Fellowship Report to the Stapledon Memorial Trust

Norbert Maczey

CABI Europe UK
Bakeham Lane, Egham, Surrey TW20 9TY
United Kingdom
Email: n.maczey@cabi.org
www.cabi.org

Ecological studies in alpine grasslands of Bhutan

1. Introduction

The fellowship allowed the extension, both geographically and temporally, of ecological assessments of Bhutanese montane grasslands that are grazed by yaks and various wild herbivores. These grasslands are of particular significance as they are colonized by the important medicinal fungus *Cordyceps sinensis*, which is a parasite of caterpillars of various hepialid ghost moths referred to the genus *Thitarodes*. The work is complementary to a project funded by the UK Government's Darwin Initiative which addresses the sustainable harvest of *Cordyceps sinensis*. This focuses on the biology/ecology of the organisms involved in the lifecycle of *Cordyceps sinensis*, researching the history of collection and use of this fungus in Bhutan. The main objective was the establishment of a research programme to:

- study the taxonomy, biology and ecology of *Cordyceps sinensis*, its host moths and the plants on which their caterpillars feed
- establish population monitoring schemes to inform the design of sustainable collection protocols to be applied to the northern region of Bhutan and potentially to other Himalayan nations in which *Cordyceps* is harvested.
- promote effective liaison between stakeholder groups for the long-term benefit of the indigenous peoples reliant on yak herding

The purpose of the fellowship was to provide particular ecological baseline data for the high montane grasslands in the Jigme Dorji National Park and other protected areas in Bhutan, which are the prime site for *Cordyceps sinensis.* The major objective was to gather as much solid background information as possible on the botanical composition of *Cordyceps* habitats in Bhutan and to look into the impacts of grazing by pure bred or hybrid yaks but also, as far as possible, into the correlation of wild herbivore numbers with *Cordyceps* densities in this fragile alpine system. Data was collated mainly through vegetation quadrats and exclusion experiments during a period of five weeks in summer 2008.

The author visited Bhutan between June 18 and July 24 2008 to carry out research work in liaison with the Council of Renewable Natural Resources Research (CORRB), Ministry of Agriculture, the main partner in Bhutan of this project. This year's objectives included the exploration of new *Cordyceps* sites in Bumthang in central Bhutan, collecting of *Cordyceps* and host moth samples at these new sites, and a second mountain trip to the previously established field research site in northwestern Bhutan to continue and finalise experiments at this site.

2. Background

Cordyceps sinensis is one species out of 300+ *Cordyceps* recognised for the world. They are entomopathogenic fungi of which *C. sinensis* infects root feeding larvae of hepialid ghost moths belonging to the genus *Thitarodes*. *C. sinensis* is used as a highly prized Oriental traditional medicine and occurs in the high mountains (above 4,000 m elevation) of the central Himalayan region in cold, relatively arid, remote locations. Within Bhutan many habitats are in National Parks or other protected areas. In summer, as alpine grasses are sprouting, the fungus produces small fruiting bodies. These emerge from the cadavers of infected caterpillars in the soil. The fruiting bodies including caterpillar cadavers are collected by local villagers (primarily yak herders), and are sold on through regional traders to national and international brokers. Harvest of the fungus *C. sinensis* in fragile natural ecosystems in Bhutan is currently highly lucrative but almost certainly unsustainable.

The Nature Conservation Division (NCD) and Council of Renewable Natural Resources Research of Bhutan (CORRB) have been concerned for several years about the sustainability of *Cordyceps* harvest. An initial prohibition policy led to extensive cross-border poaching from Tibet, and the ban was subsequently modified to allow regulated collection by Bhutanese citizens. There is however little information on what level of exploitation would be sustainable. Harvest involves large numbers of people scouring fragile montane grasslands, and impact is also unknown on the flora (including CITES-regulated medicinal plants), or of grazing by the endangered bharal (Himalayan blue sheep) and by yaks. To address illegal collection of *Cordyceps sinensis* in Bhutan the government has introduced a strictly regulated collecting regime to prevent the loss of this species from upland, alpine-meadow habitats. However due to the lack in understanding of the ecology of both the fungus and its caterpillar host the sustainability of the current collecting scheme is not secured. It is clear that while government regulations are generally adhered to by citizens of Bhutan there is a problem with the illegal and unsustainable harvesting of *Cordyceps sinensis* ascribed to Tibetan poachers supplying to the Chinese market which has a monopoly that feeds its domestic and international needs. The Darwin Initiative project works therefore with local stakeholders to achieve sustainable harvest through regulation of collection and habitat preservation, contributing also to protection of other vulnerable species. Capacity building as part of the project aims to enable research into the biology of the fungus and its insect host.

Conservation and sustainable harvest of *Cordyceps* is a high priority for the Royal Government of Bhutan. Another major conservation concern is the impact of yak grazing on the natural montane grassland ecosystems. In some parts of Bhutan the hillsides show significant erosion and degradation that is likely to be largely due to yak activity, but there are wild herbivores in the region (especially the culturally valued blue sheep) that may also have an impact on the environment if populations are large. We also do not know whether yak grazing has a negative or positive effect on *Cordyceps* populations; it is possible that grazing and fertilization of the grasslands by yaks might improve *Cordyceps* production and facilitate spore transmission.

Investigation of yak grazing impact is outside of the main remit of the Darwin project, but the fellowship of the Stapledon Memorial Trust enabled the project team to gather further information on this subject considered to be highly complementary and which might in the future lead to new management plans for the protected areas in which yaks are herded.

The study sites are remote and can only be reached by trekking (3-5 days each way) with horses to carry baggage and experimental materials. Five weeks therefore allowed only two relative short field site visits in separate mountain ranges following admin activities in Thimphu.

