Vegetation change in the Pretty Valley alpine grasslands from 1945 to 2003: the influence of grazing on plant community succession

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Summary

The Pretty Valley Grassland Plots on the Bogong High Plains are of National Significance. Established 1945-1947, they constitute the second longest running ecological experiment in Australia. The study, to examine how cattle grazing impacts the range condition (i.e. vegetation cover, bare ground, litter) of alpine grassland, have been monitored periodically ever since their establishment. However, data analyses have been largely restricted to analysing trends in the cover of common species. In this ambitious project, we used Australia Flora Foundation funds to help database the original data (1946-2009). Much of this data was stored as paper copy in filing cabinets. Hence, it was no small task to database 60 years of information, collected as point quadrat data from over 80 permanent transects, and then check the data entry to identify and rectify the many errors. Having achieved this aim, we have undertaken the first study to analyse patterns of change in the plant community over time in the presence / absence of grazing. Using non-metric multidimensional ordination techniques, we show that alpine grassland has changed substantially over time. In part this reflects the impacts of grazing – the vegetation has changed as it recovered from grazing. However, grazed 'control' plots have also changed, albeit less than the ungrazed plots. This probably reflects the underlying role that climate variation (e.g. drought, variation in snow duration) plays on plant community change. Our database and initial analyses provide an excellent opportunity to track future change in alpine grassland in response to fire and climate change.

Introduction

Between 1945 and 1947, Maisie Fawcett (later Carr) and Professor John Turner of the University of Melbourne School of Botany established permanent transects on the Bogong High Plains, Victoria to study the effects of cattle grazing on vegetation condition. Grazed and ungrazed plots were established in grassland, short turf snowpatch, open heath and burned heath (after the 1939 fires) and these plots have been maintained and monitored regularly ever since, the most recent data being collected in January 2013.

The plots established by Fawcett and Turner have had a major influence and indeed, have been pivotal, in developing the ecological understanding of alpine vegetation dynamics in Victoria. At least five significant scientific publications have arisen directly from research on the plots. Carr & Turner (1958a, b) *Aust J Bot* examined the initial vegetation changes with fencing while Carr (1962) *Proc Roy Soc Vic* articulated the demographic responses of the key shrub species to disturbance. Wahren et al. (1994) *Aust J Bot* focused on four plots (grassland/open heath, grazed/ungrazed) and reported upon the vegetation changes observed between 1947 and 1994. Most recently, Williams et al (2008) *International J Wildland Fire* used the plots as part of a wider analysis to report on the response of alpine vegetation to fire.

In this study, funded by the Australian Flora Foundation, we proposed to (a) database all original data associated with these plots (1947-2003 inclusive) using database software capable of storing large volumes of data, (b) analyse the structural and floristic changes that have occurred in all plots over this time (an analysis that has not yet been undertaken) and place these changes in the context of grazing and plant community succession and (c) publish the work in high quality scientific journals. We achieved aim (a), although this proved a bigger challenge than anticipated. Most of the AFF funds were used to enter data into an Access Database, and check the data that was then entered. This was a substantial task – 60 yrs of data, collected by different recorders, with changes in taxonomy meant much of our effort was used on data entry. However, we have also achieved aim (b) of analysing the Pretty Valley Grassland data, showing that both grazed and ungrazed plots have been dynamic over the last six decades, and that cattle grazing impacts are obvious in this alpine grassland. Aim (c) has yet to be realised.

We report the findings of our work here.

