Elevation patterns of plant diversity and recent altitudinal range shifts in Sinai's high mountain flora

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Abstract

Questions: Is there evidence of recent altitudinal range shifts in a hyper-arid Middle Eastern desert mountain flora?

How do the directions of shift for upper and lower altitudinal range limits of plants vary?

Location: Hyper-arid mountain desert, St Katherine Protectorate, South Sinai, Egypt.

Method: We tested for shifts in both upper and lower altitudinal range limits by comparing a 1970s dataset of recorded species' limits with recent surveys using altitudinal transects across 36 sites. Altitudinal limits between 63 paired upper-limit and 22 paired lower-limit values from the 1970s and 2014 were compared using paired t-tests; binomial tests were used to indicate the dominant direction of change. The upper and lower limits of 22 species were considered together to allow assessment of overall altitudinal range-size changes. In order to avoid the potential effect of yearly environmental fluctuations on the distributions of annual species, subsets of upper and lower limit shifts were taken for perennials, and trees and shrubs.

Results: Our results show significant overall upslope shifts in mean upper altitudinal limits and significant overall downslope shifts in mean lower altitudinal limits. A majority of assessed species expanded their altitudinal ranges, but the responses of individual species varied. Since perennial herbs/graminoids, and trees and shrubs, show strong patterns of change, we suggest there has been a long-term shift in altitudinal range in South Sinai's mountain flora. Greater research effort needs to be focussed upon the drivers of range-shift responses in arid regions.

Introduction

Recent range shifts in both latitudinal and altitudinal distributions have been recorded across animal and plant taxa in response to changes in climate, with ranges expanding at high latitudes and altitudes, and contracting at lower latitudes and altitudes (e.g. Wilson et al. 2005; Chen et al. 2011). Lower latitudinal and altitudinal range limits, the rear or trailing edges of distributions, have received little attention (Hampe & Petit 2005), despite these margins often contributing to higher levels of regional genetic diversity (e.g. Hewitt 2004) and being important in the maintenance of biodiversity (Hampe & Petit 2005). Given the potential conservation implications of the lower-margin shifts of plants, it is therefore surprising that empirical studies are so poorly represented in the literature (Lenoir & Svenning 2015). It is true that lower limits are harder to assess, with a less clear-cut position influenced by a multitude of factors rather than mainly climatic (e.g. biotic interactions, and propagules moving downhill under gravity). Nevertheless, in arid regions, water availability is a crucial factor, which is expected to ameliorate towards higher elevations through convective cloud formation, and hence lower limits may be more easily recognised.

Under conditions of global warming it seems logical that up-slope range shifts of plants attributed to changing climatic factors would be the norm(Klanderud & Birks 2003; Walther et al. 2005; Stöckl et al. 2011; Gottfried et al. 2012; Pauli et al. 2007, 2012; Jump et al. 2012; Matteodo et al. 2013; Wipf et al. 2013). It is important to note that changes such as these are not necessarily always consistent with temperature being the sole dominant factor inducing change (Grytnes et al. 2014). However it seems probable that changes in both the thermal regime and water availability will be the main drivers of altitudinal changes, with adverse changes in both (e.g. warmer and drier) causing the greatest pressure (McCain & Colwell 2011).

Globally, mountainous regions represent important hotspots of endemism (e.g. Körner 2003; Nagy & Grabherr 2009), but mountain species are especially vulnerable to extinction due to habitat loss induced by climate change, because shifting climatic zones will reduce suitable habitat area, leading to 'mountain-top extinctions' (Dirnböck et al. 2011). Plant species in arid regions may also be very susceptible to climate change, and the loss of arid-land endemics may occur in both lowland (Foden et al. 2007) and mountain (Van de Ven et al. 2007) environments under increased levels of global warming.

There are very few studies of recent altitudinal changes in plant distributions from subtropical or arid regions (Jump et al. 2012; Lenoir & Svenning 2015). We study here the flora of the hyper-arid desert mountains of South Sinai, Egypt. Egypt and the wider Middle East region has seen recent temperature increases (Domroes & El- Tantawi 2005; Zhang et al. 2005), with average warmest daily maximum temperatures increasing by >1^{o}C since the 1970s (Donat et al. 2014). Sinai's southern montane regions contain relatively high levels of biodiversity (Zalat et al. 2009), and are home to 19 of Egypt's 33 endemic plant species (Rashad et al. 2002). The area is recognised as one of the most important centres of plant diversity in the Middle East (IUCN 1994). Greater botanical diversity has been suggested to occur at higher altitudes in Sinai due to a diversity of habitat types and favourable environmental factors, especially the greater water availability, precipitation, and soil moisture retention, in high altitude areas (Moustafa & Klopatek 1996; Moustafa & Zaghloul 1996).

Many species of plants in the high mountains of southern Sinai exhibit disjunct distributions of Holarctic species found more commonly further north, suggesting that these species are relics of a more humid, colder past (Shmida 1977). The isolation of plants which thrive in cooler damper climates in refugia on the highest of Sinai's mountains suggests their vulnerability to rising temperatures. Recent shifts in plant altitudinal distributions in the Middle

East are expected, but remain completely unstudied until now, and especially not with the multifaceted approach of looking at leading and trailing changes simultaneously.

Therefore, we focus here on the following hypotheses. First we ask whether there is evidence of recent range shifts in the high mountain flora in South Sinai, predicting that these should be evident as largely up-slope movements. The null hypothesis is of course no change, but alternatively the mean response may be zero because of idiosyncratic responses of the different species, which may not be responding to temperature but to other factors, especially water balance (cf. Rapacciuolo et al. 2014). Second, we study the directions of shift for upper and lower altitudinal range limits, and split the species into growth forms to help interpret the results. The prediction is that upper and lower limits should move in concert, and that all plants should show the same patterns.

Methods

We use the approach of comparing modern with historical data (Stöckl et al. 2011). Ideally the methodologies and locations should be identical, but in this case the earlier surveys were not quantitative and did not locate the transects with geographic coordinates. With this caveat, the unique existence of the earlier data for the Middle East makes the comparison worthwhile.

Study region

The St Katherine Protectorate covers much (4350 km^2, almost half the area) of the southern peninsula of Sinai, encompassing the majority of a high-altitude massif and reaching down to sea level to form one of Egypt's largest protected areas (Grainger & Gilbert 2008). An igneous pre-Cambrian ring-dyke encircles 640 km^2 of the centre of the Protectorate. The ring-dyke contains Egypt's highest mountain, Mt St Katherine, at 2643 m. The mountainous terrain is inter-cut with dry steep-sided wadis (valleys). South Sinai receives higher than average rainfall

(62 mm) (Zahran & Willis 2008) and generally cooler temperatures (summer mean 30°C) than the rest of Egypt (Grainger & Gilbert 2008).

Historical data

To assess temporal changes in upper altitudinal range limits, we compared our field data with a 1970s dataset compiled by Arbel & Shmida (1979) in a semi-quantitative format. Data were collected during the years 1974-1976 and focused upon the mountainous area within the St Katherine ring-dyke (see Fig. 1 map-inset: shaded area).

Vegetation was sampled by recording species richness in quadrats of area 100 m^2. Quadrats were placed along transects divided into altitudinal units of 200 m running up wadis and mountain slopes. In addition, quadrats were placed wherever habitat type or plant dominance changed noticeably. Each altitudinal unit was sampled several times in different locations but the coordinates for each quadrat were not recorded. Additional incidental vegetation observations were included from lower altitudes in the St Katherine Protectorate falling outside the ring-dyke and its high mountains; these observations were incorporated into the main dataset. Unfortunately the only remaining details of the original dataset available to this study were records of minimum and maximum altitudes for plant species recorded at a resolution of 100 m altitude, together with a subjective assessment of relative abundance (common, very frequent, frequent, rare, very rare, found once) and statements of their common habitats (gorges, weathered slopes, gravel wadis, rock cracks, wet places, etc) (see Table S1).

New data

Quantitative data were collected during field surveys running from late October to mid-December 2014. Surveys were carried out in the high mountains within the igneous ring-dyke area over an altitude range of 1324 m to 2629 m (see Fig. 1 for survey locations, Table S3 for quadrat GPS locations, Table S4 for site photos and descriptions, and Table S5 for species lists and abundances by quadrat). We were not able to revisit exact sites surveyed in the 1970s as quadrat location had not been recorded; instead we surveyed extensively within the same mountainous region (Fig 1) including the same mountains and habitats as the older surveys. It is probable that new and old quadrats were close or very close to one another.

Vegetation was sampled along sloped transects running through wadis, mountain slopes, and gullies. The lengths of each transect were determined by the scale of the landscape, running from the lower to the upper altitudinal limits to encompass as great an altitudinal range as possible. As landform/habitat type is a major determinant of the diversity and community composition of the vegetation in Sinai (Moustafa & Klopatek 1996), the location of transects was chosen to cover all major habitat types.

Quadrats of area 100 m^2 were demarcated along transects approximately every 50 m change in elevation where terrain permitted. In total 283 quadrats were placed in 36 sites covering 28300 m^2. Location and altitude above sea level were measured at the centre of the quadrats using a Garmin etrex 30 hand-held GPS with the GPS+GLONASS (± 3 m) and barometric altimeter (± 3 m) functions respectively. At each quadrat, we recorded: aspect of slope to the nearest cardinal point; gradient to the nearest five degrees (360^o scale); a brief site description; and a photograph. All vascular plant species in the quadrats were identified (using Boulos 1995-2005) and individually counted (with individuals of multiple stemmed/clumping plants defined as those with stems returning to a common root-stock): plant names follow Boulos (1995-2005).

A total of 241 species were recorded from the 1970s: of these, notable absences compared with the plants of 2014 were *Lavandula pubescens*, and *Gomphocarpus sinaicus*. The identity of *Chiliadenus montanus* was uncertain from records and was therefore not included in analyses to avoid inaccuracy due to ambiguity. *Fagonia arabica* and *F. bruguieri* were not differentiated in the earlier dataset, and therefore for the purposes of comparison the records collected in 2014 were amalgamated for these species. In total, 81 species were available with upper altitudinal limits from both the 1970s and 2014. The significantly greater sampling effort required to establish accurately the lower altitudinal limits for the more widespread species was beyond the scope of this study which deals specifically with the high-altitude flora of South Sinai. However, the lower altitudinal limits of 25 species fell within the altitudinal range surveyed, thereby permitting their analysis.

