupied suggests other factors are operating on those sites. Further study is necessary to elucidate what are these other factors.

We found some differences in soil characteristics among the 2011 transects, but none were well-linked to OTB occupancy. The strong association of OTB with Watsonville loam soils appears to be solid, but we did not find evidence that variations within this soil series made a difference in occupancy.

Our results do show which factors can exclude occupancy, so management needs to be directed towards providing a sufficient amounts of good quality habitat for the OTB. The differences between the amount of bare soil related to a threshold of occupancy of Trail/Road and grassland habitats is strongly suggestive. This relationship held up as predicted for occupied sites added in the 2012 transects. Lower amounts of bare soil in grassland were occupied than on Trails/Roads. Does this make it easier to provide suitable habitat in grasslands? If this were the case, then creating small patches with more than 5% bare soil in grassland could enhance OTB numbers.

Because the amount of bare soil is so important, management needs to be directed toward maintaining it. This can include roads and trails averaging 50 % bare soil or grass areas averaging 12% bare soil. Grazing would likely be more effectively directed at trail maintenance. The amount of bare soil in grass habitat will likely be more dependent on fluctuations in cover due to weather. However, it might be possible to directly intervene by creating small scale bare areas in good grassland habitat.

UPDATED GUIDELINES FOR OTB HABITAT MANAGEMENT

Results of the Detrended Correspondence Analysis (DCA) revealed relationships among the physical and vegetation habitat features of the OTB, as well as between these habitat features and the occupied and unoccupied OTB study sites and subsites. These results better define the habitat characteristics that are associated with continued occupation by OTB at some locations and its absence or limited occupation at other locations within the beetle's historical geographic range. The statistical confidence associated with these results are strong enough to guide future adaptive management by identifying the habitat features which land managers should focus upon and the habitat features they should monitor to not only increase the amount of suitable habitat for the beetle habitat, but also to reverse the decline in the numbers of viable OTB populations. These results can also guide habitat rehabilitation and restoration efforts at sites that are no longer occupied by the OTB.

The findings of our current study, along with those of our Phase 1 OTB study (Arnold et al. 2012), indicate that OTB females oviposit and larvae successfully complete their development in grasslands characterized by Watsonville loam soils, where the cover of non-native perennial grasses is 35% or less and there is more than 12% bare or sparsely-vegetated soil. On similarly occupied trails and roads, the amount of bare ground exceeds 50%. The extra amount of bare soil required on occupied trails and roads compared to off-trail grasslands may be related to the amount of hiking and biking traffic that the trails experience, but this aspect requires further study. Although we examined several physical and chemical properties of the Watsonville loam soils at the occupied and unoccupied OTB locations, no clear distinctions in these soil properties were detected. Although not specifically tested in this study, grassland areas characterized by saturated Watsonville loam soils or areas that temporarily pond water for more than a few days are generally not suitable for habitation by the OTB (Arnold, personal observation).

Because the amount of sunlit, bare soil is so important to OTB habitat quality, management should be focused upon maintaining it, and whenever feasible, expanding the amount of sunlit, bare soil. This can include roads and trails averaging 50% or more bare soil or grassland areas averaging 12% or more bare soil. Although we can expect the amount of bare soil in grassland sites to be more dependent on fluctuations in cover due to weather (which varies between years) rather than management, the effects of livestock grazing, livestock trailing, weed-whacking, scraping, and other management treatments are likely to be most important during years with weather more favorable to herbaceous vegetation growth. Also, control of non-native perennial grasses should be a high priority management objective for sites with potential OTB habitat.

