Preliminary investigation of Aquatic Macro-Invertebrate Biodiversity in the Gairloch Hill Lochs, Wester-Ross Shire

Vu H. Dang – M00262288

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Acknowledgements

This report was written with the aim of investigating the aquatic macro-invertebrates biodiversity of Lochs at varying altitudes, located in the Gairloch district, Wester Ross Shire, Scotland. Sampling of the Lochs was done using the Pond Action method (Pond action 1986). Environmental data were recorded on site and gathered using secondary sources. The macro-invertebrate samples were identified using literature keys and the species information was compiled with the environmental data to produce baseline records for the Gairloch district. The species presence/absence information was run through the cluster analyses programs TWINSPAN and DECORANA and the information was also used to quantify a measurement of biodiversity for each loch. Correlation analyses were undertaken to determine trends in the environmental baseline data to investigate what the primary influences may be on the biodiversity of these aquatic macro-invertebrates. The results indicate the biodiversity levels vary from loch to loch, some more markedly than others. The degree of spread of abundance of each species in a loch however is more similar throughout the samples and may be influenced by the presence of floating vegetation. The primary influences on species selection, thus the biodiversity for each loch, have been determined to be water pH, water conductivity, the altitude of the loch and the presence or absence of fish.

Contents

0. Figure & Table title list

1. Introduction

1.1 Biodiversity. The concept of *biodiversity* should be understood in both practical terms and statistical terms, since the exact definition of *biodiversity* is often subjective in meaning, especially when referred to as a statistical measurement (Harper and Hawksworth, 1995). This has logical basis since biodiversity really encompasses many aspects of communities in their respective biomes. In a practical sense, biodiversity combines all the aspects of a particular community of organisms that have some level of interaction with each other within a geographic area at the same time. Biodiversity is highly dependent on the environmental selection, meaning that as the environment differs, so does the species that are part of that community, some may adapt, others will 'lose', while others may 'win'.

1.2 Climate change. Climate change is an issue that is still progressing. It continues to change, regardless of human efforts to slow it down. Wigley (2001) wrote that since the 1800's greenhouse gas concentrations in the atmosphere have increased dramatically due to anthropogenic activity. At the same time the Earth's average surface temperature had increased by 0.7°C, and the evidence strongly suggests that the two are related. Smith (2001) states that this increase in temperature is responsible for the 10-25cm rise in the average global sea level. Such changes in global conditions can raise or decrease global temperature, as it does many of the Earth's environments will most likely change with it.

Whether this climate change is being encouraged by anthropogenic activity or not is not the issue of this report. What is important is that Climate change is seen as the biggest threat to the world's environments says Godrej (2002).

1.3 Highland biomes at risk. Upon high altitude mountainous terrain, temperature drops 0.6°C per 100m, Ford (1982). Should atmospheric temperatures increase in high altitude regions, organisms not adapted for warmer environments can only escape towards one direction, up; becoming trapped at ever higher altitudes until they are not able to gather resources necessary for survival. Disappearances of species in these situations have already been recorded and the evidence that describes their demise ultimately suggests climate change as a primary factor. Pounds and Crump (2002) reported that two species of high altitude frogs disappeared from Costa Rica's Monteverde Cloud Forest Preserve after 1987. The entire species of the Golden toad (*Bufo periglenes)* was endemic to the region and is now extinct, along with the local populations of Harlequin frog (*Atelopus varius*).

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They both hypothesised that climatic changes led to unnatural seasonal patterns and temperature increases that both frog species were unable either to escape or endure. Researchers examined a 30km^2 area in the region and were unable to establish the presence of 20 out of 50 indigenous frogs and toad species. Whether these disappearances resulted from extinctions or migrations, both could cause hunger ripple effects through food webs, not necessarily even of that habitat; or it may be beneficial to certain species, providing an access to new resources. In this case, the 'winners' are birds, Godrej (2002) reports fifteen bird species now occupy the cloud forests where they have never been seen before. If we could understand how communities respond to such drastic environmental changes, it may be possible to conserve them, possibly buffering effects that pose the community high risk.

Ford (1982) describes that one of the biggest fears and also a focus of this report is how climatic shifts will affect the biodiversity of organisms within a particular biome. A biome is characterised in terms of the dominant vegetation which has been selected to exist in the prevailing climatic conditions, for example a tropical rainforest biome or a savannah grassland biome; in this case, the interest lies with examining a Moorland heath biome, specifically the aquatic Lochs that are situated from Moor-lowland heath up to Lochs in high altitude Moorland heath. This biome was created by geologically recent glaciations; glacial ice removed surface sediments and eroded deep valleys that, in the current cool, wet climate encouraged formation of these characteristic oligotrophic lakes (Jeffries and Mills, 1990).