Numerical abundance data were not available for species from the 1970s dataset. In the 2014 dataset, to allow reasonably accurate estimation of altitudinal limits, only species for which more than 10 individuals had been recorded during the entirety of the 2014 field surveys were selected (see Table S2). This selection allowed the upper limits of 63 and lower limits of 22 species to be identified. Subsets of upper- and lower-limit shifts were taken for perennials, and trees and shrubs to allow comparisons to be made that avoided the potential effect of yearly environmental (specifically rainfall) fluctuation on the distributions of annual species.

Statistical methods

All statistical and graphical analyses were carried out using R (Version 3.1.2, R Foundation for Statistical Computing, Vienna, Austria).

(a) Patterns of diversity in the new data

To describe the 2014 dataset, weighted mean (± SE) elevations were calculated for all species recorded. For each quadrat, the three Hill's numbers (Chao et al. 2012) were calculated as measures of components of diversity representing effective species richness. The general equation is:

$$^{q}D = (\sum p_i^{q})^{(1/(1-q))}$$

where q = 0, 1, or 2. Ascending Hill's numbers (q values) give reducing weight to the less-abundant species, reflecting the relative ecological importance of more abundant species (Hill 1973). Thus ${}^{0}D$ measures species richness, ${}^{1}D$ represents the number of 'typical' common species, while ${}^{2}D$ represents the number of 'very abundant' species present in the community (Chao et al. 2012). Therefore considered together, Hill's numbers present a picture of community evenness.

To describe altitudinal patterns of diversity in the 2014 data, abundances were assigned to altitudinal bands of 50 m. Smoothing splines were fitted to the three Hill's numbers with altitude as the predictor, using the GAM (Generalized Additive Model) function of R-package *ggplot2* (Wickham 2009).

(b) Range-shift comparison

To estimate shifts in altitudinal ranges, the altitudinal limits between 63 paired upper-limit and 22 paired lower-limit values from the 1970s and 2014 were compared using paired t-tests to test the null hypothesis that the mean difference was zero. Sign tests (i.e. binomial tests on the numbers of negative and positive changes) were used to indicate the dominant direction of change. 22 species had estimates of both upper and lower limits, and so were considered together to allow assessment of overall altitudinal range-size changes. Species were categorised as showing no change, expanded range, or contracted range (Table 1). Movement of less than 100 m for either limit was regarded as stationary in view of the measurement resolution of the 1970s data. A binomial test was used to identify whether expansion or contraction of ranges was the dominant pattern.

As an aid to interpretation, reasons for the changes were explored in a GLM by using the differences in altitudinal limits between 2014 and the 1970s as the response variable, and a variety of predictors: flowering season(s), basic growth-form (herb, shrub or tree), Raunkiær life-form, and basic life-form (annual or perennial). The best fitting models and predictors were selected by use of AICs.

Results

Patterns of diversity in the new data

The overall patterns of diversity were indicated by the three Hill's numbers, but each followed a distinct altitudinal pattern (see Fig. 2). The highest levels of species richness (^{0}D) were found at higher altitudes, decreasing down a shallow concave curve with the lowest values at lower altitude (approx. 1400-1600 m). The number of 'typical' (common) species, ^{1}D, was highest at lower-middle elevations (approx. 1700-1800 m), and declined with increasing altitude. In contrast, the number of abundant species, ^{2}D, was lowest at lower-middle elevations, with highest values at the top of the altitude range. The summary data are in Tables S2 and S3.

Range-shift comparisons

Comparison of the upper altitudinal limits from the 1970s and 2014 for 63 plant species indicated a significant difference between mean past and present upper altitudinal limits, with the current limit (mean 2228.6 ± 294.5 m) greater than in the past (mean 2125.2 ± 350.2 m: paired $t = 3.37$, $df = 61$, $p=0.0013$). Although the mean upper altitude limit for all species was found to be significantly higher, there was no evidence of a preponderance of species increasing rather than decreasing their upper altitudinal limit (38 of 63 spp, binomial test $p=0.065$: see Fig. 3 for details). However, for species differing by more than 100 m, a significantly greater number of species moved upslope (26/40, binomial test $p=0.04$). This was also the case for species differing by more than 250 m (16/18, binomial test $p<0.001$).

The 22 species whose lower altitudinal limits were assessed showed a significantly downwardly shifted mean lower altitudinal limit (current mean 1568.0 ± 162.1 m, past mean

1668.2 ± 166.6 m; paired t = 3.02, df = 20, p=0.0064). In addition to this downward shift overall, a significantly greater number of species shifted their individual lower altitudinal limits downwards than did not (17/22, binomial test p=0.008) (see Fig. 4 for details). This finding also held true when only considering species for which movement was greater than 100 m (12/13, binomial test p=0.002).

In species with measurements for both upper and lower altitudinal limits, a significant majority expanded their altitudinal ranges between the 1970s and 2014 (15/22, binomial test p<0.001). Three species showed divergence of altitudinal limits (lower limit moved downslope, upper limit moved upslope) and one convergence (lower limit upslope, upper limit downslope) (see Table 1), whilst four showed parallel downslope movement of upper and lower limits. The upper and lower limits of each species thus appeared to move independently. Lower limits moved down in 12 species, up in one, and remained stationary for nine. Upper limits moved down in eight species, up in eight, and remained stationary for six species. Of the species which shifted their lower limits downslope, there was no preponderance which also showed parallel downslope movement of their upper limits (4/12, binomial test p=0.927).

Basic life form (annual or perennial) was the best predictor of the change in upper altitudinal limit ($F_{1,61}$ = 6.9, p=0.01), with annuals on average moving up four times further than perennials (292 m vs. 72 m). There was only one annual and 21 perennials with measured changes in lower altitudinal limit, and the value for the former (downslope 75 m) was not different from the distribution of values for the perennials (which on average moved downslope 101.4 ± 34.7 m: one-sample t = 0.76, df=19, n.s.). Basic life form was the best additional predictor in a GLM predicting the 2014 upper limits from those of the 1970s, with a much steeper slope for perennials (0.70) than annuals (0.29) ($F_{1,59}$ = 4.49, p=0.038).

Analysis of only the perennial species showed significantly higher mean upper altitudinal limits in 2014 (mean 2220.8 ± 307.3 m) than in the 1970s (mean 2148.9 ± 342.6

m: paired t = 2.45, df = 52, p=0.018). There was no evidence of a majority of perennial species increasing their upper limits (31/54, binomial test p=0.17), even amongst those which differed by more than 100 m (20/32, binomial test p=0.12). However, for species that differed by more than 250 m, a significantly greater number moved upslope (10/12, binomial test p=0.02).

The subset of only shrubs and trees also showed significantly higher mean upper limits (present mean 2219.1 ± 311.2 m, past mean 2139.5 ± 353.3 m: paired t = 2.30, df = 36, p=0.027). Again there was no preponderance of increased upper limits among all species (21/38, binomial test p=0.31) or those which differed by more than 100 m (15/22, binomial test p=0.07). Again, however, amongst species that differed by more than 250 m, there was a preponderance of upslope movement (7/8, binomial test p=0.04).

The mean lower altitudinal limits of perennials moved significantly downwards in 2014 compared to the 1970s (present mean 1574.8 ± 162.9 m, past mean 1676.2 ± 166.3 m: paired t = 2.92, df = 19, p=0.009). As with all plant species, a significantly greater number of species moved their lower limit downwards (16/21, binomial test p=0.01), even amongst those that differed by more than 100 m (12/13, binomial test p=0.002). The mean lower limits of shrubs and trees also shifted significantly downwards in the 2014 data (1585.7 ± 145.7 m) than in the 1970s (1725.0 ± 171.8 m: paired t = 5.27, df = 12, p=0.0002). Again a significantly greater number of species moved downslope (14/16, binomial test p=0.006) and this was particularly the case for species that differed by more than 100 m (9/9, binomial test p=0.002).

Discussion

Patterns of diversity in the new data

The three Hill's number diversity indices provide a greater insight than a single measure (Chao et al. 2012), with higher-order measures emphasising more dominant species. Each index exhibited a different pattern of diversity with altitude. Species richness (^{0}D) was greatest at high altitudes with low richness found at low to mid-altitudes. This pattern contrasts with more humid mountain systems where plant species richness typically peaks at low to mid-altitudes (e.g. Vetaas & Grytnes 2002; Poulos et al. 2007). The refugial nature of South Sinai's high mountains may explain the discrepancy in the pattern of species richness. Favourable climatic conditions, primarily increased availability and retention of moisture (Moustafa & Klopatek 1996; Moustafa & Zaghloul 1996), at higher altitude support a greater richness than the comparative extremes of temperature and water stress encountered at mid to low altitudes. While the temperate flora has largely been lost from much of low-altitude Sinai, in the mountain region of St Katherine remnant species remain only at higher altitudes, leading to a pattern of increasing species richness with increasing altitude (Moustafa et al. 2001). The Hill's number ^{1}D (the number of typical common species) was highest at the lower altitudes sampled, decreasing in higher areas, whilst ^{2}D (the number of very abundant species) increases with altitude. These patterns suggest that higher-altitude communities are dominated to a greater extent by a few abundant species. The joint interpretation of the patterns of all three diversity indices is that species richness increases with altitude, most likely due to more favourable climatic conditions of lower temperatures and greater moisture on mountain peaks and, although richer, communities become more uneven at higher altitudes with a few species showing increasing levels of dominance. The endemic species recorded in this study peaked in density at generally high altitudes, and around mountain peaks, as in other studies in arid landscapes (e.g. Noroozi et al. 2011) and more widely (Vetaas & Grytnes 2002; Essl et al. 2009), although glaciation history is often also important in more northern studies.

Range shifts since the 1970s

We have found clear evidence of temporal altitudinal range shifts in South Sinai's high-mountain flora, although species showing shifts of less than 100 m may be artefacts of the differing methodologies of the 1970s and 2014 studies, using different resolutions and elevation intervals for vegetation recording. Species with larger range shifts, however, showed an obvious pattern of upslope movement of the upper limit, but also downslope movement of the lower limit.

There have certainly been globally reported trends towards upwards shifts in range limits and changing community assemblages on mountain peaks, often attributed to climate change (McCain & Colwell 2011; Gottfried et al. 2012; Matteodo et al. 2013). Indeed climate change is expected to be the main cause of range shifts, especially when considering both core components temperature and precipitation. Nevertheless, wider consequences of climate change, including changes in water balance (Crimmins et al. 2011), the area of bare soil surface (Walther et al. 2002), and elevated atmospheric carbon dioxide levels (Wayne et al. 1998) can all influence range shifts in plants, albeit probably of lesser importance. In the case of South Sinai, unfortunately we do not have reliable local long-term site specific climatic and environmental information. Coupled with high levels of small-scale variability in microhabitat conditions (Moustafa & Klopatek 1995; Moustafa & Zaghloul 1996) means that accurately determining causes for the observed range shifts is beyond the scope of this study. No good data on long term precipitation in the South Sinai mountains exist. It is therefore difficult conclusively to attribute downward shifts of lower limits to increased precipitation. Donat et al. (2014) suggest "a slight wetting trend" across the Arab region since the 1970s. However this must be viewed in light of high site-specificity in precipitation and moisture availability in the South Sinai mountains, as noted by Moustafa & Zaghloul (1996).