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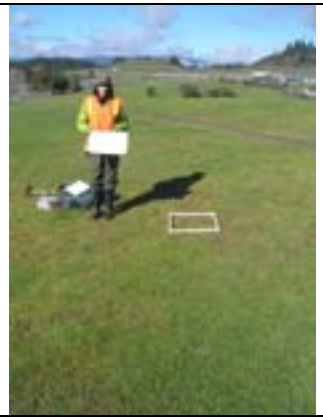
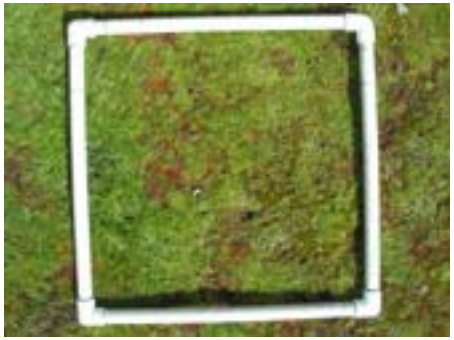
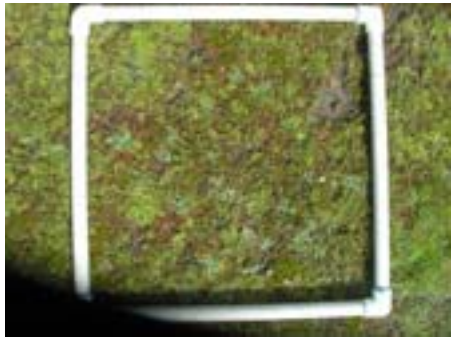
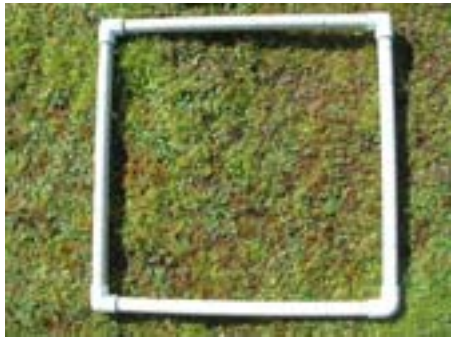
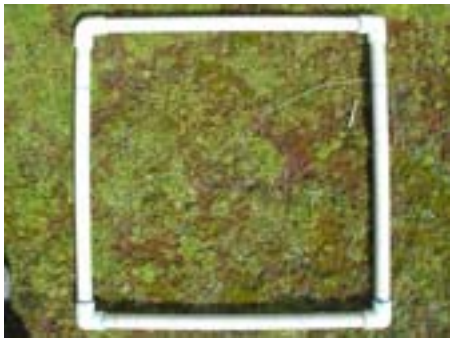
APPENDIX:

Photos of Transects and Quadrats from the Phase 2 Oviposition Study

OTB Photos From February 2011
Site #2 – Grassland Occupied Transects

2-GO		6-GO	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

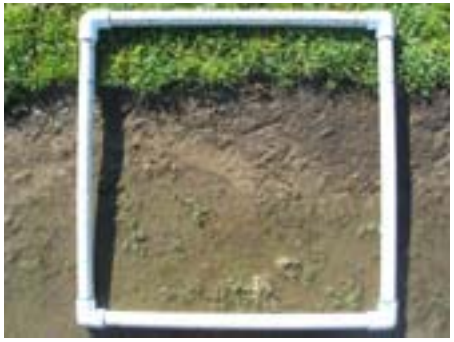
Site #2 – Grassland Unoccupied Transects

1-GU		5-GU	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

Site #2 – Trail Occupied Transects

3-TO		4-TO	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

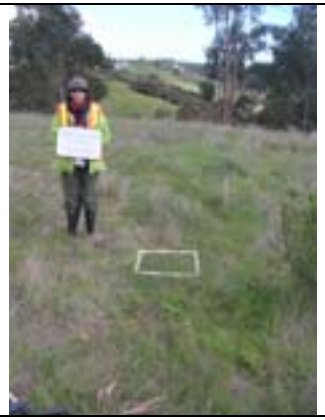
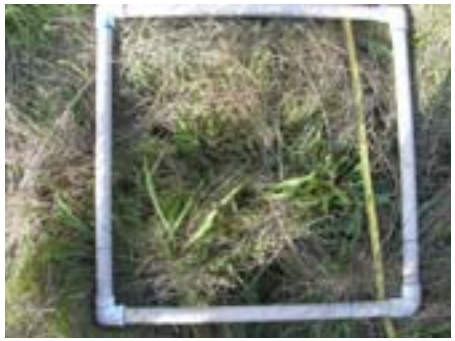
Site #2 – Trail Unoccupied Transects

7-TU		8-TU	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

Site #1 – Grassland Formerly Occupied Transects

12-GFO		14-GFO	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

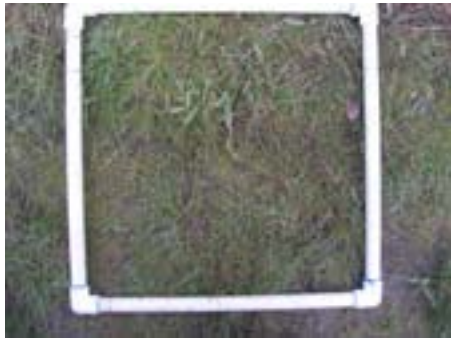
Site #1 – Grassland Unoccupied Transects