1.4 The Gairloch Hill Lochs. The moorland heath biome under scrutiny is in Gairloch, part of the Wester Ross area, in the highlands of North West Scotland. An area where much of the exposed geology consists of Scourian/Lewisian gneiss complexes (Harris, 1991). If regional temperature increased significantly, it could cause major risk to the current communities inhabiting the Gairloch hill Lochs. In order to conserve any ecosystem/community subject to influence of climate change it is necessary to carry out initial sampling of biotic and abiotic measurements to provide baseline data by which to judge effects of any regional climatic shift. Such biotic/environmental data can be examined for possible biodiversity trends in relation to climate shift. Resampling the same environment after a climatic shift would result in differences in data, permitting analysis and may suggest possible causality – in a perfect understanding, rather than simply anticipating climate change, it may be possible to predict how climatic changes affect high altitude environments. If this is possible, not only could many organisms and their respective communities be

conserved; the local public would benefit by conserving the way of life for many of who depend on it.

1.5 Objective. It should be said that this report cannot entail the latter of the previous paragraph, it describes the gathering and investigation of the baseline data, as to what may be current influences on the biodiversity of the aquatic macro-invertebrates found in the Gairloch hill Lochs.

The Gairloch hill Lochs, also known as the 'Loch Maree group', is an ideal location to do such investigations concerning high altitude aquatic environments. The lochs of concern are largely unexplored in this manner and outflow to the Atlantic Ocean. Within an area approximately $10km^2$ next to Gairloch, there are water bodies with varying attributes such as size, altitude, geology, pH, conductivity and the presence of fish are some examples, and so sampling varying Lochs of this area provides a wider scope for this investigation.

The aims of this current project are to investigate the Gairloch hill Lochs to quantify current levels of biodiversity of the aquatic macro-invertebrate (hereafter aquatic macro-inverts) communities to produce a baseline set of data prior to climate change for the regional area. Statistically analyse baseline data to determine likely environmental influences upon the biodiversity of these aquatic macro-invert communities in relation to their location and environment, and to suggest probable primary influences upon their biodiversity.

2. Methodology

2.1 Sampling method. The raw data of this research was obtained by two Wester Ross Fisheries trust volunteer workers lead by their mentor and his colleague. The fisheries trust Biologist, Peter Cunningham, collaborated with Dr Stephen Kett to decide which Lochs would provide best data to represent a Gairloch Hill Loch baseline (*refer to appendix 1*).

Lochs were visited on foot. Lochs closest to each other geographically were visited in groups over a four day period from 18/07/2012 - 21/07/2012. Weather was consistent throughout; sun and clouds with occasional drizzle.

At each site, a standard sweep sampling method (Pond Action Method 1986) was used to gather the sample of aquatic macro-inverts. The number of 'accessible' microhabitats was counted and had 3 minutes divided between them, for example a Loch with three microhabitats would be sweep sampled for 1 minute individually per microhabitat. Upon timing the sweep net was immediately emptied into a large tray containing the lake water so that large debris such as vegetation could be removed, taking care as to minimize any invertebrate loss. The samples were then placed in air tight plastic bottles filled with the water from their respective Lochs and taken back to the laboratory at the Wester Ross Fisheries Trust. There, the macro invertebrates were placed once again placed on trays, isolated and preserved inside the same plastic bottles, this time filled with 70% absolute ethanol diluted with 30% Scottish, Gairloch tap water. Environmental data was also measured on site such as water pH, conductivity, vegetation cover etc.

2.2 Identification. The preserved samples were driven down to a laboratory at the Middlesex University, London, where the majority of the samples were identified down to species level using the specialised literature keys and equipment necessary for entomological taxonomic classification. The equipment include a stereoscopic microscope equipped with a graticule eye piece, entomology pins, forceps, large pipettes, Some taxa which are notoriously tedious to identify down to species were grouped as one taxon group to meet time constraints. This provided the species list for each Loch, which contains the number of different species for each Loch and the abundance of each species.

2.3 Geological and geographical measurements. Secondary geological data was obtained from maps and the use of the program Google Earth (©2010 Google™)

provided satellite imaging to gather geographical information such as the distance to the nearest town and the distance between Lochs for example.