During the period 1971-2000 Egypt as a whole showed overall mean annual temperature increases of 0.62^{o}C per decade (Domroes & El-Tantawi 2005), which greatly exceeds the global trend of 0.17^{o}C per decade (IPCC 2001). Measures of precipitation across the wider Middle East and North Africa show increasing spatial and temporal variability (Zhang et al. 2005) but little evidence of significant changes in average values in Egypt (Donat et al. 2014).

Overgrazing by livestock has been suggested to be a determinant of vegetation diversity and range, including in the South Sinai mountains (e.g. Moustafa 2001), but as with grazing by indigenous peoples worldwide (Davis 2016), these are interpretations with little if any empirical evidence (see Gilbert 2013 for full discussion). Numbers of grazing livestock and flock sizes have decreased substantially since the 1960s (Perevolotsky et al. 1989; Gilbert 2013), and hence it is possible that relaxed grazing pressure has permitted downslope movement of plant range limits. However, the bulk of livestock flock-size decreases occurred before the date of the 1974-1976 surveys (Perevolotsky et al. 1989), with average flock sizes changing from 78 pre-1968 to ~13 in the 1970s, 10 in 1982, and 7-8 now (Gilbert 2013). Rashad et al. (2002) found the majority of grazing to occur in an altitudinal band between 1500 and 1800 m. Only one species (*Rubus sanctus*) in our datset has its upper limit within this grazing zone, and this was stationary between the 1970s and 2014. Thus we do not believe that grazing has affected the upper altitudinal limits. Of the lower limits recorded in our dataset from the 1970s, 17 of the 22 species fell within this altitudinal grazing zone, but only eight of these showed downslope movement between the 1970s and 2014 (see Table 1 for detail). Therefore, whilst changes in grazing intensity *may* have affected downslope range shifts, we suggest that climatic change explains the observed upwards range shifts better.

Here, in this arid mountain system, we have documented what we think is the first record of significant downslope shifts of plant lower-altitudinal limits outside Europe. Despite the less-than-ideal quality of the historical data, mean upper limits have increased whilst lower limits have decreased since the 1970s, leading to a divergent pattern of mean altitude limits. When considering the upper and lower altitudinal limits of individual species, we found heterogeneity in the joint responses with no clear predominant pattern. One must bear in mind that these species are a subset of the selected group of high-mountain species that may not be representative of all the species present in that environment.

We now know that there have been significant upwards shifts in the upper altitudinal limits of South Sinai plant species since the 1970s. Our data are limited to those species with lower limits within the sampled range, but a significantly large proportion show expansions of the altitudinal ranges, suggesting that, at least for now, range contractions are not affecting the majority of high-mountain species. However, the Sinai endemic *Silene schimperiana* has contracted in altitudinal range. The risk imposed by contracting ranges and habitat loss would therefore be best considered on a case-by-case basis with regard to Sinai's endemic and rare species. No plant extinctions have been recorded for South Sinai, at least within the last 30 years, although some are very close to extinction (e.g. *Primula boveana*: Omar 2014; Jimenez et al. 2014). However this does not mean that shifts in altitudinal limits are not a cause for concern. Modelling of plant ranges under climate change has indicated lags in population dynamics leading to extinction debts (Dullinger et al. 2012). The isolated, refugial nature of South Sinai's plant communities leave them vulnerable to extinction from a number of ecological factors not limited to climate warming. Whilst we cannot conclusively state that observed shifts in altitudinal limits constitute 'fingerprints' of climate warming, they do point to ecological change posing potential ecological and conservation issues for the future.

In this study we have presented the first recorded instance of contemporary altitudinal-limit shifts in Middle Eastern mountain flora. The fine-scale variability of environmental and ecological factors within the South Sinai mountain ecosystem highlights the necessity of ecological monitoring, and makes a case for increasing the comprehensiveness and quality of the region's environmental monitoring programmes. Our GPS-marked survey quadrats (supplementary information Table S2) will provide a baseline for future fine-scale monitoring. We also stress how important it is to consider both upper and lower altitudinal limits to give an accurate indication of overall altitudinal range changes. We need to focus on lower limits to understand better the ecological drivers and dynamics underlying heterogeneous responses at the range limits.

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Figures & Tables

Table 1
Description of pattern of movement of upper and lower altitudinal limits for 22 individual plant species where both upper and lower limits could be measured. Limits are in metres above sea level.

Figure 1
Outline of igneous ring-dyke delimiting the high mountain region within the St Katherine Protectorate. Positions of 2014 survey sites shown as white dots with 5 km scale bar.
Inset: St Katherine Protectorate outline in South Sinai; shaded area St Katherine ring-dyke and region of 1970s transect surveys.

Figure 2
Hill's numbers (see Chao et al. 2012) for diversity by altitude with fitted GAM model with Normal errors and 95% confidence region. Ascending Hill's numbers give reducing weight to less-abundant species: **(a)** mean ^{0}D (= species richness); **(b)** mean ^{1}D (number of 'typical' common species); **(c)** mean ^{2}D (number of 'abundant' species).

Figure 3
Difference in upper altitude limit for each plant species between the 1970s and 2014.

Figure 4
Difference in lower altitude limit for each plant species between the 1970s and 2014.

Supporting information

Table S1
Supporting information to the paper Coals et al. Elevation patterns of plant diversity and recent altitudinal range shifts in Sinai's high mountain flora. *Journal of Vegetation Science*. Appendix Figure S2. Altitudinal distributions of each species from 2014 data.

Table S2
Supporting information to the paper Coals et al. Elevation patterns of plant diversity and recent altitudinal range shifts in Sinai's high mountain flora. *Journal of Vegetation Science*. Appendix Table S2 Summary data on the occupancy and abundance of each species from the 2014 surveys. There were a total of 283 quadrats in 36 sites in the study.

Table S3
Supporting information to the paper Coals et al. Elevation patterns of plant diversity and recent altitudinal range shifts in Sinai's high mountain flora. *Journal of Vegetation Science*. Appendix Table S3. GPS locations (decimal degrees) of 100 m^2 quadrats (centre point ± 3 m) along with site information and Hill's number diversity indices for each quadrat sampled in 2014.

Table S4

Supporting information to the paper Coals et al. Elevation patterns of plant diversity and recent altitudinal range shifts in Sinai's high mountain flora. *Journal of Vegetation Science*. Appendix Table S4. Site descriptions and photos for 100 m^2 quadrats sampled in 2014.

Table S5

Supporting information to the paper Coals et al. Elevation patterns of plant diversity and recent altitudinal range shifts in Sinai's high mountain flora. *Journal of Vegetation Science*. Appendix Table S5. Species abundance for quadrats surveyed in 2014.

Figure S1

Supporting information to the paper Coals et al. Elevation patterns of plant diversity and recent altitudinal range shifts in Sinai's high mountain flora. *Journal of Vegetation Science*. Appendix Figure S1. Abundance-weighted altitudinal distributions of each species from 2014 data. The weighting works by each individual plant observed in each quadrat contributing an altitude to the calculation of the mean and se.

Figure S2

Supporting information to the paper Coals et al. Elevation patterns of plant diversity and recent altitudinal range shifts in Sinai's high mountain flora. *Journal of Vegetation Science*. Appendix Figure S2. Altitudinal distributions of each species from 2014 data.

Table 1
Description of pattern of movement of upper and lower altitudinal limits for 22 individual plant species where both upper and lower limits could be measured. Limits are in metres above sea level.

Species	Upper limit 1970s	Upper limit 2014	Lower limit 1970s	Lower limit 2014	Limit movement patterns		Range size change
					Lower limit	Upper limit	
Alkanna orientalis	2500	2575	1500	1375	down	stationary	expanded
Astragalus echinus	2600	2425	2000	1825	down	down	no change
Calipeltis cucullaris	2100	2425	1500	1425	stationary	up	expanded
Colchicum guessfeldtianum	2500	2325	1500	1925	Up	down	contracted
Cotoneaster orbicularis	2200	2425	1800	1725	stationary	up	expanded
Crataegus x sinaica	2300	2375	1600	1625	stationary	stationary	no change
Globularia arabica	2100	2275	1700	1425	down	up	expanded
Nepeta septemcrenata	2640	2325	1700	1725	stationary	down	contracted
Origanum syriacum	2000	1975	1600	1425	down	stationary	expanded
Phlomis aurea	2200	2425	1550	1375	down	up	expanded
Polygala sinaica	2640	2625	1900	1675	down	stationary	expanded
Pterocephalus sanctus	2640	2575	1600	1625	stationary	stationary	no change
Pulicaria undulata	1900	2175	1400	1375	stationary	up	expanded
Rubus sanctus	1800	1725	1800	1625	down	stationary	expanded
Salvia multicaulis	2100	1975	1900	1725	down	down	expanded
Scariola orientalis	2500	2325	1800	1525	down	down	expanded
Silene leucophylla	2300	2625	1750	1425	down	up	expanded
Silene schimperiana	2300	2175	1500	1521	stationary	down	contracted
Stipa parviflora	2500	2325	1600	1525	stationary	down	contracted
Thymus decussatus	2400	2275	1900	1725	down	down	expanded
Verbascum decaisneanum	2300	2525	1600	1525	stationary	up	expanded
Verbascum sinaiticum	2400	2575	1500	1375	down	up	expanded

Figure 1
Outline of igneous ring-dyke delimiting the high mountain region within the St Katherine Protectorate. Positions of 2014 survey sites shown as white dots with 5 km scale bar.
Inset: St Katherine Protectorate outline in South Sinai; shaded area St Katherine ring-dyke and region of 1970s transect surveys.