MATERIALS AND METHODS

Sites

The study was conducted on the Bogong High Plains of Victoria (Australia), 250 km northeast of Melbourne. This alpine plateau covers an area of about 70 km2 above the treeline, and varies in altitude from 1660 m to 1880 m. The average annual precipitation at Falls Creek (36° 52′ S, 147° 17′ E, 1765 m altitude) is 1216 mm (1990-2006), with mean annual maximum and minimum temperatures of 9.3 °C and 2.5 °C, respectively. Snow falls between June and October, and average minimum temperatures reach -2.8 °C and -2.5 °C in July and August. The grazing exclusion experiment is located at Pretty Valley (36 °54′S, 147 °18′E, 1700 m asl), in tussock grassland about 4 km south of Falls Creek. These grasslands are dominated by a variety grasses (Poaceae; mainly *Poa*, but also *Agropyron*, *Agrostis*, *Deyeuxia* and *Trisetum*), and also contain sedges (Cyperaceae; *Carex*) and herbs (mostly Asteraceae; *Brachyscome*, *Celmisia*, *Craspedia*, *Erigeron*, *Euchiton*, *Leptorhynchos*, *Microseris*, *Podolepis* and *Senecio*). There are also a variety of woody shrubs, including Fabaceae (*Hovea*, *Oxylobium*), Myrtaceae (*Kunzea*) and Proteaceae (*Grevillea*), but these are uncommon

Grazing on the Bogong High Plains

The Bogong High Plains have been grazed by domestic stock (cattle, sheep and horses) over the summer months since 1850s until 2005. Stocking rates probably peaked in the 1930s, about a decade prior to the establishment of the grazing exclusion experiment. Stock density was especially high during severe droughts, such that in 1901, there were an estimated 100,000 sheep grazing the high plains. In 1946, concerns about over-grazing lead to the banning of sheep and horses from the High Plains, and cattle numbers were limited to about 8,000 adult cattle plus calves. By the early 1980s graziers were permitted to graze 4,000 cows plus calves (van Rees and Hutson 1983), and there was effectively been no grazing on the High Plains since the extensive wildfires of 2003. The Pretty Valley area has been grazed continuously by cattle throughout the period of study (1947-2003), but the intensity of grazing is likely to have fallen by around 50% since the 1950s. All stock grazing on the Bogong High Plains was banned from 2006.

The Grazing Exclusion Experiment

The grazing exclusion experiment consists of two plots, each 15 m x 60 m. The plots lie adjacent to each other on a gentle south facing slope, and one has been fenced to exclude cattle since 1947. Both the control and exclusion plots were monitored annually during the austral summer (in January or February) between 1947 and 1951, and then once or twice per decade thereafter. For this study, we used data from 10 surveys, in 1947, 1951, 1958, 1966, 1979, 1982, 1989, 1994, 1999, 2003. Species composition and relative species frequencies were assessed at each survey date with point quadrats, where the identities of all species touching a 4 mm diameter pin were recorded (hereafter 'species hits'). For the first several years of this study, the point quadrats were arranged in racks of 10 pins spaced at approximately 10 cm intervals, and the rack was repeatedly repositioned at random locations within each plot. In 1951, the sampling scheme was changed to single pins spaced either 0.5 m or 1.0 m apart, along 44 short, permanently marked transects running across the short axis of each plot. The total number of point quadrats has varied between 540 and 1100 in each survey. Earlier analyses of these data were limited to the dominant grasses, herbs and shrubs. For this study, we consulted original field note books to calculate change in abundance of all species occurring on the plots.

Data Analyses

In the absence of replication, we compared the trajectories of the plots from their initial states in 1947, and looked for evidence of divergence. For floristic composition, we took significant, negative temporal trends in the Bray-Curtis similarity coefficient to indicate divergence from the 1947 state within either plot over time, or between the plots over time. All species were included in these community analyses, and for consistency, we used NH when calculating relative species frequencies. Bray-Curtis similarity coefficients were calculated on both log(%frequency+1)-transformed data and presence-absence data to gauge whether any floristic divergence was driven primarily by differences in the suite of species on each plot (presence-absence), or by shifts in the relative abundances of a common set of species.