Activities covered by the fellowship were timed to commence shortly after fruiting bodies of *Cordyceps* have started to mature, and at the most likely peak of the flight period of adult *Thitarodes* moths at the beginning of July. They included:

- Continuation of the botanical assessment of grazed and ungrazed vegetation quadrats in northwestern Bhutan
- Assessment of the botanical composition in other *Cordyceps* sites in northwestern and central Bhutan
- Survey of yak populations, timing of their transhumance (they winter at lower altitudes), and extent of their grazing activities (geographically and altitudinally)
- Gathering of available information on blue sheep habitats and population levels

Other core activities of the DI project conducted at the same time such as the monitoring of *Cordyceps* phenology, host plant experiments, the collecting of *Thitarodes* moths, socioeconomic studies including the participation at *Cordyceps* auctions, conduct of workshops with stakeholders and the development of a catalogue of recommendations to the Bhutanese government are not or only very briefly covered in this report.

3. Survey and results: field site visit 2008

To cover the height of both the *Cordyceps* collecting and yak herding season the field surveys of *Cordyceps* habitats were scheduled for June/July, the time when the emerging fungus has mostly already started to mature and towards the end of the legal collecting period in Bhutan. The botanical assessment of vegetation quadrats was done by estimating percentage coverage of the occurring plant species, which than were subsequently converted into the domin scale according to DAHL & HADAC (1941).

3.1 *Cordyceps* sites in Bumthang (Central Bhutan)

After establishing field experiments to survey the phenology of *Cordyceps sinensis* both in northwestern and eastern Bhutan in 2006 and 2007 as part of the DI project, the Bhutanese research organisation RNRRC in Jakar was keen to set up a similar experiment in Bumthang in central Bhutan, one of the major collecting areas for *Cordyceps* in the country. During our visit we were aiming to visit some of the easier reachable sites in the area together with a team of Bhutanese researchers to facilitate future research activities. Although it would have perhaps been possible to initiate this experiment through a mere training season at the research station in Jakar the Stapledon Memorial Trust travel grant allowed an actual visit to the *Cordyceps* sites and – in addition to the setup of this monitoring experiment for *Cordyceps* – to gather data on botanical habitat composition and current grazing regimes. We also intended to obtain adult host moth specimens to establish whether the same hepialid species functions as a host for *Cordyceps sinensis* throughout different mountain ranges of the country. The timing was planned to fit into the anticipated flight period of adult moths and mature *Cordyceps* specimens at the collecting sites at an altitude believed to be between 4000 and 4300 m, therefore slightly lower than at our established research site at Namna at 4700-4900 m altitude. There was however a lack of existing direct knowledge of the *Cordyceps* sites at RNRRC Jakar, which led to some logistical delays and suboptimal timing of the fieldwork. Nevertheless two *Cordyceps* sites in the Bumthang valley were surveyed, one at Kerap near the tree line at an altitude of about 4000 m, and the other at Chachanaphuggongma, between 5000 and 5200 m. The estimates of travel times we had received from local yak herders and horsemen proved to be based on the capacities of rather fit yak herders but not on what the average western researcher can achieve on very muddy and rocky mountain tracks during the height of the monsoon season. In the end instead of the anticipated two days, five were needed to reach Chachanaphuggongma. Here, only immature *Cordyceps* specimens could be collected and light trapping for ghost moths was unsuccessful, most likely because the survey occurred before the start of the flight period at this extreme altitude. However, suitable methods to setup and conduct a survey experiment by the Bhutanese researchers from 2009 onwards were developed and put into place ready for an early start at the beginning of next years *Cordyceps* season.

Botanical investigation at Chachanaphuggongma

Cordyceps sinensis was found at an elevation between 5000 and 5200 m in north to northeast exposed parts of the upper third of a large mountain slope. Coordinates taken approximately at the centre of the site are: N 27˚ 56′ 53.7″; E 90˚ 36′ 52.0″. The slope is part of a sandstone formation dominated by scree and loose boulders, which is partially covered with sandy loam. Figure 1 shows an overview over the *Cordyceps* site, which is locally known as Chachanaphuggongma.

Fig. 1: Cordyceps site at Chachanaphuggongma

All *Cordyceps* found, except for one specimen, were still of immature appearance. However a number of small digging holes indicated intensive *Cordyceps* collecting activities during the weeks prior to our visit and local yak herders confirmed that collecting had stopped at the site a few days before our visit.

The vegetation at the site is characterised by a small scale mosaic of bare rocky ground, alpine sedges and forbs and a high dominance of dwarf rhododendron, in this case mostly *Rhododendron anthopogon*. In contrast to the sites in northwestern Bhutan this place was characterised by a higher elevation, higher proportion of open bare ground and rocky scree but most importantly by a different plant composition with a characteristic high density of *Diapensia himalaica* and *Salix lindleyana* and a more dominant occurrence of *Rhododendron anthopogon*. On the other hand it lacks *Bistorta macrophylla var. stenophylla* and has only very little *Potentilla coriandrifolia*, both plants being constant at *Cordyceps* sites in northwest Bhutan and considered to be potential food plants of the host moths. Other characteristic plant species recorded at the site are: *Rhodiola crenulata, Festuca tibetica, Saussurea gossipiphora, Cassiope fastigiata, Spongiocarpella purpurea, Leontopodium himalayanum, Anaphalis* sp., *Primula sapphirina, P. tsariensis* and *Rhodiola humilis*.