11-GU		13-GU	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

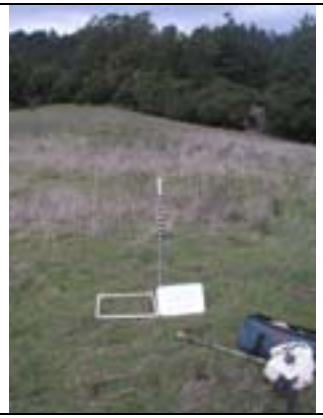
Site #1 – Trail Formerly Occupied Transects

9-TFO		10-TFO	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

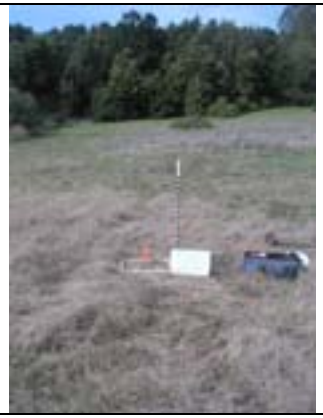
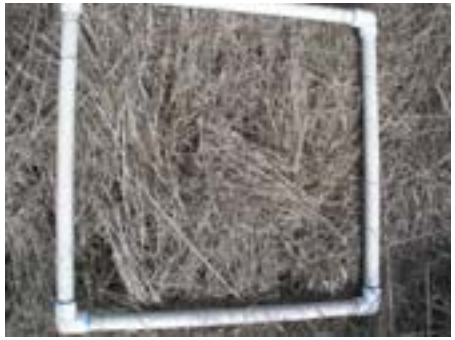
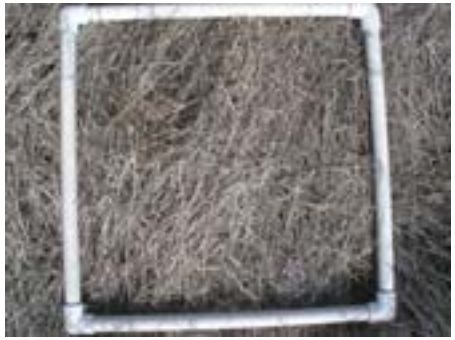
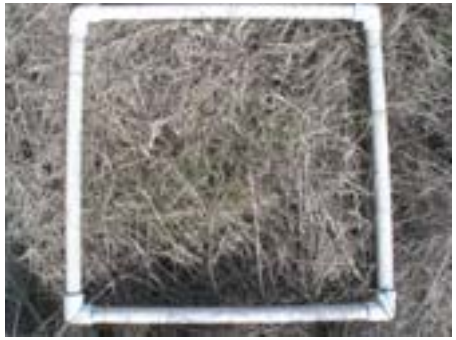
Site #1 – Trail Unoccupied Transects

15-TU		16-TU	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

Site #5 – Grassland Formerly Occupied Transects

25-GFO		27-GFO	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

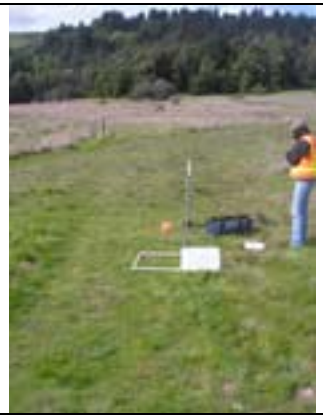
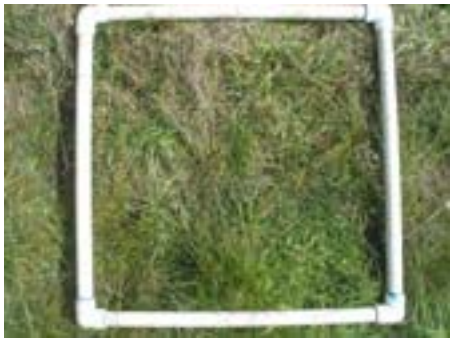
Site #5 – Grassland Unoccupied Transects