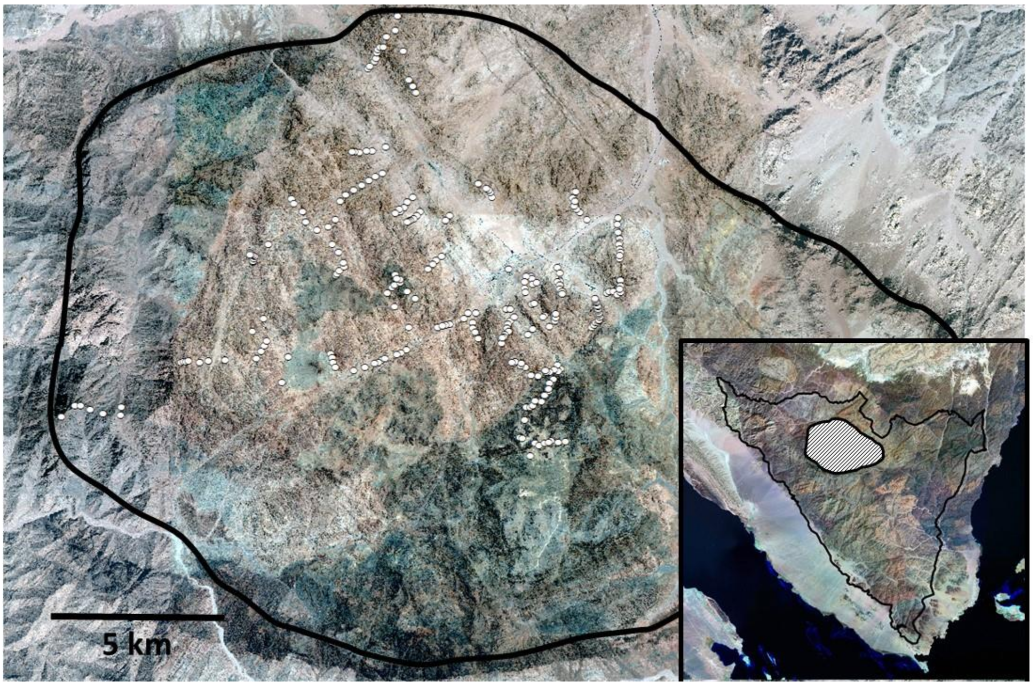
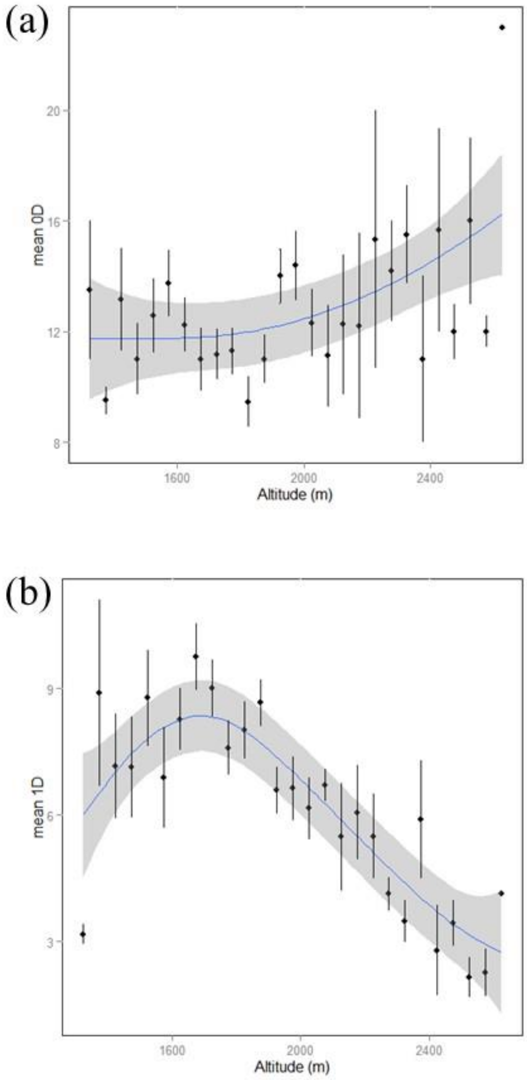


Figure 2
Hill's numbers (see Chao et al. 2012) for diversity by altitude with fitted GAM model with Normal errors and 95% confidence region. Ascending Hill's numbers give reducing weight to less-abundant species: **(a)** mean ^{0}D (= species richness); **(b)** mean ^{1}D (number of 'typical' common species); **(c)** mean ^{2}D (number of 'abundant' species).



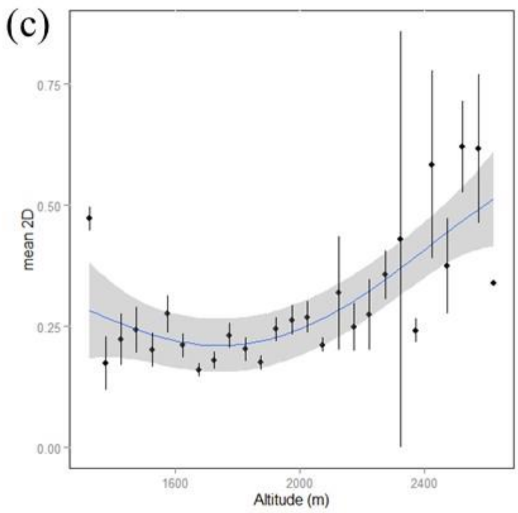


Figure 3
Difference in upper altitude limit for each plant species between the 1970s and 2014.

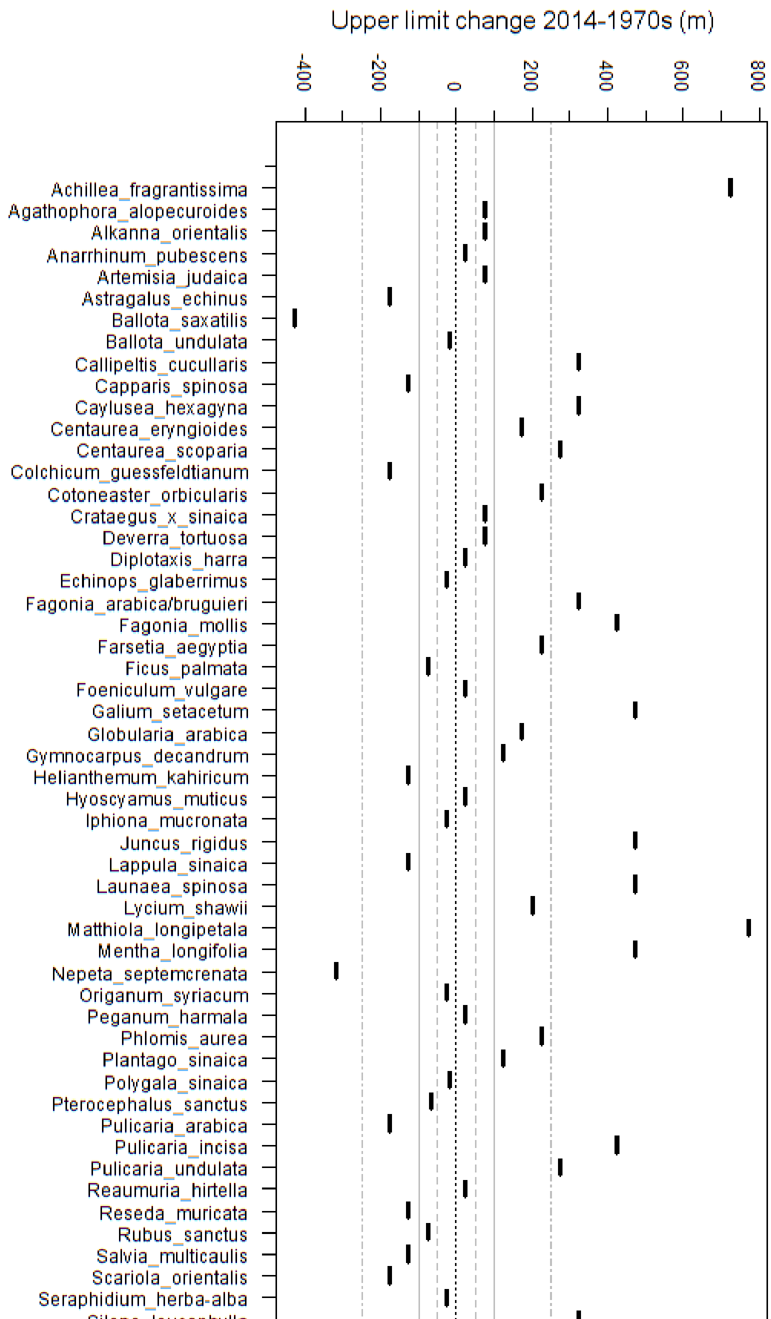
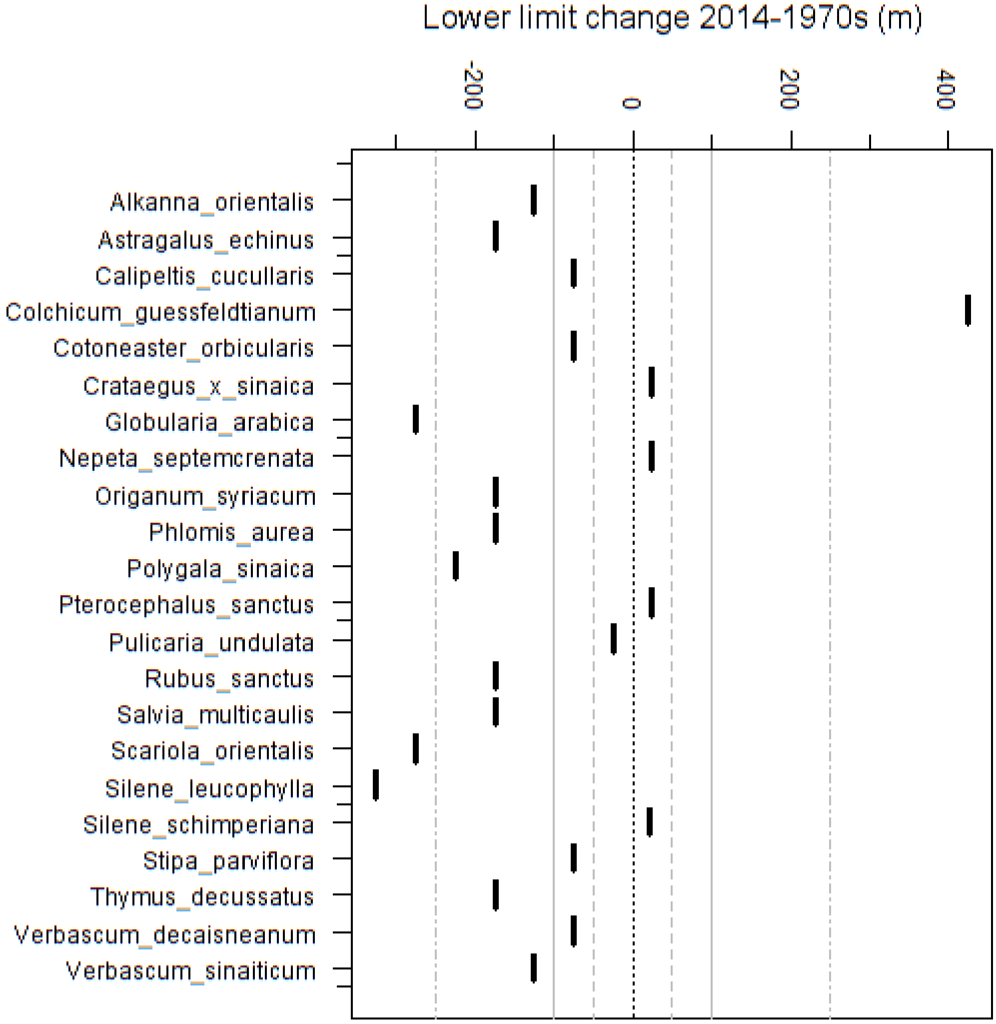


Figure 4
Difference in lower altitude limit for each plant species between the 1970s and 2014.