Table 1: Vegetation quadrats at Chachanaphuggongma

Quadrat No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Occurrence of *Cordyceps*	**no**	**no**	**no**	**yes**	**yes**	**yes**	**yes**	**yes**	**yes**
Plant coverage (domin scale)									
Bare ground	**5**	**4**	**4**	**7**	**8**	**7**	**7**	**7**	**7**
Moss & Lichens	**4**	**5**	**5**	**4**	**5**	**5**	**5**	**5**	**5**
Rhododendron scrub	**7**	**5**	**7**	**5**	**5**	**5**	**4**	**4**	**5**
Grasses/sedges	**7**	**9**	**5**	**5**	**5**	**4**	**5**	**5**	**5**
Forbs	**5**	**5**	**5**	**8**	**4**	**6**	**8**	**7**	**8**
Shrubs									
Rhododendron nivale	**7**	**5**	**4**		**4**				
Rhododendron setosum			**6**			**5**	**3**		**4**
Salix lindleyana			**4**	**8**	**4**	**6**	**7**	**7**	**8**
Rhododendron anthopogon				**5**			**4**	**4**	**4**
Poaceae/Cyperaceae									
Kobresia pygmea	**6**	**8**	**5**	**5**	**4**	**4**	**5**	**5**	**5**
Kobresia humilis	**4**		**2**			**2**			
Kobresia schoenoides		**4**							
Festuca tibetica				**2**					
***Carex* sp.**					**4**	**2**			**2**
Forbs									
Bistorta macrophylla	**4**	**2**	**2**		**3**	**1**	**2**	**2**	**2**
Swertia multicaulis	**4**	**2**		**2**					
***Saussurea* sp. 1**	**2**	**1**							
***Gentiana* sp. 1**	**2**	**1**							
Potentilla coriandrifolia	**1**								
Pedicularis roylei	**1**								
Primula tenuiloba	**1**								
Potentilla microphylla		**5**			**4**		**3**	**4**	
Anemone obtusiloba		**2**							
***Saussurea* sp. 2**		**2**							
Arenaria polytrichoides		**1**							
Diapensia himalaica			**5**	**2**			**5**	**5**	**5**
Sibbaldia macropetala					**1**				
Leontopodium himalayanum							**2**	**2**	**1**
Average vegetation height (cm)	**3.8**	**2.5**	**1.4**	**1.0**	**0.8**	**1.0**	**1.1**	**0.5**	**1.4**

Nine vegetation quadrats were recorded on 1 July 2008, six of them centred around a *Cordyceps* specimen. The altitude of the quadrats ranged between 4,970 and 5,010 m. Quadrats 1 to 3 were recorded before the first *Cordyceps* specimens were discovered by the team and due to a more southerly exposition and a slightly different vegetation composition might not represent samples from inside the *Cordyceps* habitat itself.

Yak grazing at Chachanaphug and Chachanaphuggongma

Two herder families are grazing the valley and its adjacent slopes with yak-hybrids. Together they own 105 animals, including about 35 calves. The herders first move up to the lower parts of the valley at the beginning of June, setting up camp at an altitude of 4300 m at a place called Chachanaphug. At the time of our visit they were still staying at this place but planned to move later in the season (at some time during August) higher up to set camp near the *Cordyceps* site (Chachanaphuggongma) at an altitude of 5000 m before moving back down again in September.

The productivity of the *Cordyceps* site itself is apparently very low. Estimating from the still very low vegetation and a high amount of bare ground at the time of our visit snow melt must have been very late in the year, probably not before June. Consequently, at this altitude there is little and only occasional grazing during the time *Cordyceps* is occurring and even later in the season from mid-August into September grazing intensity is probably rather limited. There were no yaks seen at the *Cordyceps* site during our visit, although some hoof marks could be seen during the site visit indicating occasional visits by yaks already at the end of June. Almost certainly grazing by blue sheep occurs at this *Cordyceps* site although due to the adverse weather no animals or other signs of their occurrence could be seen during our stay and the impact of grazing by wild herbivores could be estimated.

Forest *Cordyceps* at Kerap

While setting up camp on the way up to the main *Cordyceps* area a second small site with a relatively high density of *Cordyceps* specimens was discovered by the team at the edge of a fir forest. The occurrence of *Cordyceps* at this site, locally known as Kerap, was previously unknown even to local herders. The size of the mummified caterpillars of the collected specimens, which was on average larger than the specimens from higher altitudes, suggests the possibility of a different hepialid moths acting as the main host in this area. Habitat structures and a number of vegetation quadrats were recorded at this new site, but light trapping turned out again to be fruitless; this time probably being too late in the season.

Botanical investigation at Kerap

The place with unexpectedly high densities of matured *Cordyceps* specimens was discovered by the team at the edge of a fir forest glade, which is a grazing ground for yak herders in the summer. The site lies at an altitude of 3900 m above sea level and is located at the edge of a flood plain of the upper Bumthang river on sandy loam with medium drainage capacities. Figure 2 shows a view into this part of the valley.

Fig.2: View into the upper Bumthang river valley near Kerap

Cordyceps was found at the edge of a grazed forest glade, dominated in most part by *Rumex nepalensis* and *Bistorta vivipara*. Other plant species encountered within the glade were *Aster soulieri, Capsella bursa-pastoris, Aconogonum molle, Anemone rivularis, Carex* sp., *Pedicularis siphonantha, Erigeron multiradiatus, Senecio raphanifolius, Acronema bellum, Primula dentata/capitata, Gymnadenia orchidis, Primula sikkimensis* and *Gueldenstaedtia himalaica.*

Plant species at the edge of the adjacent fir forest comprised *Abies densa, Juniper recurva, Berberis* cf. *virescens, Rosa sericea* and *Rhododendron campylocarpum*. The ground layer inside the forest itself was characterised by the high dominance of a dense moss layer together with widespread *Rubus fragarioides*. Other plant species surveyed here were *Primula sikkimensis* and *Potentilla penduncularis*. The forest itself was a mature old-growth stand of *Abies densa* with a high proportion of deadwood but only sparse undergrowth.

Four vegetation quadrats were surveyed on 2 July 2008, each centred around a *Cordyceps* specimen. All quadrats lay at a distance of around 40 m from the rivers edge. Usage in the area was characterised by less intensive grazing and trampling by yak-hybrids and horses than in the open areas of the glade. The vegetation height inside the quadrats was generally low with average measurements between 2 and 5 cm. Results of the quadrat survey are shown below in Table 2.

