DISTRIBUTION OF ABIOTIC FACTORS IN CANRAY CHICO AND THEIR RELATIONSHIP TO VEGETATION

A study into the relationship between several abiotic factors and the vegetation found in a river catchment in the Peruvian Andes.

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ABSTRACT

Glacial retreat leads to large changes in ecosystems around the globe. In the Peruvian Andes, a small river catchment is coping with problems linked to these changes. Three weeks of fieldwork resulted in a large database containing information on both abiotic factors and vegetation. This data was analyzed to find information on the distribution of abiotic factors, as well as the relationship between these factors and vegetation. Several indicator species have been identified to assist in the assessment of the area. Several indicator species have been determined based on the relationship between the vegetation and the abiotic factors. *Piptochaetium featherstoni* shows a clear correlation with both the degradation state and the grazing intensity, while both *Bidens andicola* and *Matucana yanganucensis* show a correlation with the presence of soil crust.

INTRODUCTION

SCIENTIFIC BACKGROUND

Mountain water is responsible for about half the fresh water used by the world's population (Liniger et al. 1998). Glaciers play an important role in the hydrology of mountain areas (Fagre et al. 1997), as they are the main source of water. Retreating glaciers lead to differences in the amount of melt water, which can globally result in ecosystem changes. These changes not only affect the area closest to the glacier, but can also lead to major issues further downstream. Changes in runoff may have an even bigger impact in developing countries that have fewer resources at their disposal to cope with the changing circumstances. Whilst these changes are most prominent in the hydrology of mountains, changes in different soil aspects, vegetation distribution and abiotic environment are also to be expected in these areas. These changes may be less visible than changes in hydrology, even so they play an important role in ecosystem and landscape dynamics. It is therefore important to analyze the distribution and variation in these factors.

INTRODUCTION TO THE FIELDWORK

In the *Cordillera Blanca* mountain range of the Peruvian Andes lies a catchment, that is increasingly troubled by these changes. The Glacier area in this mountain range has retreated for more than 15% within 25 years (1970-1996) (Silverio, et al. 2005). This catchment, characterized by *puna* grassland vegetation, is known locally as the *Canray Chico*. The area is coping with the pollution of the present water sources by high concentrations of heavy metals. Due to a lack of available data and knowledge on the hydrological, geological and geomorphological situation of the catchment, effective solutions for the problem are not readily available. Several origins of the pollution have been hypothesized.

One of the possible causes of the pollution could be the recent exposure of pyrite formations, which have been uncovered due to the aforementioned glacial retreat. Resulting issues for the inhabitants of the *Canray Chico* include for one polluted drinking water, for people as well as for cattle. The process of leaching of this polluted water into surrounding soils also has possible negative effects on vegetation, reducing the agricultural yield. This will be even more so when polluted water is used for irrigation. It is also likely that the natural buffering capacity of the soil is reduced because this polluted water generally has a rather low pH (Yong & Phadungchewit, 1993). Negative impacts are not only limited to the catchment, this pollution is also a problem for those living further downstream. Water from the catchment eventually flows into the *rio Santa*, which is a primary source of water for nearly half of the inhabitants of Peru (Wellmann, 2008).

A thorough study of the abiotic factors of the area is a first step in building the knowledge needed to understand why the catchment is polluted, and what the spatial distribution of the contamination is. The key to success in understanding and solving the problem is the cooperation of the locals inhabiting the *Canray Chico*, who are in a position to actively monitor the area and manage the problems.

Non-governmental organization The Mountain Institute (TMI)[1] is actively working with the local community to monitor water and soil quality in the area, but it lacks the knowledge on abiotic factors influencing the quality and methods to improve the water quality. By working together with TMI, we had the opportunity to work in the catchment, and provide them with information in the form of this paper.

AIM

The aim of this research is to provide insights in the distribution of abiotic factors in the *Canray Chico* catchment and the relationship between these factors. Determination of indicator species for several of the abiotic factors is also attempted. These indicator species can then be used by TMI and the local community to quickly assess the abiotics of a certain area, without the need for in-depth understanding of the different parameters and factors playing a role.

Insights in the distribution of, and relationships between, abiotic factors will give the local community a better indication of the nature of the problems they are facing. This gives them the opportunity to actively work to counter these problems. In the long run better management will lead to improved water and soil quality and improve the quality of life in the area.

The following research questions are asked to support the aim of the research:

1. How are abiotic factors distributed in the *Canray Chico* catchment?
2. What relationships are found between the different abiotic factors?
3. Which kind of vegetation can be indicative for certain abiotic factors?

[1] About us
"The mountain Institute empowers communities in the world's great mountain system through education, conservation and sustainable development. TMI has been supporting the environment, economy and culture of mountain populations for more than 38 years"(cited from: www.mountain.org)

EXPECTATIONS

Little is known of this particular catchment in terms of soil types and abiotic parameters. Since the catchment lies at a high altitude and is exposed to concurrent low temperatures, it is expected that soil development is not far advanced. The puna grassland type vegetation leads us to expect that we will not find a particularly high species diversity, rather a low-density vegetation, dominated by grasses and shrubs. Nevertheless puna grassland can have complex patterns of spatial variation (Lambrinos et al., 2006). We expect to find several species that can be linked to their abiotic surroundings; in particular we expect to find relationships between vegetation and soil parameters, soil quality respectively.

METHOD

FIELDWORK

Fieldwork for our research took place in the context of the Field course Geoecological Systems, a course given at the University of Amsterdam. Our fieldwork took place in the *Canray Chico* catchment, previously described in the introduction. This river catchment is situated about 10 kilometers southeast of the city of *Huaraz*, in the *Cordillera Blanca* mountain range of the Peruvian Andes.

To prevent subjectivity and miscommunication, a standardized field form was used for the observations; this form was also used to systematically keep track of the observations. Parameters included on the field form are land use, vegetation coverage, soil characteristics and other relevant abiotic and biotic factors and indicators. A full copy and an explanation of the field form can be found in appendix A of this paper. To describe the soils the FAO WRB[2] was used. For the soil profile, use of natural exposures was preferred. If such exposures were absent, a hole was dug to the depth necessary to classify the soil.

The actual fieldwork took place over a period of three weeks in June and July of 2012, during which observations were made along transects in the catchment. Ten students made the observations, and took samples, in small groups varying in size and composition. Samples were taken from most of the surface water present, as well as from the soil at many of the observation points. Soil samples were taken for points that seemed to be significantly different, or were relatively distant from other sites, resulting in semi-randomly distributed sample sites, to get an overview of the soil characteristics in the area. In total, 175 observation points have been assessed, from which a total of 56 soil samples have been taken. Appendix B shows an overview of all the observation and sample points.

PRELIMINARY ANALYSIS

To get an indication of the areas important for further research during the fieldwork, all water and soil samples were measured for pH and electric conductivity (EC) while still being in Peru. These measurements were taken at the TMI headquarters in *Huaraz*, Peru.

[2] IUSS Working Group WRB. 2006. **World Soil Resources Reports No. 103**. FAO, Rome

The soil samples were prepared for analysis with a mixture of soil sample in demineralized in a water ratio of 1:5. This mixture was stirred to make it homogeneous, after which the pH was measured using a field pH meter. An EC meter was then used to measure the electric conductivity, using the same mixture.

The water sample measurements were taken by pouring about 50 milliliters in a small cup, which was then shaken by hand for two minutes. Measurements of pH and EC were taken using the same equipment as described above for the soil samples.

After the measurements all material used for the analysis was cleaned using demineralized water. The filtered water was stored in new bottles, ready for the final laboratory analysis. These samples were taken to the University of Amsterdam for further analysis when necessary.

ANALYSIS

At the University of Amsterdam all samples were freeze dried, and a CHNS-analysis was performed on the samples. This gave exact numbers for the amount of carbon, nitrogen, hydrogen and sulfur in the samples.

To prepare the samples for this CHNS-analysis, the samples were sieved using a 2-millimeter sieve. This removes the largest coarse material from each sample, as this material could damage the machine used for the analysis. The remainder of each of the samples was then ground using a standard ball mill grinder, to make sure that all material was small enough to be analyzed. These grounded samples were then dried in a 105 degrees Celsius oven, to get rid of any moisture added to the sample while handling it.

After drying overnight, between 30µg and 40µg of each sample was weighed and wrapped in a small piece of tin. These individual pieces of tin have been put in the carousel of the CHNS-Analyzer to be measured.