RESULTS

Species trends

Fifty six species were recorded on the plots over nearly six decades, with a mean of 32 species on both the control and exclusion plots in any one survey year. Summed over years and plots, the six most common species were *Poa hiemata* (40.3% of species hits), *Leptorhyncos squamatus* (15.1%), *Celmisia pugioniformis* (10.5%), *Carex hebes* (6.4%), *Asterolasia trymalioides* (5.6%) and *Rytidosperma nudiflora* (2.9%), which together accounted for 81% of all species hits recorded in 10 surveys since 1947. The cover of *Poa* showed no consistent trends over time on either plot (Fig. 1a), being recorded at 60-80% of all point quadrats consistently through the study. *Leptorynchos* was equally abundant in both plots for the first two decades of the study (Fig. 1b), but became relatively more common on the unfenced plot in latter two thirds of the study. *Celmisia* has stayed uncommon on the unfenced plot, occurring at less than 4% of point quadrats for most of the study, while it has increased dramatically on the fenced plot through the study, to almost 50% cover by 2003. The cover of *Carex* (Fig. 1d) has declined four-fold (c. 20% to c. 5%) on the fenced plot more or less consistently from the start of the experiment, whereas a similar decline has only been noticeable on the unfenced plot since 1982. *Asterolasia* (Fig. 1e) has remained consistently rare on the unfenced plot, occurring at than 1% of all sample points for the duration of the study. However, the cover of this species underwent a sustained increase in cover on the fenced plot until it reached 38% in 1982, and then declined by half (to c. 17%) by 2003. There was slight drop in the cover of *Danthonia* on the unfenced plot over the period of the study (Fig. 1f), while the cover of this species increased markedly on the unfenced plot later in the study.

Change in species composition through time

There have been significant floristic changes on both plots since 1947, but the pace and degree of change has been greatest on the exclusion plot (Fig. 2a). Based on relative species abundances, the unfenced plot was still 74% similar to its 1947 state by 2003, and the rate of change has remained virtually constant throughout the study (Fig. 2b). This is indicated by the minor increase in the regression coefficient from a linear model ($r2=0.885$, $p<0.001$, $n=9$ omitting the 1947 data point when similarity=100%) to one including extra terms (3rd order polynomial regression coefficient $r2=0.893$, $p<0.001$). In contrast, the fenced plot was only 50% similar to its 1947 condition by 2003 (Fig. 2b), and a 3rd order polynomial regression gave a substantially better fit ($r2=0.966$) than a simple linear regression ($r2=0.898$), suggesting that most of the floristic change on the fenced plot occurred during the first 40 years of the experiment.

These trajectories do not show floristic divergence between the plots over time, because they track change against initial conditions on each plot, rather than tracking change in floristic similarity between the plots. To do this, we calculated Bray-Curtis Similarity between the plots in each survey year. From being 81% similar in 1947 (Fig. 2c), vegetation on the fenced and unfenced plots diverged over time to be only 52% similar by the late 1990s. Again, a 3rd order polynomial regression gave a substantially better fit (r2=0.958, p<0.001, n=10) than a simple linear regression (r2=0.893), and the shape of the fitted curve suggests that most of the divergence occurred in the first half of this long study.

Repeating all of these analyses with presence/absence data showed that change within plots, and the divergence between them, was driven mostly by shifts in the relative abundances of what was a substantially similar suite of species (Fig. 3). First, the 'drift' of the plots through 2-dimensional ordination space (Fig. 3a) did not follow the same ordered, temporal sequence that was apparent for the relative abundance data (Fig. 2a). Second, there was no significant temporal trend in changes in similarity on unfenced plot (linear r2=0.161, p=0.284; Fig. 3b) and a weak trend on the fenced plot (linear r2=0.613, p=0.013). Third, the plots were between 70% and 80% similar for most of the study, with no evidence of divergence between them over time (linear r2=0.150, p=0.268).

DISCUSSION

Did cattle exclusion drive the observed differences between the plots?

Our data confirm that individual species and, perhaps more importantly, plant communities *per se* were dynamic over 60 years. Clearly, vegetation dynamics in the presence of cattle grazing is determined by physical disturbance and/or herbivory, as affected by differences in species palatability, but this occurs within the context of large variation in climate as this affects abiotic factors such as drought intensity and duration of snowcover. Clearly, plant communities have diverged over time, suggesting that cattle grazing fundamentally impacts of successional processes. This has not previously been observed in this important dataset. Ungrazed plots were more dynamic, and diverged more than grazed plots, hinting that grazing 'dampens' underlying or background vegetation change. However, grazed plots *did* change in time, albeit less so than ungrazed plots, perhaps reflecting the fact that cattle grazing numbers were in decline during the duration of the study. By the 2003 survey, there were effectively very few cattle grazing the area.