Table 2: Vegetation quadrats at Kerap

Quadrat No.	**1**	**2**	**3**	**4**
Plant coverage (domin scale)				
Bare ground & Litter				6
Moss	8	8	8	5
Grasses/sedges	6	2	4	
Forbs	5	6	4	8
Plant species				
Viola biflora	2	2	2	2
Potentilla leuconota	4	2	2	
Poaceae sp.	6	2		
Saussurea sp.3	2	4		
Acronema bellum	2	4		
Anemone rupestris	2	2		
Geranium cf. *donianum*	2	2		
Apiaceae sp.	2	2		
Fragaria nubicola	1	2		
Bistorta vivipara	4			
Carex sp.	2			
Athyrium micropterum		4	4	
Veronica umbelliformis		2	2	
Abies densa		1		
Saussurea sp. 4		1		2
Asteraceae sp.		1		2
Rubus fragarioides			2	4
Persicaria runcinata			2	2
Primula sikkimensis			1	2
Orchidaceae sp.			2	
Arisaema griffithii			1	
Rosa sericea			1	
Potentilla peduncularis				8

Grazing at Kerap

At the time of our visit only 15 animals including calves, all yak-hybrids, were grazing at the site. In addition our own six pack horses were foraging here for a few days. However, information given by locals indicate that this site undergoes a dynamic grazing regime and is used mainly during interim periods whilst moving cattle up and down the mountains with highest grazing pressures most likely occurring in May and September. At the time of our visit the effect of trampling and grazing through yak-hybrids and to a lesser extend by horses was clearly visible although not very severe at this time of the year. However, substantial stands of *Rumex nepalensis* indicate an overall intensive grazing at this site at times.

3.2 Survey sites in northwestern Bhutan

After an initial survey in 2005 visiting a number of *Cordyceps* sites in northwestern Bhutan, one site at a place locally called Namna was selected for more intense studies of the phenology of *Cordyceps sinensis*, its host moth and also the botanical composition of the habitat (Figure 3). During 2006 twenty 1 x 1 m quadrats were marked out along two transects across the site. Ten of these were covered with cages made out of chicken wire to exclude grazing initially until the end of the season in 2007 (Figure 4). Survey of vegetation was done by estimating percentage coverage of the occurring plant species. However, changes in vegetation height and composition had not been significant between 2006 and 2007. The support through the Stapledon Memorial Trust allowed a continuation of this experiment into a third year and also to record additional vegetation quadrats on another *Cordyceps* site, which the team passed on the way up to Namna. Additionally, when staying at suitable *Cordyceps* sites, light trapping was conducted every night to catch adult ghost moths.

Fig.3: Study site at Namna

The field survey in 2008 started on 12 July at the road head of Drugyel Dzong following the Paro river into the Jigme Dorji National Park. Field equipment and supplies were carried by six horses and mules. In contrast to Bumthang the field site visit to Namna went smoothly according to plan despite at times very bad weather conditions. Our camp at the edge of the *Cordyceps* site at an altitude of 4750 m was reached on the fourth day after climbing over Namna La at an altitude of approximately 5000 m. During the visit work at Namna concentrated on light-trapping for *Hepialidae* and the surveying of vegetation quadrats both at the field site itself and at a second site visited during the way up. Several 2 x 20 m transects had been established in 2006 at Namna to measure density, heights and phenology (first time of appearance, maturity) of any appearing fruiting bodies. Since then these transects have been continuously monitored by a team of Bhutanese scientists and this survey just came to an end while we visited the site in July 2008. A host plant experiment had also been set up in 2007 at Namna including 60 flower pots filled with local plant species from the *Cordyceps* site, into which ghost moth caterpillars were introduced in spring 2008. Possible host plant species tested were *Rhododendron setosum, R. anthopogon, R. nivale, Salix lindleyana, Bistorta macrophylla var. stenophylla, B. macrophylla var.macrophylla, Kobresia schoenoides, K. pygmea, K. humilis, Potentilla microphylla* and *P. coriandrifolia*. The host plant experiment established in 2007 was checked but left untouched during the visit to give any surviving caterpillars more time to grow. This experiment will be finalised by the Bhutanese team at a later stage this year.

Fig. 4: Wire cages at Namna

A data logger recording temperature and relative air humidity within the *Cordyceps* site was exchanged during this site visit, so that continuous temperature recordings covering more than 2 years have now been obtained.

Light-trapping took place during five evenings using three different light sources (gas lamp, car battery-powered fluorescent light tube and a LED-16lux bicycle lamp. The light sources were running between 6:30 and 8:00 pm every evening (ghost moths are known to have only short flight periods at dusk). During this time nine adult *Thitarodes* specimens were collected are are now awaiting further identification. All came to light within a very short time window between 7:10 and 7:35 pm.

Botanical investigation at Namna

In contrast to the main site visited in Bhumtang the *Cordyceps* site at Namna lies at a lower elevation between 4700 and 4900 m within northwest exposed parts of the upper third of a large mountain slope. Although the site at Namna is also part of a similar sandstone formation it is characterised by a much more developed soil on top of the underlying scree with a rather deep layer of peaty loam showing only limited drainage capacities. The vegetation is characterised by a small scale mosaic of dense coverage by *Kobresia* sedges mixed with dwarf rhododendrons. Dominating species are *Rhododendron setosum* and to a lesser extent *R. nivale*. Characteristic forb species are *Bistorta macrophylla var. stenophylla, Bistorta macrophylla var. macrophylla, Potentilla microphylla, P. coriandrifolia* and in some parts *Cassiope fastigiata* and *Salix lindleyana*.

The 20 vegetation quadrats established in 2006 show a layout as demonstrated in figure 5. Coordinates for quadrat 1a are: N 27˚ 44′ 00.5″; E 89˚ 23′ 29.7″ (these coordinates allow a very good overview of the field site using 'Google Earth' since this part of Bhutan - in contrast to the sites in Bhumtang - is covered in high resolution). The recording of the quadrats was done by estimating percentage coverage of the occurring plant species, which than were subsequently converted into the domin scale according to DAHL & HADAC (1941). In 2008 the quadrats were recorded on 14 and 15 July. An overview of the results is shown in table 3.

