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ORIGINAL PAPER

The effect of grazing on bumblebees in the high rangelands of the eastern Tibetan Plateau of Sichuan

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Abstract Many Tibetans who were formerly nomadic yak herders are settling near towns. However, yak remain a traditional symbol of wealth, which can lead to increased local stocking densities and severe over-grazing. We used belt-transect counts to study the area around Hongyuan in Sichuan. We find that intensive summer grazing significantly reduces the vegetation height and is associated with significant reductions in bumblebee-food-plant abundance and bumblebee diversity. For the significantly reduced bumblebee species, we identify the most frequently used and preferred bumblebee-food plants. For the food plants, we identify changes in absolute flower availability and changes in bumblebee visits. In particular, reductions in the bumblebees *Bombus supremus, B. filchnerae*, *B. humilis* and *B. impetuosus* are associated with reductions in flowers of the food plants *Hedysarum* and *Saussurea*.

Keywords Diversity · Pollinator · Decline · Food-plant preference · Environmental change

Introduction

In Europe, agricultural practices are widely believed to have caused a great decline in bumblebees (*Bombus* spp.) in agricultural systems (e.g. Williams 1986; Rasmont 1988; Dramstad and Fry 1995; Bäckman and Tiainen 2002; Croxton et al. 2002; Pywell et al. 2005; Benton 2006; Fitzpatrick et al. 2007). Bumblebee abundance and species richness differ between agricultural habitats and semi-natural habitats (Williams 1988; Mänd et al. 2002; Pywell et al. 2005), sown and unsown field margins (Carvell et al. 2004), and intensively farmed landscapes and less intensively farmed landscapes (Sepp et al. 2004). Degradation of forage flowers in agricultural habitats (Williams 1986; Osborne et al. 1991; Meek et al. 2002) and use of pesticides and fertilizer (Williams 1986; Pywell et al. 2005) are likely to be among the main causes for the decline. It is presumed that bumblebees would need to fly longer distances to their food resources when the foraging habitats are broken into fragments (Goverde et al. 2002), but field observations describe bumblebees foraging over distances of only a few hundred metres (Osborne et al. 1999; Walther-Hellwig and Frankl 2000; Kreyer et al. 2004). Because bumblebees have food-plant preferences (e.g. Williams 1989, 2005; Osborne et al. 1999; Osborne and Williams 2001) and nest-site preferences (Svensson et al. 2000; Kells and Goulson 2003), they should face increasing constraints when suitable habitats become fragmented, which might lead to bumblebee declines in degraded landscapes. Comparisons with field data from other regions of the world should help in understanding the mechanisms.

Agricultural intensification has also been considered to be a major component of environmental change in China (Xiang and Tang 2006) and is believed to be affecting bumblebees (Yang 1999). However, appropriate methods to assess the quality of agricultural environments are not well established. Since bumblebee communities are easy to sample, and because some bumblebee species are closely dependent on habitat characteristics, bumblebees are

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suggested to be good biological indicators for assessing the health of the agricultural environment (Kevan 1999; Sepp et al. 2004). For example, bumblebee communities have already been used as an indicator of the differences between intensive and less intensive agriculture in Estonia (Sepp et al. 2004).

Located on the eastern fringe of the Tibetan Plateau, western Sichuan Province forms part of the principal hotspot of bumblebee diversity world-wide (Williams 1998; Williams et al. 2008). In recent decades, however, growing human disturbance of rangelands in western Sichuan has become very noticeable. The management of stock-breeding and farming has changed considerably since the late 1990s (Zhang 2004) with many local Tibetans changing from a nomadic to a settled lifestyle. Rangelands have been allotted to families and many have been fenced. Although livestock is grazed mainly within the rangelands of each family, some areas are for open or free grazing. As a result of the increasing livestock population, more than 50% of the rangelands are overgrazed (Bao and Wu 2003). To minimize the impacts of grazing, some improved spatial and temporal management models have been promoted. Families fenced their rangelands, grazing intensively each rangeland in rotation while allowing the others to rest. This goes some way to reducing the mean intensity of grazing, although problems remain (Li et al. 2003). These remarkable changes may already have had a great impact on the bumblebees in this area. However, hitherto no studies have been undertaken to investigate the impacts of grazing and rangeland change on bumblebee diversity in China. Previous field studies have indicated that Hongyuan County in western Sichuan Province is rich in bumblebees (Macior and Tang 1997; Macior et al. 2001; Williams et al. 2008). In this county, the population of livestock, especially of yak, has increased considerably and degradation of rangelands has been common (personal observation).