STATISTICS

To analyze the distribution and relationships of the different abiotic factors measured, descriptive statistics have been used. This gave an overview of the differences between the spread of the different abiotic factors and how they relate to each other. This first analysis has been used to further determine which of the factors will be used in the subsequent analyses.

Further analysis has been performed using a Canonical Correspondence Analysis (CCA), to determine the relationship between vegetation species and the abiotic factors. The results of this CCA show the influences of the different variables on the different species, allowing one to identify potential indicator species. The CCA was performed using the computer program PAST 2.16.

Results of the several CCA analyses have then been used to choose a number of likely indicator species. The correlation between these species and the corresponding abiotic factors has been further analyzed using R (version 2.15.1) .

GIS

After using statistics to determine which abiotic factors are most relevant for our research, ArcGIS 10 was used to visualize the distribution of these factors. Due to the irregular distribution of the sample points, the usage of interpolation methods or *Thiessen* polygons would lead to a distorted image of the distribution.

Therefore, the maps only display the different points at which samples were taken, along with the respective values of these field points. The maps will help in better understanding the spatial distribution of the different factors, but also how the factors are spatially linked to each other.

RESULTS

LABORATORY

The results of the CHNS analysis were quite straightforward, with not many outliers. Both carbon and nitrogen show a relatively normal distribution, with some small outliers as seen in figure 1. Values are also as was to be expected from the sample sites. This will be discussed further in the distribution of abiotic factors sector.

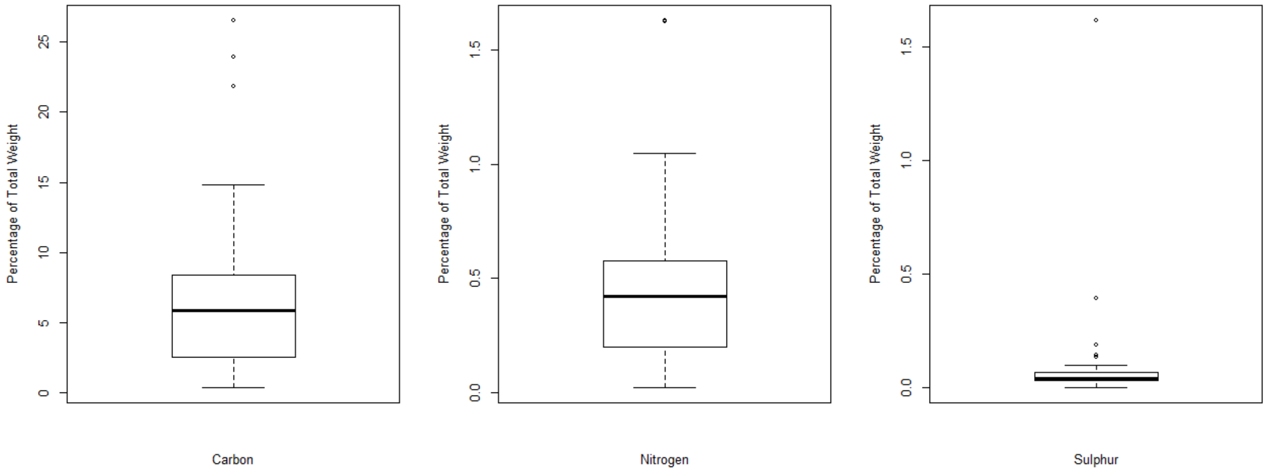


Fig. 1 Percentages of carbon, nitrogen and sulfur in the *Canray Chico* soil samples

Figure 1 also shows the spread of the percentages sulfur in the samples. One sample stands out from the others, in being significantly higher than all other values, and even than the other outliers. Looking at the location of the sample shows that this value is highly unlikely for it's location. This will be discussed further on in the paper.

DATA EXPLORATION

Before further analysis was performed on the data obtained from both the fieldwork and the following laboratory work, this data was first explored to get an impression of the distribution, spread and relevance of the different factors. Looking at the lithology it is no surprise that most frequently either subglacial till or ablation till was found, as the fieldwork area that we worked in has a history of glacial activity. In concurrence with this most of the rock types that were encountered fell into the category of sedimentary rocks. A distinction was made between sedimentary rocks and sedimentary rocks that had a so-called '*capa roja*', a thin layer of iron oxide covering the rock. These rocks can be indicative for water polluted with metals, or for weathering of pyrite in the rock itself.

LITHOLOGY

Lithology can be an important factor when looking at the soil quality of a region. It can influence the abiotic factors present, or it might be that more data points were taken on a certain lithology type. If there is a difference in the spread of data points, this could possibly influence the data, and is important to see. The three most abundant lithology types were subglacial till, ablation till and unconsolidated gravel.

When comparing these three for factors important for soil quality, the following interesting differences were found.

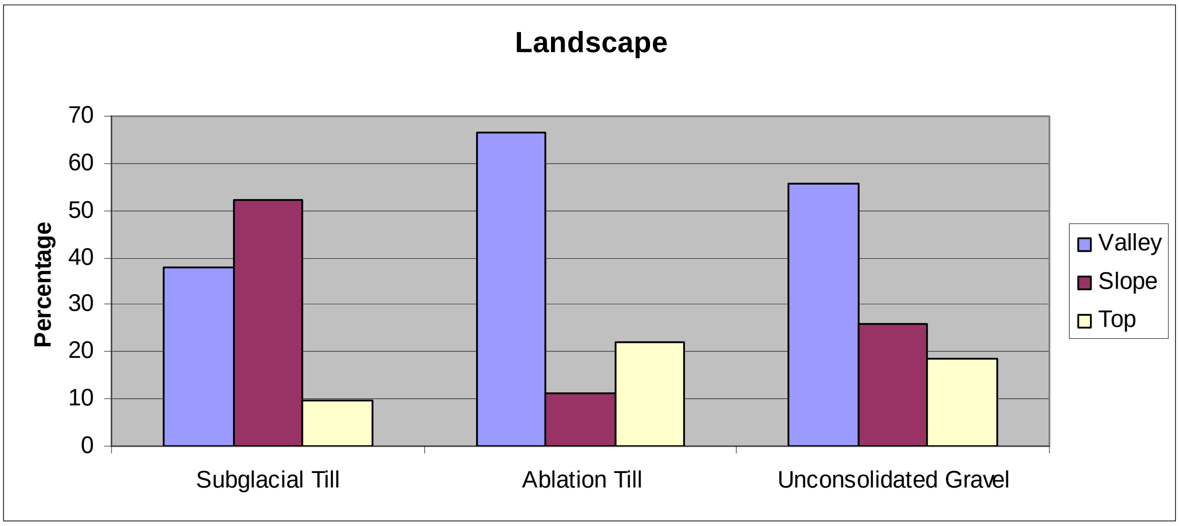


Fig. 2 Spread of occurence of several landscape positions, based on the top layer of the soil.

From figure 2 it becomes evident that most plots with subglacial till were taken on a slope. Most plots with ablation till and unconsolidated gravel, on the other hand, were taken in the valley.

This graph does not show which of the three types of lithology were most abundant though. The amount of samples taken within each of the three main lithology types is different. So the only comparison that can be made here is a comparison of distribution within the three lithology types.

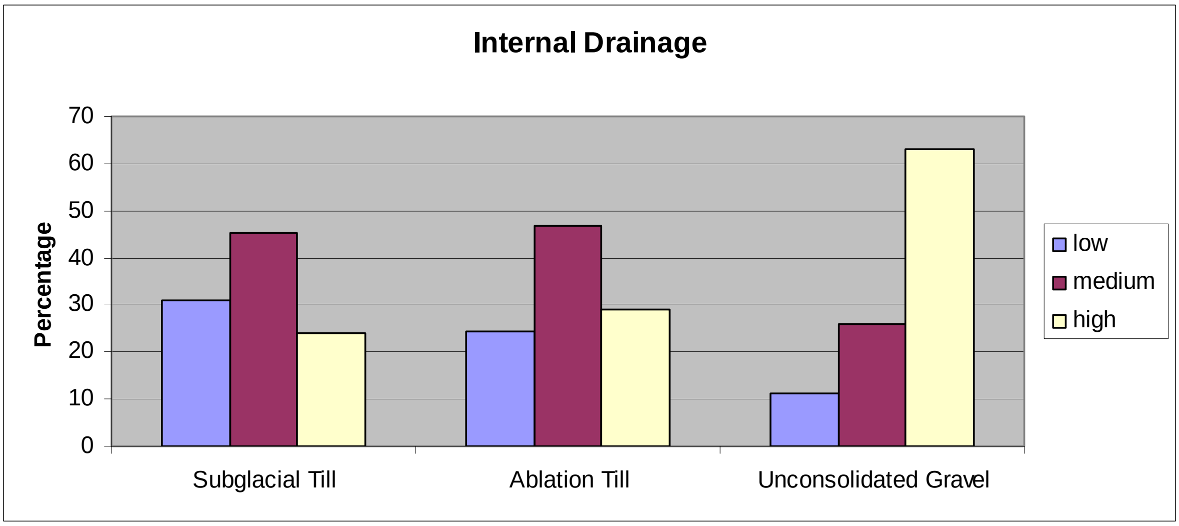


Fig. 3 Occurence of internal drainage over the different lithology types, based on the top layer of the soil

Figure 3 shows that from all the plots that were taken on unconsolidated gravel, most had a high internal drainage. The other two types show a more medium internal drainage.