The interpretation of our study rests entirely on whether we accept the proposition that the exclusion of cattle has been responsible for the divergent floristic trajectories of the plots in this unreplicated experiment. Three lines of argument suggest strongly that this is the case. First, the alternative hypothesis of underlying environmental variation has been all but ruled out by Kirkpatrick (1997). In a forensic dissection of plant ecology in Australia, and issues of replication in particular, he considered the specific case of the Pretty Valley experiment and concluded that one would have to try ‘really hard’ (pg 295) to hypothesize that underlying variation in edaphic or topographic factors were key drivers of floristic differences across the fenceline. He further concluded that it was ‘hard to doubt’ (pg. 295) that the exclusion of grazing has been the major cause of the differences between the plots.

Second, the temporal trends in cover of several species are consistent with what would be expected of either their palatability to cattle, their tolerance to trampling or their response to soil disturbance. For example, Wahren et al. (1994) argued persuasively that contrasting trends in the cover of the two main herbaceous species in the experiment is consistent with the effects of cattle grazing; *Celmisia* is highly palatable to cattle (van Rees 1982, 1984) and increased in cover in the absence of grazing. On the other hand, *Leptorhyncos* is a vigorous colonist of bare, inter-tussock spaces that result from cattle grazing (Carr & Turner 1959b), and at Pretty Valley this species declined in cover abundance in the absence of disturbance. Further, the consistently low cover of the shrub *Asterolasia* on the grazed plot, and its initial, dramatic increase in cover on the exclusion plot is consistent with its high palatability to cattle (van Rees 1984) and sensitivity to trampling (Carr and Turner 1959b, Carr 1962, Williams and Ashton 1987). Its decline in cover from 1982 is probably due to the senescence of individual shrubs (Wahren et al. 1994), which are obligate reseeders (Williams and Ashton 1987).

Third, this experiment has been one of several long-term studies at the centre of a decades-long debate about the impact of cattle grazing on the biodiversity and conservation values of the Bogong High Plains (e.g. Williams et al. 2006 and references therein). Scientific claims for a significant exclusion effect at the Pretty Valley experiment have been tested and passed in reviews by both the Australian Academy of Sciences (1957) and more recently by CSIRO (Groves 1998), Australia’s peak national research institution. There has never been any scientifically-based doubt of a real treatment effect, although we concede that in the absence of replication, we have no estimate of the spatial variability in effect size for floristic composition.

Conclusion

As the second longest running ecological and land management study in Australia and hence, a dataset of National Significance, this dataset is an outstanding benchmark for assessing how alpine vegetation will change with future climate change (perhaps the next 60 yrs of data!). These data have relevance to the entire alpine zone in Australia because they provide a unique opportunity to assess and interpret the vegetation changes that have been observed in the context of land management and plant community succession.

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Figure Captions

Figure 1. Temporal trends in the cover of (a) *Poa hiemata*, (b) *Leptorhyncos squamatus*, (c) *Celmisia pugionoformis*, (d) *Carex hebes*, (e) *Asterolasia trymalioides* and (f) *Rytidosperma nudiflora* in the grazed (open symbols) and ungrazed (closed symbols) plots. Cover was assessed as Nx/NP x 100, where Nx was the number of point quadrats where Species X was recorded, and NP was the number of point quadrats surveyed.

Figure 2. Community change and divergence on the grazed and ungrazed plots from the start of the experiment in 1947, based on log(x+1) transformed data of relative species abundances (see text); (a) NMDS ordination showing growing divergence through time. Sample years connected sequentially by solid black lines, stress = 0.06, (b) the decline in the Bray-Curtis estimate of similarity for each plot through time, compared to their initial state in 1947, and (c) the decline in Bray-Curtis estimate of similarity between the plots, from their initial similarity of 81% in 1947. In (a) and (b), open symbols depict the grazed plot, and closed symbols depict the ungrazed plot.

Figure 3. Community change and divergence on the grazed and ungrazed plots from the start of the experiment in 1947, based on species presence/absence data (see text); (a) NMDS ordination showing no divergence through time. Sample years connected sequentially by solid black lines, stress = 0.16, (b) the divergence of the community on the ungrazed plot (but not the grazed plot) from its initial state in 1947, and (c) the no consistent change in the Bray-Curtis estimate of similarity between the plots, from their initial similarity of 76% in 1947. In (a) and (b), open symbols depict the grazed plot, and closed symbols depict the ungrazed plot.