Supplementary Information

Figure S1

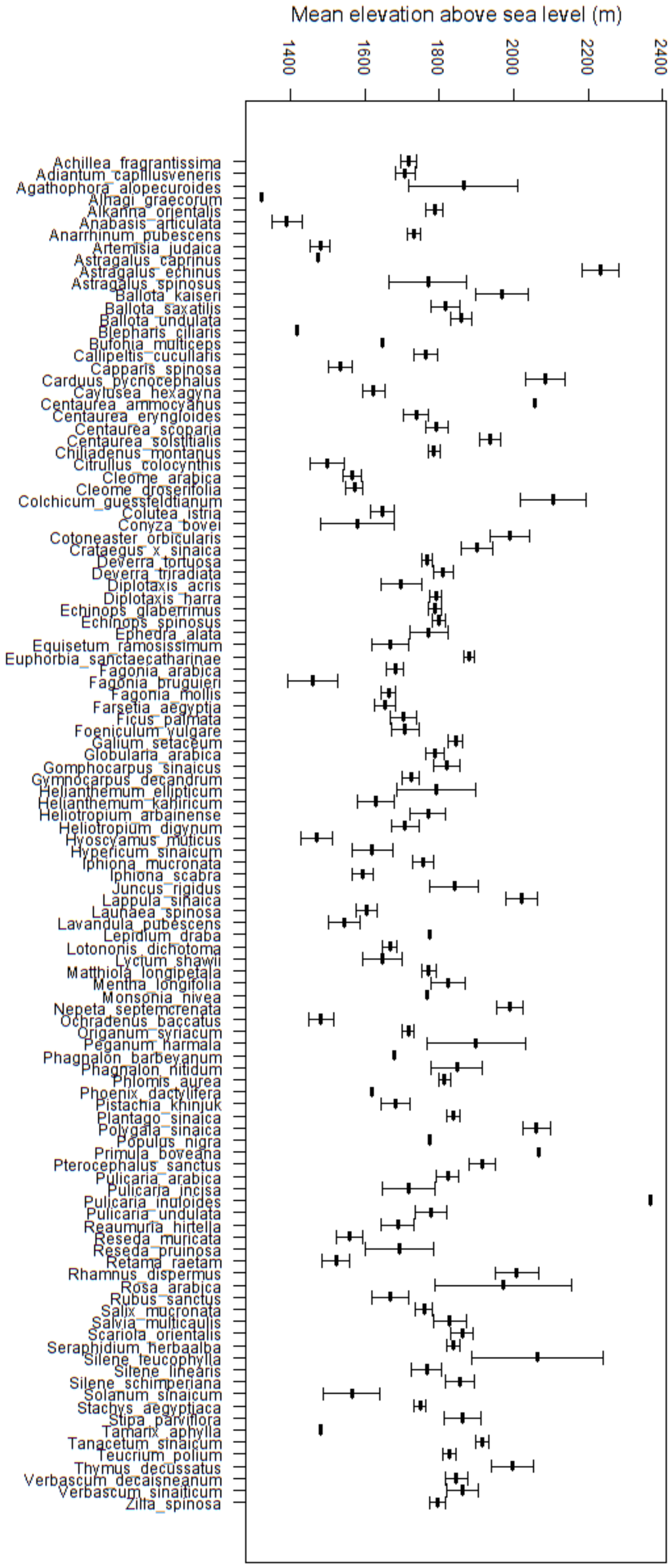


Figure S2

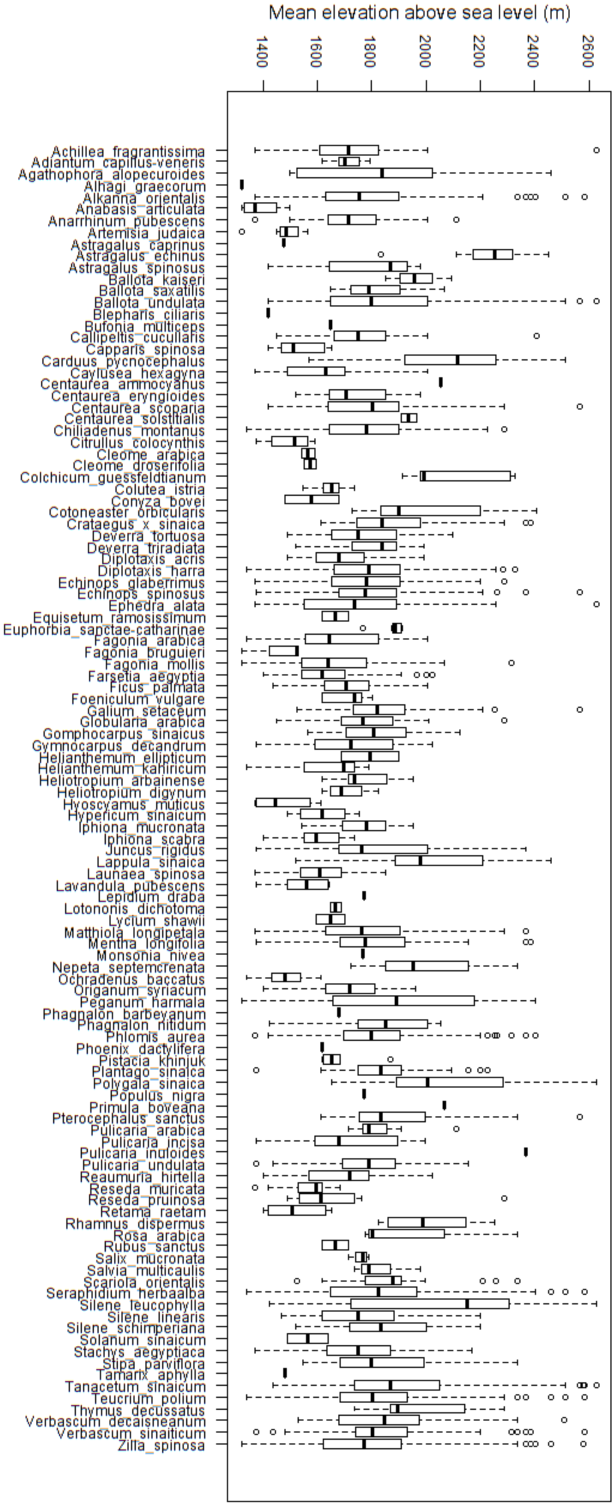

Mean elevation above sea level (m)
1400
1600
1800
2000
2200
2400
2600
Achillea_fragrantissima
Adiantum_capillus-veneris
Agathophora_alopecuroides
Alhagi_graecorum
Alkanna_orientalis
Anabasis_articulata
Anarrhinum_pubescens
Artemisia_judaica
Astragalus_caprinus
Astragalus_echinus
Astragalus_spinosus
Ballota_kaiseri
Ballota_saxatilis
Ballota_undulata
Blepharis_ciliaris
Bufonia_multiceps
Callipeltis_cucullaris
Capparis_spinosa
Carduus_pycnocephalus
Caylusea_hexagyna
Centaurea_ammocyanus
Centaurea_eryngioides
Centaurea_scoparia
Centaurea_solstitialis
Chiliadenus_montanus
Citrullus_colocynthis
Cleome_arabica
Cleome_droserifolia
Colchicum_guessfeldtianum
Colutea_istria
Conyza_bovei
Cotoneaster_orbicularis
Crataegus_x_sinaica
Deverra_tortuosa
Deverra_triradiata
Diplotaxis_acris
Diplotaxis_harra
Echinops_glaberrimus
Echinops_spinosus
Ephedra_alata
Equisetum_ramosissimum
Euphorbia_sanctae-catharinae
Fagonia_arabica
Fagonia_bruguieri
Fagonia_mollis
Farsetia_aegyptia
Ficus_palmata
Foeniculum_vulgare
Galium_setaceum
Globularia_arabica
Gomphocarpus_sinaicus
Gymnocarpus_decandrum
Helianthemum_ellipticum
Helianthemum_kahiricum
Heliotropium_arbainense
Heliotropium_digynum
Hyoscyamus_muticus
Hypericum_sinaicum
Iphiona_mucronata
Iphiona_scabra
Juncus_rigidus
Lappula_sinaica
Launaea_spinosa
Lavandula_pubescens
Lepidium_draba
Lotononis_dichotoma
Lycium_shawii
Matthiola_longipetala
Mentha_longifolia
Monsonia_nivea
Nepeta_septemcrenata
Ochradenus_baccatus
Origanum_syriacum
Peganum_harmala
Phagnalon_barbeyanum
Phagnalon_nitidum
Phlomis_aurea
Phoenix_dactylifera
Pistacia_khinjuk
Plantago_sinaica
Polygala_sinaica
Populus_nigra
Primula_boveana
Pterocephalus_sanctus
Pulicaria_arabica
Pulicaria_incisa
Pulicaria_inuloides
Pulicaria_undulata
Reaumuria_hirtella
Reseda_muricata
Reseda_pruinosa
Retama_raetam
Rhamnus_dispermus
Rosa_arabica
Rubus_sanctus
Salix_mucronata
Salvia_multicaulis
Scariola_orientalis
Seraphidium_herbaalba
Silene_leucophylla
Silene_linearis
Silene_schimperiana
Solanum_sinaicum
Stachys_aegyptiaca
Stipa_parviflora
Tamarix_aphylla
Tanacetum_sinaicum
Teucrium_polium
Thymus_decussatus
Verbascum_decaisneanum
Verbascum_sinaiticum
Zilla_spinosa

