Monitoring the condition of rangelands in the Gobi Desert

Monitoring strategies to detect change

K. Batpurev, C. Liu, S.J. Sinclair,
O. Avirmed and K. Olson

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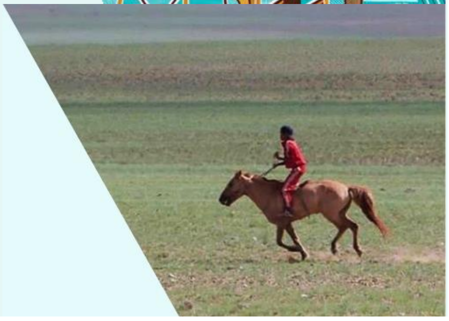
Acknowledgment

We acknowledge and respect Victorian Traditional Owners as the original custodians of Victoria's land and waters, their unique ability to care for Country and deep spiritual connection to it. We honour Elders past and present whose knowledge and wisdom has ensured the continuation of culture and traditional practices.

We are committed to genuinely partner, and meaningfully engage, with Victoria's Traditional Owners and Aboriginal communities to support the protection of Country, the maintenance of spiritual and cultural practices and their broader aspirations in the 21st century and beyond.

In the Gobi Desert, we acknowledge and respect nomadic pastoralists as the custodians and managers of the land. We honour Elders past and present whose knowledge and wisdom has ensured the continuation of culture and traditional practices.

We are committed to genuinely partner, and meaningfully engage, with local herding communities in the Gobi to support the protection of the land, the maintenance of spiritual and cultural practices and their broader aspirations in the 21st century and beyond.



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Front cover photo: Botanists conducting vegetation monitoring in a point-intercept plot in the Gobi region, Mongolia (Steve Sinclair).

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Monitoring the condition of rangelands in the Gobi Desert

Monitoring strategies to detect change

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Context:

Overgrazing of rangelands has become a signifciant issue in Mongolia’s Gobi Desert. The South Gobi Cashmere Project (SGCP, part of the mitigation for the Oyu Tolgoi copper and gold mine) intends to reduce grazing pressure by working with about 130-140 herding families to reduce their livestock numbers in exchange for certification and improved market access.

SGCP is supported by a monitoring program that aims to assess whether the mitigation target is achieved: a 10 percentage point improvement in rangeland condition in the SGCP area, compared to a control area, measured by a published metric devised by the Arthur Rylah Institute for Environmental Research. Monitoring commenced in 2017 and has been conducted annually by the Wildlife Conservation Society (WCS). No on-ground action has yet occurred that would be expected to result in reduced grazing intensity, so all monitoring data available at the time of writing is considered pre-treatment data. The intervention program will begin shortly.

It is timely to review the monitoring scheme and ensure it is likely to detect the anticipated change in rangeland condition. The Arthur Rylah Institute has been contracted by WCS to examine the monitoring data and provide advice.

Aims:

ARI committed to provide WCS with:

- a review of the existing monitoring data, to understand any trends or patterns that influence the condition score, and are likely to be relevant to the design of a monitoring program,
- a quantitative power analysis, using simulations informed by the existing data to assess the probability of detecting a 10 percentage point increase in condition score, under different sampling strategies, and
- practical recommendations about the design of the future monitoring program.

Methods:

WCS provided all monitoring data between 2017 and 2021. We developed data visualisations to summarise the main patterns apparent in the data. We then used the monitoring data to structure a quantitative power analysis, which enabled us to examine the effect of sampling pastures of different numbers of families, with different levels of within-family replication and different spatial arrangements of plots, in summer-grazed or winter-grazed pastures.

Results:

We found that the SGCP project is being undertaken in a region of the Gobi Desert with particularly low rainfall and low vegetation condition. The SGCP area has similar stocking rates to the rest of the Gobi region. This suggests that the location of the program is well chosen. We confirmed that condition scores relate to rainfall (positive relationship) and grazing pressure (negative relationship), as expected.

We found that the most important factor in increasing power was to increase the number of family pastures sampled (SGCP and non-SGCP). Of secondary importance is ensuring that each family’s pasture is sampled by multiple plots (3-6). We weigh up the benefits of sampling in summer or winter pastures.

Conclusions and implications:

We provide specific recommendations to WCS that may be used (alongside practical considerations of cost and logistics) to alter the design of the monitoring strategy in a way that improves the chance of detecting the impacts of the SGCP.

Introduction

The Gobi Desert is one of the world’s great arid regions, spanning much of Mongolia and northern China. It supports a range of distinctive ecosystems and many wild species, and has been home to nomadic herders for millennia (Fernandez-Gimenez 1999, Janz et al. 2017). Human land-use has intensified in recent decades, leading to concerns for the region’s biodiversity (Berger et al. 2013, Batsaikhan et al. 2014). Livestock numbers in the Mongolian Gobi, particularly goats, have more than doubled since the 1960s (Addison et al. 2012, Rao et al. 2015), leading to the degradation of native vegetation (Densambuu et al. 2018; Jamiyansharav et al. 2018). More recently, mining has become the major economic activity. The Oyu Tolgoi copper and gold mine is one of the largest mining operations, making a substantial contribution to Mongolia’s GDP (Suzuki 2013, Jackson 2015).

Planning and approval of the Oyu Tolgoi mine included plans to minimise and mitigate environmental harms, including the Oyu Tolgoi Offset Management Plan (unpublished 2016). This plan recommended the development of an ‘alternative livelihoods programme’ to assist herders to reduce their livestock numbers, resulting in the South Gobi Cashmere Project (SGCP; SAA 2018). This project is expected to achieve gains in rangeland quality amounting to a ‘10% improvement’ realised over the area covered by the SGCP scheme, by the closure of the OT mine in several decades time. The SGCP intends to achieve this improvement by working with about 130–140 herding families to reduce their goat grazing pressure (SAA 2018). In return, herding families would receive certification and improved market access to buyers interested in sustainable luxury cashmere products (Franco and Hussain 2019).

The SGCP is supported by a monitoring program with a primary purpose of assessing whether the quality improvement target is being achieved. Rangeland condition (the target variable for assessment) is quantified by a metric devised specifically for this purpose (Sinclair et al. 2021). The metric is based on expert judgement and represents the consensus view of a large and diverse stakeholder group, including nomadic pastoralists, botanists, wildlife ecologists and policymakers. It takes plant species cover and richness data from 30 x 30 m plots and transforms these data into a single index of condition (the ‘condition score’). The mathematical structure of the metric varies slightly, depending on the biome (ecosystem). The condition metric monitoring commenced in 2017 and has been conducted annually by the Wildlife Conservation Society (WCS), Mongolia (WCS 2020). The monitoring program has several components, which are summarised in Table 1.

Figure 1 shows the locations of all monitoring plots, which cover 8 soums (Mongolian administrative regions), collectively referred to as the ‘South Gobi’ region. The monitoring plots sample two areas of pasture for each family: their summer pasture (sampled in summer, while grazing is occurring), and their winter pasture (also sampled in summer, after the intense grazing pressure removed for several months).

The SGCP covers an area which supports three main biomes: True Desert, Semi-Desert and Desert Steppe. Other biomes occur in some places. These three biomes differ in rainfall and plant species composition: True Desert occupies the driest places and supporting mostly small shrubs, Desert Steppe occupies relatively moister places and supporting mostly grasses and bulbous monocots, and Semi-Desert occupies an intermediate position. These biomes are described in detail in Hilbig (1995), Radnaak (2016) and Sinclair et al. (2021).

The SGCP has commenced its organisational and recruitment phase, but no on-ground action has yet been taken that would be expected to result in reduced grazing intensity, so all monitoring data available at the time of writing is considered pre-treatment data. Now that 5 years of data has amassed, it is timely to examine it and use it to plan a robust monitoring scheme that is likely to detect the anticipated change in rangeland condition. The Arthur Rylah Institute for Environmental Research has been contracted by the Wildlife Conservation Society to examine the monitoring data and provide advice. The work has three main components, which are treated as separate sections in this report:

- A review of the existing monitoring data to understand any trends or patterns that influence the condition score and are likely to be relevant to the design of a monitoring program.
- A quantitative power analysis, using simulations informed by the existing data to assess the probability of detecting a 10% improvement in condition score, under different sampling strategies.
- Practical recommendations about the design of the future monitoring program.

Table 1. Summary of relevant rangeland monitoring activities designed and undertaken by WCS.

Monitoring component	Purpose and description
SGCP evaluation	**Purpose:** To assess the impacts of SGCP on rangeland condition. **Description:** The pastures of 38 SGCP families (treatment; out of 130 SGCP families in total) and 10 non-SGCP families (control) are monitored. Every year in summer (August), monitoring occurs (a) within each family's summer pastures (while livestock are grazing), and (b) within each family's winter pasture (about 6 months after stock have left). At each camp, 1 plot is located 1000 m away from the family camp, and a second plot is located randomly within a 3000 m radius of the camp. The pastures sampled include three biomes (True Desert, Semi Desert, Desert Steppe), with the majority of plots in Semi Desert (268 out of 315 plots in 2021).
SGCP disturbance gradient experiment	**Purpose:** To justify and optimise the locations for the SGCP evaluation plots and to show how distance from a camp affects condtion score. **Description:** For a minority of families (n=9) monitored under the SGCP evaluation, additional plots sample various distances (50, 250, 500, 750 m; along with 1000 m used in every case).These additional plots are not ongoing.
Core Biodiversity Monitoring (Baseline Plots)	**Purpose:** To provide background information on the patterns of rangeland condition across the south Gobi region as a whole, including how they fluctuate between years of different rainfall. **Description:** 142 plots are randomly located across the South Gobi region, covering multipe biomes, and an area far larger than the SGCP. These plots are refered as 'baseline' plots in this report to clarify their purpose.
Grazing exclusion experiment	**Purpose:** To investigate the extent and rate of rangeland recovery when grazing is removed completely from degraded pasture, to show the maximum possible effect of grazing reduction. **Description:** Two well locations have been selected in each of three biomes (Desert Steppe, Semi Desert, True Desert; 6 locations in total). Each well location has a pair of plots (1 fenced, 1 unfenced) at 100 m from a well, and another pair 1000 m from the well (24 plots in total). The fences were installed in 2015, monitoring commenced in 2017.

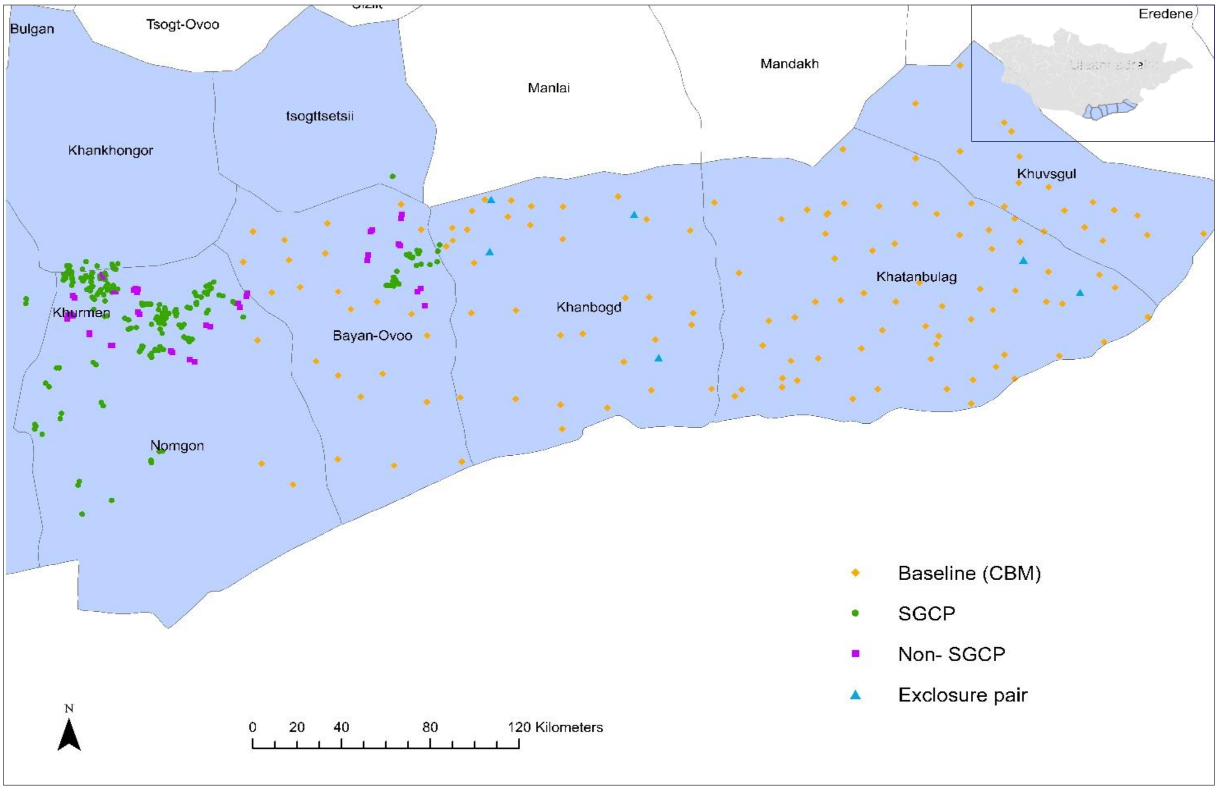

Figure 1. Plot locations by type. Inset: Locations of the South Gobi soums on a map of Mongolia (grey).