Prior to this study, observations in 2000–2005 and over a broad region of western Sichuan lead us to suggest that grazing by yak might cause a reduction in bumblebee abundance and diversity. Therefore, this study aims to evaluate the impacts of livestock grazing on bumblebees in Hongyuan, with three specific questions: (1) Does summer grazing affect bumblebee abundance and diversity? (2) Can differences in bumblebee diversity be explained by differences in bumblebee-food-plant abundance or diversity? and (3) Can lower bumblebee diversity be explained by lower abundance of particular bumblebee-food plants? Since bumblebees usually hibernate below the soil (Alford 1975; Kells and Goulson 2003), winter grazing should have little direct effect on bumblebee populations, except through its effects on the grassland in the following summer.

Materials and methods

Hongyuan County is one of a few counties in Sichuan where most of the population is engaged in pastoral production and in this respect it resembles the adjacent provinces of Xizang (Tibet) and Qinghai. Hongyuan County covers an area of 8,433 km^2, 90% of which is rangeland (Zhao 1996). The warmest air temperature is in July (10.9°C) and the coldest is in January (−10.3°C) (SMB undated). The mean annual temperature varies between 0.5 and 4.0°C. Mean annual highest temperature varies between 8.5 and 12.1°C and mean annual lowest temperature ranges from −0.8 to +2.4°C. Mean annual precipitation is around 650 mm (SMB undated; Yao et al. 2000).

Field surveys were conducted from 10 July to 10 August 2006 and from 22 July to 3 August 2007, when most bumblebee species were at their foraging peak and most plant flowers were in full bloom. Two different sites were selected, each of which represents a landscape common around Hongyuan (Table 1). The geographical position and altitude were determined using a Garmin III Plus GPS receiver in the field for the two sites and for each bee walk transect.

Waqie has undulating topography and a slope of less than 5°. The vegetation was originally plateau steppe, but is now pastureland, grazed primarily (estimated >90%) by yak. There had previously been extensive marshes, but many were drained in the mid-1960s to create more pastureland for livestock development (Gao 2006). As a result of drainage, and possibly as a result of global warming, the wetlands have declined by 20% since the mid-1980s, so that the wetlands now cover only 7.65% of the total area around Hongyuan (Zhou et al. 1999). The extensive subalpine and alpine meadows support large numbers of livestock, both on the hills and in the valleys.

Qiongxi has undulating topography and a slope of less than 5°. Compared with Waqie, marshes were always uncommon, although during recent decades, the limited wetlands have also declined, largely due to human disturbance. The vegetation is now pasturelands and the grazing has been intensive.

Bumblebees were surveyed in the field using a standard “bee walk” belt-transect method (Banaszak 1980). The 100 m × 2 m transects were placed randomly across the summer-grazed rangelands and the summer-ungrazed rangelands at each site, but not within at least 10 m of the edge of the rangelands. Bumblebees were recorded as the observers walked along the central line of the transects. The duration of each transect walk was kept the same to reduce the effects of variations in sampling effort. For some sites where walking for 100 m was not possible, bumblebees were counted along two parallel transects,

Table 1 Characteristics of the sample sites near Hongyuan

Site name	Landform	Vegetation	Land use	Latitude (N)	Longitude (E)	Altitude (m)
Waqie	Slope gradient <5°	Temperate marsh meadows, sub-alpine meadows and sub-alpine shrub	Grazing	33° 05′	102° 37′	3,526
Qiongxi	Slope gradient <5°	Sub-alpine meadows and sub-alpine shrub	Grazing	32° 47′	102° 31′	3,565

each 50 m × 2 m. To reduce the effect of differences in the weather and season, the summer-grazed areas and the summer-ungrazed areas were surveyed alternately. The bumblebee species and the plant species were recorded when bumblebees visited flowers for pollen or nectar. Taxonomy of bumblebee species follows (Williams et al. 2008). Each walk was made between 9:00 and 17:00 hours when the weather was sunny, dry, warm and not excessively windy for bumblebee foraging (Beaufort scale <= 5, moderate breeze). Since cuckoo bumblebees (subgenus *Psithyrus*) have different foraging constraints to the non-parasitic species, they were excluded from the analysis.