Table S2

Species	Presence (number of quadrats)	Total abundance (individuals)
Fagonia mollis	90	2943
Seraphidium herba-alba	194	2766
Tanacetum sinaicum	181	1953
Diplotaxis harra	139	1678
Zilla spinosa	145	977
Teucrium polium	145	955
Fagonia arabica	60	937
Matthiola longipetala	109	830
Echinops glaberrimus	119	771
Stachys aegyptiaca	119	757
Chiliadenus montanus	137	726
Achillea fragrantissima	67	637
Phlomis aurea	127	529
Alkanna orientalis	108	521
Verbascum sinaiticum	39	461
Echinops spinosus	104	435
Plantago sinaica	72	367
Gymnocarpus decandrum	57	366
Origanum syriacum	70	357
Lappula sinaica	30	307
Pulicaria undulata	20	301
Mentha longifolia	27	267
Ballota undulata	91	253
Scariola orientalis	33	252
Deverra tortuosa	92	234
Galium setaceum	74	220
Centaurea scoparia	50	213
Anarrhinum pubescens	62	175
Euphorbia sanctae-catharinae	9	166
Polygala sinaica	44	163
Verbascum decaisneanum	51	143
Agathophora alopecuroides	6	129
Globularia arabica	36	126
Juncus rigidus	18	119
Pterocephalus sanctus	40	111
Callipeltis cucullaris	31	100
Farsetia aegyptia	40	89
Reaumuria hirtella	14	81
Caylusea hexagyna	26	80
Nepeta septemcrenata	26	71
Stipa parviflora	21	70

Carduus pycnocephalus	21	66
Artemisia judaica	8	63
Centaurea eryngioides	19	63
Pulicaria arabica	12	62
Thymus decussatus	11	57
Pulicaria incisa	9	56
Silene schimperiana	25	53
Ephedra alata	30	51
Helianthemum kahiricum	10	51
Crataegus x sinaica	28	50
Cotoneaster orbicularis	17	47
Launaea spinosa	18	43
Ficus palmata	20	36
Iphiona mucronata	17	34
Primula boveana	1	32
Salvia multicaulis	5	32
Silene linearis	20	32
Silene leucophylla	6	30
Ballota saxatilis	11	29
Deverra triradiata	20	29
Gomphocarpus sinaicus	20	29
Reseda muricata	9	29
Reseda pruinosa	8	27
Fagonia bruguieri	3	24
Lavandula pubescens	6	24
Astragalus echinus	11	22
Iphiona scabra	13	21
Hyoscyamus muticus	6	20
Peganum harmala	8	20
Centaurea solstitialis	2	19
Phagnalon nitidum	9	19
Capparis spinosa	8	17
Anabasis articulata	4	16
Rubus sanctus	2	16
Diplotaxis acris	8	13
Foeniculum vulgare	5	12
Colchicum guessfeldtianum	5	11
Lycium shawii	2	11
Adiantum capillus-veneris	6	10
Heliotropium arbainense	6	10
Hypericum sinaicum	4	10
Ochradenus baccatus	7	10
Retama raetam	8	10
Rhamnus dispermus	8	10
Equisetum ramosissimum	2	9
Pistacia khinjuk	6	8

Astragalus spinosus	5	6
Ballota kaiseri	3	6
Colutea istria	5	6
Rosa arabica	3	6
Centaurea ammocyanus	1	5
Heliotropium digynum	5	5
Lotononis dichotoma	2	5
Citrullus colocynthis	4	4
Blepharis ciliaris	1	3
Cleome arabica	2	3
Salix mucronata	3	3
Bufonia multiceps	1	2
Cleome droserifolia	2	2
Conyza bovei	2	2
Helianthemum ellipticum	2	2
Solanum sinaicum	2	2
Alhagi graecorum	1	1
Astragalus caprinus	1	1
Lepidium draba	1	1
Monsonia nivea	1	1
Phagnalon barbeyanum	1	1
Phoenix dactylifera	1	1
Populus nigra	1	1
Pulicaria inuloides	1	1
Tamarix aphylla	1	1

Table S3

	Quadrat	Elevation (m above sea level)	Aspect	Gradient (nearest 5º)	Hill's number diversity index 0D	1D	2D	Latitude (DD)	Longitude (DD)
1	AP01	1898	SE	5	17	8.276886339	0.183739705	28.5447833	33.9212500
2	AP02	1951	SE	10	18	4.455565566	0.342351717	28.5480000	33.9182333
3	AP03	1993	SE	10	8	12.729872204	0.107438017	28.5510833	33.9170000
4	AP04	2051	S	10	20	6.362835676	0.210007305	28.5535667	33.9152167
5	AP05	2117	S	25	11	4.775667817	0.264860323	28.5550333	33.9150167
6	AP06	2169	SW	15	6	5.100217354	0.256296296	28.5565667	33.9164167
7	AP07	2209	W	40	20	5.993925881	0.224445646	28.5572500	33.9171000
8	AP08	2255	SW	35	8	5.319148793	0.220324865	28.5580500	33.9187333
9	AP09	2282	NE	25	20	4.600885544	0.239612188	28.5589833	33.9187500
10	AP10	2305	NW	10	13	3.549357156	0.303402647	28.5604500	33.9173667
11	AP11	2296	SW	25	17	5.180051270	0.215419501	28.5591500	33.9177500
12	AP12	2328	SW	0	23	3.864313298	0.367346939	28.5555000	33.9209500
13	AP13	2228	S	10	6	6.922381747	0.180695847	28.5534000	33.9231000
14	BC01	1773	N	5	11	7.056663610	0.266302787	28.5457000	33.9334167
15	BC02	1826	NE	25	9	12.848107080	0.100936524	28.5455333	33.9320667
16	BC03	1931	SW	5	15	6.853384027	0.210154541	28.5448167	33.9298000
17	BC04	1880	NE	25	11	6.765023325	0.25047259	28.5452500	33.9312167
18	FAH01	1755	W	10	13	1.822161436	0.628683408	28.6364333	33.9181000
19	FAH02	1789	S	5	11	7.400633968	0.163295657	28.6323333	33.9174333
20	FUS01	1867	NW	10	11	10.068516231	0.128515486	28.5693000	33.8800333
21	GAZ01	1783	N	10	15	4.358064359	0.348927336	28.5640500	33.8754833
22	GAZ02	1760	N	40	9	4.147843289	0.37716263	28.5643667	33.8756167
23	GAZ03	1731	NW	25	13	4.820125265	0.366151101	28.5650833	33.8757667
24	GAZ04	1703	W	25	10	10.354978743	0.113034072	28.5656667	33.8758833
25	GAZ05	1676	W	25	14	8.624473332	0.173203228	28.5660833	33.8755000
26	GAZ06	1652	W	20	7	8.382184096	0.154778393	28.5661667	33.8751000
27	GAZ07	1633	W	25	15	8.928165435	0.126369613	28.5663500	33.8746667
28	GAZ08	1620	SW	5	6	14.071099758	0.091050989	28.5667333	33.8746667
29	GAZ09	1618	W	0	18	4.614706611	0.262222222	28.5663333	33.8746000
30	HHL01	1755	S	10	14	5.161474634	0.23739645	28.6261000	33.9196000
31	JAL01	1594	N	5	8	2.625109050	0.472623967	28.4124333	33.8551500
32	JAL02	1569	N	35	14	4.279674007	0.380859375	28.4128000	33.8553833
33	JAL03	1544	N	15	22	5.149496180	0.237024221	28.4134667	33.8557333
34	JAL04	1521	N	5	11	5.751040151	0.210463734	28.4140167	33.8560333
35	JAL05	1497	N	5	10	3.974862032	0.316326531	28.4150167	33.8557667
36	JAL06	1480	W	5	13	6.457058359	0.204444444	28.4159500	33.8552500
37	JB01	1856	E	5	12	6.014585347	0.20661157	28.5287167	33.8839500
38	JB02	1963	NW	5	30	3.219481402	0.40433925	28.5351000	33.8622500
39	JB03	1981	NE	5	17	3.651078640	0.37352071	28.5346167	33.8597000
40	JB04	2098	NW	5	7	6.864232066	0.177469136	28.5346333	33.8544833
41	JB05	2056	E	25	13	7.089149015	0.208569628	28.5347000	33.8551333

42	JB06	2022	E	25	11	7.987816513	0.207305782	28.5348667	33.8558000
43	JB07	2000	NE	10	13	6.669820221	0.207596254	28.5350333	33.8563833
44	JB08	1992	NW	5	15	5.568833860	0.301050598	28.5353333	33.8672000
45	JB09	1980	NW	15	15	4.961891966	0.294589858	28.5358167	33.8763833
46	JB10	1943	N	20	10	10.580910642	0.139674761	28.5377667	33.8778333
47	JB11	1870	N	5	7	10.863718305	0.115	28.5394000	33.8788333
48	JB12	1798	NE	15	13	13.989417065	0.094482237	28.5409000	33.8795000
49	JDR01	1595	W	10	16	5.711203839	0.27456382	28.5548833	33.9794833
50	JDR02	1647	NW	20	17	4.455659734	0.25	28.5555500	33.9804000
51	JDR03	1700	W	15	6	14.048959039	0.088643645	28.5555000	33.9815833
52	JDR04	1746	NW	10	3	6.127589359	0.185595568	28.5545333	33.9825667
53	JDR05	1762	W	5	9	5.551994498	0.293514828	28.5551833	33.9836000
54	JDR06	1904	S	5	24	6.224367226	0.209342561	28.5586667	33.9835333
55	JDR07	1852	S	20	18	6.833374829	0.200617284	28.5571000	33.9836500
56	JDR08	1801	S	10	11	8.781124772	0.154368493	28.5561667	33.9833833
57	JHA01	1324	NW	5	11	2.924929108	0.495867769	28.6209833	33.9093333
58	JHA02	1340	SW	15	16	3.416293383	0.447809627	28.6216667	33.9097167
59	JHA03	1402	W	10	11	9.450662911	0.117346939	28.6231333	33.9112167
60	JHA04	1449	SW	10	10	9.004546757	0.130177515	28.6239500	33.9117333
61	JHA05	1500	S	15	16	6.265274407	0.224732461	28.6247167	33.9120500
62	JHA06	1550	S	10	15	13.123801022	0.103305785	28.6257667	33.9118667
63	JHA07	1604	SW	0	9	9.747187539	0.162629758	28.6266667	33.9121667
64	JHA08	1649	SW	5	7	9.650258715	0.129757785	28.6272500	33.9127500
65	JHA09	1689	NW	10	7	9.941375297	0.125868056	28.6273333	33.9137167
66	JHA10	1710	S	5	12	9.836764227	0.157017909	28.6304500	33.9147000
67	JK01	1791	N	15	13	2.109056370	0.599609375	28.5327667	33.9660833
68	JK02	1816	N	20	15	6.769217557	0.200951249	28.5318500	33.9653000
69	JK03	1853	N	10	8	11.785537012	0.114257813	28.5297167	33.9638000
70	JK04	1924	NE	30	15	6.290185201	0.214915596	28.5284667	33.9627500
71	JK05	2008	E	35	8	4.117429200	0.372767857	28.5260333	33.9623833
72	JK06	2069	SE	15	8	7.639556102	0.164352131	28.5244500	33.9603667
73	JK07	2067	N	5	2	7.774078838	0.18766901	28.5229167	33.9602667
74	JK08	2288	NW	20	23	3.212213639	0.432942708	28.5213167	33.9558167
75	JK09	2336	W	15	12	6.374258180	0.228099174	28.5176667	33.9554333
76	JK10	2368	E	15	14	7.284091195	0.216792181	28.5114333	33.9630667
77	JK11	2315	E	10	14	3.556787336	0.391242435	28.5110167	33.9653167
78	JK12	2263	SE	25	13	5.739525321	0.231866825	28.5112167	33.9674667
79	JK13	2629	E	5	23	4.139487244	0.338842975	28.5125500	33.9539000
80	JK14	2583	E	20	13	2.454140787	0.455970452	28.5121333	33.9545833
81	JK15	2512	E	25	19	2.618137363	0.526367188	28.5108000	33.9584500
82	JK16	2462	E	25	13	3.973202083	0.275495547	28.5101833	33.9596333
83	JK17	2404	E	15	23	4.858931394	0.2421875	28.5108833	33.9613500
84	JK18	2462	E	20	11	2.888341165	0.471886714	28.5069500	33.9571500
85	JK19	2385	NE	10	8	4.497226112	0.265432099	28.5110833	33.9623333
86	JK20	2257	NE	35	10	2.911299308	0.470204082	28.5213333	33.9571500
87	JK21	2208	NE	30	20	3.555222559	0.417888757	28.5219500	33.9577000