The accumulation of the raw data include the environmental data gathered on site, the species list identified in the laboratory and the geological and geographical data gathered from geo-maps and satellite imagining together provide the baseline data for the Gairloch hill Lochs before climate change. For the accumulation of the raw baseline data, refer to *appendix 4* (CD enclosed at the back).

2.4 Analyses and statistical methods. The species list was then run through two algorithmic programs TWINSPAN and DECORANA. For the raw TWINSPAN and DECORANA results output, refer to *appendixes 1.3* and *1.4* respectively.

Simpson's D Index of biodiversity was used to calculate a measure of biodiversity for each loch's aquatic macro-invert community.

All statistical analysis for this report was done using Minitab® v16.2.2, © 2010 Minitab Inc.

To analyse environmental statistics for trends, Pearson's Correlation analysis was carried out for parametric data sets and Spearman's Rank Correlation was undertaken for non-parametric data sets.

Testing for differences between lochs was done using 2-Sample t-test where the data in question was both parametric and equal in variances. Where the variances were equal for non-parametric data, the Mann-Whitney test was used to test for difference.

3.   Results

Due to constraints on the report only the significant results will be discussed. All the insignificant results (including those deemed coincidental) and the tests and graphs required to validate the choice of statistical tests (such as the normality tests) can be found throughout *appendix 1*.

3.1 Biodiversity measurements:
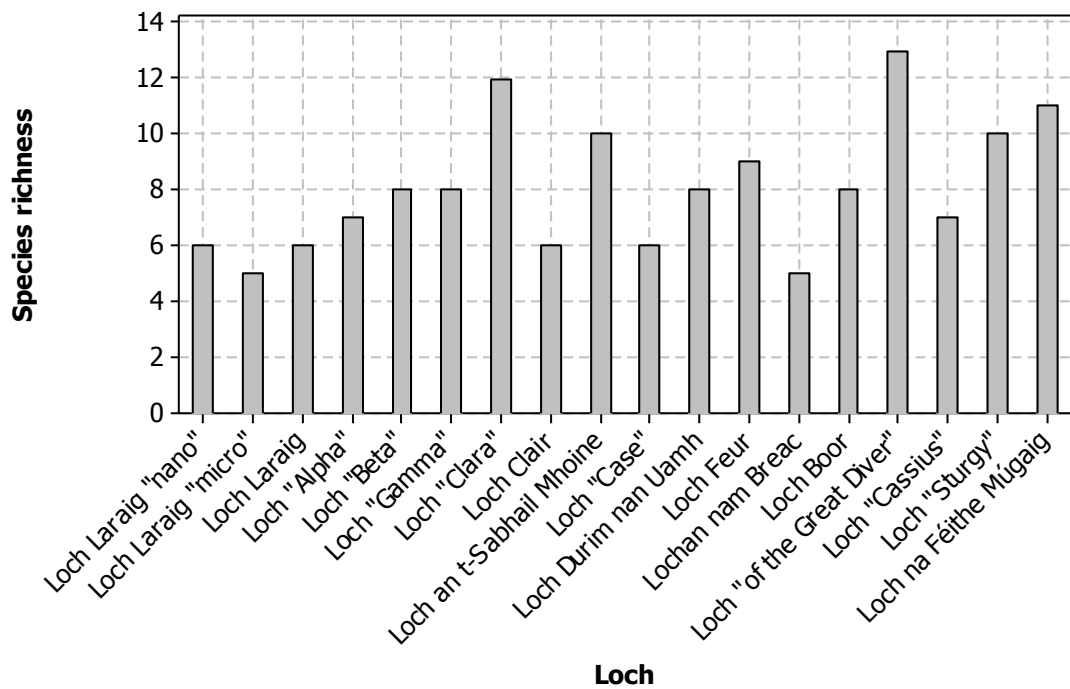
Figure 3.1.1: Measured species richness for each Loch sample illustrating the number of different macro-invert species obtained in each sample.