Review of existing monitoring data (2017 – 2021)

Introduction

This section examines the amassed data from all monitoring between 2017 and 2021. Here we summarise some basic patterns that are evident in the data and explore how condition scores change in relation to various factors, including grazing history and rainfall. We begin with some basic patterns across the South Gobi region, and then focus on some specific trends that are apparent in the data. The main purpose of this section is to provide background information that will assist, alongside the results of the quantitative power analysis, in the design of future monitoring.

We report the main patterns below and include additional detailed data in Appendices A1–A3.

Summer rainfall across the monitoring region

Figure 2 shows the 30-year average of summer rainfall in all relevant soums (June, July and August). The soums where the SGCP participants are located (Bayan-ovoo and Nomgon: brown bars) receive less rainfall than other parts of the South Gobi (compare Khanbogd, Khatanbulag and Khuvsgul: blue bars). The baseline plots are distributed across all of these soums, but concentrated mainly in the last three mentioned.

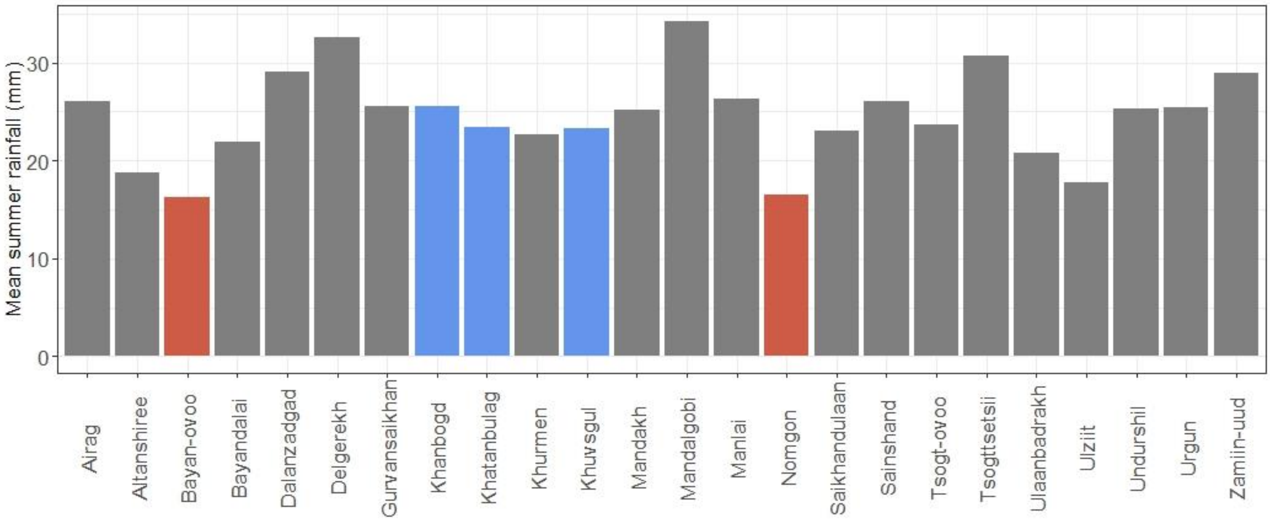

Figure 2. Thirty-year average of summer rainfall in southern Gobi region soums.

Livestock density across the monitoring region

Figure 3 shows the 2020 livestock density data from SGCP families alongside the 2020 soum-level census data from the Mongolian Statistical Information Service (www.1212.mn) (total number of livestock per km^2). In general the SGCP families had relatively low livestock densities; only a few families were at or slightly above the average density. This is a single year comparison and does not provide spatial resolution for smaller constituents (bag, Pasture User Group).

We have no livestock data on non-SGCP families. If they match the average livestock density for their soum, then the SGCP project may be hampered by underlying pre-treatment differences between the treatment (SGCP) and control (non-SGCP) groups.

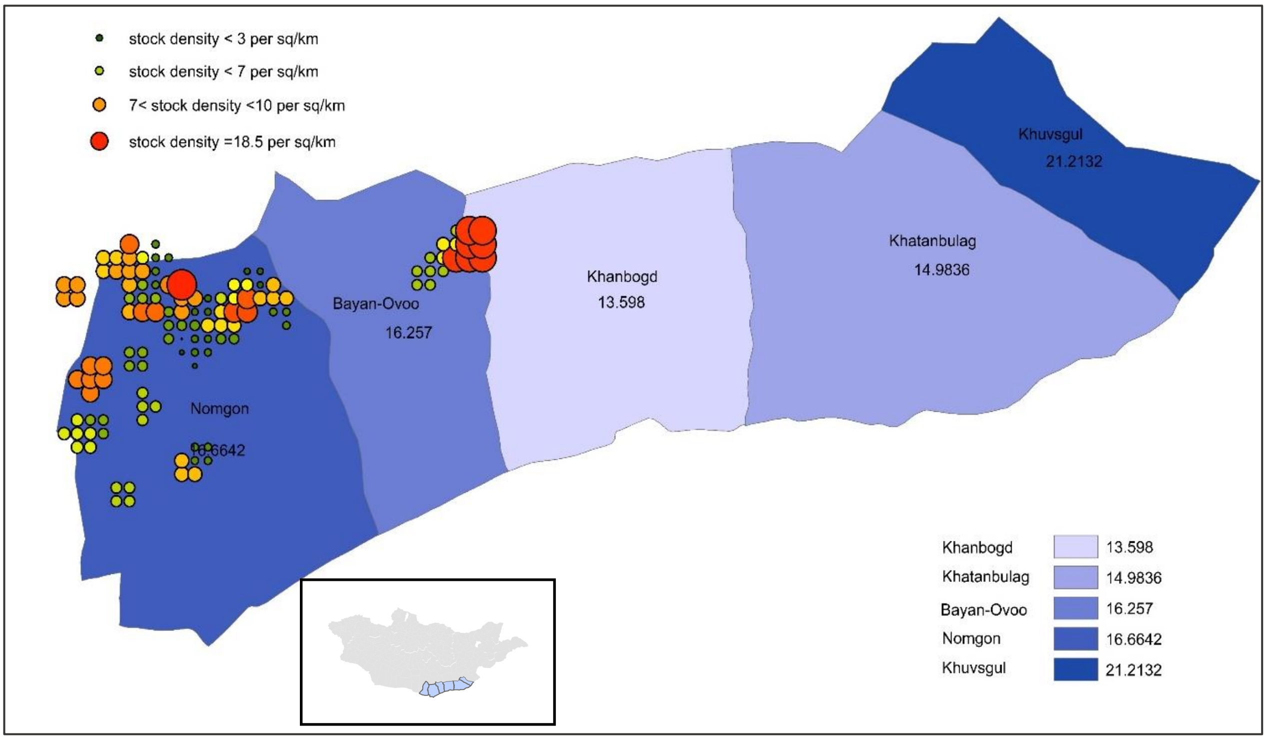

Figure 3. Livestock density for the SGCP families (circles) overlaid on the average density per soum (blue polygons).

Spatial distribution of condition score

Figure 4 shows the spatial distribution of condition scores from all plots, from all monitoring components. Because the plots are sometimes clustered together, we have shown the average score across larger grid cells for clarity (14.5 x 9.2 km cells). There is a clear spatial gradient of condition score, with plots in the west, where the SGCP families are located, generally with lower scores.

It seems likely that condition scores are lower in this western region due to the combination of low rainfall (Figure 2) and slightly elevated stock density (Figure 3). If indeed grazing is contributing to the lower condition in this region, it is reasonable to expect that the intervention of SGCP would permit scores to increase.

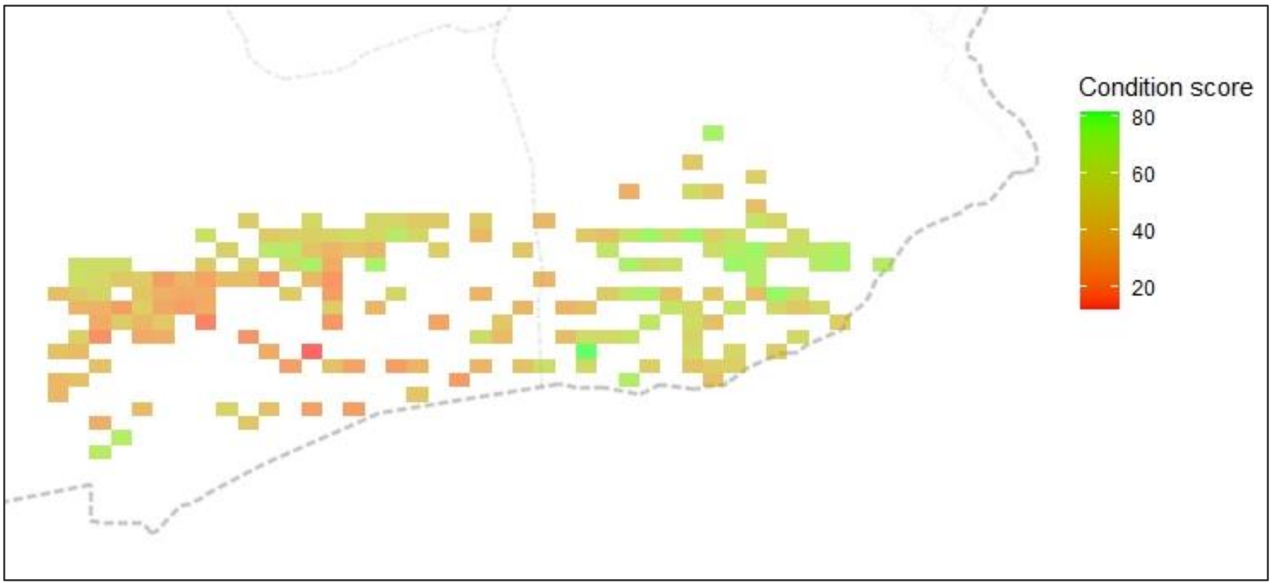

Figure 4. Spatial distribution of condition scores for all plots. Grid dimension: 14.5 x 9.2 km.

Influence of grazing on condition score

Influence of grazing exclusion

We examined grazing effects using the pairs of adjacent plots: one enclosed by a grazing exclusion fence, the other exposed to grazing. There are four pairs for each biome. Two pairs are 100 m from a well, where grazing would be expected to be particularly intense. Another two pairs are 1000 m from a well, where grazing is expected to be less intense. The fences were installed in 2015, and the plots were measured every year from 2017 to 2021.

These plots are important because they are expected to reveal the rate and degree of change that can be expected with grazing manipulation. Eventually, recovery of vegetation within the fenced plot may provide a glimpse of what ungrazed (by livestock) systems may look like.

Figure 5 shows that condition score was higher in protected plots (panel A) and increased as distance from well increased (panel B). This improvement in condition was more apparent when plots were averaged across biomes (panel B). The general increase in condition between 2017 and 2021 for both enclosed and grazed plots (for True Desert and Semi Desert) is presumably related to system-wide differences in rainfall.