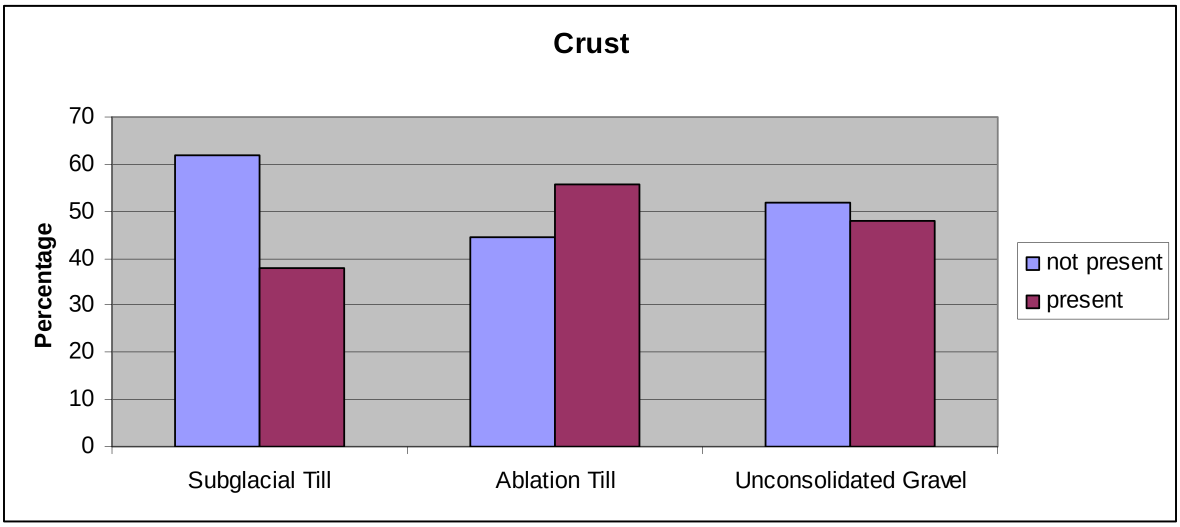


Fig. 4 Occurrence of crust on different lithology types

Figure 4 shows that most plots taken on subglacial till did not have crusting. On the other two types the presence and absence were about equally divided over the plots.

STATISTICS

The fieldwork resulted in a large database of data on many abiotic factors. A selection had to be made from this database, based on several criteria. The variables for the analysis were chosen based on the spread in frequency of occurrence, as well as the method of acquiring the data in the field and relevance to the research. This process of choosing the variables will be discussed briefly below.

Histograms were made for groups of variables with the same method of data collection, for instance, all categorical, nominal or continuous. This allows comparison in the spread between the different variables.

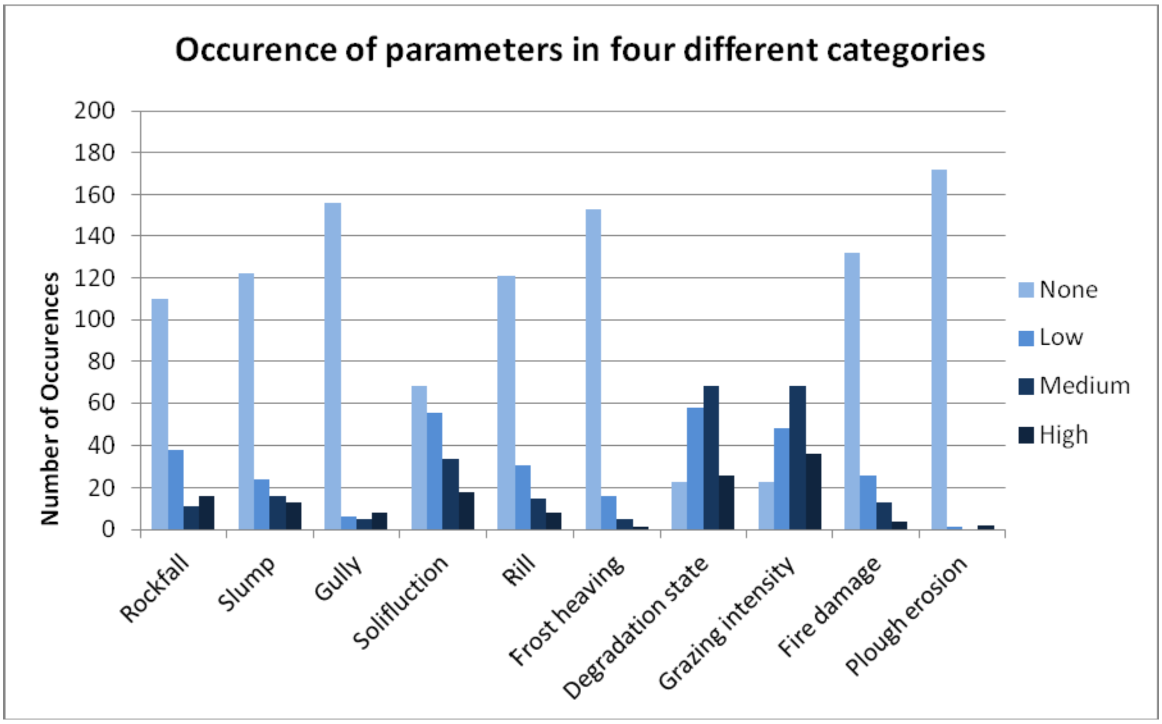


Fig. 5 Frequency histogram of all parameters in the categories none, low, medium and high that were present on a total of 175 fieldsites.

Figure 5 shows the histogram of all variables, which were categorized in one of the four categories from not present (none) to highly present. Seven of these variables show a low occurrence rate, and low spread amongst the different categories, these are: rockfall, slump, gully, rill erosion, frost heaving, fire damage, and plough erosion. The other three variables: solifluction, degradation state and grazing intensity, show a larger spread and higher frequency. Because of their low spread, the variables gully, frost heaving and plough erosion were left out of further analysis. The other variables were either thought to have a large enough variety or to have a significant relevance to vegetation and soil quality when present, i.e. fire damage.

The variables water availability, aggregate stability and internal drainage are all included in the CCA analysis as they are all considered important aspects of soil quality. They also show a considerable spread in the occurrence of the different categories high, medium and low (see figure 6).

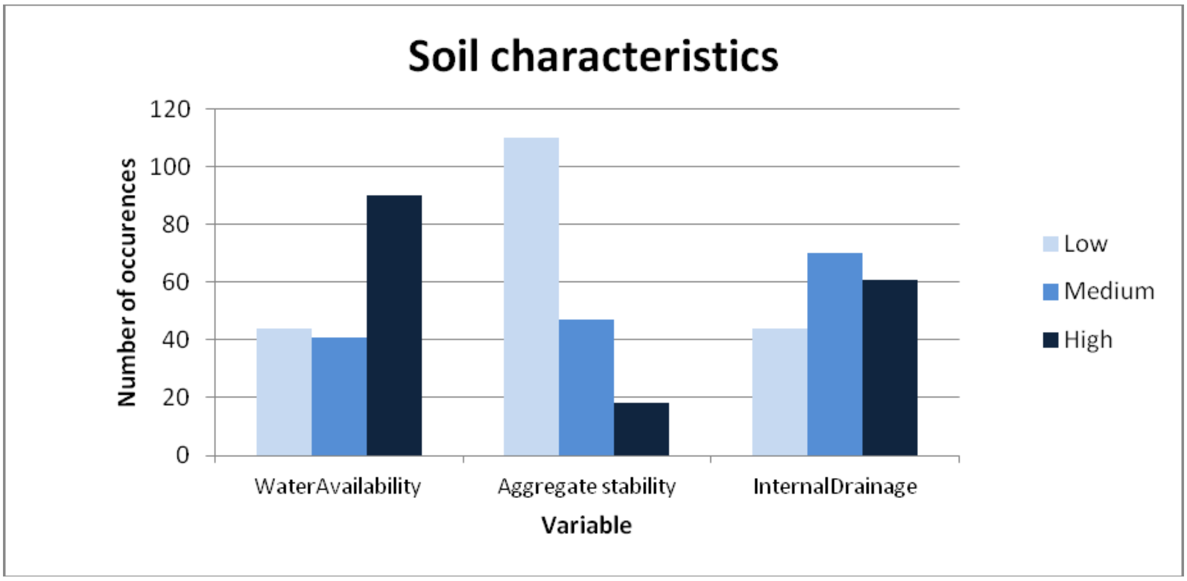


Fig. 6 Occurrence of different soil characteristics

Figure 7 displays the histogram of 9 variables that have a binominal distribution (either present or not present). All of these variables, with the exception of crust, show a very low occurrence. Off these variables, most were left out of the CCA. Apart from the parameter crust, the parameters swamp/wetland, temporary swamp and overland flow were selected for the CCA because they are expected to have a substantial impact when present.