Figure 3.1.1 presents a column graph for the biodiversity for each sample in respect to their species richness. This is the number of different species sampled at each Loch. The lowest species richness recorded was 5 for Loch Laraig "nano" and Lochan nam Breac. Loch "of the Great Diver" had the highest species richness of 13. A significant difference between the highest and lowest indicates there may be something influencing the species richness of these lochs.
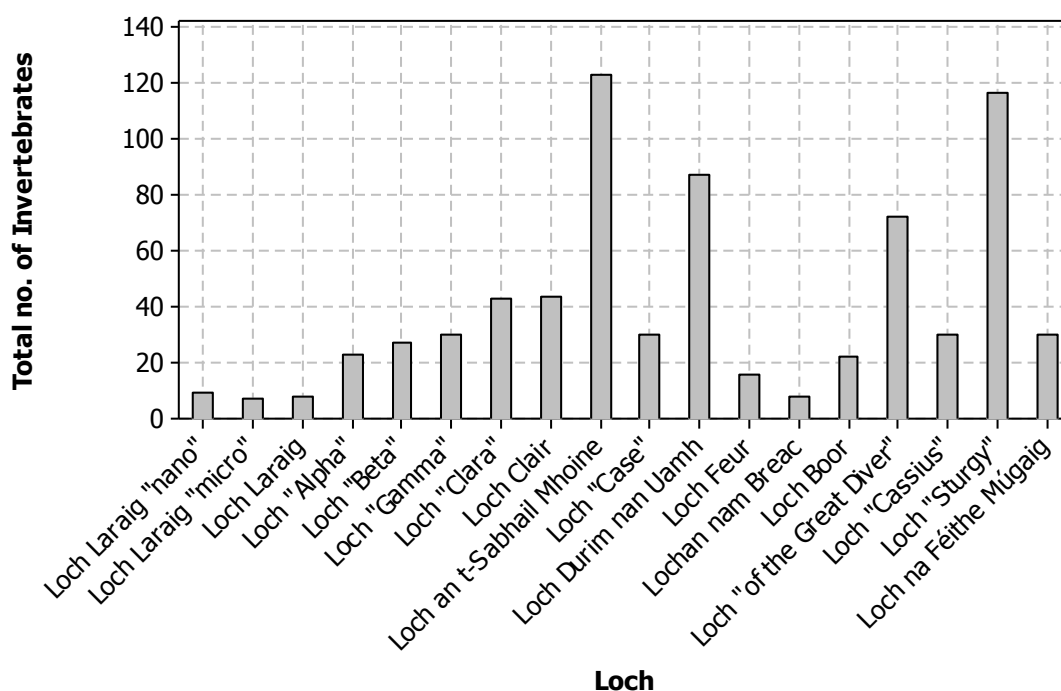
Figure 3.1.2: Total number of individual aquatic macro-inverts sampled from each loch.

Figure 3.1.2 shows the total abundance of invertebrates obtained in each sample. Loch an t-Sabhail Mhoine had the highest reading of 123, much greater than the majority of the samples. The lowest number of organisms sampled was 7 for Loch Laraig "micro". Such a variance between the two could be influenced by environmental factors.
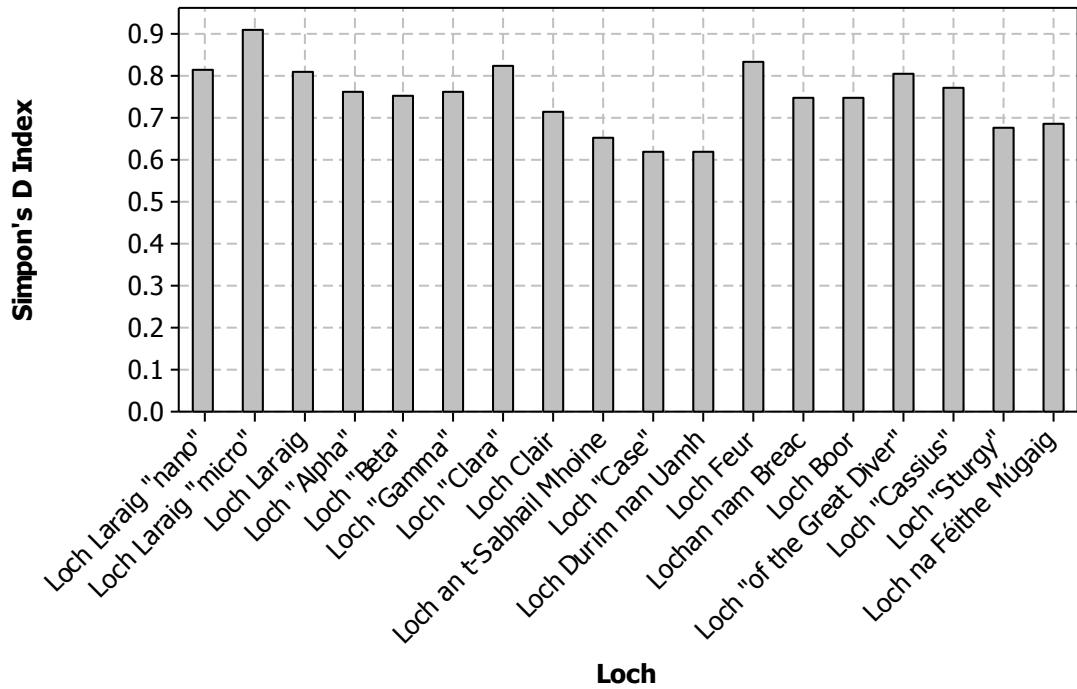
Figure 3.1.3: Calculated Simpson's D Index for each sample showing the relative levels of proportional abundance of each species within each sample.