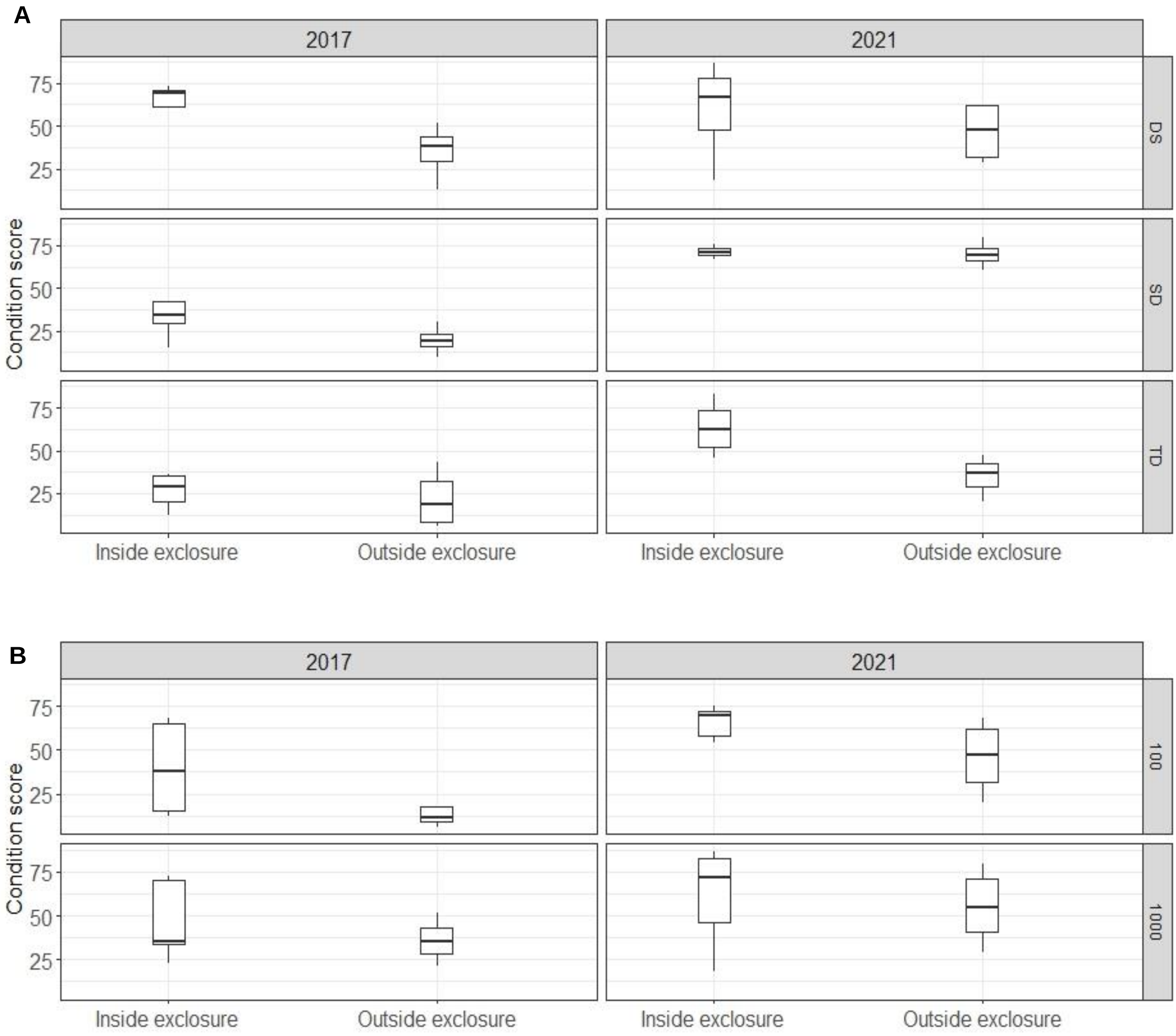

Figure 5. Box plots summarising the condition scores of paired exclosure plots. In panel A, data for 2017 and 2021 are shown separately for each biome, while in panel B they are averaged across three biomes but show the effect of distance (100 m and 1000 m from well) on condition score.

Figure 6 (Panel A) summarises the median condition score of the paired plots, for each biome, in each year. When examined alongside the rainfall data for each year (Figure 6, Panel B), it can be seen that wetter years generally yield higher condition scores. This is expected given the design of the metric (Sinclair et al. 2021) and is discussed further below.

The interaction between rainfall, year and biome is complex. In True Desert it seems that rainfall has little effect, and the protected plots are gradually improving in condition as the vegetation recovers from grazing. In contrast, Semi Desert plots seem to respond to rainfall, because both grazed and protected plots showed higher condition scores in wet years. Changes in Desert Steppe are similar to Semi Desert, except that there is more variation in condition score.

These effects probably relate to the dominant life-forms within each biome: True Desert supports shrubs which do not respond markedly to rainfall and take a long time to recover after grazing, whereas Semi Desert contains forbs and grasses which respond rapidly to rainfall.

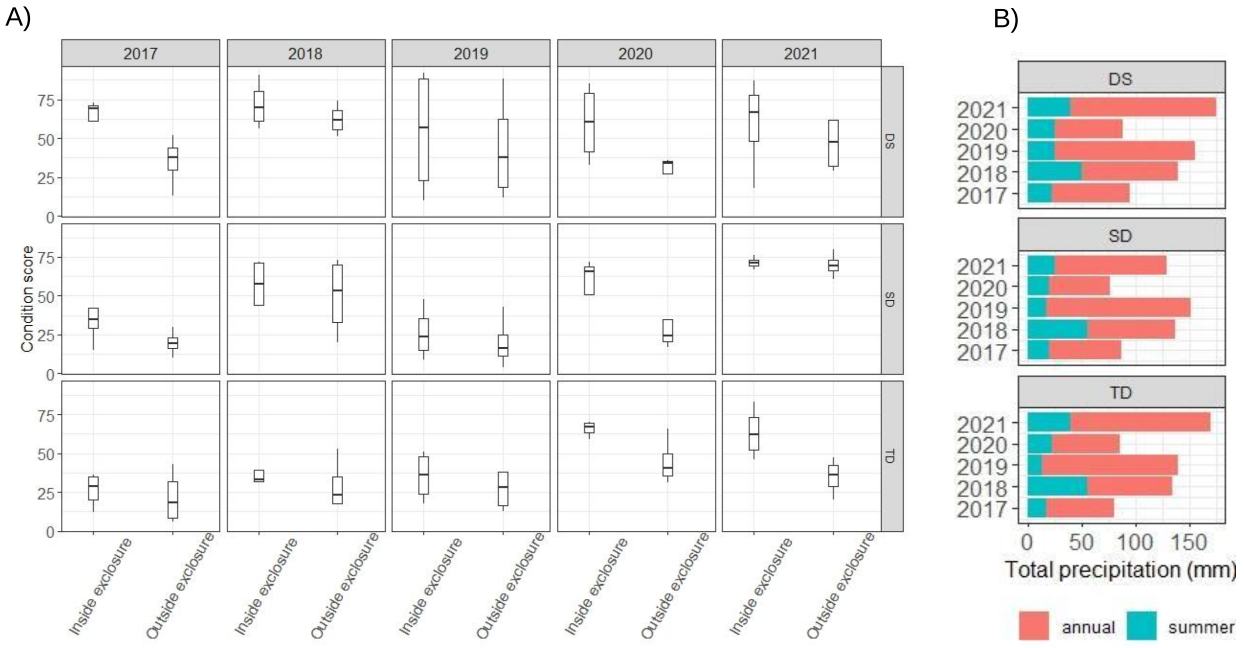

Figure 6. Boxplots showing the condition scores of plots in the grazing exclusion experiment, in each year, by biome (DS Desert Steppe, SD Semi Desert, TD True Desert), alongside annual and summer (June–August) precipitation in panel B. Note that bars are stacked, so blue and red do not overlap.

Influence of camp proximity

In general, areas close to camps are expected to have higher livestock densities and therefore lower condition scores. The different monitoring components all vary in how close their plots are to family camps:

- The baseline plots are randomly located in relation to camps and subject to some unrecorded level of grazing.
- In the SGCP dataset, the different biomes have different arrangements of plot distances from camps. (In Semi Desert, most SGCP plots are positioned along a distance gradient between 50 and 3000 m away from campsites, but some plots are placed randomly in relation to campsites. In Desert Steppe and True Desert, SGCP plots are positioned either between 100 and 1000 m from a campsite or randomly).
- For the exclusion experiment the plots are either 100 or 1000 m from wells, which tend to be close to camps (noting that, for the fenced plots, the proximity to camp is not expected to influence livestock density, although legacies from heavy grazing prior to fence construction may be expected).

Given this complexity, we compressed the data into four distance categories: <100 m, 100–1000 m, >1000 m and ‘Random / not recorded’.

Figure 7 shows how condition scores varied according to these distance classes. As expected, the unfenced plots in the exclusion experiment that are close to wells (100 m) had the lowest scores for all biomes. In all cases the fenced plots had higher scores than the equivalent grazed plots. Condition scores in True Desert were generally lower than in the other biomes. In Semi Desert, plots close (<100 m) to wells were in worse condition than plots close to family camps.

The influence of camp proximity on SGCP plots is more difficult to interpret. For Semi Desert—the only biome for which good distance data are available—the scores do not seem to have any clear relationship to distance from camp.

The SGCP plots scored consistently lower than baseline plots, which is consistent with the region-wide trends shown above.

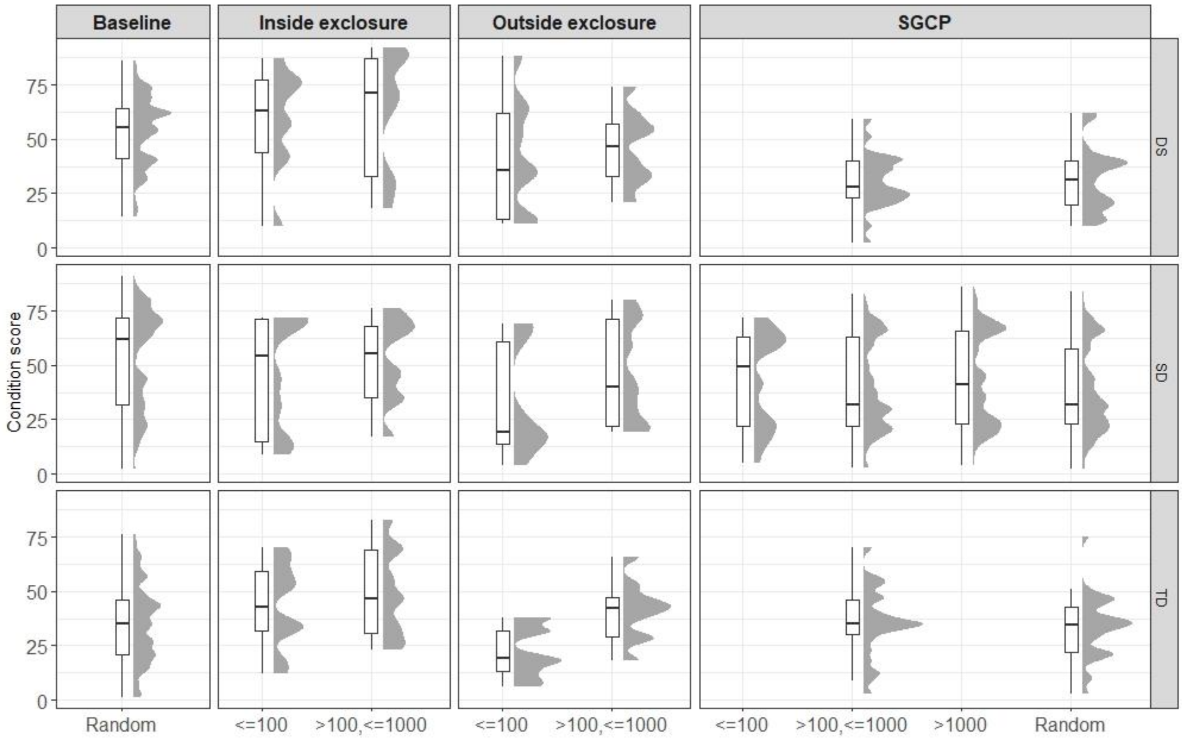

Figure 7. Condition score in relation to distance (in metres) from family camps (SGCP) and wells (inside and outside exclosure). The grey plots next to the boxplots represent the frequency distribution of scores.