We have no direct data on yak stocking density, but we can assess the effect of summer grazing on vegetation height and composition. Summer-grazed rangelands (grazing allowed in late spring and summer) were extensively grazed during the bumblebee foraging season. Summer-ungrazed rangelands (grazing not allowed in summer but allowed in winter) were inaccessible to yak during our field survey.

The height of the vegetation for each transect was estimated with three replicated point measures of the maximum length of grass from root to tip. To give a measure of the foraging resources available, three 2 m × 2 m quadrats were placed randomly within each transect and the number of plant species that bumblebees visited and that were in open flower was scored (adapted from Croxton et al. 2002, and Carvell et al. 2004). Although some plant species, such as *Microula* Bentham and *Aconitum* Linnaeus, have been reported to provide good resources for bumblebees (Macior et al. 2001; unpublished observations), we did not include them because they were not visited by bumblebees during the present survey. Most plants were identified only to genus, although *Pedicularis* was identified to species because foraging-related flower morphology varies strongly between *P. verticillata* and *P. polyodonta*. Single-flowered stems and multi-flowered stems in each quadrat were counted on a scale from 0 to 5 as follows: 0: absent; 1: 1–25 flowers; 2: 26–200 flowers; 3: 201–500 flowers; 4: 501–1,000 flowers; 5: more than 1,000 flowers. We removed *Spiraea*-rich transects from those analyses that use vegetation height. This was because *Spiraea* bushes are unpalatable to yak and persist despite summer grazing, so that measurements of the vegetation height in some of the *Spiraea*-rich transects may remain relatively high despite grazing. Including them would confound the use of vegetation height as a surrogate to represent food-plant suppression by grazing.

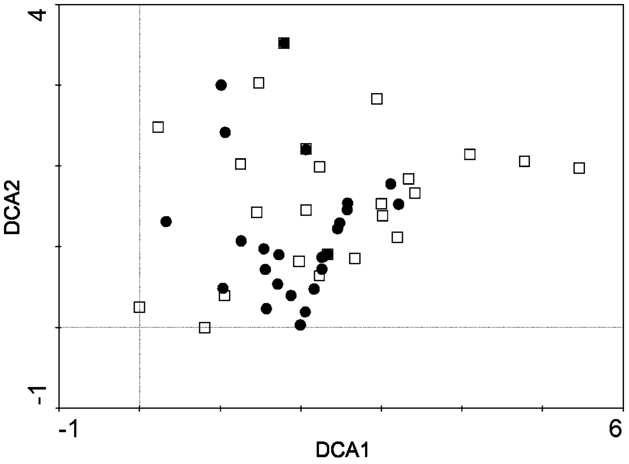

Fig. 1 DCA plot of transects by their bumblebee species assemblages (excluding *Psithyrus* records and *Spiraea*-rich transects). *x* axis DCA1, *y* axis DCA2, filled circles Waqie, open squares Qiongxi

A detrended correspondence analysis (DCA) plot (Fig. 1) shows the homogeneity of the bumblebee species assemblages among transects within and between the two sites. The broad overlap in the scatter of transects shows that the two sites are similar in the variation of their bumblebee species composition. Therefore, the two sites can be treated together for further analyses.