Fig 1.

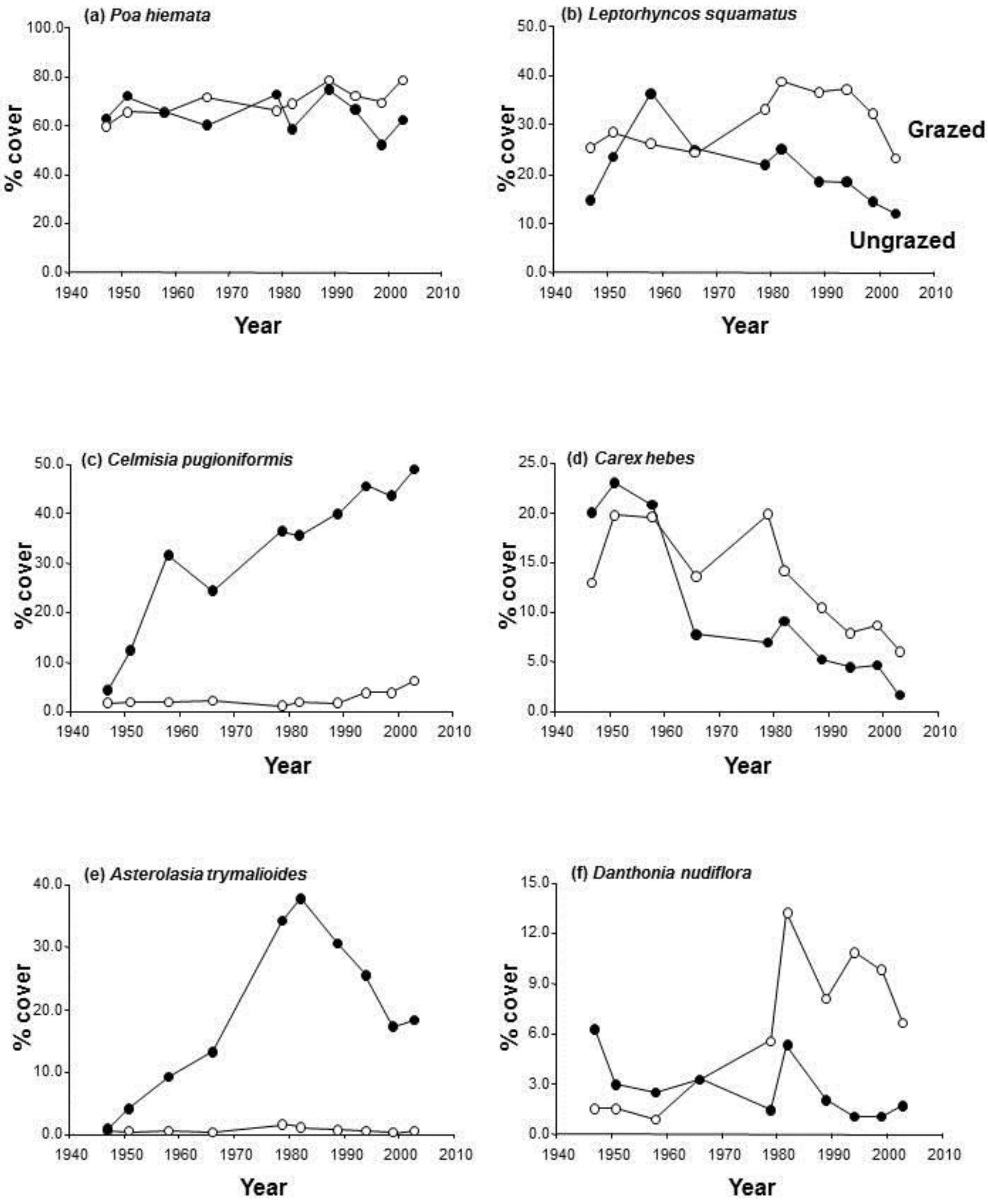

(a) *Poa hiemata*
(b) *Leptorhyncos squamatus*
(c) *Celmisia pugioniformis*
(d) *Carex hebes*
(e) *Asterolasia trymalioides*
(f) *Danthonia nudiflora*
% cover
Year
Grazed
Ungrazed
1940
1950
1960
1970
1980
1990
2000
2010
0.0
3.0
6.0
9.0
12.0
15.0
5.0
10.0
20.0
25.0
30.0
40.0
50.0
60.0
80.0
100.0

Fig 2.