Effects of precipitation on condition score

When condition scores are plotted per year, the fluctuations in score closely follow summer rainfall patterns (Figure 8). In general, years with higher rainfall produce higher scores (e.g. 2018 and 2021). This effect is most obvious in Semi Desert. For Desert Steppe and True Desert, high rainfall in 2021 did not result in elevated scores. This may indicate a limit above which summer rainfall under any grazing regime cannot improve the score; or a delayed recovery after a particularly dry summer in 2019 (about 20mm on average). The rate of response would be expected to differ between systems, given their species composition (e.g. True Desert vegetation is composed largely of slow-growing shrubs). A more detailed analysis of rainfall effect is explored in Appendix A2.

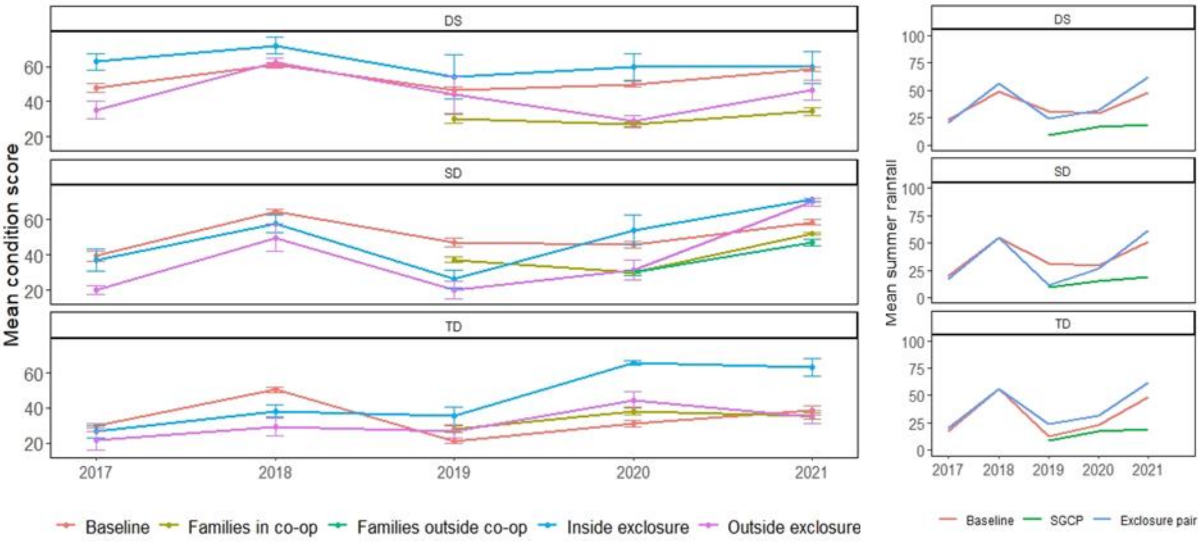

Figure 8. Condition score of SGCP plots, baseline, and exclosure plots in the 2017–2021 monitoring seasons.

Power analysis

Introduction

This section develops a power analysis to inform the design of an appropriate monitoring scheme for evaluating the SGCP. The main focus is to identify the optimal sample size and design to detect a difference in the mean condition score in pastures of SGCP-families, compared to pastures of control (non-SGCP) families.

Power analysis is vital for a sound research design. Statistical power is the probability of rejecting the null hypothesis (H_0 = there is no treatment effect) when it is false, i.e., the probability of detecting an effect given it exists (Johnson et al., 2015). Due to the limited and uneven data replication (e.g. uneven number of SGCP participants (38) and non-SGCP (10), sparse data on distance from camp), our power analysis used simulation to estimate the sample size (number of families, number of plots around each family camp) needed to detect (with a significance level of 5%) the anticipated effect (i.e., difference between SGCP and non-SGCP families) of a given magnitude (10%, or 10 points score change).

We examine the results of this analysis in light of the vegetation data presented above and make recommendations for monitoring.

Assumptions

The SGCP project and its data are complex, and a number of assumptions must be made clear in order to proceed with any quantitative analysis. The most important are:

- The improvement target refers to an improvement of 10 percentage points, regardless of starting score. In other words, a change from 10 to 20 represents a 10 percentage point change as does a change from 50 to 60.
  The alternative way of interpreting this target is that the change must be 10% of the base score (10 to 11, 50 to 55). We address both interpretations in our analysis.
- The improvement is assessed across all biomes together; not separately for each biome. In other words, condition trade-offs are allowed between biomes (i.e. we take the view that the landscape as a whole matters).
- Not every family must achieve the 10% improvement (i.e. condition trade-offs are permitted between families), but collectively the SGCP families must.
- Winter and summer pastures are assessed separately, as two entirely separate problems. The reasons for this assumption are discussed further below.
- The improvement is assessed year-by-year. Each year is an independent assessment. This has the advantage of removing the variation caused by inter-year variation in precipitation. Over time, some

years may register as success, others failure. (Assessing long term success remains an open question: one approach would be to apply the 10% test to a rolling average over multiple years).
- The improvement is assumed to refer only to the immediate area of the plots, not to a defined expanse or acreage of pasture. We do not know how large the pasture grazed by each family is, and how far the influence of their animals extends. Further data from collared animals may allow us to relate plot measurements to pasture extent.

There are also other difficulties which complicate the power analysis, but which are difficult to address with simple assumptions such as those above:

- We do not know the likelihood of a score change of a particular magnitude. Presumably, a larger score change is less likely than a smaller change; but a larger change is easier to detect. This means that being cautious about the magnitude of change (assuming a smaller change) demands much more sampling to achieve reasonable power. The 10 percentage point change we have used is a relatively large change (given the data presented above), and is presumably less likely than a smaller change.
- We do not know the costs of undertaking monitoring plots under different circumstances, making it difficult to trade off different sampling designs. Common sense tells us that adding more replicates in close proximity within a family pasture is likely to be cheaper per plot than adding plots in different and far-distant camps; but without actual or simulated cost data, we can consider this only informally, not quantitatively.
- We do not know the likely pattern of score change that may result from the implementation of SGCP (neither between seasons, nor across regions or the starting score range). It seems unlikely that SGCP will result in a consistent rise in condition score, across all years, and across pastures that were already in good condition, and pastures beginning with a very low score. It seems more likely that improvements will be patchy in time and space. Without knowing the nature of this patchiness, we cannot undertake a fully representative power analysis. The current data are insufficient to examine this patchiness in any detail, and we have not seriously addressed it here.

Given the above considerations, we cannot undertake a power analysis which is all-encompassing, and which provides a clear a directive. Instead, we must interpret the results of a more limited power analysis with caution and with other qualitative and peripheral information in mind.

Methods

General approach

We explored the effect of varying two main factors:

- The number of families sampled.
- The number of plots sampled per family.

We considered these factors in the context of three separate design considerations:

- The effect of the season of pasture that is sampled (winter or summer pastures).
- The effect of distance from camp, using (a) 1 km fixed distance, or (b) a random distance between 1 and 3 km from a family camp.
- The effect of starting / control condition, using either a low base (defined here as 38.48, the mean condition score of SGCP families) or a high base (defined here as 48.62, the mean of baseline monitoring plots).

Three factors affect statistical power: effect size, sample size, and variability of the data. It is usually efficient to specify a minimal effect size that is practically meaningful, on the assumption that if this effect can be detected then any larger effect can also be detected.

Here, we selected *n* (a set of fixed numbers) families (both SGCP and non-SGCP families which are the two levels of the treatment), set up m (another set of fixed numbers) plots in each family's camp. In order to characterise the pattern of the condition scores between SGCP and non-SGCP families, a linear mixed model was built:

$$y_{ij} = \mu + cf_i + \gamma_i + \varepsilon_{ij} \qquad \text{(Model 1)}$$

$$\gamma_i \sim N(0, \sigma_f^2)$$

$$\varepsilon_{ij} \sim N(0, \sigma_p^2)$$

where y_{ij} is the condition score of plot j within family i (i = 1, 2, …, *n*; j = 1, 2, …, *m*), which is the transformed score (*y*) from the raw score (*x*) using $y = \mathrm{asin}\,[sqrt\left(\frac{x}{100}\right)]$; μ is average transformed condition for non SGCP families; c is treatment effect; $f_i = 1$ if family *i* is part of SGCP and $f_i = 0$ if family *i* is non-SGCP; γ_i is family random effect with zero mean and variance σ_f^2; and ε_{ij} is random error with zero mean and variance σ_p^2. We used the existing data to fit Model 1, and obtained the parameters μ, σ_f^2 and σ_p^2.

Estimating the power using simulation approach requires the following steps (Bolker 2008):

1. Simulation of multiple (200 in our analysis) datasets assuming the treatment effect is not zero using the parameters we obtained in the above. We used two levels of base condition score (low and high control scores). On the transformed scale (square root arcsine) the corresponding treatment effect size is 0.0486 and 0.0392 respectively. They correspond to condition score change from 48.62 to 58.62 and 38.48 to 48.48 respectively. We specified a fixed number (5–200) of families in each of the two groups and the number of plots in each family (2–30).
2. Model construction (1) using the simulated data to see if our specified treatment effect is significant or not (significance level 5%).
3. Calculation of the proportion of datasets that the treatment effect is significant. This proportion is the power we require. We set 23 levels (5–200) for number of families (each group) and 8 levels (2–30) for number of plots in each family’s camp. Therefore, we had 184 combinations for each of the two levels of treatment effect and for each of the two seasonal pasture data.

We conducted the same set of analyses using a 10 percentage point score change with 10 levels (5–50) for number of families (each group) and 4 levels (2–10) for number of plots in each family’s camp.

To display the results of the power analysis, we have plotted examples of specific simulation runs that achieve power between 85 and 90%. We present the 85–90% power range showing maximum of 300 families (150 SGCP/150 non-SGCP), given this is the upper limit of the possible number of families in the SGCP area.

Analysis of different effect sizes

In line with the Oyu Tolgoi Offset Management Plan (unpublished 2016), our primary analysis assumes that the effect size of interest is a 10 percentage point increase in score (e.g. 10 to 20%).

However, given the possibility that a change this large is less likely than a smaller change, we also present an analysis using a 10% change from the base score (e.g. 10 to 11%). The latter effect is always smaller, and would always result in more sampling to achieve comparable power. Our intention is to show how much additional sampling would be required to achieve reasonable power to detect more subtle changes.

Use of real data and simulated data

Due to lack of samples within and between years, for the main analysis we pooled multiyear data together to train the model (above; and displayed in Figure 9). By doing this, we assumed that within plot inter year variation is equivalent to within family variation.

From the data presented in the first part of this report, we strongly suspect that within plot inter-year variation is greater than within year family variation. If so, our analysis is likely to over-estimate the sampling effort required. To explore this effect, we ran a parallel analysis using synthetic data generated by sampling randomly from a simulated distribution based on the standard deviation of the existing field data.

Results

Allocating sampling effort between- and within-families

Our primary focus was to explore the implications of sampling different numbers of families, and different degrees of replication within each family’s pasture.

Our results show that increasing the number of families sampled rapidly increases power in all simulations. We also observed increases in power as the number of plots within each camp increased, but this effect on power was less pronounced. In most scenarios we tested, the benefit of within-family replication is seen mostly between 1 and 6 plots; adding more plots beyond about 10 generally results in little or no increase in power. The addition of plots sampling new families is more powerful than the addition of the same number of plots that replicate sampling within existing families. An example of raw results showing power in relation to plot numbers are shown in Figure 17 in Appendix A3.

Figure 9 summarises the relationship between within-family and between-family sampling for a given power (always set at 85–90%). To detect the 10 percentage point change at this power, it is necessary to sample

100 families (50 SGCP and 50 non-SGCP) with 3–5 plots each. This applies to both high or low control scores, both summer and winter pastures, and any arrangement of plots within the family pasture.

As noted in the Methods section, we believe that a 10 percentage point change is less likely to occur than a smaller percent change. When we tested the sampling strategy required to detect the smaller 10% proportional change, we found that it was necessary to sample much more intensively. To achieve 85–90% power, it is necessary to sample over 200 families with 5 plots in each family's pasture in summer pasture. Even this level of sampling is unlikely to detect the change in winter pasture or in situations with a low control score. Even if every available SGCP family was sampled (280 in total including non-SGCP controls) with 10 plots each, 85% power cannot be achieved for winter pastures or situations with low control scores.

The analyses so far (Figure 9) used data that pooled multi-year data and assumed that within plot inter year variation is equivalent to within family variation. This means we likely overestimated variance (σ_p^2) within family. To explore the implications of this, we applied the analysis to a simulated dataset with lower variance (Figure 10). According to this test version, the total number of families required to achieve statistical power between 85 and 90% (for a 10 percentage point change) is only approximately 70 families (35 SGCP, 35 non-SGCP) with 3–5 plots each. To detect the 10% change, this number increases to approximately 150 families with 5 plots in each camp (in a high control score scenario).