28-GU		30-GU	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

Site #5 – Trail Formerly Occupied Transects

26-TFO		29-TFO	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

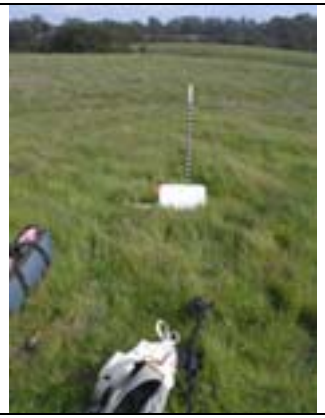
Site #5 – Trail Unoccupied Transects

31-TU		32-TU	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

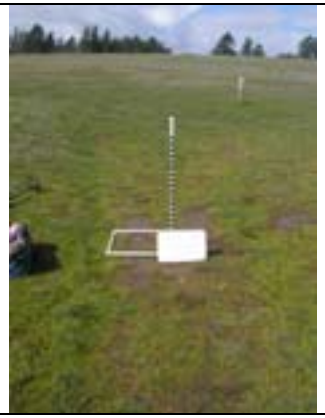
Site #3 – Grassland Occupied Transects

37-GO		38-GO	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

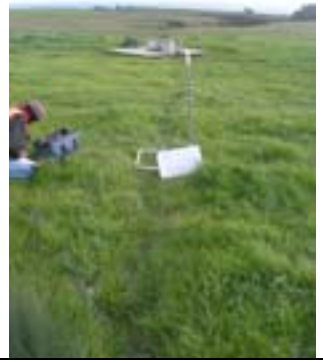
Site #3 – Grassland Unoccupied Transects

34-GU		36-GU	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

Site #3 – Trail Occupied Transects

33-TO		35-TO	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

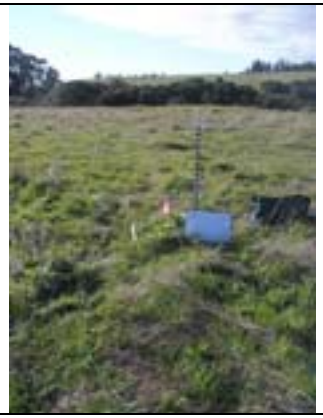
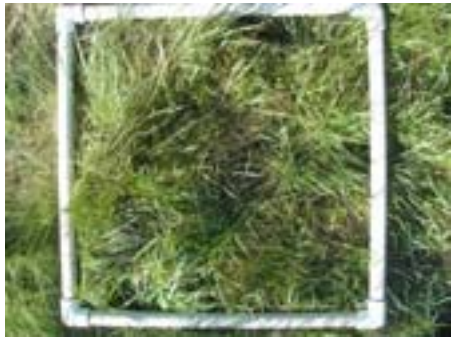
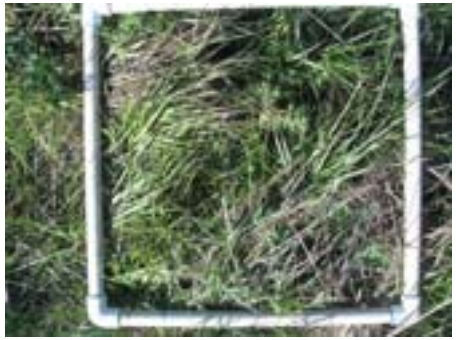
Site #3 – Trail Unoccupied Transects

39-TU		40-TU	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

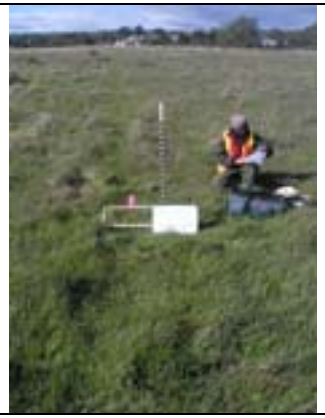
Site #13 – Grassland Formerly Occupied Transects