The levels of biodiversity (in terms of proportional abundance of species within the samples) do have some variability but show a much less variance, *figure 3.1.3* shows the lowest value being 0.62 calculated for Lochs "Case" and Durim nan Uamh, while the highest value obtained was 0.91 for Loch Laraig "micro". The differences between the samples are not erratic, and indicate spread of abundance of species throughout Gairloch is fairly typical.
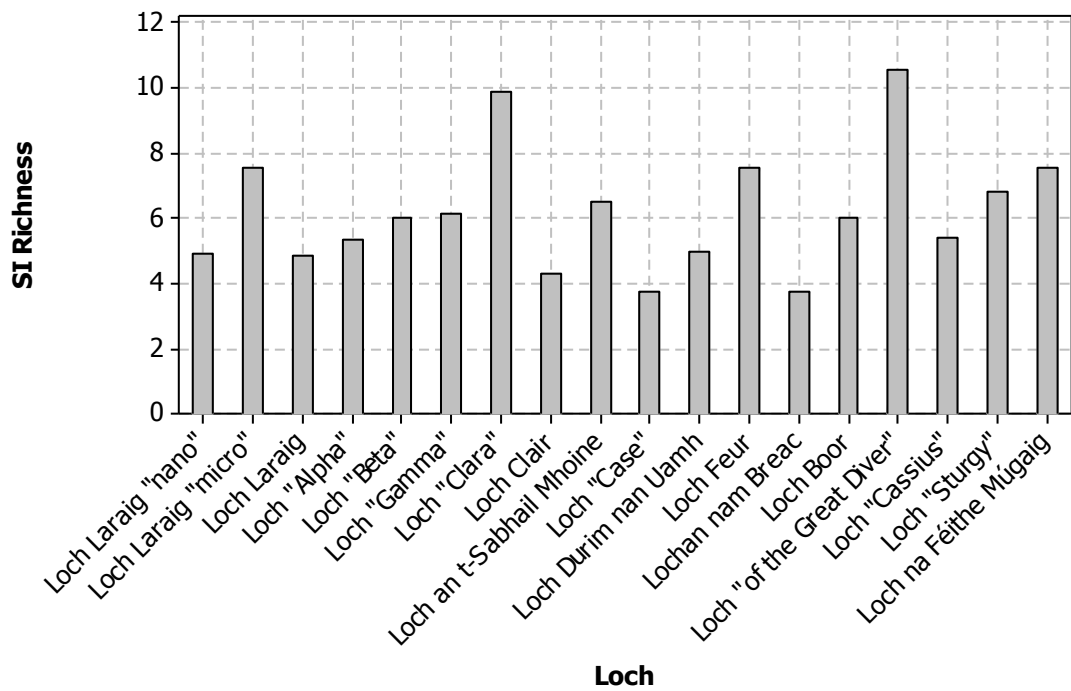
Figure 3.1.4: SI Richness for each Loch, reflecting the levels of biodiversity for each
sample in terms of proportional spread of abundance and species richness.

The biodiversity is suggested to vary markedly between the Lochs by *figure 3.1.4*.
The highest value was 10.5 calculated for Loch "of the Great Diver"; the lowest
reading belonged to Lochan nam Breac at 3.75.