Counts of species richness and of bumblebee abundance are summed and differences between summer-ungrazed areas and summer-grazed areas are examined with *t*-tests. Means were log-transformed prior to analysis (Meek et al. 2002). Food-plant preferences can be identified from the excess of visits above those expected if bumblebees were unselective and encountered the same flowers in proportion to the numbers of recorded bumblebee visits and numbers of plant visits. These expected frequencies are calculated from the observed counts of visits as the products of the marginal totals divided by the grand total ((*sum for bee species* × *sum for plant species*)/*grand total of all visits*). The preference index is then calculated as ((*observed*−*expected*)/*expected*).

Results

Does grazing affect bumblebee abundance and diversity?

The field survey recorded a total of 15 bumblebee species (Table 2). Taken together, summer-ungrazed transects had 14 bumblebee species and summer-grazed transects had 12 bumblebee species. Individually, summer-grazed transects had a significantly lower mean number of bumblebee species and a lower mean bumblebee abundance than the summer-ungrazed transects. The mean numbers of *B. filchnerae*, *B. humilis*, *B. supremus* and *B. impetuosus* (initially among the more abundant species) were significantly lower in the summer-grazed rangelands than in the summer-ungrazed rangelands. Significant differences in some other species may be undetectable because sample sizes are too small.

The height of the vegetation was significantly lower in the summer-grazed transects than in the summer-ungrazed transects (Fig. 2: $t_{71} = 23.84$, $P < 0.001$). Therefore, we can use vegetation height as an inverse surrogate or proxy for the intensity of summer grazing.

There is a significant and approximately linear relationship between the height of the vegetation and the bumblebee species richness among transects (Fig. 3: $r^2 = 0.28$, $P < 0.0001$). A hump-shaped quadratic model was considered likely *a priori* because flower density and bumblebee species richness might be expected to be higher at the mid range of vegetation height but lower at the extremes (i.e. lower with very short [<5 cm] or very long [> 50 cm] grass). For these data, the best model was identified using the Akaike Information Criterion (AIC), comparing a linear

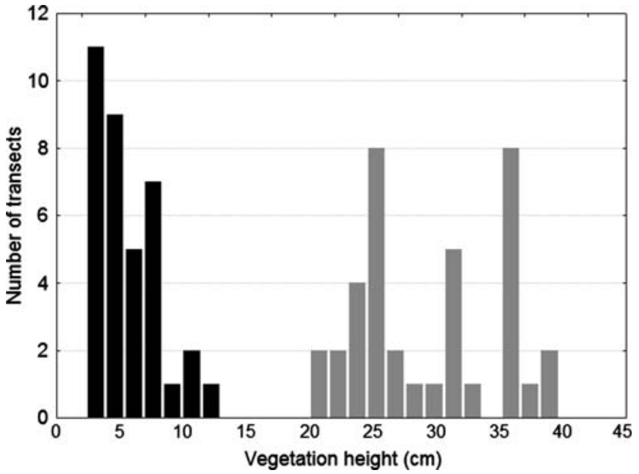

Fig. 2 Frequency (*y* axis) of height of vegetation in cm (*x* axis) among transects (excluding *Spiraea*-rich transects), the black bars represent the summer-grazed transects, and the grey bars represent the summer-ungrazed transects

Table 2 Bumblebee species richness and abundance per 100 m in the summer-ungrazed transects and the summer-grazed transects (including *Spiraea*-rich transects) at Waqie and Qiongxi