42-GFO		43-GFO	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

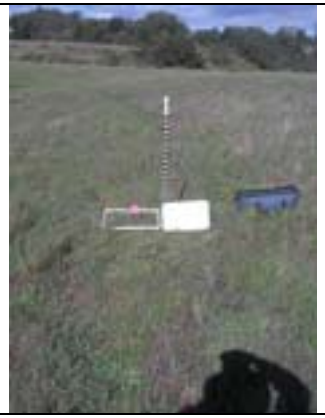
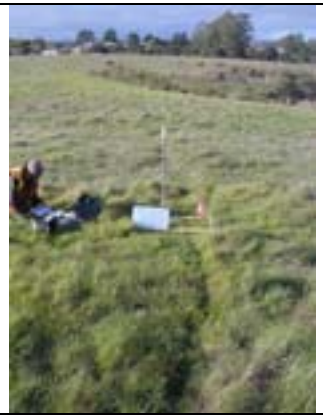
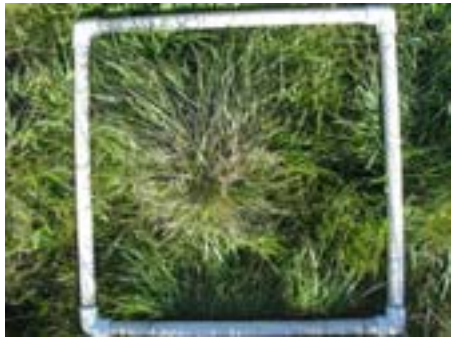
Site #13 – Grassland Unoccupied Transects

45-GU		46-GU	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

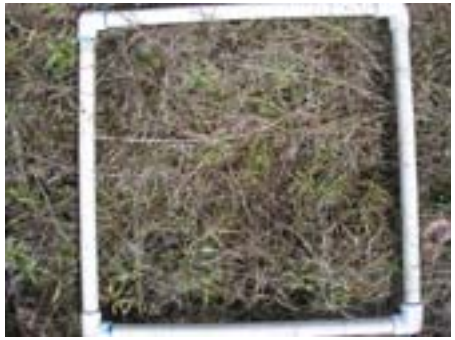
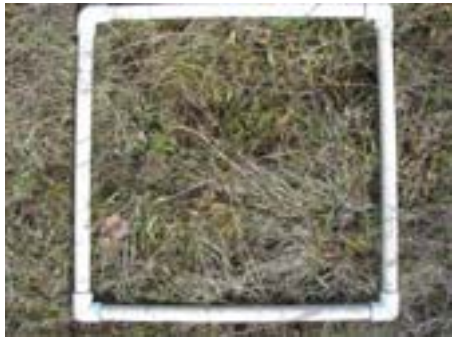
Site #13 – Trail Formerly Occupied Transects

44-TFO		48-TFO	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

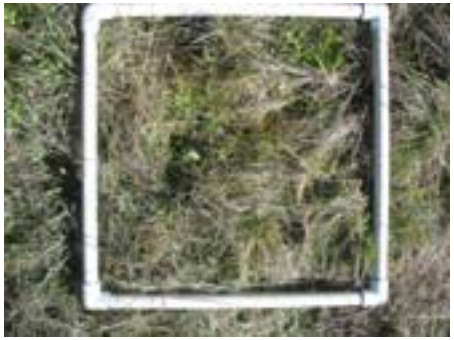
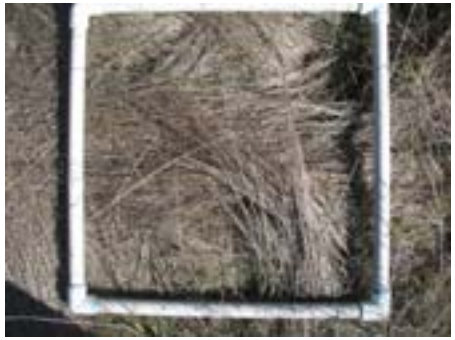
Site #13 – Trail Unoccupied Transects