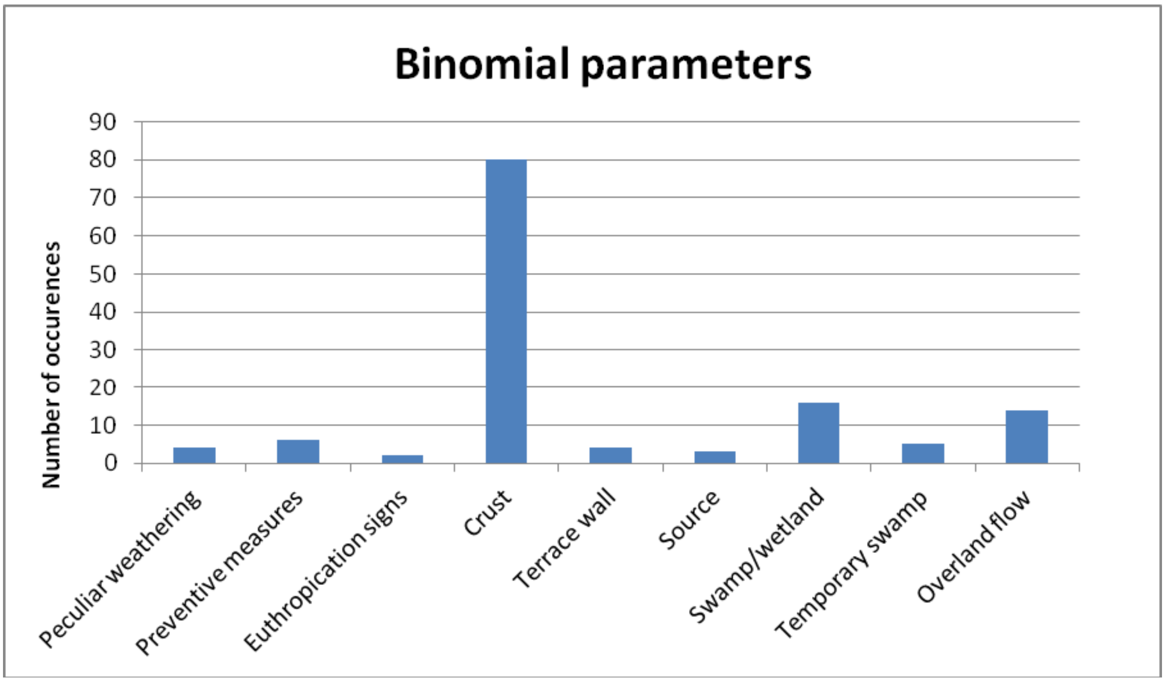


Fig. 7 Frequency of different binomial parameters at a total of 175 sites.

Figure 1 displays the results of the NCHS analysis. It is prominent that there is one sulfur percentage that is a significantly higher than all other values and even higher than all the other outliers. The sample site for this sample is located in the southwestern part of the catchment. Surprisingly, other samples close to it do not display such an high sulfur content. Inspection of pictures taken of the field site revealed that the probable cause of this extremely high value was an irrigation channel leaking into the surrounding soil. Opposed to sulfur, carbon and nitrogen show a normal distribution with no extreme outliers.

A CCA was performed using the selected variables and the vegetation species that occurred on at least 10 different field sites. The result of this CCA is shown in appendix D.

When looking at the results of the CCA some abiotic parameters seem to be correlated with each other. Statistic analyses were performed to check for any significant relation. All statistic analyses were performed using the R statistical program (version 2.15.1).

Table 1. Crust and internal drainage contingency table

	Internal drainage		
Crust	Low	Medium	High
No	38	29	28
Yes	6	41	33

Table 1 shows the contingency table for the parameters crust and internal drainage. As the CCA suggests these two abiotic factors are likely to be interdependent. This is confirmed by Pearson's Chi-squared test (p = 4.47e-06). In specific there are less sites with crust and low internal drainage than would be expected if they were independent of each other. This makes sense because a soil that has a low internal drainage, which is often linked with high water retention, would be sufficiently moist to not have crust-forming.

Because grazing intensity and degradation state are displayed as almost one line in the outcome of the CCA it is very likely that they are interdependent. When tested with Pearson's Chi-squared test they were statistically significant (p = 1.047e-05).

Root depth and rock type are almost significantly correlated (Anova, p = 0.0821).

Further statistical analysis was performed to investigate whether certain species were significantly correlated to abiotic factors as suggested by the results of the CCA.

Since the vegetation was taken down in cover percentages the data is not normally distributed. Because of this a Generalized Linear Model (glm) with a binomial, or in case of overdispersion a quasibinomial, error structure was used to check for a significant relation between the vegetation species and the abiotic variables. We checked for a significant relation between on the one hand *Piptochaetium featherstoni* and on the other grazing intensity as well as degradation state. Between *Piptochaetium featherstoni* and grazing intensity, this returned a p-value of 0.0178, meaning a significant relation is present. A significant relation between *Piptochaetium featherstoni* and degradation state was also found, with a p-value of 0.0381.

Next we looked at the species *Bidens andicola*, also using a glm with quasibinomial error structure. No significant relationship was found between *Bidens andicola* and degradation state (p-value of 0.141), but one was found with crust (p-value of 0.00382).

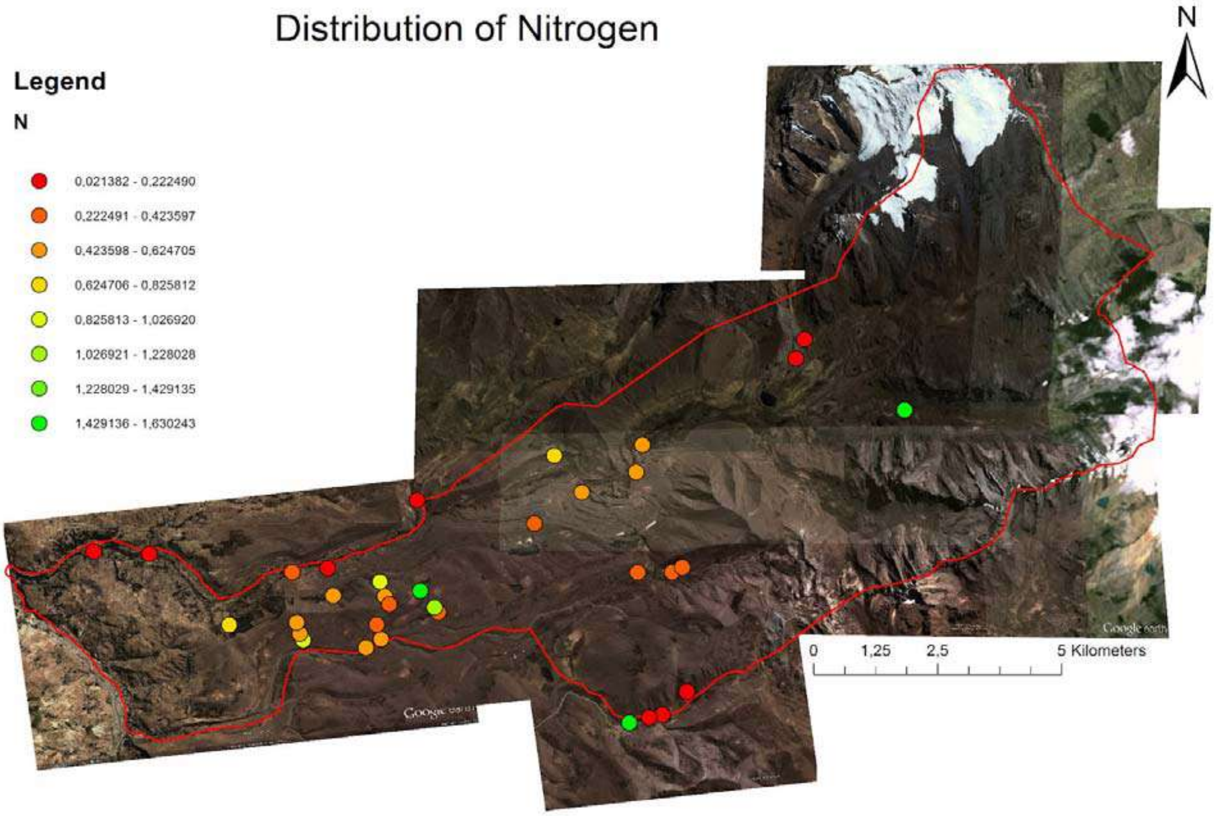
The species *Matucana yanganucensis* is positively correlated with abiotic factor crust (p-value of 0.000825). A glm gives a significant relation for "*Starplant*" and rockfall, however when looking closely at the data we can see that the model does not have a good fit. One outlier in the data is mostly responsible for this relationship and, when omitted from the data, there is no significant relationship between these variables anymore. *Calceolaria* spec is not significantly correlated to slope angle ($p = 0.29$).