88	JK22	2156	NE	35	22	3.758306151	0.324150597	28.5233167	33.9585333
89	JK23	2124	SE	20	6	7.108166386	0.18494898	28.5238667	33.9589167
90	JK24	2052	E	25	14	4.527606171	0.281965848	28.5249167	33.9612167
91	JK25	1998	NE	30	19	3.285351440	0.484764543	28.5268000	33.9624500
92	JM01	2007	NE	5	13	5.635406567	0.257487217	28.5448333	33.9751167
93	JM02	1984	E	5	10	6.797283149	0.218934911	28.5455167	33.9758000
94	JM03	1962	NE	35	8	3.485685549	0.475529584	28.5461500	33.9762667
95	JM04	1955	NE	30	16	5.115472599	0.25	28.5463333	33.9763000
96	JM05	1923	NE	15	15	4.557099647	0.386258455	28.5463000	33.9769000
97	JM06	1907	NE	30	16	8.048360735	0.135	28.5467000	33.9772000
98	JM07	1896	N	5	11	9.616002619	0.131113424	28.5469833	33.9772667
99	JM08	1871	N	15	20	6.407700219	0.183364839	28.5479833	33.9774333
100	JM09	1849	N	10	6	6.738781224	0.1936	28.5487500	33.9772833
101	JM10	1823	N	15	4	6.829510706	0.17578125	28.5491833	33.9772167
102	JM11	1799	N	10	16	5.910927457	0.229166667	28.5498000	33.9770167
103	JM12	1774	N	15	11	6.938642678	0.160493827	28.5502833	33.9768667
104	JM13	1753	N	10	4	4.598826845	0.323675871	28.5503667	33.9770167
105	JM14	1724	N	15	11	5.591783761	0.232142857	28.5508667	33.9769500
106	JM15	1702	N	5	17	11.251507824	0.117283951	28.5513000	33.9768333
107	JM16	1674	N	20	6	5.139412479	0.248699272	28.5520667	33.9765667
108	JM17	1654	N	25	14	5.306341291	0.26625	28.5524500	33.9762000
109	JM18	1624	N	20	15	6.604129943	0.243764172	28.5529833	33.9760500
110	JM19	1605	NE	10	16	6.696333460	0.256804734	28.5533833	33.9759500
111	JMA01	2025	SW	5	17	3.290796164	0.379108839	28.5184500	33.8191667
112	JMA02	1925	E	10	14	2.637477816	0.4984	28.5218500	33.8231000
113	JMA03	1825	SW	35	3	4.086469860	0.319615912	28.5219500	33.8248667
114	JMA04	1725	SE	35	9	5.760243565	0.193877551	28.5206667	33.8276000
115	JMA05	1619	NE	40	14	5.612155029	0.209876543	28.5195000	33.8312333
116	JMA06	1524	NE	20	8	7.604828622	0.166015625	28.5189833	33.8364833
117	JMA07	1424	NE	15	21	3.198153155	0.440329218	28.5214833	33.8368500
118	SGRS01	1739	SE	5	13	13.924583918	0.095802469	28.6177333	33.9213833
119	SGRS02	1686	SE	5	7	9.445633781	0.153539172	28.6158333	33.9224167
120	SGRS03	1642	N	5	19	12.703171975	0.094227336	28.6140000	33.9234667
121	US01	2580	NE	5	12	1.182870543	0.9232	28.3617500	33.9171833
122	US02	2566	E	25	11	3.139821206	0.470507545	28.3615333	33.9173333
123	US03	2509	NE	25	13	1.680201839	0.715419501	28.3610167	33.9180000
124	US04	2449	NE	30	12	1.206969808	0.911303407	28.3609667	33.9189833
125	US05	2405	NE	15	12	2.295966888	0.598097503	28.3614333	33.9193667
126	US06	2337	E	10	14	1.859801362	0.723865878	28.3623000	33.9199333
127	US07	2304	NE	15	8	3.283998677	0.426035503	28.3627333	33.9203333
128	US08	2252	N	20	5	1.773062949	0.735294118	28.3633333	33.9209333
129	US09	2199	NE	20	17	4.057488356	0.384688091	28.3644500	33.9207833
130	US10	2148	NE	25	18	2.181483295	0.662290629	28.3653500	33.9215500
131	US11	2111	NE	15	14	7.844588219	0.161652893	28.3654667	33.9225167
132	US12	2049	NW	15	7	4.854844706	0.317174515	28.3675333	33.9236667
133	WA01	1589	NE	20	16	3.232395322	0.4086	28.5503000	33.9501000

134	WA02	1632	SW	10	13	3.921979462	0.346342651	28.5502167	33.9512000
135	WA03	1704	N	30	14	11.102946765	0.1434375	28.5466833	33.9511333
136	WA04	1634	N	5	14	8.024092252	0.209420154	28.5478500	33.9524500
137	WA05	1703	SW	40	17	10.989182916	0.119872	28.5443833	33.9578000
138	WA06	1734	N	25	7	8.029984818	0.176762354	28.5428167	33.9562833
139	WAH01	1729	N	20	4	7.874831968	0.1938	28.5457500	33.9505333
140	WAH02	1792	N	10	18	6.201041903	0.249155767	28.5446667	33.9503000
141	WAH03	1853	N	30	22	3.927592272	0.414836911	28.5436833	33.9505833
142	WAH04	1901	N	25	17	7.169118748	0.199538639	28.5428333	33.9495500
143	WAH05	1956	N	5	18	8.687395617	0.139053254	28.5420167	33.9491833
144	WAH06	2094	N	20	9	7.304906223	0.197355372	28.5401000	33.9485000
145	WAH07	2006	NE	30	15	4.158923154	0.402729139	28.5417500	33.9487333
146	WAJ01	1687	NE	15	18	12.191800915	0.132315017	28.5491667	33.9387833
147	WAJ02	1782	NW	35	21	7.386183796	0.203546407	28.5475667	33.9375500
148	WAR01	1476	N	5	13	5.633223222	0.284489796	28.5771833	33.9829000
149	WAR02	1526	N	20	20	16.111785766	0.0752	28.5750833	33.9826667
150	WAR03	1573	N	20	13	9.428775119	0.134696955	28.5742000	33.9827000
151	WAR04	1627	N	30	5	7.471667103	0.175384615	28.5733333	33.9826500
152	WAR05	1677	N	35	11	6.088077006	0.231426693	28.5727167	33.9828000
153	WAR06	1721	N	30	10	3.746225576	0.37964357	28.5721000	33.9829667
154	WAR07	1781	SE	15	14	5.362322807	0.252739226	28.5713000	33.9831333
155	WAR08	1761	N	5	6	11.140920952	0.111531191	28.5709000	33.9833667
156	WAR09	1795	N	20	12	12.122806836	0.102638556	28.5697333	33.9834500
157	WAR10	1804	N	10	8	9.002771765	0.165619835	28.5693833	33.9831167
158	WAR11	1850	N	10	15	7.437873350	0.16805411	28.5679833	33.9834500
159	WAR12	1871	N	5	9	3.835363652	0.374710744	28.5669833	33.9836333
160	WAR13	1938	N	20	6	9.120347455	0.151962304	28.5650000	33.9834000
161	WAR14	1893	N	25	14	10.846300118	0.129529363	28.5660833	33.9833667
162	WAT01	1737	NW	10	19	16.312125209	0.069243761	28.5827833	33.8869000
163	WAT02	1764	N	5	5	10.500936888	0.124705882	28.5812000	33.8875833
164	WAT03	1789	W	10	12	10.117803512	0.1178125	28.5788500	33.8899833
165	WAT04	1801	NW	5	10	5.638814736	0.313432836	28.5759333	33.8911167
166	WAT05	1825	SW	10	5	7.997850222	0.149101837	28.5736333	33.8943667
167	WAT06	1996	N	0	14	8.055573001	0.134986226	28.5600667	33.9000333
168	WAT07	1974	NE	10	10	7.796129288	0.22972973	28.5606833	33.9001333
169	WAT08	1951	NE	5	15	9.383467289	0.133674215	28.5615833	33.9007667
170	WAT09	1921	N	10	18	5.590505195	0.28625	28.5626333	33.9022333
171	WAT10	1898	N	15	8	7.877810406	0.158464035	28.5639167	33.9020833
172	WAT11	1870	NW	0	10	7.110831302	0.180423667	28.5669167	33.9006500
173	WAT12	1850	N	10	8	10.529704964	0.110082645	28.5693500	33.8986833
174	WB01	1452	N	15	11	5.954147518	0.212653486	28.5788667	33.9245167
175	WB02	1502	N	15	12	8.604623787	0.131944444	28.5777500	33.9236333
176	WB03	1549	NE	10	12	14.250960116	0.093449626	28.5769000	33.9226833
177	WB04	1604	NE	20	6	12.262803336	0.089382716	28.5764333	33.9217500
178	WB05	1652	NE	20	6	11.685650185	0.14852054	28.5762333	33.9212167
179	WB06	1679	NW	20	7	15.816711568	0.082138641	28.5758167	33.9208333