Sampling strategy within family camps

We examined the implications of sampling with plots at a fixed distance from camps (always 1 km), or with the same number of plots randomly positioned between 1 and 3 km from the camp. Since all of the non-participating families were sampled at the same distance, we used only the data for the participating families in this analysis.

We found that randomly dispersed sampling achieved slightly better power than 1 km fixed distance sampling. This is because condition score increases as distance from centre of camp increases. (The condition score increases about by up to 10 scores when distance increases 1 km, although this trend is non-significant for the current sample size.) Given that most plots located randomly within a 3 km radius will fall outside the 1 km radius, the random plots generally land in part of the pasture that is in better condition than the fixed-distance plots.

The difference between these strategies was small compared to the changes in power observed when varying the number of families sampled or the number of replicate plots used per family. This is evident by comparing the upper and lower panels in Figures 9 and 10, which differ little from each other. The choice of within-family sampling strategy is therefore a minor consideration with regard to power.

Other pragmatic considerations may be worth evaluating, such as the degree of disturbance and human activity that often occurs near camps, corrals and wells. For these reasons alone it may be best to sample beyond a minimum distance from camp.

Using permanent or re-allocated plots

We did not explicitly consider the difference between permanent or re-allocated plots in the power analysis. We assume that there is no general influence on power between these options, given that each year is evaluated separately. If we assume that there is a small administrative cost to re-allocation and some likely benefit to having-time series data at permanent locations, it seems best to use fixed plots. The only reason to re-allocate plots would be if herding families began avoiding known plot locations to influence their scores, but we believe this is unlikely to occur on any meaningful scale in this context.

Sampling winter vs summer camps

We explicitly tested whether comparable sampling regimes achieved a higher power when applied to summer pasture or winter pasture. We varied the number of families sampled, and the number of replicates within each family.

For an equivalent sampling regime, we found that sampling summer camps always achieved higher power than winter camps (Figure 9). This is caused by the fact that winter camps generally have higher variability than summer camps.

On face value, the analysis suggests that monitoring should be prioritised towards summer camps. However, important practical and ecological considerations not represented in the data may influence this decision (Table 2). Some of these factors favour summer pasture sampling, others winter, and it is not clear which season is more informative overall.

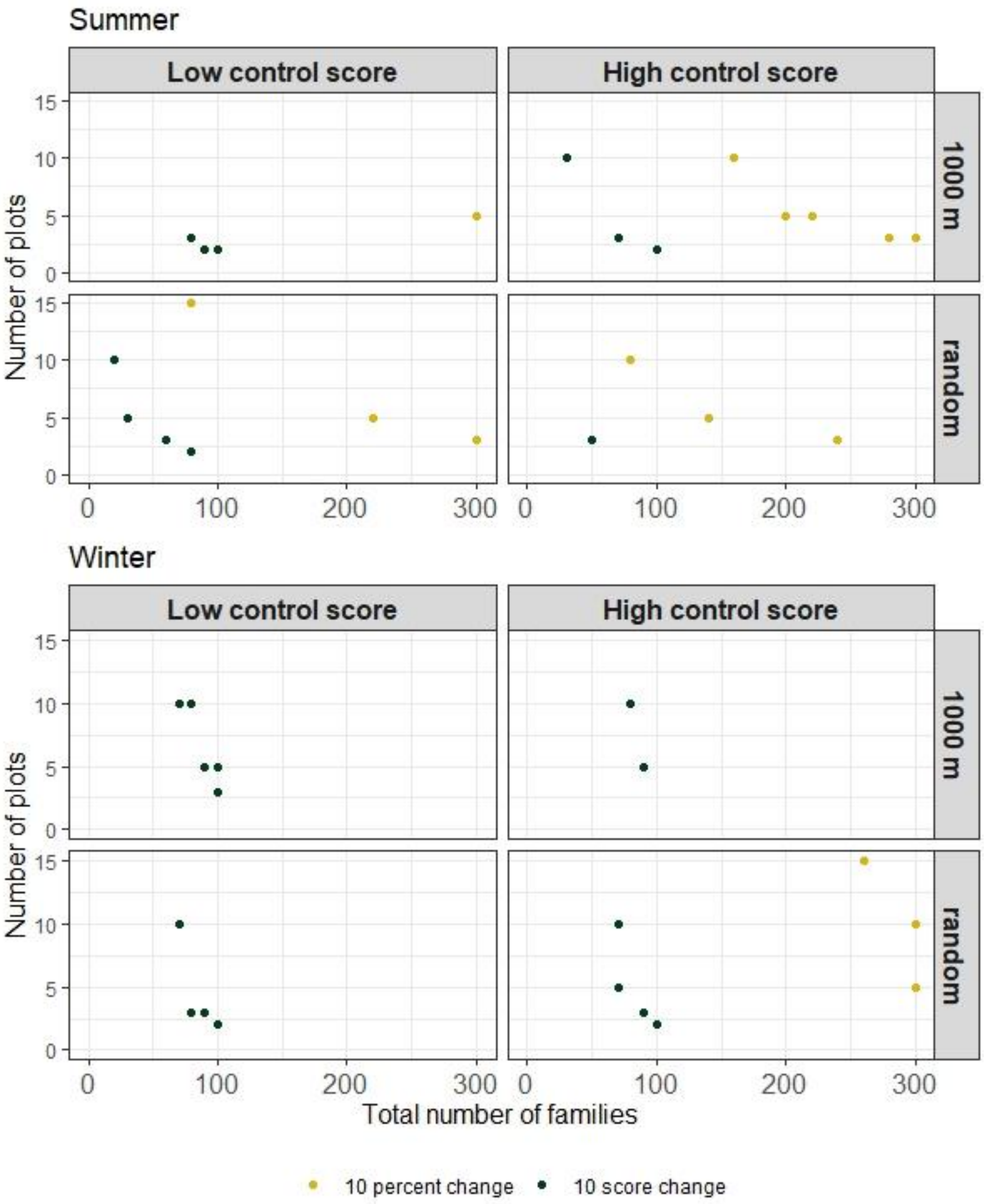

Figure 9. Number of plots required to achieve 85–90% statistical power. X axis shows the total number of families necessary, comprising of equal numbers of SGCP and non-SGCP families. The vertical axis shows the number of plots within each family's camp. The two upper plots show the distance arrangements of plots within a family camp (1000 m = 1 km from centre of camp; random = random distance between 1 and 3 km from centre of camp). The two lower plots show the baseline condition score category (Low control score = mean condition score of 38.48, High control score = mean condition score of 48.62 for non-SGCP families). The colouring scheme of dots shows the two different interpretations of '10% improvement in condition' statement from the Oyu Tolgoi Offset Management Plan (unpublished 2016).

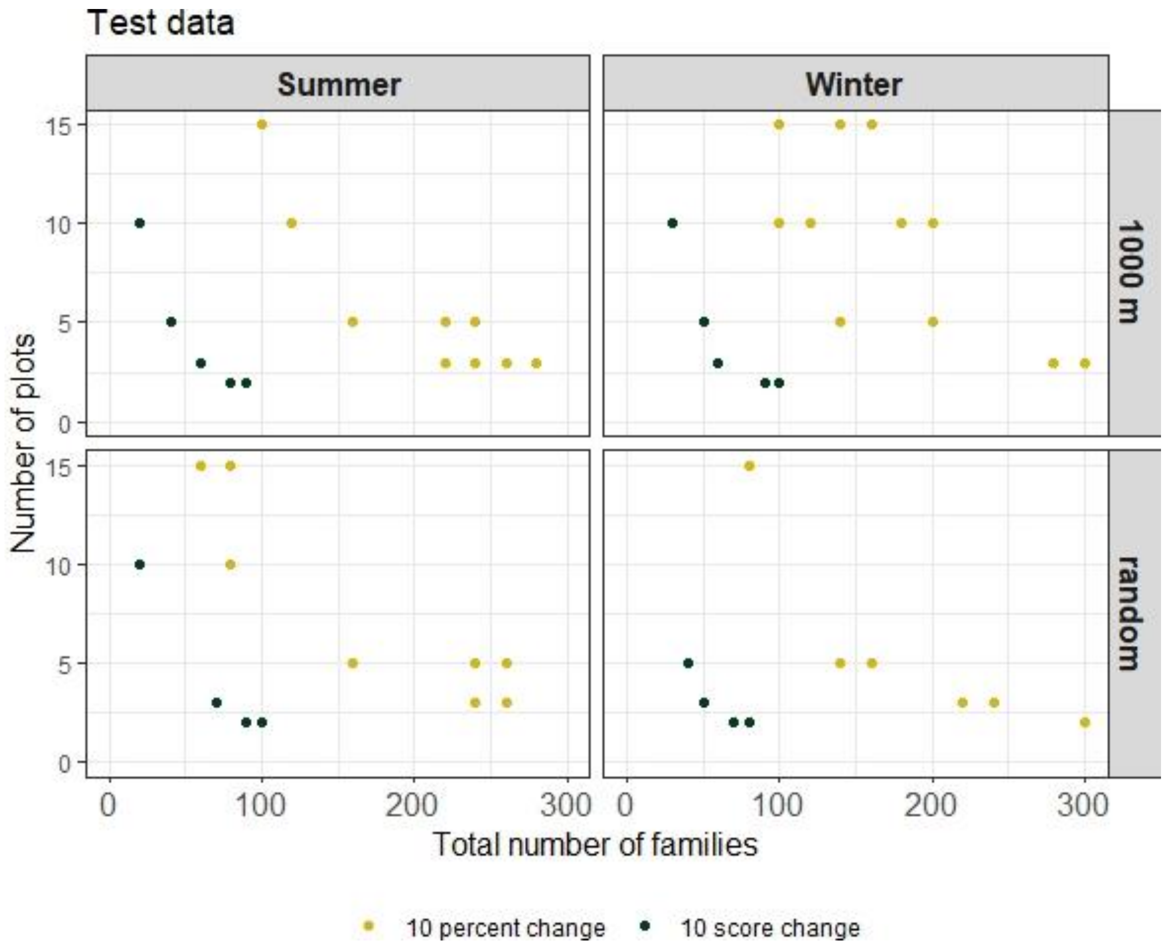

Figure 10. Power analysis based on expert data for high control score (mean condition score of 48.62). X axis shows the total number of families necessary, ideally comprising of equal numbers of SGCP and non-SGCP families. The vertical axis shows the number of plots within each family's camp. The two upper plots show the distance arrangements of plots within a family camp (1000 m = 1 km from centre of camp; random = random distance between 1 and 3 km from centre of camp). The two lower plots show the pastures to be sampled. The colouring scheme of dots shows the two different interpretations of '10% improvement in condition' statement from the Oyu Tolgoi Offset Management Plan (unpublished 2016).

There are also reasons to sample both pasture types, because they may provide complementary datasets. Perhaps the most compelling are intertwined, as follows:

- Summer and winter grazing effects are different. Summer grazing removes actively growing tissues and reproductive material from most species of plants. Grazing in winter removes material from perennial shrubs and largely senescent or dormant material from plants and does not touch those species which retreat underground during winter. In other words, winter grazing affects slow-growing perennial components, while summer grazing has different impacts via the reduction in seed production and the ability of plants to store resources. The different biomes are dominated by different life-forms, such that the effects of summer or winter grazing will differ between biomes.
- The condition metrics for each biome are more or less sensitive to changes in different life-forms. The metric for True Desert is particularly sensitive to the removal of shrubs (accentuated in winter camps). The Desert Steppe metric is more sensitive to the removal of grass (accentuated in summer camps) (evident from Figure 6, Sinclair et al. 2021). This means that summer and winter camp sampling are likely to be more or less sensitive to change in different biomes. The current SGCP families occupy mostly Semi Desert (83%), with more minor occupancy in True Desert and Desert Steppe (8% and 9% respectively). This suggests that while the effect of biome may cause some variation, there is no systematic bias that would suggest that summer or winter sampling is better, owing to metric performance.

Taken together, the insights from the power analysis and from pragmatic observations offer no clear answer as to whether sampling should focus on summer or winter pastures, and suggest that there are benefits to sampling both.