Bumblebees per 100-m transect	Summer-ungrazed mean abundance ± SE Number of transects = 55, number of bees = 214	Summer-grazed mean abundance ± SE Number of transects = 40, number of bees = 65	*t*	*P*	Significance
B. filchnerae	1.01 ± 0.10	0.31 ± 0.08	5.32	0.000	***
B. humilis	0.57 ± 0.10	0.03 ± 0.03	4.81	0.000	***
B. supremus	0.20 ± 0.06	0.03 ± 0.03	2.42	0.017	*
B. impetuosus	0.32 ± 0.07	0.12 ± 0.06	2.19	0.031	*
B. laesus	0.15 ± 0.05	0.05 ± 0.03	1.50	0.137	ns
B. lemniscatus	0.04 ± 0.03	0.00 ± 0.00	1.22	0.227	ns
B. waltoni	0.09 ± 0.04	0.03 ± 0.03	1.30	0.196	ns
B. lepidus	0.02 ± 0.02	0.00 ± 0.00	0.85	0.397	ns
B. ladakhensis	0.02 ± 0.02	0.00 ± 0.00	0.85	0.397	ns
B. sichelii	0.09 ± 0.04	0.06 ± 0.04	0.53	0.599	ns
B. kashmirensis	0.22 ± 0.06	0.18 ± 0.06	0.47	0.638	ns
B. patagiatus	0.06 ± 0.04	0.08 ± 0.04	−0.23	0.815	ns
B. convexus	0.00 ± 0.00	0.03 ± 0.07	−1.18	0.243	ns
B. rufofasciatus	0.09 ± 0.04	0.19 ± 0.07	−1.33	0.193	ns
B. friseanus	0.22 ± 0.06	0.40 ± 0.09	−1.80	0.076	ns
Transect bumblebee species richness	1.59 ± 0.04	1.14 ± 0.04	7.04	0.000	***
Transect bumblebee abundance	1.90 ± 0.07	1.23 ± 0.05	7.13	0.000	***

Significant differences are given in bold: ns, no significant difference; $*P \leq 0.05$; $**P \leq 0.01$; $***P \leq 0.001$

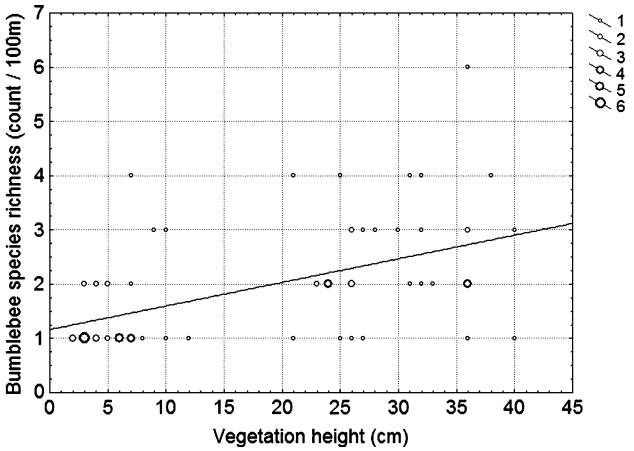

Fig. 3 Scatterplot of the frequency of transects by (x axis) height of vegetation and (y axis) bumblebee species richness, using larger circular symbols for higher frequencies (excluding *Spiraea*-rich transects), the linear regression line represents *bumblebee richness* = 1.163 + (0.0435**vegetation height*) ($r^2 = 0.28$, $P < 0.0001$)

function of vegetation height with a quadratic function of vegetation height. Marginally the best compromise between fit and complexity was the simple linear model because it has the lowest AIC (196) compared with either the linear + quadratic model (AIC 197) or the simple quadratic model (AIC 198). The linear regression has residuals that are near-normally distributed and the normal probability against residual (quantile–quantile) plot is approximately linear; the plot of residuals against predictors (x) shows a near-random scatter; the plot of residuals against observed predicted (y) is nearly linear: all indications that confirm there is no need for a more complex regression model. Nonetheless, much variation remains to be explained.

Can differences in bumblebee diversity be explained by differences in bumblebee-food-plant abundance or diversity?

There were significant positive relationships between vegetation height and both the quadrat-counted food-plant species richness (Pearson $r = 0.67$, $P < 0.001$) and the available food-plant abundance ($r = 0.75, P < 0.001$) among transects. There were also significant positive relationships between bumblebee species richness and both the quadrat-counted food-plant species richness ($r = 0.53$, $P < 0.001$) and the food-plant abundance ($r = 0.54$, $P < 0.001$).

Can lower bumblebee diversity be explained by lower abundance in particular bumblebee-food plants?

First, for the bumblebee species from Table 2 that had significantly lower abundance in the summer-grazed transects, we identify the bumblebee-food plants that were both (a) most frequently visited (so that they make up much of the diet: Table 3) and (b) preferred by these bumblebees (so that the bumblebees are also actively selecting them above random expectation: Table 4). For *B. supremus*, both criteria were met by *Hedysarum*; for *B. filchnerae*, both criteria were met by *Halenia* and *Hedysarum*; for *B. humilis*, both criteria were met by *Saussurea*; and for *B. impetuosus*, both criteria were met by *Halenia*, and although there were many visits to *Hedysarum*, this plant was not preferred.