180	WF01	1751	NE	25	16	6.055643585	0.244760899	28.5516500	33.9576000
181	WF02	1750	W	10	15	6.747559589	0.202371252	28.5519167	33.9583167
182	WF03	1823	SW	40	12	2.573079233	0.529369883	28.5483167	33.9613333
183	WF04	1801	NE	30	6	8.496554652	0.149689523	28.5479167	33.9607333
184	WF05	1836	N	35	9	10.102815878	0.126704785	38.5451167	33.9626500
185	WF06	1870	SW	30	11	9.937875681	0.130430604	28.5467833	33.9643833
186	WF07	1931	S	40	18	3.701760308	0.394048776	28.5476333	33.9644667
187	WF08	2007	S	45	10	9.685842451	0.123981033	28.5488000	33.9646167
188	WG01	1914	NW	5	12	4.195849081	0.292165511	28.5383000	33.9206167
189	WG02	1912	NW	5	7	8.879955221	0.176767677	28.5374333	33.9190500
190	WG03	1907	W	10	14	6.180754087	0.225618451	28.5369500	33.9177000
191	WG04	1891	NW	5	10	9.877623239	0.140310204	28.5356000	33.9143167
192	WG05	1889	SW	5	9	9.246870243	0.160950912	28.5351333	33.9133833
193	WG06	1888	N	10	5	8.653556032	0.149653434	28.5346333	33.9124833
194	WG07	1887	SE	15	12	6.881538708	0.198333333	28.5343833	33.9113167
195	WG08	1875	W	5	14	5.816177212	0.214285714	28.5332333	33.9083500
196	WG09	1876	SE	15	2	7.262543835	0.184285714	28.5322833	33.9052167
197	WG10	2011	SW	20	10	5.344409808	0.293207908	28.5371500	33.8983500
198	WG11	1965	S	20	9	7.671860555	0.146449704	28.5358833	33.8988833
199	WG12	1910	SW	10	19	11.250003570	0.121957815	28.5346000	33.8990833
200	WG13	1885	SE	5	9	11.848855916	0.09815586	28.5331667	33.8996833
201	WG14	1792	NE	5	5	7.038790151	0.193201526	28.5360667	33.8858000
202	WG15	1768	NE	5	6	12.205056450	0.107354184	28.5474833	33.8786333
203	WG16	1717	NW	0	12	9.341550033	0.141111111	28.5436667	33.8753000
204	WJ01	1646	SE	10	18	2.412012300	0.661599619	28.5832167	33.9457167
205	WJ02	1710	SE	30	14	6.467887368	0.264060357	28.5845667	33.9452833
206	WJ03	1766	SE	40	8	9.522124811	0.147727273	28.5853500	33.9447833
207	WJ04	1822	NE	25	15	5.005337212	0.287407407	28.5858500	33.9440667
208	WJ05	1878	SE	5	14	5.932466299	0.229275061	28.5867833	33.9431000
209	WJ06	1929	NE	20	12	3.580854321	0.385354377	28.5872000	33.9417333
210	WJA01	1792	N	5	18	5.079225877	0.273662551	28.5337333	33.9649500
211	WJA02	1810	NE	10	11	11.685068171	0.105916728	28.5325000	33.9641500
212	WJA03	1852	NE	10	10	17.708575024	0.07231405	28.5316833	33.9627833
213	WJA04	1901	S	20	12	8.987254776	0.154840563	28.5316333	33.9617500
214	WJA05	1954	E	15	10	14.409980678	0.085648148	28.5323000	33.9614333
215	WJA06	2007	NE	25	19	9.807889383	0.125	28.5310667	33.9596000
216	WJA07	2060	N	30	10	5.097383596	0.290816327	28.5305333	33.9593000
217	WJA08	2094	E	5	17	7.640075026	0.183391003	28.5308000	33.9573000
218	WJA09	2156	SE	5	12	7.869019257	0.142733564	28.5330500	33.9557167
219	WJA10	2199	NE	10	4	9.510517013	0.135147929	28.5335167	33.9543000
220	WJA11	2251	NE	0	13	4.324772196	0.345	28.5341667	33.9532333
221	WJA12	2290	NE	5	20	4.489406338	0.339359504	28.5343500	33.9524167
222	WJA13	2287	NE	5	13	3.692375380	0.327032136	28.5347000	33.9525167
223	WJA14	2312	E	5	20	1.783049832	0.69550173	28.5345000	33.9515333
224	WJA15	2188	SE	0	20	3.582729340	0.303312835	28.5344000	33.9544833
225	WL01	1490	SE	5	7	10.981542241	0.142115088	28.5766333	33.9736667

226	WL02	1541	SE	15	5	6.771214482	0.191485969	28.5787000	33.9716333
227	WL03	1590	SE	15	11	15.847571912	0.0819161	28.5797333	33.9706333
228	WL04	1640	SE	20	9	13.664292435	0.115646259	28.5805833	33.9698833
229	WL05	1693	SW	15	9	9.556318536	0.162644628	28.5820333	33.9702833
230	WL06	1749	SE	10	16	4.324926757	0.366804141	28.5828667	33.9695833
231	WL07	1829	N	10	8	4.846199789	0.307218935	28.5847333	33.9699500
232	WL08	1859	W	20	8	8.475029492	0.162238996	28.5848500	33.9704667
233	WMS01	1648	NW	20	10	6.826910689	0.236131657	28.5490333	33.9410333
234	WMS02	1713	N	5	13	11.880561164	0.102880658	28.5463667	33.9400167
235	WMS03	1754	NW	5	8	15.727444662	0.0853125	28.5445500	33.9400500
236	WMS04	1816	W	30	13	9.861461969	0.120772246	28.5435167	33.9408333
237	WMS05	1912	W	30	12	5.329006922	0.225847593	28.5415500	33.9417167
238	WS01	1522	NW	25	17	12.318286720	0.098689792	28.5598500	33.9573667
239	WS02	1569	NW	25	21	3.193428132	0.450612731	28.5591500	33.9574667
240	WS03	1618	NW	30	9	4.379130451	0.271224643	28.5575667	33.9577167
241	WS04	1646	NW	35	10	11.607547527	0.109026063	28.5580833	33.9588333
242	WS05	1546	SE	20	14	3.510011735	0.370844074	28.5598833	33.9559500
243	WS06	1573	E	25	15	7.139434172	0.174702278	28.5581833	33.9553500
244	WS07	1629	N	25	9	9.218326161	0.157123736	28.5563500	33.9554500
245	WS08	1700	N	40	6	6.849377289	0.19459285	28.5551833	33.9555833
246	WSG01	1369	NW	30	9	6.688585857	0.228373702	28.5903167	33.9134667
247	WSG02	1436	SE	5	9	10.430281342	0.115420129	28.5893833	33.9114667
248	WSG03	1481	NE	5	8	12.385712618	0.101105592	28.5882167	33.9095833
249	WSG04	1539	NE	5	6	9.167128240	0.154147383	28.5867167	33.9075500
250	WSG05	1612	NE	20	4	16.674020984	0.088960302	28.5851667	33.9051167
251	WSG06	1679	NE	5	13	11.730822701	0.103537981	28.5839667	33.9026667
252	WSGR01	1825	N	5	6	13.236936949	0.107744304	28.5744500	33.8975000
253	WSGR02	1776	N	10	7	10.012945871	0.169876543	28.5767000	33.8996500
254	WSGR03	1725	NW	5	6	9.519204795	0.152199762	28.5821000	33.9012167
255	WSH01	1525	NE	5	13	2.603865656	0.567593292	28.5625667	33.9651333
256	WSH02	1531	N	10	8	15.125281669	0.086894133	28.5620667	33.9507667
257	WSH03	1565	E	25	10	7.206660808	0.231649324	28.5608167	33.9656667
258	WSH04	1649	N	40	10	9.910363956	0.135371901	28.5585833	33.9656667
259	WSH05	1686	NE	25	12	12.195763229	0.117101322	28.5582833	33.9649667
260	WSH06	1747	N	35	9	7.431920152	0.171600666	28.5572667	33.9656833
261	WSH07	1838	N	40	19	4.994300261	0.278806584	28.5561167	33.9656333
262	WSH08	1905	NE	40	10	5.927843623	0.214625446	28.5553667	33.9663333
263	WSH09	1987	N	30	11	6.770962645	0.199372057	28.5547333	33.9663833
264	WT01	1421	NE	30	12	3.886348037	0.30825831	28.5831667	33.9224833
265	WT02	1477	NE	20	18	2.739831165	0.522928994	28.5816500	33.9207500
266	WT03	1530	E	10	12	9.657941631	0.196361059	28.5802167	33.9199000
267	WT04	1624	NE	35	14	5.110547604	0.3155116	28.5789333	33.9187833
268	WT05	1596	E	15	20	6.196609235	0.257610515	28.5795500	33.9185500
269	WT06	1674	N	30	15	12.986866443	0.093834505	28.5784667	33.9174000
270	WT07	1732	NE	20	18	12.342102612	0.106305267	28.5777000	33.9333167
271	WT08	1832	NE	20	11	8.944431660	0.140758203	28.5764167	33.9320333

272	WT101	1585	NE	10	8	4.915314629	0.316144786	28.5656833	33.9309500
273	WT102	1641	NW	15	23	5.204469215	0.298155128	28.5646500	33.9292167
274	WT103	1706	N	20	9	8.321153091	0.153687371	28.5634667	33.9283667
275	WT104	1771	N	40	6	8.322876191	0.149368559	28.5625833	33.9280333
276	WT105	1832	N	15	8	11.908791223	0.110893556	28.5621167	33.9269833
277	WT106	1893	SE	20	3	12.685687001	0.098072562	28.5609833	33.9266833
278	WTF01	1377	N	25	10	11.116419013	0.118227732	28.5979667	33.9144167
279	WTF02	1418	E	20	16	6.932389446	0.22175981	28.5967000	33.9105333
280	WTF03	1470	E	20	8	8.957490523	0.15451895	28.5967000	33.9088167
281	WTF04	1572	NE	35	14	2.943697947	0.4190625	28.5963167	33.9068333
282	WTF05	1621	E	35	16	6.896264163	0.223494089	28.5966167	33.9053333
283	WTF06	1654	NE	15	19	7.200292335	0.199432892	28.5966500	33.9046500