Table 2. Pros and cons of sampling winter and summer pastures

Factors favouring winter pasture	Factors favouring summer pasture
Seasonal livestock movement: Livestock concentrate around permanent shelters in winter but wander widely in summer. Winter sampling reliably samples the grazed area, while summer sampling may miss the main areas of grazing; this was confirmed by comparing tracked animals with sampling locations ostensibly within summer pasture (O. Avirmed, WCS, pers, comm.). So variation in winter camps is likely to contain more signal, and summer camps more noise.	Terrain of camp locations: Winter camps are often in sheltered rocky sites that offer protection from cold winds (grazing impact localised), while summer camps are widely dispersed (grazing impact widely dispersed). This means that summer camps are more representative of the Gobi as a whole.
Multi-family movement patterns Summer pastures may be influenced by several families, or by a different family (passing by or overlapping pasture use), and therefore summer sampling cannot be attributed reliably to SGCP vs non-SGCP.	Time of sampling in relation to grazing: All field sampling occurs in summer. Summer pastures are sampled when grazing impacts are current, winter pastures are sampled 4–6 months after stock have left, allowing growth in response to rainfall that dampens differences attributable to grazing.

Future steps for power analysis

We established that summer rainfall is one of the key predictors of condition, and therefore it is safe to assume that most of the temporal variation comes from year-to-year variation in summer rainfall. Another way to account for temporal change in the analysis is by adding rainfall data as a covariate in the model. This will help separate the temporal fluctuations from the treatment effect and therefore enable a more accurate estimation of treatment effect (c in Model 1) and the family random effect (γ_i in Model 1).

Synthesis and caveats

We confirmed that condition scores have a positive relationship to summer rainfall and are negatively correlated to grazing pressure. We found that the SGCP project is being undertaken in a region of the Gobi Desert with particularly low rainfall and low vegetation condition. Future expansion of the program should account for the climatic limitation. The SGCP area supports similar stocking rates to the rest of the Gobi region (if not slightly lower). To keep the treatment effect balanced, livestock numbers of future SGCP families and non-SGCP families must be similar.

We found that the most important factor in increasing power was to increase the number of family pastures sampled (SGCP and non-SGCP). Of secondary importance is ensuring that each family's pasture is sampled by multiple plots to cover variation in condition score within a family's camp. There are pros and cons of sampling winter and summer pastures, which are tabulated in Table 2.

The current structure of power analysis does not explicitly account for change in the condition score between years; rather, it assumes that the relevant comparison is between treatments within a year. We made this simplification because the current dataset lacks sufficient multi-year sampling to adequately describe between-year variation. As future data is collected it will be possible to assess changes over multiple years. Such analysis may benefit from the incorporation of rainfall data as a covariate in the model. This means that future evaluation of SGCP could use the simple within-year approach assumed here or could take the form of a before-after / control-impact (BACI) design that considered temporal change.

Recommendations

The following recommendation applies to all monitoring components in Table 1 apart from Core Biodiversity Monitoring.

ARI recommends the following:

- Seek livestock data from non-SGCP families as soon as possible, to enable a pre-treatment comparison of herd sizes / density. If possible, data for prior years (pre-2022) should be sought.
- Interpret the 10% improvement target to mean that the pasture condition of the participating families should be at least 10 percentage points greater than non-participating families (keeping in mind that this choice is only a filter, and does not alter the underlying data, which can always be assessed for any degree of change).
- Sample both summer and winter pastures.
- Assess the improvement target in summer and winter pastures separately.
- Assess the improvement target across all biomes considered together.
- Sample as many SGCP families (about 130-140); or as close to that number as possible, given budget constraints, but at least 50.
- Sample the same number of non-SGCP families as SGCP families, selected randomly from the pool of available families within the same region as SGCP.
- Sample at least 3 (preferably 5) replicate plots in each family’s pasture.
- Position all plots randomly, within a radius of 500–2000 m of the centre of camp.
- Retain the same plot locations year after year, marking the plots physically with tags or stakes.
- If, by chance, a random plot falls on unusual features such as past ger locations, camp structures, bores or rock outcrops with exposed rock cover exceeding 40% (which are outside the limits of the condition metrics set by Sinclair et al. 2021), it should be discarded, and another random point found. This process should be documented and reported.
- For the purpose of assessing the success of SGCP, analyse the data across all ecosystems without reference to their ecosystem classification (i.e. ecosystem still need to be recorded to calculate condition score, but does not need to be part of the consideration for stratification for the monitoring program).
- Assess the plots annually.
- Consider establishing additional fenced grazing exclosure plots, measuring at least 50 x 50 m (to account for edge effects), so that here are at least six per biome, three within the pastures of participating families, three in the pastures of non-participating families.

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Appendices

A1. Vegetation cover and richness over time in each biome

The annual monitoring program incorporates field measurements of a large number of vegetation cover and richness variables (12–17 depending on biome) that underpin the condition metric. In Figures 11–13 we show a select few variables that are most influential on the condition score (>0.4 Pearson correlation coefficient) to summarise the change in vegetation over the 5-year period in Desert Steppe, Semi Desert and True Desert. The vegetation change is measured by change from mean of the 5-year period for each vegetation variable. Monitoring in SGCP only started in 2019, but the change is still assessed against the 5-year mean.

Desert Steppe

In this biome, the largest changes occur in total vegetation cover (veg_cover on horizontal axes in Figures 11–13), perennial grass cover (per_gras_cov), perennial forb cover (perforb_cov) and annual forb cover (annforb_cov) (Figure 11). Some trends are evident:

- Summer rainfall (blue bars in the diagrams) seems to relate vegetation change from the mean, particularly in plots that are not heavily grazed. In wetter summers (e.g. 2018 and 2021) the total vegetation cover is well above the 5-year mean in baseline and exclusion plots.
- In SGCP plots the vegetation variables remain below the 5-year mean, except shrub cover in 2020 and forb richness in 2021.

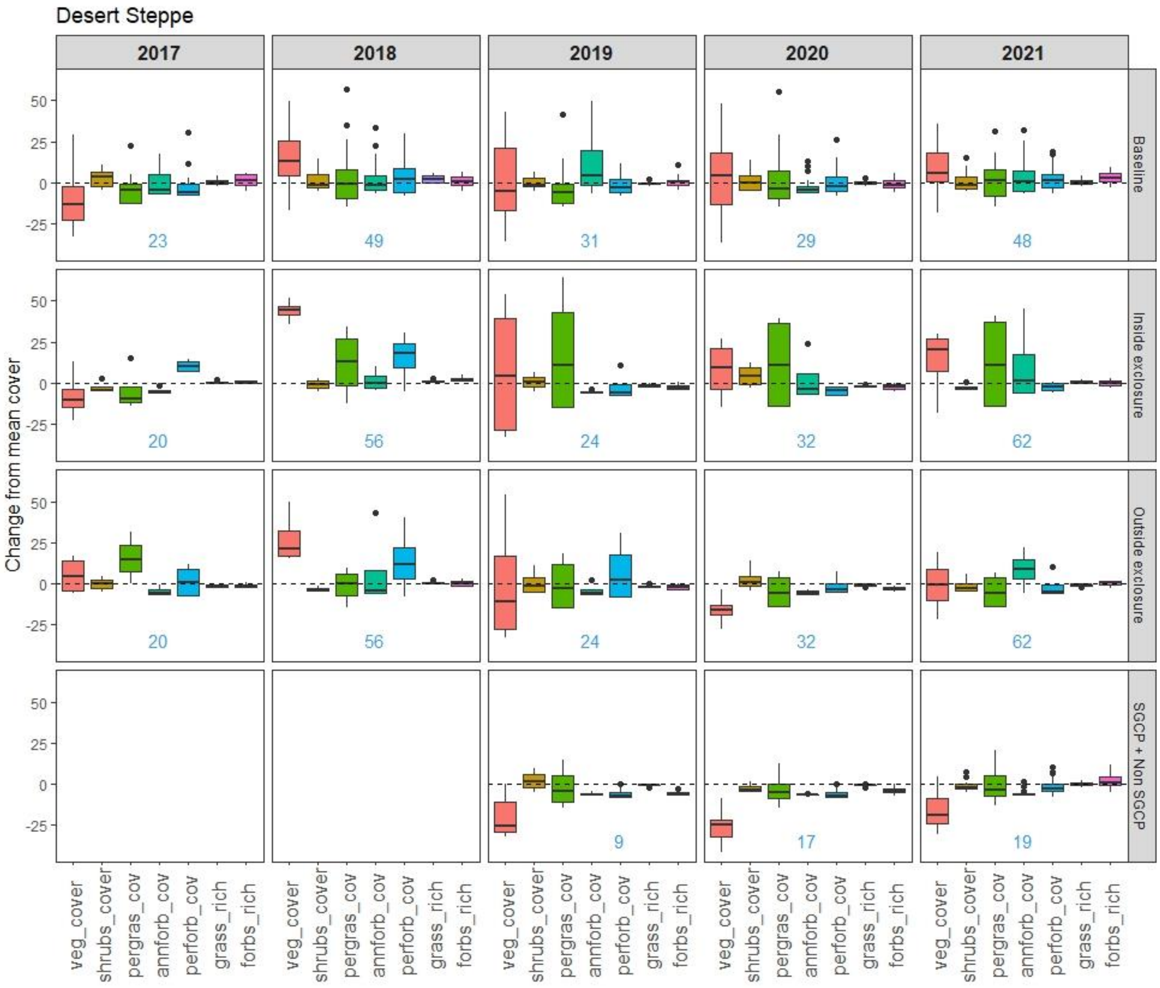

Figure 11. Changes in vegetation cover and richness variables (subset of total number of variables monitored) in years 2017–2021 in Desert Steppe biome. The horizontal axis shows change from the mean. The horizontal dashed line represents the 5-year mean of each vegetation variable.

Semi Desert

In this biome the majority of the change in vegetation cover happens in total vegetation cover (veg_cover) and to a lesser degree in perennial grass cover (Figure 12). Summer rainfall relates strongly to cover. In dry summers the total vegetation cover is often below the mean, even in protected plots inside an exclosure fence. This suggests that summer rainfall is potentially the primary driver of changes in vegetation, regardless of grazing regime. Cover and richness of vegetation variables in SGCP plots remained below the mean in most years ; the exception was 2021, when high summer rainfall kept total vegetation cover well above the 5-year mean across all treatments. This effect is more pronounced when grazing pressure is removed, i.e. in protected plots inside an exclosure fence.