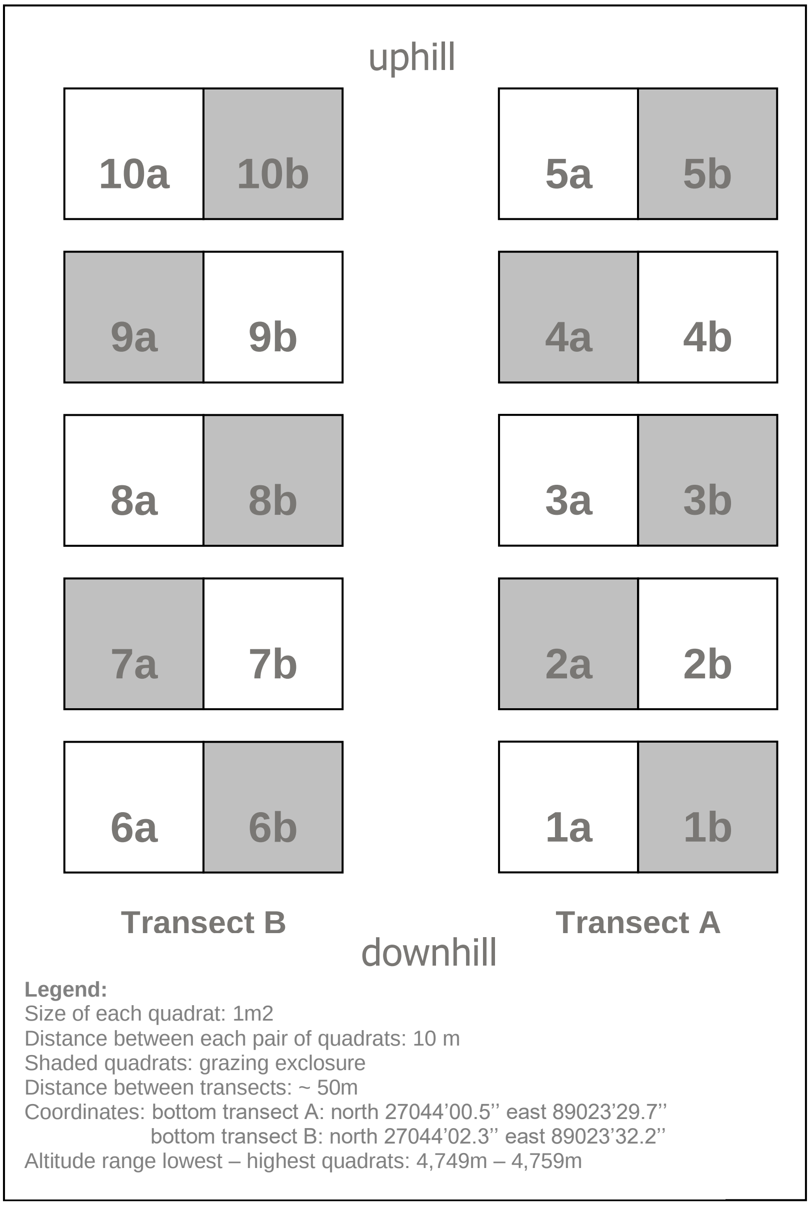


Figure 5: Layout of vegetation quadrats at Namna

Grazing at Namna

Namna is also grazed by cattle from two herder families. In 2008 they kept between 70 and 100 pure bred yaks including calves in the valley between end of May and end of September. However, due to the geo-morphological outline of the valley and slightly lower elevation there seems to be less of an organized shift of stock to different parts of the valley during the summer season. The stocking rates cannot be easily estimated since the exact number of grazing yaks is not known and grazing is also intensified by a constantly varying number of horses feeding here as well (>10 at the time of our visit). The grazed vegetation gradually peters out on the steep surrounding slopes. In addition to domestic grazing there is a rather large flock of wild bharal, in excess of 40 animals, plus a high density of marmots on the South-facing side of the valley that also contributes to grazing pressure. However, we could not find any direct evidence of grazing by wild herbivores at the *Cordyceps* site itself during the collecting season. All sightings both of marmots and blue sheep were restricted to the slopes opposing the *Cordyceps* area. Whereas marmots are probably confined to south facing slopes all year round blue sheep might only avoid the *Cordyceps* site during the yak grazing season due to the intense human disturbance. It seems highly likely that they will at least periodically visit the site between late autumn and spring particularly at times when snow levels allow at least a certain degree of grazing activities. All in all, rather intensive grazing at the Cordyceps site results in a comparably short sward height. At the same time erosion due to trampling by yaks and other herbivores or *Cordyceps* collectors does not seem to be a major problem as the tight and dense swards in most areas demonstrate.

Table 3: Vegetation quadrats at Namna

Quadrat No.	**1a**	**1b**	**2a**	**2b**	**3a**	**3b**	**4a**	**4b**	**5a**	**5b**	**6a**	**6b**	**7a**	**7b**	**8a**	**8b**	**9a**	**9b**	**10a**	**10b**
Plant coverage (%)																				
Bare ground	4	3	3	3	4	4	3	5	5	3	4	3	2	4	4	5	3	5	4	3
Moss	5	2	3	4	5	4	3	4	5	3	4	3	3	4	5	3	3	4	4	3
Rhododendron scrub	7	8	7	5	5	5	5	5	5	5	7	8	8	7	7	8	7	7	7	7
Grasses/sedges	7	7	8	6	7	8	8	7	7	8	7	7	7	7	7	7	7	7	6	7
Forbs	7	6	7	7	5	5	5	6	7	7	8	5	7	5	7	6	6	6	6	6
Plant species																				
Kobresia pygmea	4	5	4	4	6	5	7	5	5	6	5	5	5	4	5	4	6	6	5	7
Kobresia schoenoides	6	5	7	5	4	7	5	4	4	7	4	5	5	5	4	5	4	4	4	4
Kobresia humilis	4	3	4	4	4	5	4	4	3	4	3	3	4	3	4	4	3	4	4	4
Festuca tibetica		2			3	4	5			4	4	5	3	3	3	4	5			4
Juncus duthiei		2	4	2		4	3		4	3		2		2		3	3	2	2	
Rhododendron nivale		3	3	3	4	4	4	2	2	3	5	5	4	4	4	5	4	3	4	
Rhododendron setosum	7	8	7	7	5	5	5	5	5	5	5	7	8	7	6	7	7	7	7	7
Rhododendron anthopogon																				
Bistorta macrophylla var. stenophylla	2	3	4	3	3	4	4	4	3	4	3	4	4	3	2	3	3	3	3	4
Bistorta macrophylla var. macrophylla	4	5	4	4	5	3	4	4	4	4	4	4	4	4	4	4	5	4	3	4
Aconogonon hookeri							1	1												1
Potentilla microphylla	5	5		6	5	5	5	5	3	5	7	4	5	5	5	4	5	5	4	5
Potentilla coriandrifolia	4	4		4	4	4	4	4	4	5	4	4	4	4	4	3	4	3	5	4
Primula sapphirina					2		2												1	
Primula macrophylla																1				
Rhodiola humilis				1															2	
Saxifragaceae sp.		2	2	2			2	2			2		2				2		2	
Gentiana sp. 1												2		1						1
Lloydia flavonutans		1						1				1	1							
Saussurea sp. 1					1				2	2										
Taraxacum like leaves	2			1	1	2	1	2	2			2	2	2	2	1	2	2	2	2
Anemone obtusiloba					1				1	1	2								1	
Swertia multicaulis			1				1			4	2					1	1			
Gentiana sp. 2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2		2
Thalictrum alpinum							1	2		1										
Lagotis kunawurensis										1			1			2			2	1
Aster cf stracheyi					1		1			1										
Chamaesium novem-jugum																			1	
Arenaria polytrichioides									1		1									
Caryophyllacea cf Stellaria sp.					1															
Ranunculus tricuspis										1										
Vegetation heights																				
Average	2.7	5	5.7	2.6	2.4	4.4	3	2.8	2.3	4.2	4	5.4	4.9	3.8	4.4	5.4	5.8	4.4	4.6	5.5