Second, for the bumblebee-food plants above that were (a) frequently visited and (b) preferred by the significantly reduced bumblebee species, do they (c) show lowered frequencies of visits by those bumblebees in summer-grazed transects? Figure 4 shows that for *B. filchnerae*,

Table 3 Observed frequencies of visits by bumblebees to food plants from counts among 55 summer-ungrazed transects (including *Spiraea*-rich transects) at Waqie and Qiongxi

Bumblebee species	*Nepeta*	*Saussurea*	*Pedicularis polyodonta*	*Pedicularis verticillata*	*Halenia*	*Oxytropis*	*Hedysarum*	*Vicia*	Totals
B.supremus	0	0	1	0	1	0	**6**[a]	1	9
B.filchnerae	1	8	1	3	**14**	2	13	0	42
B.friseanus	0	3	0	3	2	0	1	0	9
B.rufofasciatus	0	0	0	0	0	0	2	0	2
B.impetuosus	0	0	1	1	6	0	3	0	11
B.lemniscatus	0	0	0	1	0	0	1	0	2
B.laesus	0	1	0	0	2	0	2	0	5
B.humilis	1	**20**	1	1	3	0	5	0	31
B.sichelii	0	1	0	0	0	0	0	0	1
B.lepidus	0	0	0	1	0	0	0	0	1
B.patagiatus	0	1	0	0	0	0	0	0	1
B.kashmirensis	2	0	1	0	1	0	0	0	4
Totals	4	34	5	10	29	2	33	1	118

[a] The highest frequencies of visits for each bumblebee species are underlined

Table 4 The foraging preferences[a] of bumblebees for food plants[b] from Table 3

Bumblebee species	*Nepeta*	*Saussurea*	*Pedicularis polyodonta*	*Pedicularis verticillata*	*Halenia*	*Oxytropis*	*Hedysarum*	*Vicia*
B.supremus	−1.00	−1.00	1.62	−1.00	−0.55	−1.00	1.38	**12.11**
B.filchnerae	−0.30	−0.34	−0.44	−0.16	0.36	**1.81**	0.11	−1.00
B.friseanus	−1.00	0.16	−1.00	2.93	−0.10	−1.00	−0.60	−1.00
B.rufofasciatus	−1.00	−1.00	−1.00	−1.00	−1.00	−1.00	2.58	−1.00
B.impetuosus	−1.00	−1.00	1.15	0.07	1.22	−1.00	−0.02	−1.00
B.lemniscatus	−1.00	−1.00	−1.00	4.90	−1.00	−1.00	0.79	−1.00
B.laesus	−1.00	−0.31	−1.00	−1.00	0.63	−1.00	0.43	−1.00
B.humilis	−0.05	**1.24**	−0.24	−0.62	−0.61	−1.00	−0.42	−1.00
B.sichelii	−1.00	2.47	−1.00	−1.00	−1.00	−1.00	−1.00	−1.00
B.lepidus	−1.00	−1.00	−1.00	10.80	−1.00	−1.00	−1.00	−1.00
B.patagiatus	−1.00	2.47	−1.00	−1.00	−1.00	−1.00	−1.00	−1.00
B.kashmirensis	13.75	−1.00	4.90	−1.00	0.02	−1.00	−1.00	−1.00

[a] Preference index is then calculated as ((*observed−expected*)/*expected*); observed frequencies are from Table 3; expected frequencies are calculated from the observed counts in Table 3 as the products of the marginal totals divided by the grand total ((*sum for bee species* × *sum for plant species*)/*grand total of all visits*)

[b] The highest positive preferences of each bumblebee species are underlined

visits to the frequently used and preferred *Hedysarum* stop and visits to *Halenia* were substantially lower with summer grazing. For *B. humilis*, visits to the frequently used and preferred *Saussurea* stop with summer grazing. For *B. supremus*, visits to the frequently used and preferred *Hedysarum* stop with summer grazing. And for *B. impetuosus*, visits to the frequently used and preferred *Halenia* were substantially lower, and visits to the frequently used *Hedysarum* stop with summer grazing.