41-TU		47-TU	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

Sites #16 and #6 – Grassland Occupied Transects

20-GO		23-GO	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

Site #6 – Grassland Unoccupied Transects

18-GU		19-GU	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

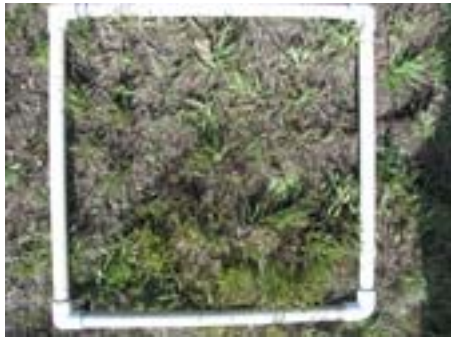
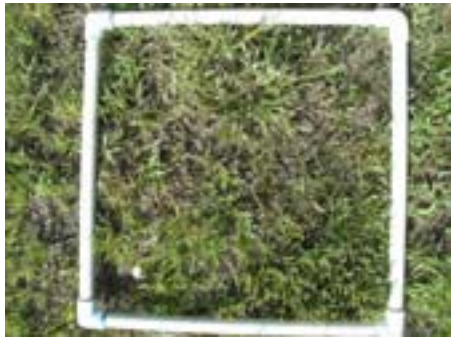
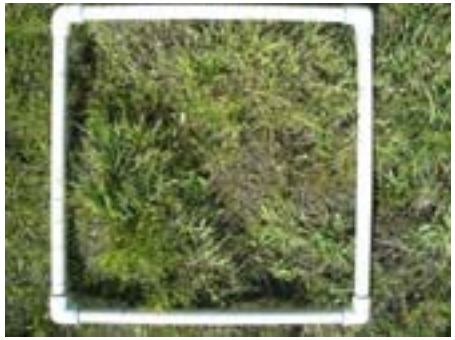
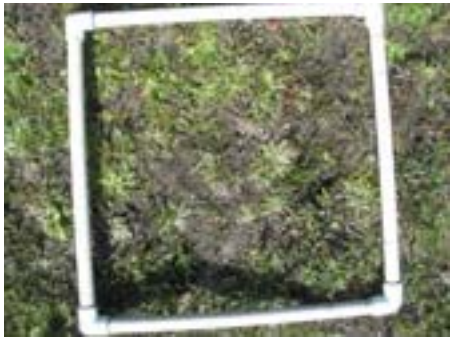
Sites #6 and #16 – Trail Occupied Transects

17-TO		21-TO	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

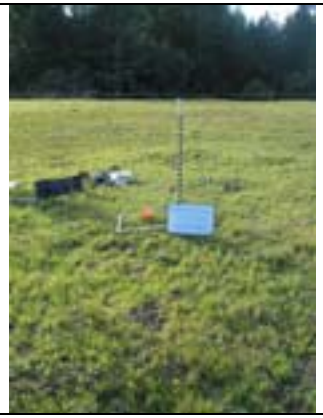
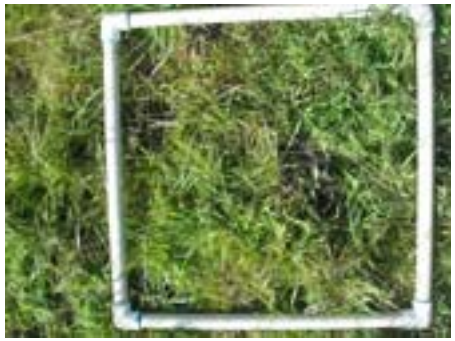
Site #6 – Trail Unoccupied Transects

22-TU		24-TU	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

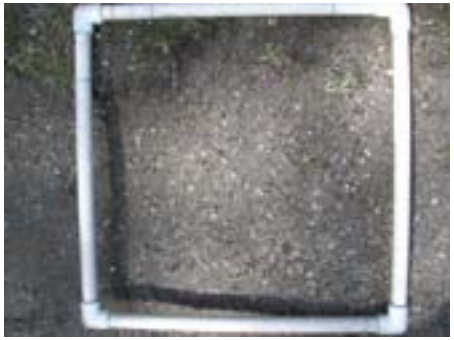
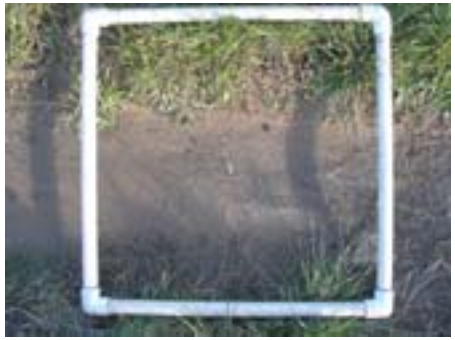
Site #14 – Grassland Occupied Transects