Another species indicated by the CCA to be possibly correlated to degradation state, grazing intensity and internal drainage is *Bartsia diffusa*. Further testing indicates that there is no significant correlation between the species and these environmental variables. The species *Alchemilla pinnata* and abiotic factor water availability are also uncorrelated.

DISTRIBUTION OF ABIOTIC FACTORS

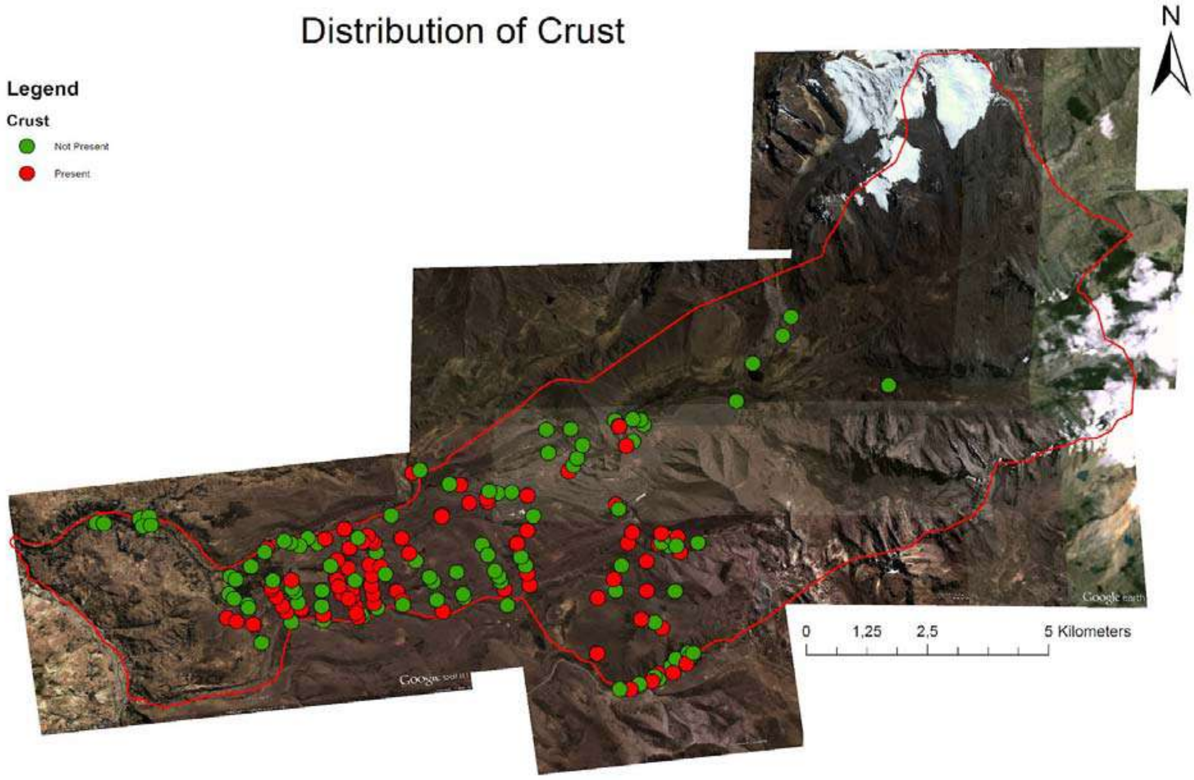
After mapping all data available on the different abiotic factors, a selection was made of the distributions with interesting results. These results are briefly reported in this section. Possible reasons for these results will be described in the discussion.

NITROGEN

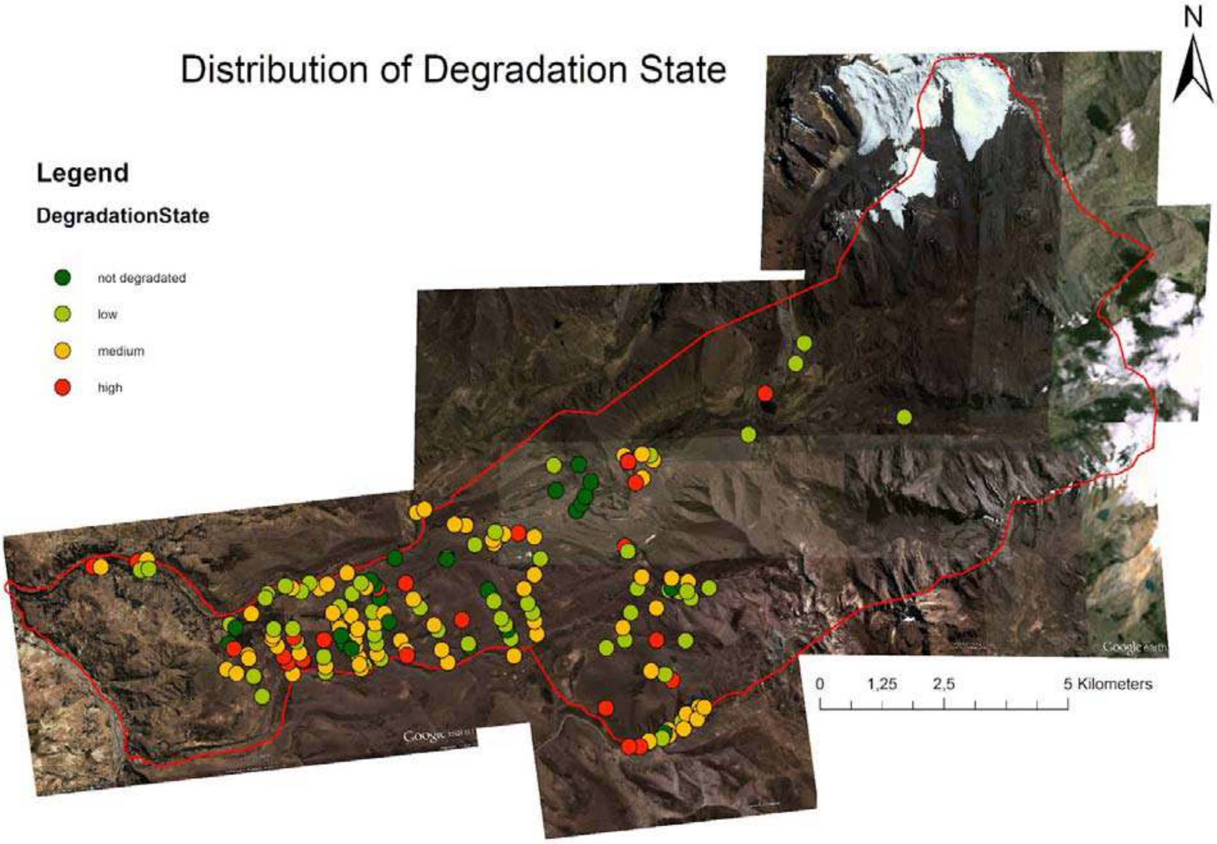


Although nitrogen is only measured at the points where soil samples were taken, some interesting results have been found when mapping the distribution. Low nitrogen values in the northern part of the fieldwork area are found mainly in soils close to the r*io Negra*, which is also the border of the fieldwork area. The other low values of nitrogen are found in the southern part of the fieldwork area, also located near a river.