Third, for the bumblebee-food plants that were (a) frequently visited, (b) preferred by the significantly reduced bumblebee species, and (c) showed fewer visits in the summer-grazed transects, do they (d) show lowered absolute availability classes in the quadrats? Table 5 shows that for *Hedysarum*, the frequently used and preferred food plant of *B. supremus* and *B. filchnerae* and frequently used food plant of *B. impetuosus*, there was significantly lower availability with summer grazing. Similarly, for *Saussurea*, the frequently used and preferred food plant of *B. humilis*, there was significantly lower availability with summer grazing. In contrast, for *Halenia*, a frequently used and preferred food plant of *B. filchnerae* and *B. impetuosus*, there was no significant difference in abundance class with summer grazing.

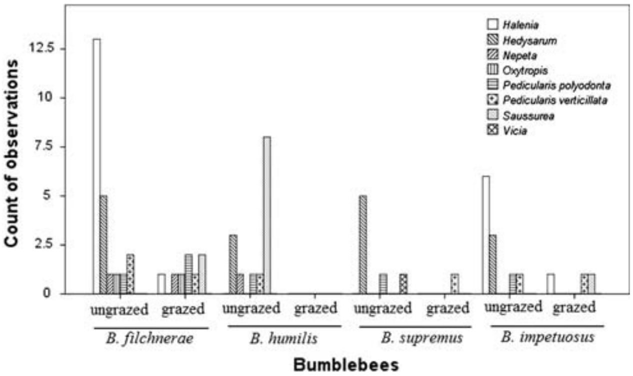

Fig. 4 Frequency of flower visits along transects to plant species (*y* axis) by bumblebee species and by summer-grazing regime (*x* axis) among transects for the four significantly lower bumblebee species in summer-grazed transects from Table 2 (including *Spiraea*-rich transects), the patterns within the bars represents the different food-plant species

Discussion

Caveats

Our results show that around Hongyuan, summer grazing by yak is associated with reductions in bumblebee abundance and diversity. This study does not measure longitudinal temporal changes in any factors directly. Nonetheless, our transverse comparisons at one point in time may still be helpful for identifying associated factors. We assume from studies in Europe (Carvell 2002) and North America (Hatfield and LeBuhm 2007) that effects of grazing on bumblebee abundance and diversity are likely to be mediated by the effects on bumblebee-food plants and have not looked at effects via other possible mediating factors, such as nesting sites, predation, etc. Potentially there could be other confounding factors in this analysis. We have seen no evidence of the use of herbicides against rangeland weeds (such as the Artichoke thistle, *Cynara cardunculus* L., in California: e.g. California Invasive Plant Council,

Table 5 Differences in the background availabilities of food plants (independent of visits by bees) estimated as abundance classes from quadrats associated with transects

Food-plant species	Difference in abundance class between summer-grazing regimes	
	t_{93}	P
Vicia	9.791	< 0.001***
Hedysarum	11.391	< 0.001***
Saussurea	5.611	< 0.001***
Halenia	−1.942	0.055 (ns)
Oxytropis	1.108	0.271 (ns)

*** $P \le 0.001$; ns, not significant at $P < 0.05$

www.cal-ipc.org). Similarly, although insecticides are known to be used against pests of yak, this is in only a few small areas which are many kilometres from where our survey transects are located (personal observation). The analysis is subject to all of the normal potential sources of error, including misidentification of bumblebees and of their food plants, the effects of the weather on flower-visiting activity, errors in measurements of vegetation height and in the scoring of plant-abundance classes. A particular concern is that small sample sizes may make inferences, including e.g. plant preferences, less reliable.

Explanations of how bumblebees decline

Previous studies of bumblebee decline in Europe suggest that it is often driven by the decline of their food plants, which may be explained by changes in land use (e.g. Williams 1986; Benton 2006; Carvell et al. 2006). In the Sichuan rangelands, we observed that summer grazing by yak, together with a few sheep and horses, was the main source of disturbance. We establish a link between the vegetation height and bumblebee species richness and abundances.