50-GO		52-GO	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

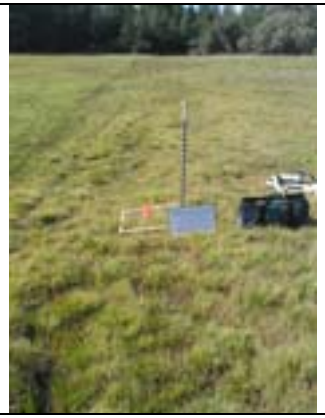
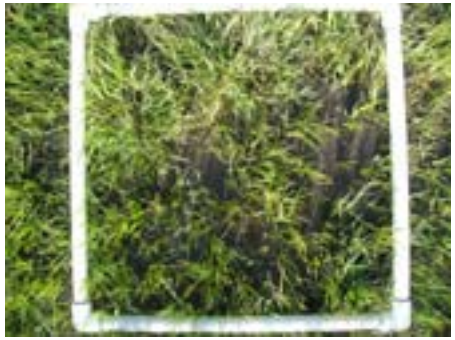
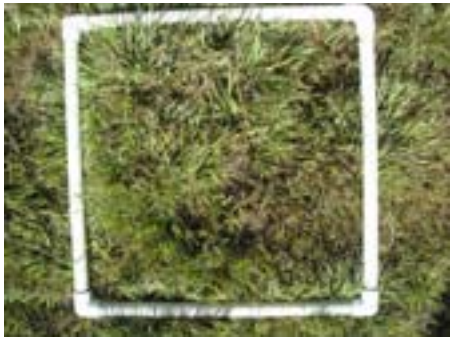
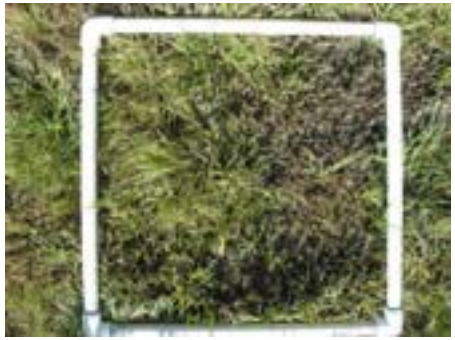
Site #14 – Grassland Unoccupied Transects

51-GU		54-GU	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

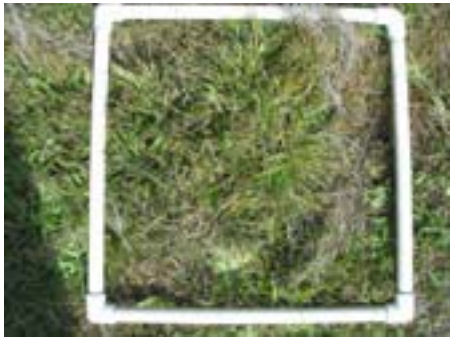
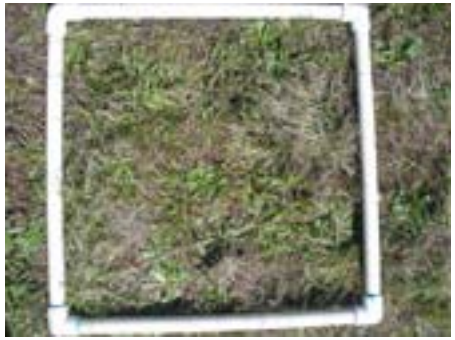
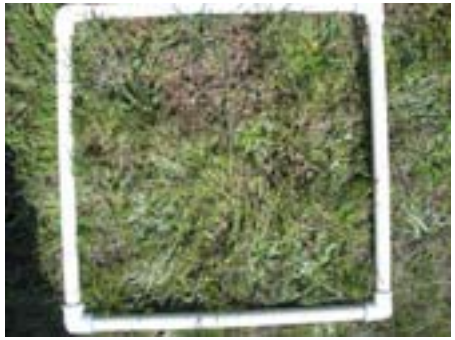
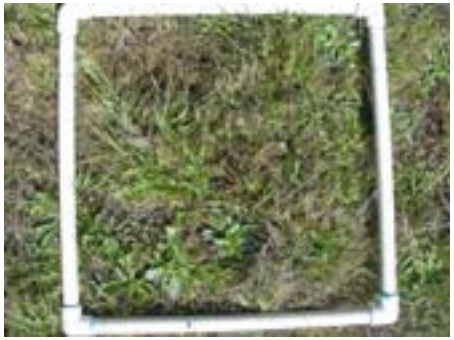
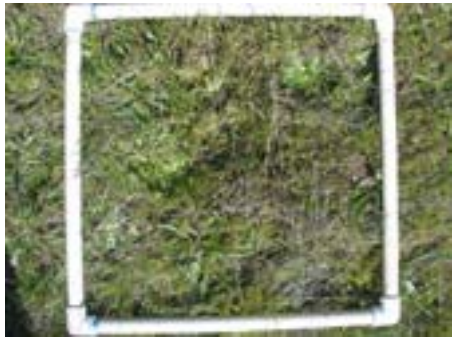
Site #14 – Trail Occupied Transects