Botanical investigation at a slope towards Namna La and below Zophu lakes

A *Cordyceps* site of similar importance to that at Namna is located alongside a slope above a place called Zophu just prior to the final ascent to a pass that leads into the Namna valley (Namna La). On the way towards Namna the team stopped at this site and was able to record three 1 x 1m vegetation quadrats, of which two were centred around a *Cordyceps* specimen. Exposition, altitude and botanical composition were very similar to Namna itself. However, there are some marked differences such as the lack of some plant species seen as likely food plants for ghost moth caterpillars at Namna as *Potentilla coriandrifolia, Rhododendron nivale* and *Kobresia schoenoides* and a higher dominance of *Rhododendron anthopogon* within the quadrats. Results of the botanical survey are given in table 4. Other characteristic plant species recorded in the vicinity of the quadrats were *Pedicularis roylei, Arenaria polytrichoides, Saussurea sp., Anemone obtusiloba* and *Cassiope fastigiata*.

In 2007 four additional quadrats were recorded at a lower site at an altitude of around 4100 m below Zophu. *Cordyceps* densities here are relatively low, but local people are still collecting at this site at least occasionally. This location is characterised by a markedly different vegetation composition with *Potentilla arbuscula* and *Trollius pumilus* characterising the sward. For comparison the results of these quadrats are shown in table 5.

Table 4: Vegetation quadrats on slope below Namna La

Quadrat No.	**1**	**2**	**3**
Occurrence of *Cordyceps*	yes	no	Yes
Plant coverage (domin scale)			
Bare ground & litter	4	4	4
Moss & Lichens	5	4	4
Rhododendron scrub	7	7	7
Grasses/sedges	7	7	6
Forbs	5	7	5
Plant species			
Kobresia pygmea	6	7	6
Rhododendron anthopogon	6	4	5
Potentilla microphylla	4	4	5
Bistorta macrophylla var. *macrophylla*	4	2	3
Swertia multicaulis	4	1	2
Bistorta macrophylla var. *stenophylla*	2	2	2
Saussurea sp. 1	2		2
Kobresia humilis	2		
Juncus duthiei	1		
Saxifraga sp.	2		
Gentiana sp. 1	2		
Lagotis kunawurensis	1		
Chamaesium novem-jugum	1		
Rhododendron setosum		6	6
Salix lindleyana		5	4
Anaphalis sp.		1	
Pedicularis roylei			1

Table 5: Vegetation quadrats below Zophu lakes

Quadrat No.	**1**	**2**	**3**	**4**
Occurrence of *Cordyceps*	no	no	yes	yes
Plant coverage (domin scale)				
Bare ground	4	5	4	4
Moss & Lichens	4	4	4	4
Grasses/sedges	8	7	7	8
Forbs	5	6	7	6
Grasses/sedges				
Kobresia pygmea	7	5	7	8
Juncus duthiei	1	3	1	1
Kobresia humilis	5	6		4
Carex sp.	4	1		
Festuca tibetica			2	1
Kobresia schoenoides			2	
Forbs				
Bistorta macrophylla var. *macrophylla*	4	4	3	3
Trollius pumilus	1	1	2	2
Potentilla microphylla	4		3	4
Primula denticulata/capitata	2		1	2
Gentiana sp. 1	1		2	2
Thalictrum alpinum	3		2	2
Aster cf. *stracheyi*	3		1	1
Aletris pauciflora	1		1	1
Chamaesium novem-jugum	3			2
Saussurea gossypiphora	1			1
Anemone trullifolia	1			1
Asteraceae sp.	3			
Potentilla arbuscula		5	4	5
Primula sikkimensis		1	2	2
Anaphalis sp.		4	5	
Potentilla cf. *saundersiana*		1	2	
Dracocephalum wallichii		4		3
Pedicularis roylei		4		
Anemone rupicola		1		
Salvia wardii		1		
Lagotis kunawarensis		2		
Gentiana sp. 3		1		
Saxifraga tangutica		1		
Unknown species with lobate leaves			2	1
Oxytropis lapponica			1	

Grazing at site below Namna La and at Zophu lakes

No data about the amount of yaks and horses and the timing of grazing could be obtained. However, both grazing grounds are used on and off by a number of yak herders since they are closely located alongside major travelling routes to higher mountain grazing areas.

4 Grazing exclosure: preliminary conclusions

The recording of the twenty 1 x 1 m quadrats established in 2006 was done by estimating percentage coverage of the occurring plant species. Whereas in 2007 no significant changes in vegetation height or botanical composition could be detected, during 2008 the differences between the grazed and ungrazed plots became much more pronounced. Graphs shown in Annex 1 demonstrate the following statistically significant differences (independent sample t test and GLM repeated measurements) between the treatments in the third year:

- percent coverage of bare ground decreases significantly in ungrazed plots during the third year of the experiment (Annex 1 a).
- percent coverage of moss and lichens decreases significantly in ungrazed plots during the third year of the experiment (Annex 1 b).
- percent coverage of grasses and sedges increases significantly in ungrazed plots during the third year of the experiment (Annex 1 c).
- in particular, the percent coverage of *Festuca tibetica* and *Kobresia schoenoides* increases significantly in ungrazed plots during the third year of the experiment (Annex 1 d, e).
- average vegetation height increases significantly in ungrazed plots during the third year of the experiment (Annex 1 f).
- percent coverage of *Rhododendron spp*. increases but not significantly in ungrazed plots during the third year of the experiment (Annex 1 g).
- percent coverage of forbs remains unchanged until the third year of the experiment (Annex 1 h).