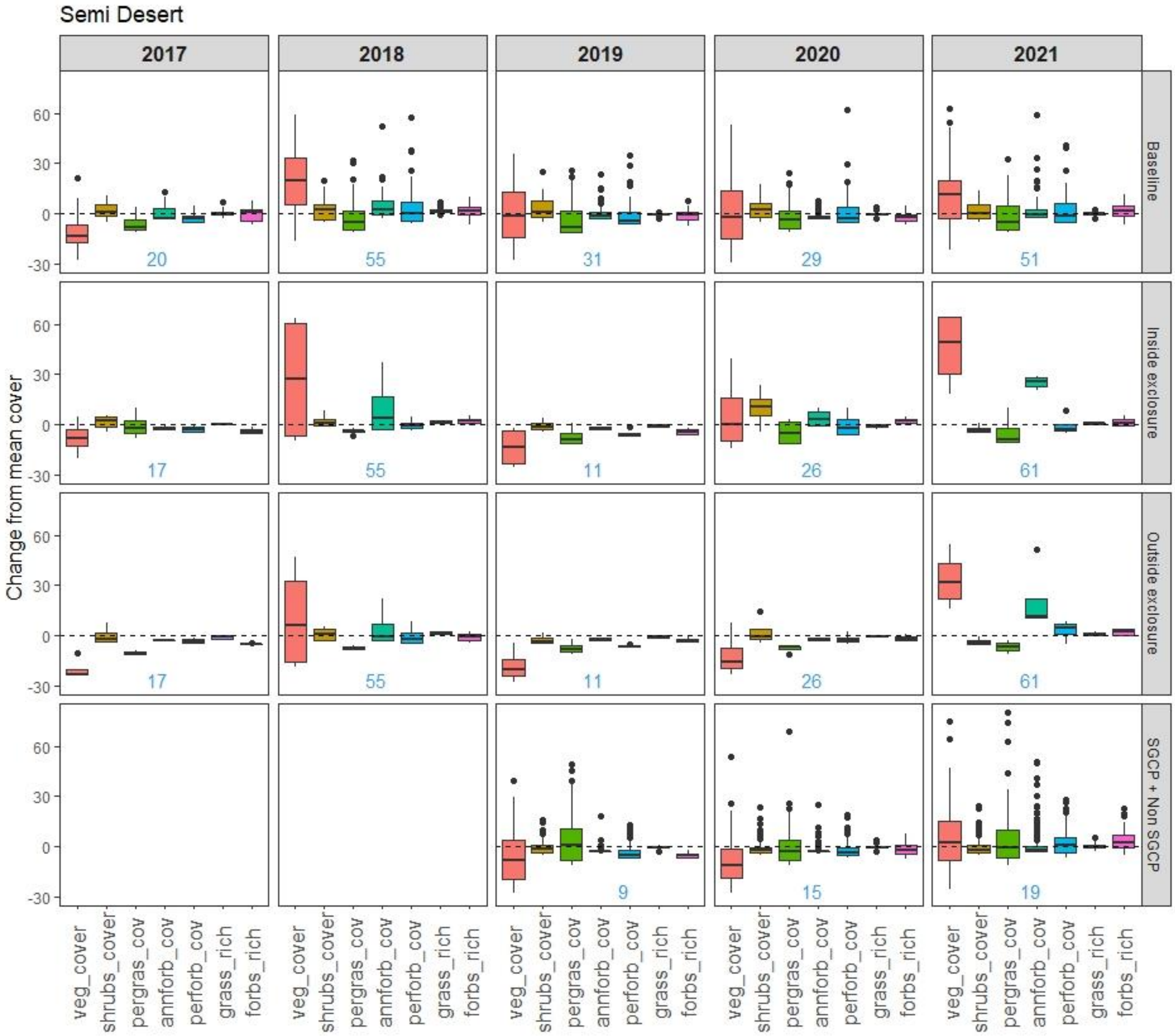

Figure 12. Changes in vegetation cover and richness variables (subset of total number of variables monitored) in years 2017–2021 in the Semi Desert biome. The horizontal axis shows change from the 5-year mean. The horizontal dashed line represents the 5-year mean of each vegetation variable.

True Desert

There are a several unique traits in vegetation change in True Desert compared to the other two biomes (Figure 13). Total vegetation cover in baseline plots remained below the 5-year mean in dry years, but in Desert Steppe and Semi Desert this variable remained at the mean or slightly above even in dry years. The plots inside exclosure improved (cover and richness increase) considerably more than their counterparts in the other two biomes. Plots outside exclosure contains have also been improving since 2019, with total vegetation cover well above the 5-year mean in True Desert, whereas in Desert Steppe and Semi Desert they consistently remain below the mean. Most vegetation variables remain below the mean for SGCP plots since their inception in 2019, with the exception of forb cover richness in 2020 and 2021.

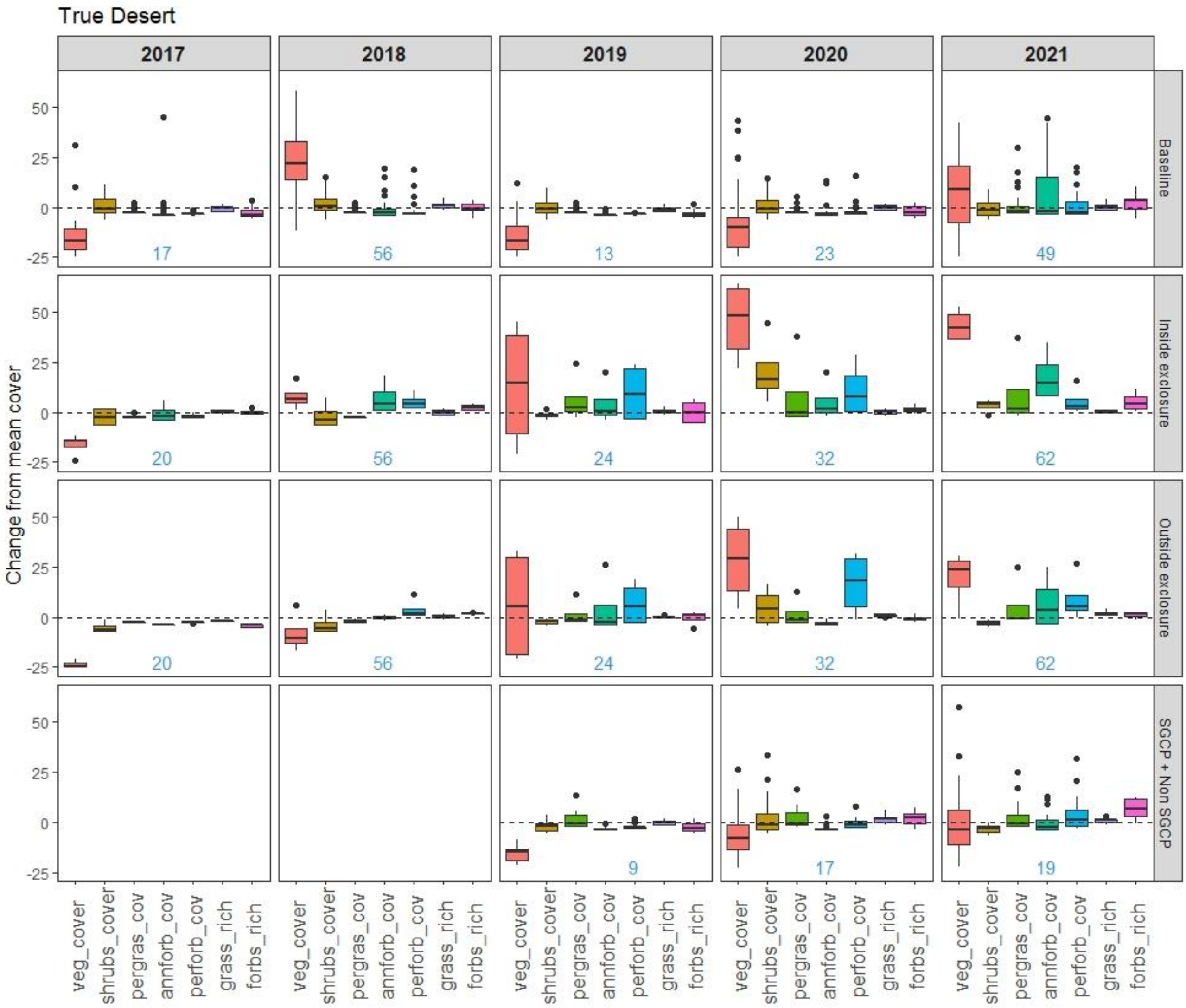

Figure 13. Changes in vegetation cover and richness variables (subset of total number of variables monitored) in years 2017–2021 in the True Desert biome. The horizontal axis shows change from the 5-year mean. The horizontal dashed line represents the 5-year mean of each vegetation variable.

A2. Modelling rainfall effect on vegetation cover and condition

From the information presented in previous sections, we believe that summer rainfall likely drives significant changes in vegetation and therefore the condition score. We also learnt that the SGCP families are in a relatively dry portion of the Gobi region, with low summer rainfall. Here we ask whether the difference in summer rainfall between different treatment types (baseline, SGCP, exclosure) has a statistically significant impact on vegetation cover and condition score.

Summer rainfall effect on total vegetation cover

We explored rainfall effects using generalised additive models (GAM). We chose to use total vegetation cover as the response variable. We fitted two types of GAM to predict total vegetation cover from mean summer rainfall. The first was a global model (dark blue line in Figure 14) that does not account for the different plot types. The second type takes variation between the data types into account and produces a prediction curve for each of the types (colours other than dark blue in Figure 14). The statistic of interest is the difference in deviances between models when including and excluding the treatment level (i.e. data type) term/function. Overall, the second type performs better than the global model (deviance explained increases from 82% to 87%), which implies that the variance in summer rainfall affects different sets of plots differently.

But this should be interpreted cautiously, considering the relatively small size of the training data for some of the groups, e.g., olive green curve for ‘families in co-op’ (SGCP) group in in Figure 14.

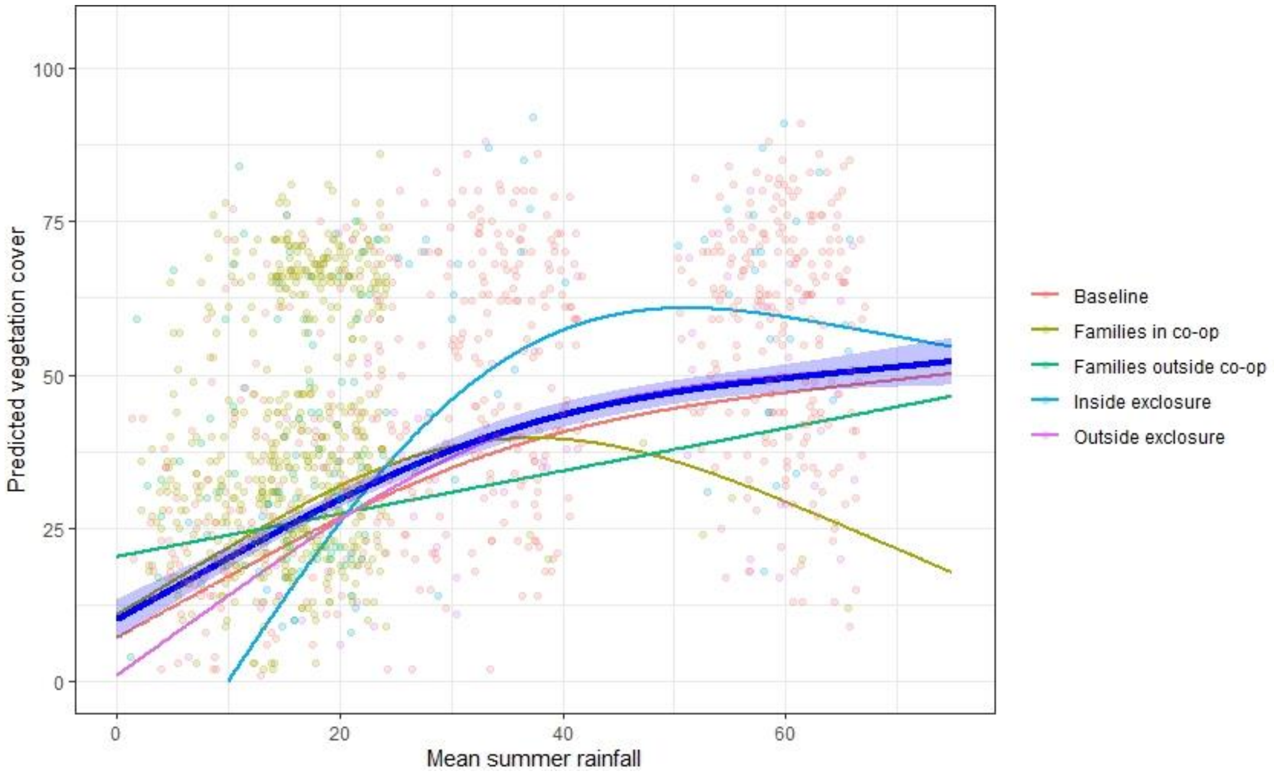

Figure 14. GAM prediction curves for two types of models predicting total vegetation cover from summer rainfall. The global model is the dark blue curve. Pale coloured curves belong to the second type model with group-level smooth terms. Coloured dots represent training data for correspondingly coloured curves. ‘Families in co-op’ means they are SGCP. ‘Families outside co-op’ are non SGCP families.

Summer rainfall effect on condition score

In a similar manner to the analysis above, we fitted two types of GAM to predict the condition score from mean summer rainfall and vegetation cover. The first type is a global model (dark blue line on Figure 15) that does not take group (plot type) level variation into account. The second type takes treatment-level variation into account and produces prediction curves for each of the treatment types (colours other than dark blue in Figure 15). The statistic of interest is the difference in the deviances of the models, including and excluding the treatment level term/function. The model performance statistics (deviance explained does not improve when a group-level smoother term added) suggest that variation in summer rainfall does not affect condition score in a statistically significant way once variance in vegetation has been accounted for. We interpret the fact that condition score does not increase proportionally after 60 mm of mean summer rainfall to be a result of stakeholders surmising that condition does not improve once there is enough vegetation cover. It might also be because of elevated cover of undesirable species, i.e. annual chenopods.