Intensive grazing is known to have caused declines in invertebrate taxa in Britain (Gibson et al. 1992). The effect of grazing on bumblebees has been found to depend on whether it is cattle or sheep that are doing the grazing (Carvell 2002; Hatfield and LeBuhm 2007). Indeed, for bumblebees, cattle grazing can be more beneficial than no management, especially if grazing is not applied every year (Carvell 2002). It is possible that around Hongyuan, summer grazing in occasional years may promote bumblebee-food plants in some subsequent years, but understanding this successional effect will require a much more long-term study with a detailed knowledge of the local grazing history. For example, one of *B. filchnerae*'s and *B. impetuosus*'s preferred food plants, *Halenia* (Table 4), may be slightly (if not significantly, Table 5) more abundant in the summer-grazed areas. *Halenia* seems to increase in abundance in the year following summer grazing, if summer grazing then stops (personal observation). Effects like this of the longer-term history of the grazing regime are likely to be very important (also for species of *Pedicularis*, another important part of bumblebee diets in Asian mountains) and need to be studied.

To identify which bumblebee-food-plant species might be particularly important in the declines of bumblebees with summer grazing, we require four criteria to be met. We show that for the four bumblebee species with significantly lowered abundances with summer grazing (Table 2: *B. supremus*, *B. filchnerae*, *B. humilis*, *B. impetuosus*), the food plants (1) that they visit most frequently (Table 3), (2) that they prefer (Table 4), (3) that show substantially fewer visits along the transects (Fig. 4), and (4) that show significantly lower available abundance in the summer-grazed quadrats (Table 5) are *Hedysarum* and *Saussurea*. Further field studies will be needed to test the importance of changes in these foraging relationships as a causal effect for bumblebee declines.

Among the three food-plant species most frequently visited by the significantly reduced bumblebees with summer grazing (Table 2), *Hedysarum* and *Halenia* are characterized particularly by their long corollas (Y. Tang unpublished data). Corolla length is among the most important factors governing flower choice by bumblebees, and declines in the abundance of food plants from particular, key corolla-length classes has been suggested to be especially important for the declines of British bumblebees (Williams 1989).

In recent literature on the declines of British bumblebees, emphasis has been placed on the importance for the declining species of food plants from the family Leguminoseae (Fabaceae, e.g. Edwards 2003; Goulson et al. 2005; Benton 2006). It is intriguing to note that in Sichuan, where none of the same bumblebee (with the exception of *B. humilis*) or food-plant species is involved, one of the most important bumblebee-food plants for the declining bumblebees (*Hedysarum*) also belongs to the Leguminoseae.

Bumblebee conservation

Bumblebees provide crucial pollination services for alpine and sub-alpine flowering plants. As yet there is no quantitative evidence to implicate a lack of pollination by bumblebees in a decline in productivity of rangelands at Hongyuan. However, it is clear from some of our transects that intensive grazing can suppress most of the food-plant flowers and bumblebees. This effect appears to be spreading in the high rangelands, which potentially might put pressure on future ecosystem sustainability, so that greater attention to the conservation of pollinators may be necessary. Removal of particular bumblebee species from pollination networks can have particularly strong effects on rates of decline in plant species diversity (Memmott et al. 2004) and can be important for endangered plants (Kearns and Thomson 2001).

Particular farming conservation programs or policies have been introduced to conserve habitats for bumblebees and other organisms in some European countries. These include the agri-environment programs in all EU member states (Kleijn et al. 2001; Sepp et al. 2005) and the Countryside Stewardship Scheme in the UK (MAFF 1998). As yet, there are no similar programs in China. The primary importance of food plants was explored here, as in other research from around the world (Kevan 1999; Ghazoul 2005), but research into this aspect will not be enough. The conservation of bumblebees will need awareness of other ecological characteristics. More study is needed of all of the factors affecting bumblebee colony development and successful reproduction in the field.

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