49-TO		55-TO	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

Site #14 – Trail Unoccupied Transects

53-TU		56-TU	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

Site #10 – Grassland Occupied Transects

63-GO		64-GO	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

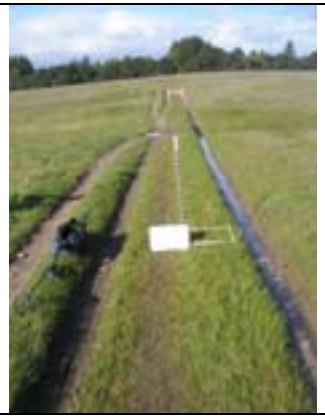
Site #10 – Grassland Unoccupied Transects

59-GU		60-GU	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

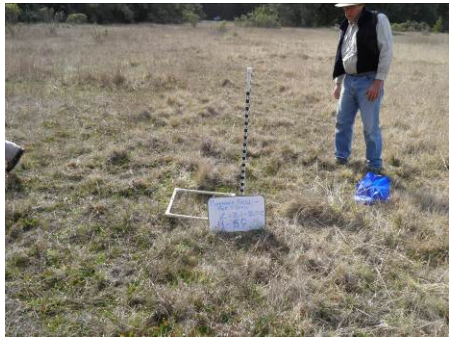
Site #10 – Trail Occupied Transects

61-TO		62-TO	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

Site #10 – Trail Unoccupied Transects

57-TU		58-TU	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

OTB Additional Photos From February 2012
Site #15 – Grassland Occupied Transects

4-GO		5-GO	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

Site #15 – Grassland Unoccupied Transects

6-GU		7-GU	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

Site #15 – Trail Occupied Transects

2-TO		3-TO	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

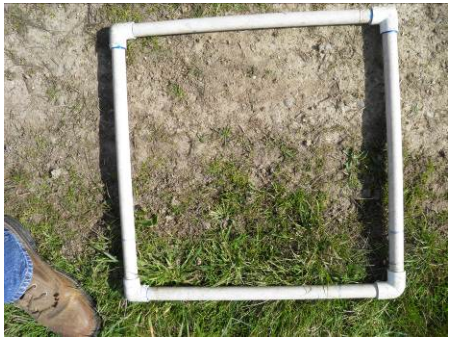
Site #15 – Trail Unoccupied Transects

1-TU		8-TU	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

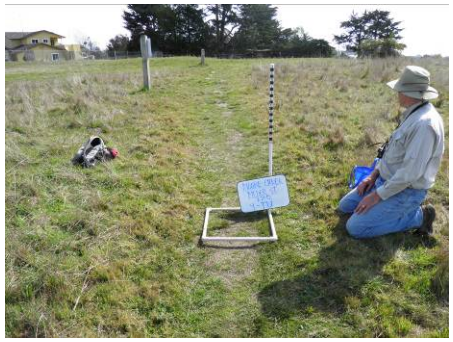
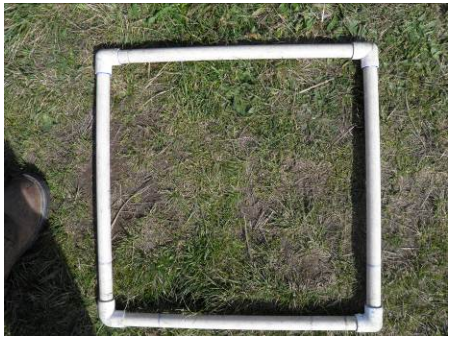
Site #11 – Grassland Unoccupied Transects

11-GU		12-GU	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

Site #11 – Trail Formerly Occupied Transects

13-TFO		14-TFO	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5

Site #11 – Trail Unoccupied Transects

9-TU		10-TU	
	 Q3		 Q3
 Q1	 Q4	 Q1	 Q4
 Q2	 Q5	 Q2	 Q5