CRUST

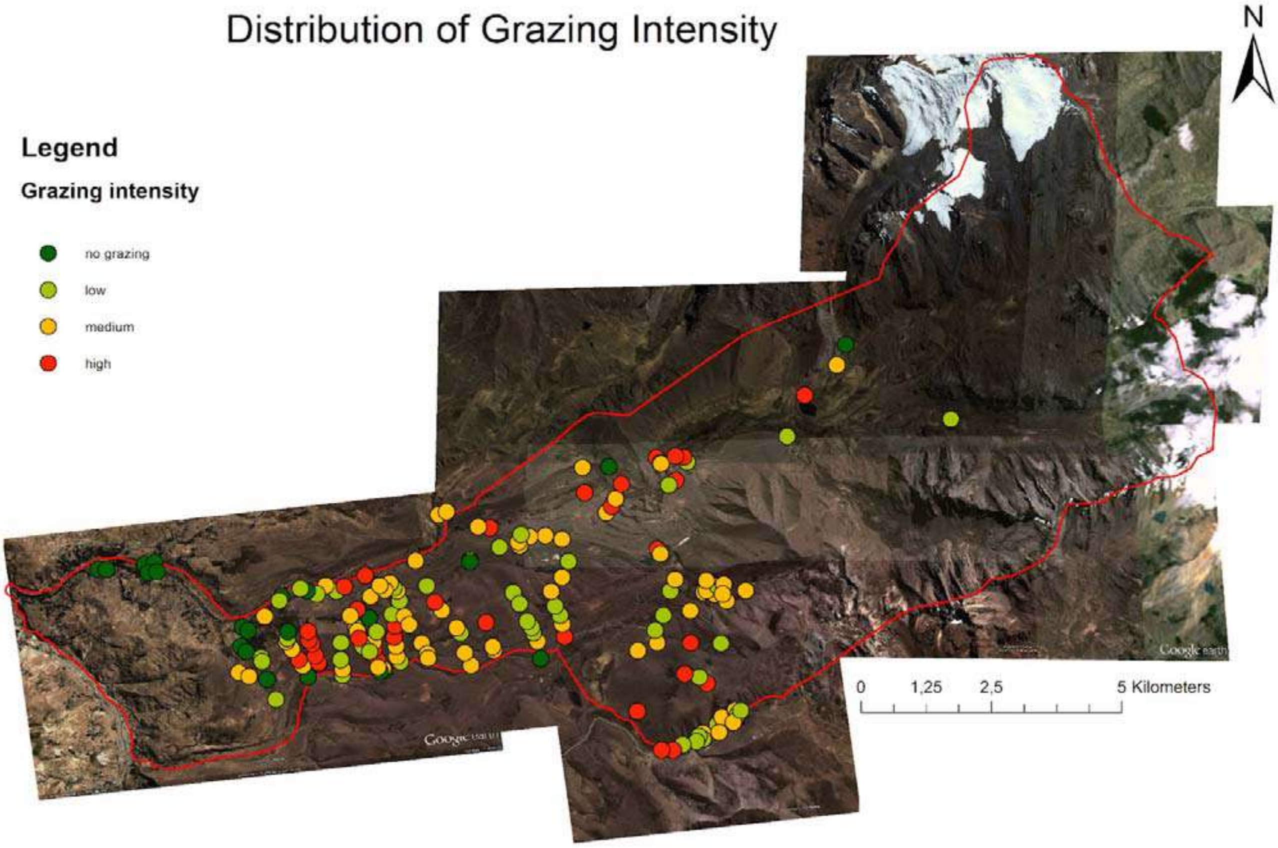


Crust seems to be abundant throughout the entire area. Sample sites with and without crust are evenly distributed throughout the area, with no signs of differences between different substrate and other factors.



The distribution of the degradation state clearly shows that the average degradation state of the soil is low to medium. With a few locations in which there is high degradation. The spatial distribution of the degradation state is evidently evenly spread.

GRAZING INTENSITY



Grazing intensity appears to be evenly distributed among the area, with the exception of the southwestern portion of the fieldwork area. The measurements in this area show a lower grazing intensity, especially in the points near human settlement.

DISCUSSION

Relationships between abiotic factors

The results obtained from the data exploration showed a lot of interesting information. Also the results of the spatial distribution of abiotic factors in the *Canray chico* catchment showed some interesting factors. Possible reasons for the distribution of the data will be discussed in this section.

LITHOLOGY

The distribution of the lithology is as to be expected from an area heavily influenced by glacial processes. On the slopes, mostly subglacial till is found, while the valleys are mostly covered by ablation till. This is due to the nature of those types of till, as explained by (Dreimanis 1989) and more recently by (Evans 2006). Unconsolidated gravel can be found throughout the area.

INTERNAL DRAINAGE

The high level of internal drainage in the plots taken on unconsolidated gravel can be attributed to the nature of such a lithology type. Unconsolidated gravel has an internal drainage that is per definition high, because it lacks the soil properties to store high amounts of water. The differences between the occurrence of internal drainage on subglacial and ablation till are not so large.

CRUST

The distribution of crust in the area showed an even heterogeneous distribution, with thus a large amount of crust present in the area. As crust can be an indicator of bad soil quality, this result shows the poor state that large parts of the area are in.

Possible reasons for the distribution of crust can be the differences in the internal drainage. A low internal drainage leads to more stationary water, keeping the soil wetter. This in turn results in less crust formation. It could be interesting to see how the grazing pressure throughout the area affects the soil crust and internal drainage, since effects of grazing can be substantial (Graetz & Tongway, 2006). For this there is more detailed information necessary on the grazing intensity than the information obtained in the field from this study.

NITROGEN

The main point of interest in the distribution of nitrogen is the fact that measurements close to the river were a lot lower than those taken further from the river. It is also remarkable that nitrogen in the soil is a lot lower closer to human settlements, when compared to the more pristine areas in the higher Andes. The higher amount of Nitrogen due to human influence was also described in a Mediterranean setting by the European Commission (2007). The low values of nitrogen in the soil might be explained by the increased discharge of nitrogen in that area.

DEGRADATION STATE

The degradation state of the soil in the area is heterogeneously distributed, when looking at the distribution map. This means that it is not possible to pinpoint a certain reason for the difference in degradation in the area. It is only possible to say that the whole area is degraded, with differences in the state of degradation throughout the area. Although overall there are a lot of places with a high degradation state, there are also places with a lower degradation state. Further studying those sites with low or no degradation might help in the future management of the area.

The high state of degradation in the catchment is possibly due to extensive grazing in an area with low nutrients (as most high mountain areas). The fact that degradation state and grazing intensity are interdependent, as tested using a Pearman's chi-squared test, may also have to do with the method of the fieldwork. When assessing the degradation state, grazing intensity was commonly used as a component herein. While degradation state also encompasses other aspects such as soil crusting, aggregate stability and drought stress, it may very well be possible that not all groups have determined the degradation state based on all of these factors and not only on grazing intensity.

GRAZING INTENSITY

The interesting thing in the map of the grazing intensity is the lower grazing intensity shown on the left side of the map in contrast to the rest of the map. Those points with low to none grazing were taken near villages. This suggests that livestock is mainly grazing higher in the mountains.

There is reason to suspect that there has been some subjectivity in assigning the grazing intensity to the four categories. Differences between groups are sometimes larger than you would expect based on the geographical distance of the different field sites. More information on grazing practices from the local residents could prove to be helpful in the future.

LINK BETWEEN ABIOTIC FACTORS AND SOIL QUALITY

Literature shows that there is a clear relationship between important abiotic factors and the quality of soils. (Arshad et al., 2009) While many abiotic factors play a role in soil quality, the focus in this paper lies on those, which have been measured during the fieldwork.

Nitrogen plays a major role in the determination of soil quality. It is a vital element for vegetation and is often the limiting factor in the spread of plants. Nitrogen is also a decisive factor for the composition of vegetation, because of different nitrogen requirements of different plants. High nitrogen content often means that the soil quality in an area is high.

Besides nitrogen, the availability of water is also an important factor in the quality of soils, because it is vital for sustaining vegetation. Water availability is determined by several factors including soil structure and texture. And has been measured during the fieldwork.