Initial results suggest that a cessation of yak grazing leads to a higher dominance of grasses and sedges versus forbs and dwarf shrubs (*Rhododendron spp.*). Some exclosure quadrats showed a substantial and clearly visible increase in vegetation height, mainly caused by thriving *Kobresia* spp. and *Festuca tibetica*. In general, the dominance of grasses and sedges, in particular of *Festuca tibetica*, increases after cessation of grazing. This goes together with a decrease of bare ground and moss within the enclosures. Also the number of flowers of the two occurring varieties of *Bistorta macrophylla* seems to be higher inside grazing enclosures although no significant differences regarding the leaf cover of these two taxa was observed.

Summarising the results from the grazing exclosure experiment it can be concluded that yak grazing results in a decrease of *Festuca tibetica* (the only sweet grass at the *Cordyceps* site) and to a lesser extent of *Kobresia* sedges. Grazing also leads to a higher amount of bare ground, probably caused by trampling, which consequently results in an increase of moss and lichen coverage, assuming that these organisms are the first colonisers of newly created bare patches. The coverage of *Rhododendron* scrub and forbs remains relatively unaffected within a course of only three years, but there may well be long term changes of these long-lived and slow growing species after a change of the current grazing regime.

It is difficult to speculate on the possible effects of grazing on *Cordyceps* densities. So far we have not yet obtained the final results of our host plant experiment and do therefore not know if the hepialid caterpillars show any preference for certain plant species or plant groups. If it turns out that the caterpillars are selective feeders preferring grasses and/or sedges a negative effect of intensive grazing activities might be possible. On the other hand grazing might play an important role in keeping swards low enough to allow a good distribution of spores considering that the fruiting bodies of *Cordyceps* protrude only a few centimetres above the ground.

The vegetation surveys from different geographical locations (northwestern and central Bhutan) and along an altitudinal gradient show a considerable variation of plant species composition within *Cordyceps* habitats. This indicates that ghost moth caterpillars are probably polyphagous, feeding on roots of a wide range of different species. However, we still do not know how many different *Thitarodes* species are involved in this particular ecological system and which of them play a major role as *Cordyceps* hosts. At Namna we have discovered two yet undescribed species, which might occupy different ecological niches via different food plant preferences.

5 Conclusions

Our small pilot experiments were able to gather a lot of valuable baseline information, but there is still a need to fill gaps in order to come to more specific recommendations for management regimes benefiting both yak herding and sustainable harvest of *Cordyceps sinensis*. It seems that at least in some of the sites surveyed, yak grazing is having a significant impact on vegetation dynamics, and may be over-intensive in terms of long-term maintenance of the ecosystem. It is also probable that yak husbandry has had a detrimental effect on populations of wild herbivores. However, the montane grasslands involved are likely to have been exploited for many (perhaps hundreds of) years both as yak pasture and for *Cordyceps* harvest, so the impact of these activities is difficult to assess.

Disturbance caused by *Cordyceps* gathering has undoubtedly increased substantially in recent years, due primarily to its increased value on the world market. This has had various impacts, from trampling and damage to the sward from excavation of *Cordyceps*, and also on local populations of woody plants through gathering for firewood. Native herbivores (at least bharal) have almost certainly declined due to this disturbance. The impact of yak grazing is more difficult to assess long-term. There are no written historical records of yak populations except in recent years, and numbers have probably fluctuated over the centuries. *Cordyceps* harvest appears to be stimulating conflicting trends in yak ownership. Herders that collect *Cordyceps* now have less need to slaughter animals for food or household income, and we have documented a number of local people who cite this as the most important impact of the recent legalization of the *Cordyceps* harvest. On the other hand, there is increasing concern by the Government that *Cordyceps* income has led to reductions in the number of transhumance farmers in border regions as they no longer need to farm yaks to gain an acceptable level of income.

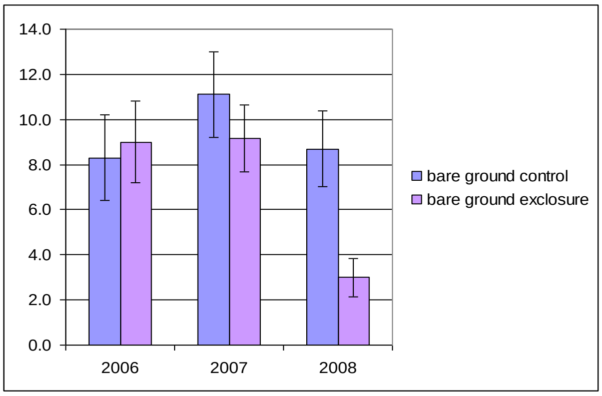
These initial studies funded by the Stapledon Memorial Trust form a solid basis for research in the future, and will be given due priority by the Royal Government of Bhutan. High priorities should be given to carrying out larger- and longer-scale exclosure experiments, and to decouple as far as possible effects caused by *Cordyceps* harvest from those of yak grazing (through comparisons of sites where yaks and *Cordyceps* coexist with those where only one human-mediated source of disturbance occurs and with sites lacking either).