3.2 TWINSPAN output results:
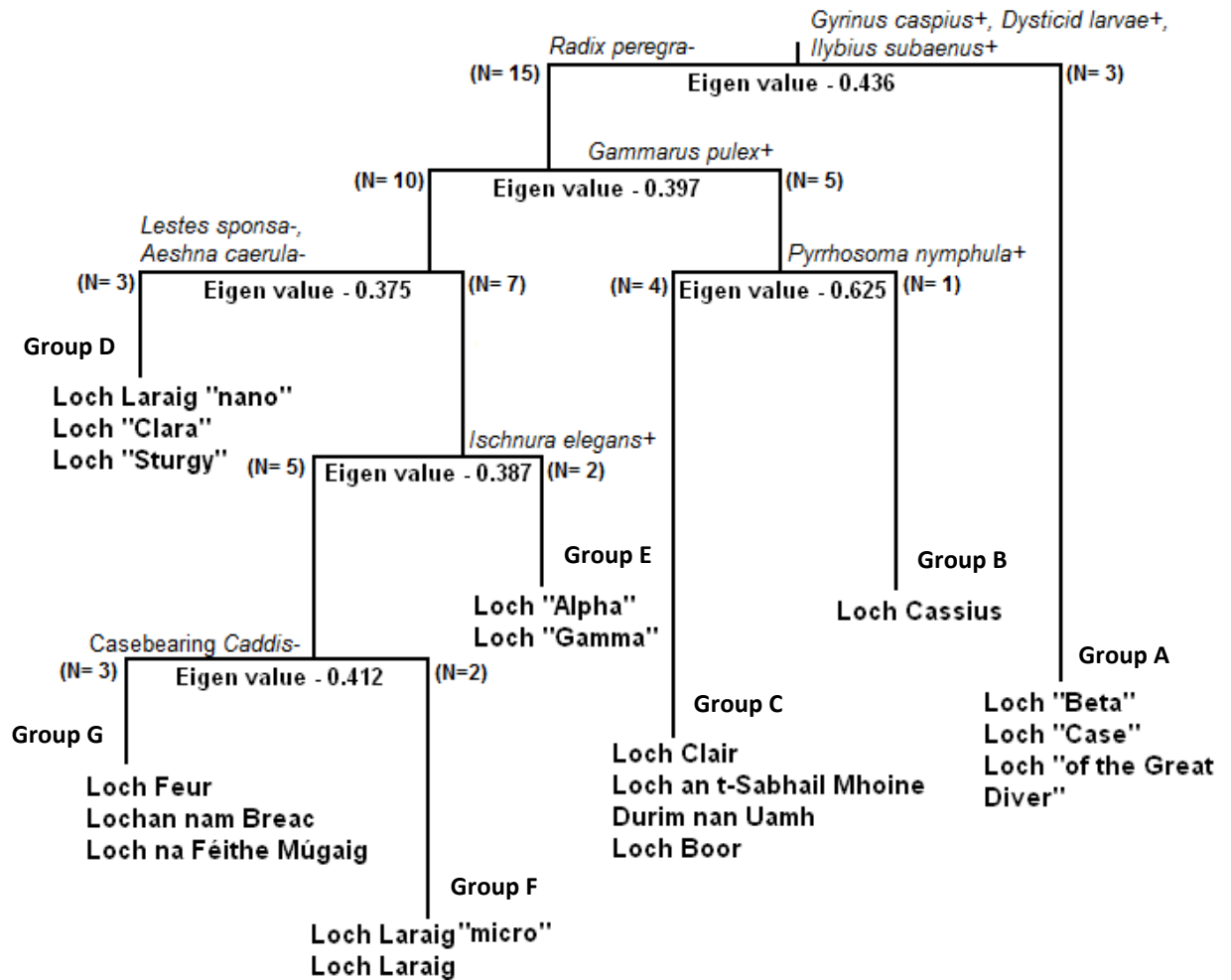
Figure 3.2.1: TWINSPAN results – A dendrogram illustrating the Lochs clustered in groups by similarity of species content. N represents the number of samples on either side of each division.

The TWINSPAN analysis shown in *figure 3.2.1* divided the Lochs into 7 clusters using species presence/absence data obtained from the identification of the macro-invertebrates of each Loch. Eigen values varied between the lochs indicating some division are more likely to reflect some real significance than others.