Together with nitrogen and the hydrology of the soil, the pH and electro conductivity also play a large role in the quality of soils. The pH has large influence on the solvability of many nutrients, and thus on the nutrient availability. Electro conductivity gives an indication of the salinity of soil, which influences vegetation as well.

The formation of crust also plays a role in the soil quality. Soil crust is formed when soil dries out during dry periods and has many negative effects on the quality of soil. The crust blocks water infiltration and exchange between atmosphere and soil. An extra problem occurs when vegetation tries to seed in areas with crust, because germination cannot get through to the surface.

POSSIBLE INDICATOR SPECIES

A number of different species come forward as indicator species in the analysis of the fieldwork data. Most clear is the relationship between *Piptochaetium featherstoni* and the variables degradation state and grazing intensity. A positive correlation was found between *Piptochaetium featherstoni* and these variables, meaning that there is a higher chance of the species being present at sites with an elevated degradation state or abundant grazing. This makes the species a useful indicator for disturbance and vulnerable sites.

A relationship can also be found between *Bidens andicola* and the presence of crust, as well as *Matucana yanganucensis* and presence of crust.. While both *Bidens andicola* and *Matucana yanganucensis* are not directly related to Internal Drainage (p = 0.0856, p = 0.835), they may still be indicative for hydrology aspects in which crust plays an important role. The relationship with crust and *Matucana yanganucensis* might be expected. *Matucana* is a succulent and flourishes on dryer soils, which are exactly the soils were crust might be expected.

Fig. 8 *Piptochaetium featherstoni*

Fig. 9 *Matucana yanganucensis*

CONCLUSION

Degradation, crusting, grazing and other abiotic factors in the *Canray Chico* catchment seem to be distributed quite evenly throughout the area with many of these variables showing occurrences on different locations in the area. Several factors, such as nitrogen show a clear spatial differentiation, indicating differences in the state of the soil and environment.

Between the various abiotic factors, relationships have been found, linking several of these factors together. The clearest relationship is the one between the grazing intensity of an area and its degradation state. A strong positive correlation was found between these two variables. A clear relation was also found between the presence of unconsolidated gravel and high internal drainage.

Several indicator species have been determined based on the relationship between the vegetation and the abiotic factors. *Piptochaetium featherstoni* shows a clear correlation with both the degradation state and the grazing intensity, while both *Bidens andicola* and *Matucana yanganucensis* show a correlation with the presence of soil crust.

FUTURE RESEARCH

Several recommendations for future research can be proposed based on the results and discussion of this paper.

It would be worthwhile to do an in depth sampling of the soil in the entire fieldwork area to have a full coverage of the nitrogen, carbon and sulfur contents of the area. This would allow for in depth research of the pollution of the soil in the area. It would also shape a better image of the variations within the region, which was not possible with the limited data to our disposal for this paper.

It is also advisable to do more research into the grazing pressure on the area, by tracking the cattle and better inventorying the grazing intensities of the area. This could lead to more information regarding the influence of grazing on the soil quality in the *Canray Chico* area.

Further analysis of the relation between vegetation and abiotic factors would also be beneficial, because this paper only focused on the relationship between individual species and environmental variables, while looking at plant functional groups could lead to more results.

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APPENDICES

APPENDIX A: FIELDFORM DESCRIPTION

General				
site ID [initials _plotnumber]			X [..°..'.." S]	
date [year _ month _ day]			Y [..°..'.." W]	
slope angle [°]			Z [m]	
aspect			Position Valley [VAL/SLO/TOP]	
picture				

The site ID consists of the first letters of the name of the group members followed by the plotnumber of that day. The slope angle and aspect were measured using a geological compass. The coordinates were estimated using GPS handheld.

Vegetation			
Distribution		Number of different species	
1 even | 2 patch s | 3 patch l | 4 isolated		Number of endemic species	
		Drought Stress	
Indicator species:	Cover [%]:	Total vegetation cover [%]	

	Amount	Cover [%]:
trees		
shrubs		
herbs (flowers)		
grasses		
lichens		
succulents		
bare		
bedrock		
rocks		
moss		

The distribution of the vegetation was estimated by eye in a 5m radius from the sample point. The species most indicative for the sample area were noted and their percentage cover within the 5m radius was noted (NB. The sum of the cover of these indicator species can exceed the 100% due to an overlap in the field. Eg. Bigger plants growing on top of smaller ones.). Drought stress was indicated with a 1 for present of a 0 for absent.

Geomorphological Processes	
0 = none | 1 = low | 2 = medium | 3 = high	
Rockfall	
Slump	
Gully erosion	
Solifluction	
Rill erosion	
Frost Heaving/Sorting	
Peculiar Weathering	
Degradation state	

Lithology		
Lithology type:		
1. Subglacial Till	6. Granite	11. Fluvioglacialtill
2. Ablation Till	7. Sandstone	
3. Uncon. Gravel	8. Shales	
4. Ignimbrite	9. Pyritic	
5. Quartzite	10. Lacustrine	
Rocks		
Rock Type(s)		
1. Intrusive	3. Sedimentary	5. Metamorphic
2. Extrusive	4. Sedimentary CR	

Geomorphological processes were indicated with a number between 0 for absent to 3 for high. Lithology and rocks can have multiple numbers; if for instance 1 and 2 are correct, 12 is noted.

Human influences		Landform	
None = 0 | Low = 1 | Medium = 2 | High = 3		Landform type:	
Grazing intensity		1. Outwash fan	
Fire damage		2. Boulders > 2m2	
Plough erosion		3. Lateral Moraine	
Preventive measures?		4. Ground Moraine Plain	
Agricultural product		5. Terminal Moraine	
Eutrophication signs [0/1]		6. Recessional Moraine	
		7. Medial Moraine	
		8. Alluvial fan	
		9. Debris cone	
		10. Ancient lake	

The human influences were also indicated with a number between 0 for none and 3 for high. Preventive measures were noted if measures were taken to counteract erosion (terraces for instance). The agricultural product was noted if present (wheat for instance). With landform types a combination of types was also possible, this was noted with a combination of numbers (eg. 1 and 3 becomes 13).

Soil				
Horizons:	Depth [cm]:	Colour:	Structure:	Texture:

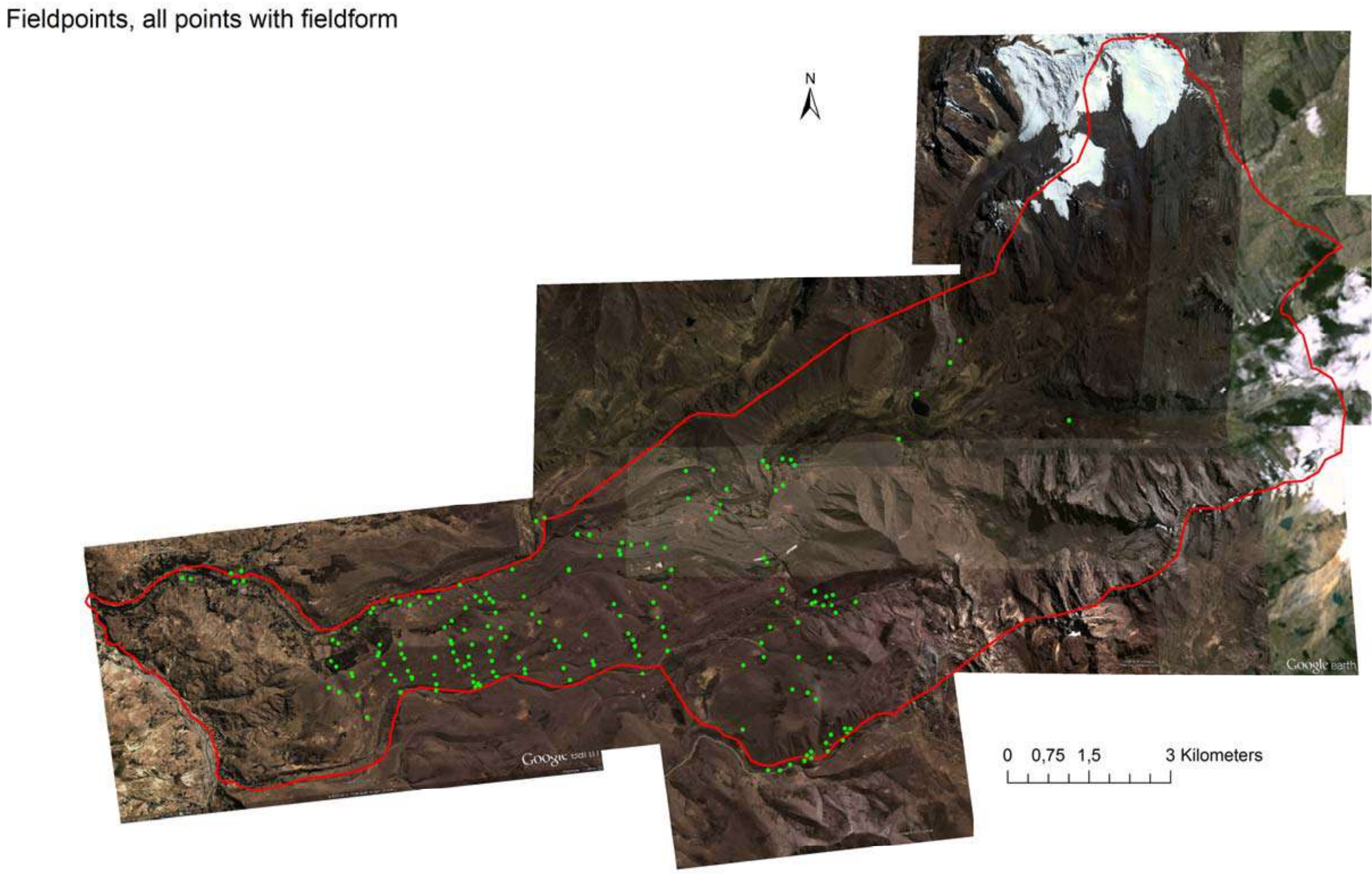
After the soil profile was bared, an estimate of the profile was made. The depth was the depth of the end of the soil profile. The colour, structure and texture were estimated using a Munsell scale.