6 Reference

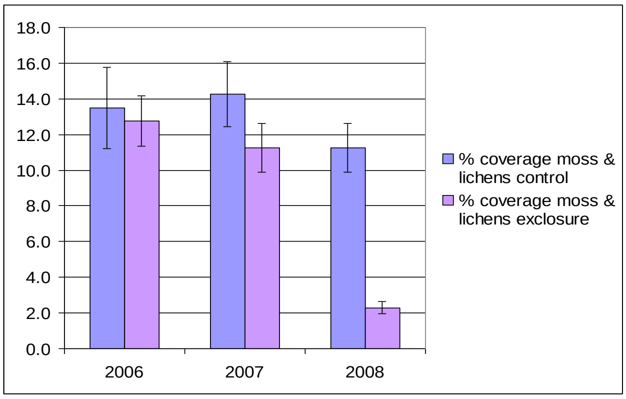
DAHL, E. & HADAC, E. (1941). Strandgesellschaften der Insel Ostøy im Oslofjord. Eine pflanzensoziologische Studie. Nytt Magasin for Naturvidenskapene B, **82**: 251-312.

Annex 1: Comparison of ungrazed (control) and ungrazed (exclosure) vegetation quadrats

a

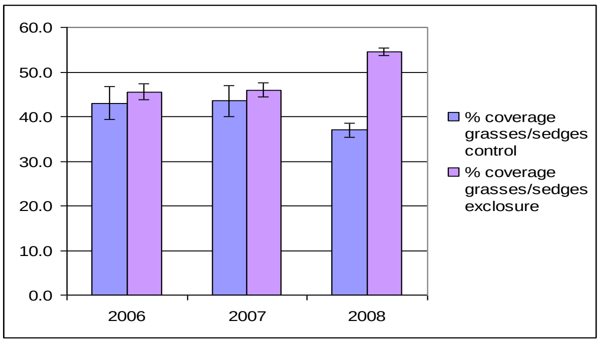


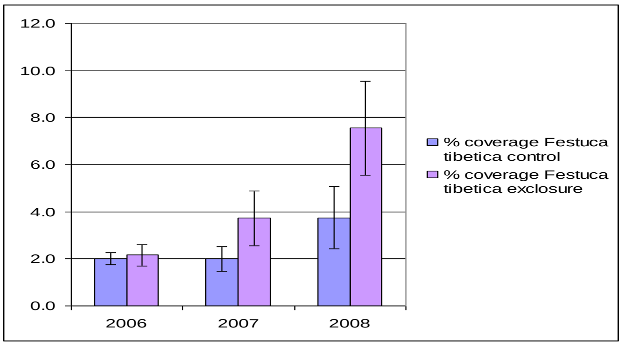
b



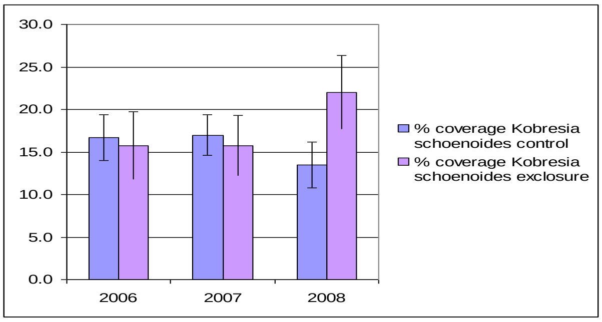
c

d

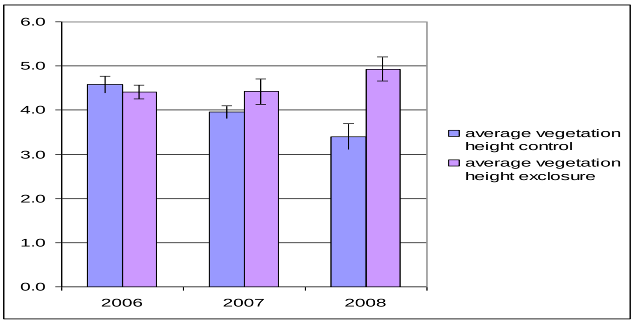

60.0
50.0
40.0
30.0
20.0
10.0
0.0
2006
2007
2008
% coverage grasses/sedges control
% coverage grasses/sedges exclosure


12.0
10.0
8.0
6.0
4.0
2.0
0.0
2006
2007
2008
% coverage Festuca tibetica control
% coverage Festuca tibetica exclosure

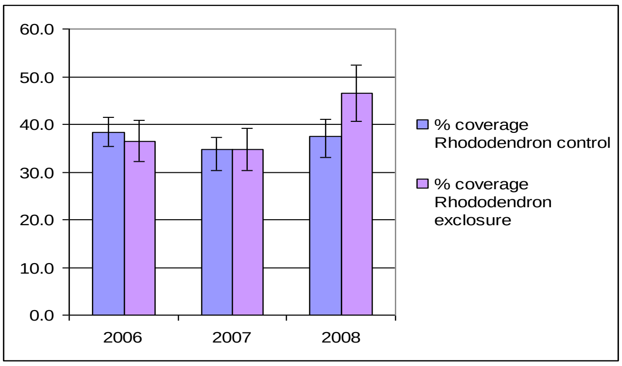
e


30.0
25.0
20.0
15.0
10.0
5.0
0.0
2006
2007
2008
% coverage Kobresia schoenoides control
% coverage Kobresia schoenoides exclosure

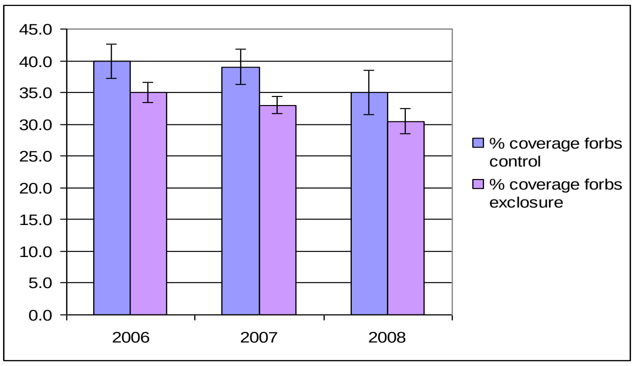
f


6.0
5.0
4.0
3.0
2.0
1.0
0.0
2006
2007
2008
average vegetation height control
average vegetation height exclosure

g


60.0
50.0
40.0
30.0
20.0
10.0
0.0
2006
2007
2008
% coverage Rhododendron control
% coverage Rhododendron exclosure

h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40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
2006
2007
2008
% coverage forbs control
% coverage forbs exclosure