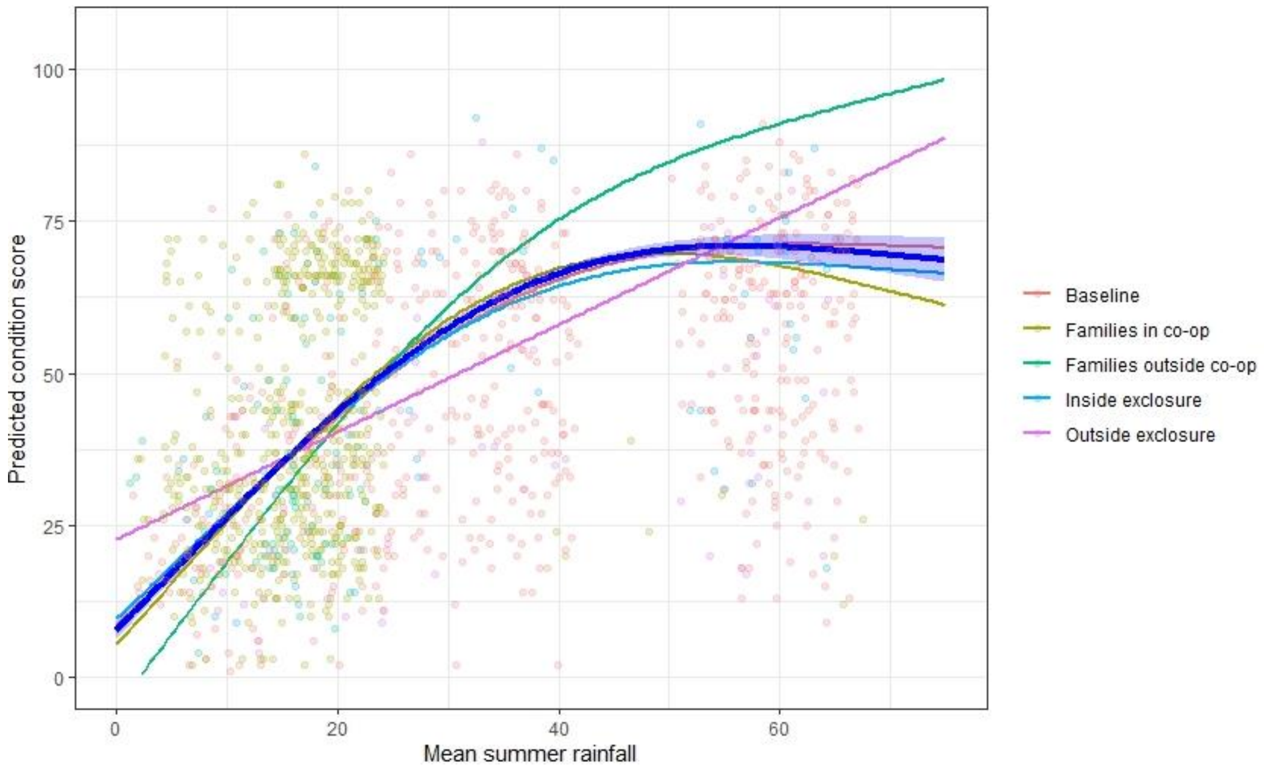

Figure 15. GAM prediction curves for two types of models prediction condition score from summer rainfall. Global model is the dark blue curve. Pale coloured curves belong to the second type model with group-level smooth terms. Coloured dots represent training data for correspondingly coloured curves.

Collapse threshold

Ecosystem collapse is a binary ecosystem risk assessment metric developed by the IUCN Redlist of Ecosystem framework (Bland et al 2017). Here we assess the ecosystem collapse risk in the 2017–2021 monitoring data. In 2017 we elicited ecosystem collapse thresholds for Desert Steppe, Semi Desert and True Desert from 92 stakeholders from the Gobi region (Batpurev et al. 2022).

The threshold of interest is the cover of total vegetation where maximum probability of collapse is reduced by 50%. For Desert Steppe and Semi Desert biomes, this threshold is at a total vegetation cover of 10.5% on average (horizontal dashed lines in the Desert Steppe and Semi Desert panels in Figure 16). In True Desert the maximum probability of collapse (pmax) is halved at a total vegetation cover of 7.6% (horizontal dashed line in the True Desert panel in Figure 16).

We analysed vegetation cover for each of the five treatment types. Vegetation cover went below this threshold multiple times, especially in True Desert and Semi Desert biomes in grazed plots outside exclosure fences. In dry summer years such as 2017 and 2019, baseline plots and SGCP plots touched the threshold in True Desert.

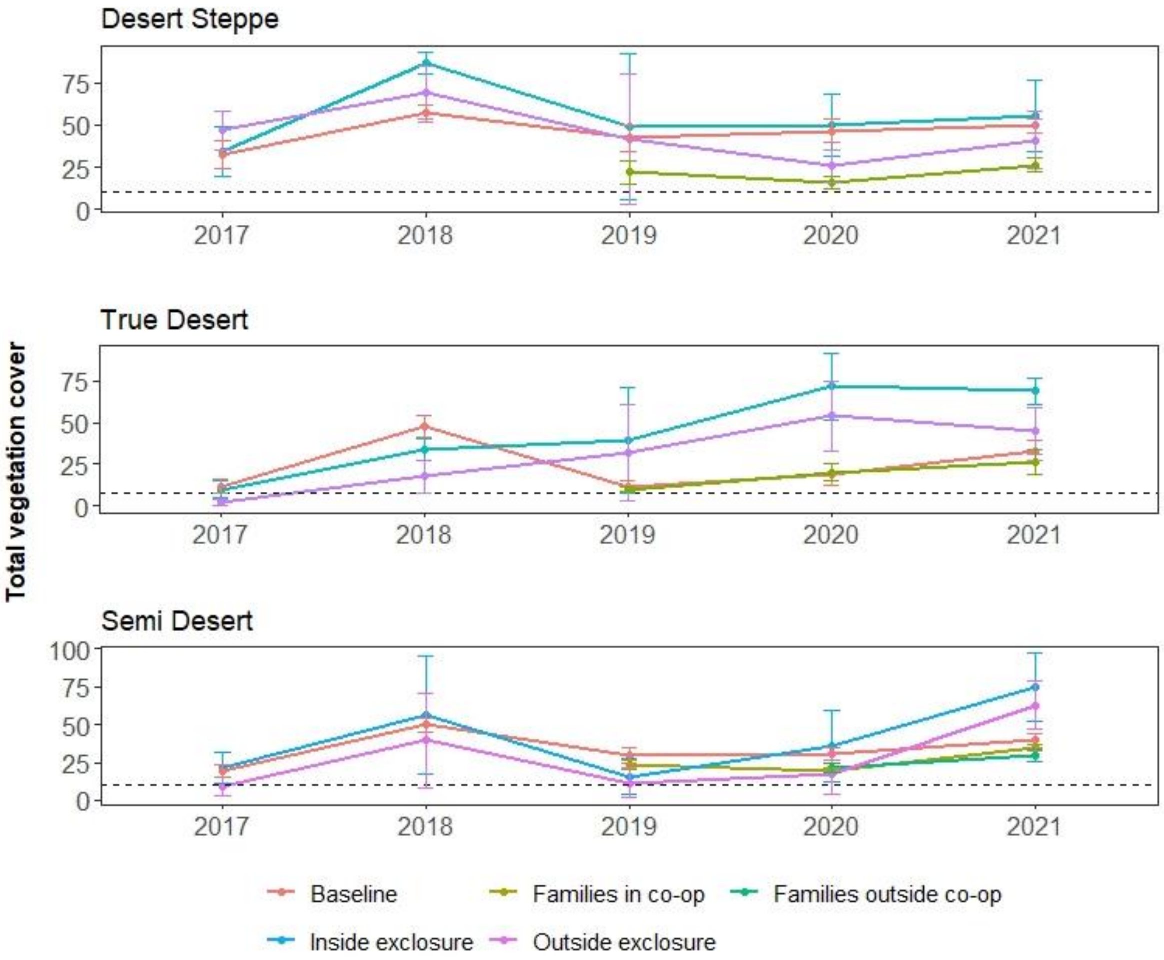

Figure 16. Ecosystem collapse threshold assessment plots. Horizontal dashed lines represent vegetation threshold, where the maximum probability of ecosystem collapse is reduced by 50%.

A3. Example of raw power analysis result

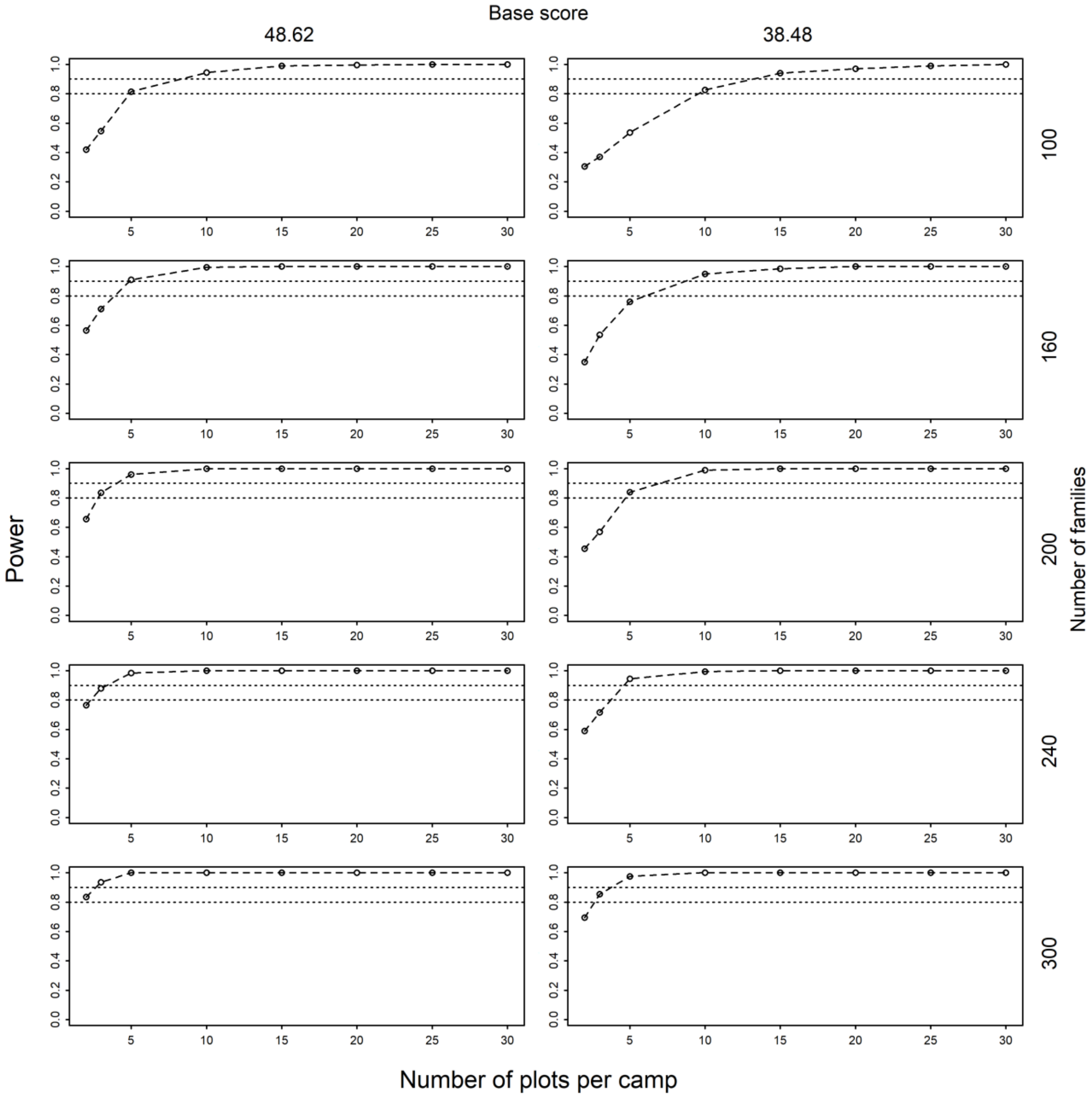

Figure 17. Result of power analysis showing power of random distance sampling (1-3km from centre of camp) in summer pasture. The horizontal axis shows the number of plot replications around a camp. Y axis on left shows the statistical power achieved. The vertical axis on the right shows the number of families. The left column titled ‘48.62’ refers to a high base control score of 48.62 (mean condition). The right column titled ‘38.48’ refers to a low base control score of 38.48.

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