Land use						Water quality	
Land use type:						EC [μS/cm]	
						Water pH	
						Water sample [0/1]	
1. Settlements							
2. Agriculture						**Hydrology**	
3. Abandoned Agriculture						Stream order	
4. Forest						Source	
5. Grassland						Swamp / Wetland	
6. Fallow						Temporary Swamp	
7. Bare Rock						Overland flow	

The land use type could also be a combination of types (as before). If water was present the water quality was measured in the field if possible, otherwise a water sample was taken. The name of the sample was the same as the site ID, but with an extra 'w'. With hydrology the stream order could have a number between 1 and 4, with 4 also for a higher order. The other hydrology factors could be noted with a 1 for present and a 0 for absent.

APPENDIX B: FIELDPOINTS

In the picture are all fieldpoints shown that were taken during the three weeks of field work.



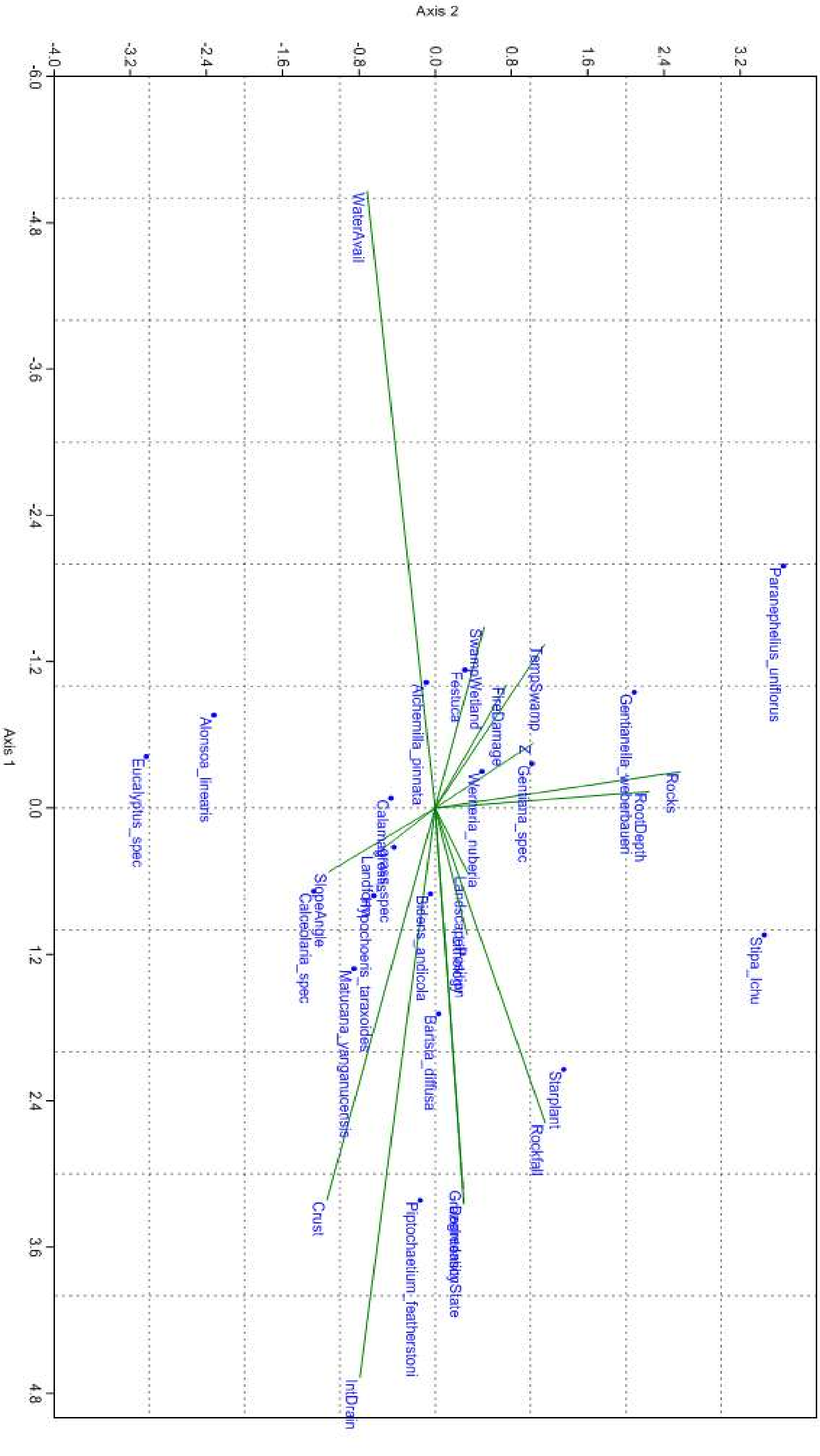
APPENDIX C: HERBARIUM LATIN NAMES

The following species were found in the field work area, and were used for possible correlations with abiotic factors. The species with an asterix (*) were species that occurred at least 10 times during the research. Those species were used for the actual analysis.

Monnina salicifolia
*Alonsoa linearis**
Rumex spec
Minthostachys mollis o andina
*Werneria nubigena**
Astragalus garbancillo
*Bartsia diffusa**
Senecio comosus
Calceolaria spec*
*Hypochoeris taraxacoides**
*Paranephelius uniflorus**
*Bidens andicola**
*Matucana yanganucensis**
Trifolium repens
Plantago australis v hirtella
*Calamagrostis**
*Stipa ichu**
*Festuca**
Lupinus spec
Orthrosanthus chimborocensis
familia: Bacharis
Berberies lutea
Margyricarpus spec
gentiana spec*
Gentianella weberbaueri
Grama achu
Pinus spec
Grass spec*
*Alchemilla pinnata**
Baccharis spec
*Eucalyptus spec**
Achichne pulvinata
*Piptochaetium featherstoni**
Opuntia floccosa
Triticum spec
plantago rigida
Quinchamalium spec
Senecio canescens
Juncus bruneus
Achyrocline alata
Family*: pteridophyta*

Perezia multiflora
Agave spec
Carpinus betulus
Reed spec
Epilobium parviflorum

APPENDIX D: CCA


Axis 2
Axis 1
WaterAvail
Paranephelius_uniflorus
Stipa_ichu
Gentianella_weberbaueri
Rocks
RootDepth
Gentiana_spec
TempSwamp
SwampWetland
FireDamage
Festuca
Alchemilla_pinnata
Werneria_nuberia
Alonsoa_linearis
Eucalyptus_spec
SlopeAngle
Calceolaria_spec
Hypochoeris_taraxoides
Matucana_yanganucensis
Bidens_andicola
Bartsia_diffusa
Starplant
Rockfall
Crust
Piptochaetium_featherstoni
InDrain