3.3 DECORANA output results:
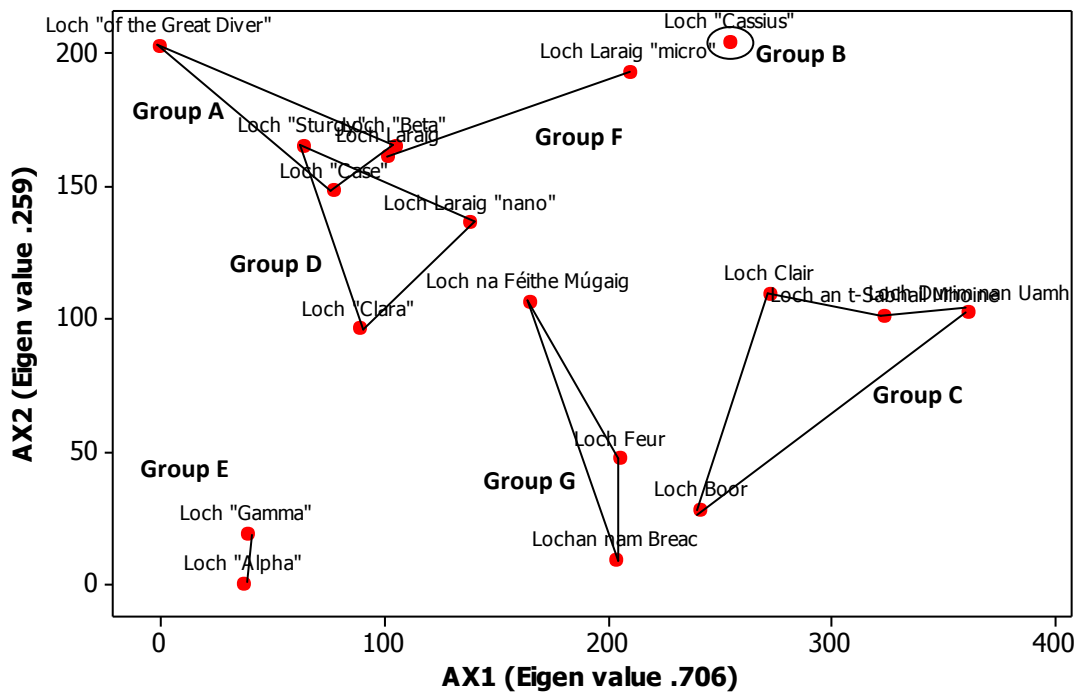
Figure 3.3.1: DECORANA results for the two axes with the highest Eigen values for each Loch.

The DECORANA analysis attempts to validate the results of TWINSPAN by improving on underlying factors within the algorithmic calculations of TWINSPAN, this validation is visual on a scatterplot if the same Groups can be joined together without any groups overlapping each other. *Figure 3.3.1* displays the results, most clusters seem valid while Groups A and D overlap suggesting possible error in the clustering of these groups.

3.4 Environmental results: All environmental measurements for each Loch sampled and the statistical manipulations used for each test can be found in the *appendix 4*.

Table 3.4.1: Environmental variables measured for each sampling site.

Environmental variables

Water pH	Surrounding land use
Water Conductivity (s/m)	Adjacent water bodies
Altitude (m)	Presence of amphibians
Surface Area (m^2)	Presence of fish
Distance to nearest town (km)	Plant cover
Inflow count and total width	Clarity
Outflow count and total width	Colour
Bedrock Geology	Pollution

Table 3.4.1 displays a list of the environmental variables measured for each site. Each variable was analysed to find any strong correlations between the variables and AX1 and AX2, correlations were also considered between the variables.

3.5 Pearson's and Spearman's Rank Correlation analysis:

Table 3.5.1: Significant results from Pearson's correlations for parametric variables

Variable 1	Variable 2	P-value	r value
AX1	pH	0.003	0.656
pH	SLU 25-100m MLH	0.010	0.589
pH	SLU 25-100m ERF	0.010	-0.589
pH	Distance to nearest town (km)	0.002	-0.674

Table 3.5.1 presents variables that demonstrated significant correlations. AX1 is correlated with pH, the surrounding land use (SLU) between 25-100m and the distance to the nearest town. pH also correlates with the same range of SLU, the distance to the nearest town and the number of adjacent water bodies (AWB) at a range between 250-500m.

Table 3.5.2: Significant results from Spearman's Rank correlations for non-parametric variables

Variable 1	Variable 2	P-value	r value
AX1	Conductivity (s/m)	0.001	0.573
AX2	Altitude	0.005	0.468
Species Richness	Inflow count	0.050	0.326
Simpson's D Index	Floating PC	0.050	0.351
Conductivity (s/m)	pH	0.001	0.824

Table 3.5.2 displays all the significant correlations between the ranked environmental data sets. The ranked values proposed many significant correlations. All non-parametric correlations reinforce the correlations made between the parametric data. Those deemed either insignificant or coincidental are not further mentioned due to constraints on the report. All of the correlation analysis can be found in the *appendix 1.6*.