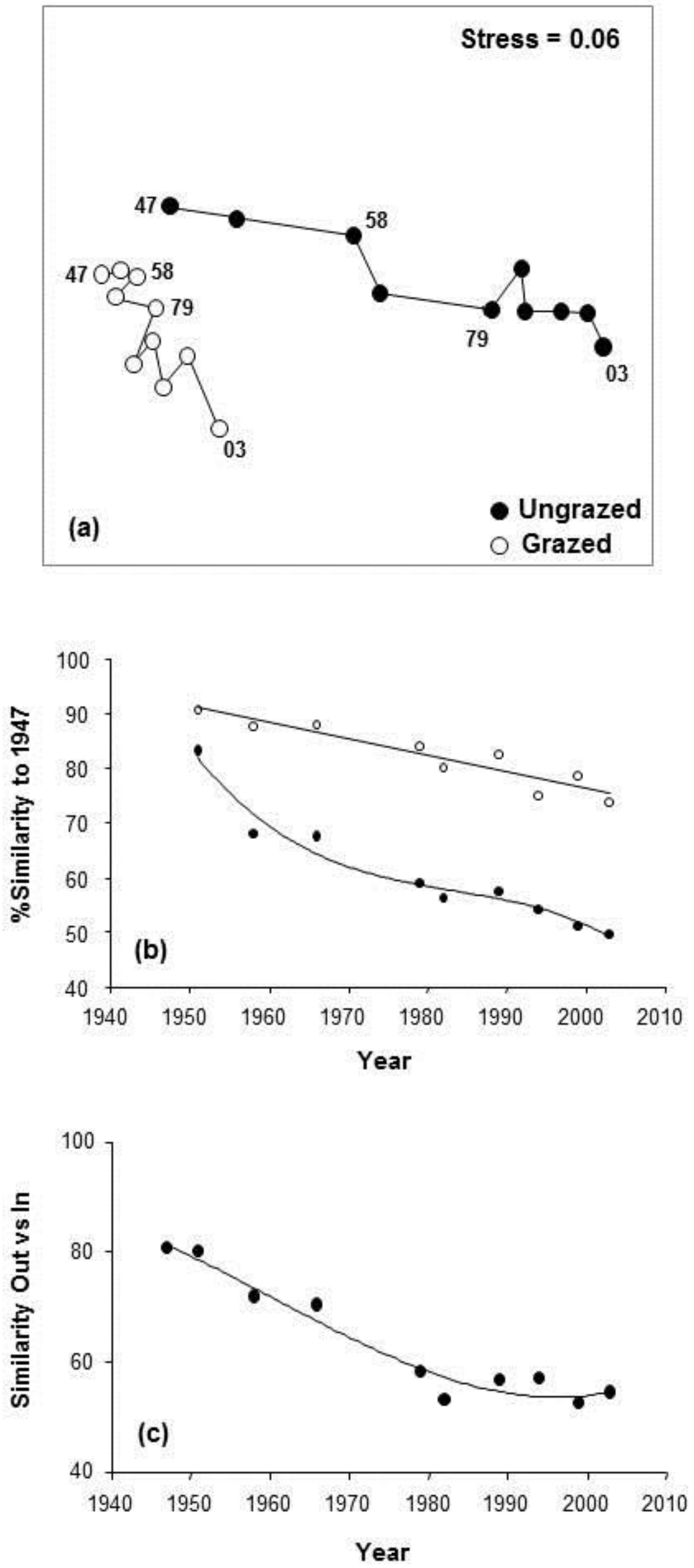
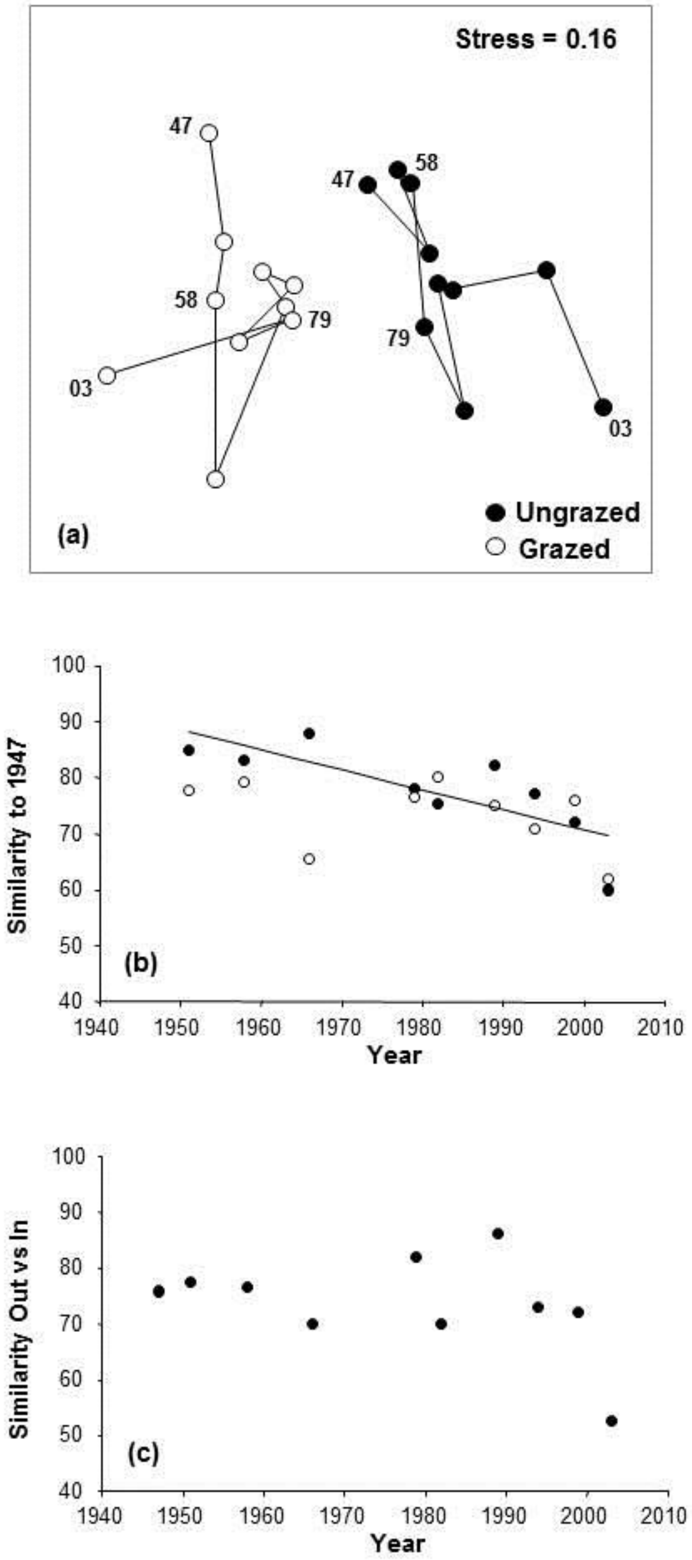

Stress = 0.06
47
58
79
03
47
58
79
03
● Ungrazed
○ Grazed
(a)
100
90
80
70
60
50
40
%Similarity to 1947
(b)
1940
1950
1960
1970
1980
1990
2000
2010
Year
100
80
60
40
Similarity Out vs In
(c)
1940
1950
1960
1970
1980
1990
2000
2010
Year

Fig 3.


Stress = 0.16
47
58
79
03
47
58
79
03
● Ungrazed
○ Grazed
(a)
Similarity to 1947
100
90
80
70
60
50
40
(b)
1940
1950
1960
1970
1980
1990
2000
2010
Year
Similarity Out vs In
100
90
80
70
60
50
40
(c)
1940
1950
1960
1970
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