4. Discussion

4.1 Biodiversity. Consider the aquatic biome of these mid to high altitude Lochs, they will likely have different numbers of different species, this is easily seen as a measurement of diversity and so enters the statistical definitions, but even within the same species there may be population diversity, there is also the abundance of each species and how proportionate that is to other species in its community. It is also very likely that there are still more fundamental aspects of biodiversity that still aren't perceived yet.

Harper and Hawksworth (1995) wrote that species richness is the number of species within a community of organisms, its one of the first attempts to measure biodiversity. Species richness is objective but it lacks the consideration of other communal properties, nonetheless it is a key premise for the concept of biodiversity.

The mean Species richness for all aquatic macro-invert samples is 8.056 (*figure 3.1.1*) however, viewing this as a standalone value can be misleading. Practically, it implies that in any hill loch there 'should be' least 8 different species of organisms; however it is clear in *figure 3.1.1* that some Lochs had species richness above and below 8. Taking into account standard deviation provides a basis for how much higher or lower on average the values can be around the mean. The standard deviation for species richness across the lochs is 2.36. By considering the mean and the standard deviation, it means that most of these lochs will have species richness on average between 6 and 10, with a few outside this range.

Species richness showed a positive correlation with the number of inflows per loch (*refer to table 3.5.2*). It may be that surrounding lochs that provide inflows to others may have different environmental factors such as geology; this may provide suitable breeding grounds for specific species that then enter the loch of inquiry through an inflow. If the two lochs have enough differences to harbour different species, but are similar enough that some may be able to survive with each other, then inflows may provide a pathway for such species to co-exist.

The total number of invertebrates sampled for each site is presented in *figure 3.1.2*. The values represent the total abundance of invertebrates for each loch. The graph indicates that most lochs have similar abundances of aquatic macro-inverts, Lochs an t-Sabhail Mhoine (highest abundance of 123), Durim nan Uamh (87), "of the great diver" (72) and "Sturgy" (117) outstood the other samples.

Another important variable when considering biodiversity is the relative spread of abundance of organisms within a species in proportion to the other species within a community. For example take hypothetical Habitat A that has 10 species, 9 of which have relatively low abundance and so are very rare to see, while 1 species has a large population and so is commonly in sight; now consider hypothetical Habitat B that has 5 species, all of which are just as common as each other; if you were to visit both hypothetical habitats, it would initially appear that Habitat B has more diversity based on the apparent number of species visible. This concept of proportional spread of abundance is not taken into account with Species richness but should be considered when investigating ecological biodiversity.

The Simpson's D Index was introduced by Edward H. Simpson in 1949 to measure the proportional abundance when individuals are classified into types; this calculation effectively incorporates each species abundance as well as species richness of the sample – this may be viewed as an index of the spread of abundance. *Figure 3.1.3* shows the results for the Simpson's D Index calculated for each sample – note that the Simpson's D Index formula used for this investigation is simplified and is outlined in the *appendix 1.1*.

The mean Simpson's D Index for the aquatic macro-inverts in the Gairloch Hill Lochs is 0.75, with a standard deviation of 0.08. Not a low index for an average and the standard deviation is low which means the mean is more likely to occur; it suggests that the spread of abundance of species is more even throughout the samples of Lochs. If these Lochs are a true sample of Gairloch's region then it may possible to generalise these results to Gairloch itself and other environments similar to it.

The Simpson's D Index provides a value closer to 1.0 the more evenly spread the proportional abundance of each species. A benefit of this is that it automatically accounts for species rarity. However, a problem with the index is that a sample may have high biodiversity in this context while also having relatively low species richness; this may be confusing as species richness is a fundamental reflection of diversity. For example, Loch Laraig "micro" which has the highest index (*figure 3.1.3*) also shows one of the lowest species richness (*figure 3.1.1*). This presents two valid measurements of properties of biodiversity but in an almost contradictory manner if both are assumed to reflect *biodiversity*.

Simpson's D Index had one significant variable according to the data. A P-value of 0.05 and an r value of 0.351 indicate some evidence for a trend (*refer to table 3.5.2*),

whereby the higher the percentage of floating plants (*Potamogeton spp.*) the more evenly spread the abundance of species in a loch. The reason for this is unclear; however it may be that floating vegetation provides a kind of 'safe haven' for invertebrates, possibly as a nursery which could aid many species to increase their populations, or may provide a rich food source.

In an attempt to objectively measure the biodiversity in both the perspectives of species richness and the proportional abundance of each species as a single value, a simple formula is being proposed, by multiplying the Simpson's D Index by the species richness, the result is a value that represents biodiversity which accounts for species richness as a base value (whole values with no limits) and adjust for it using an index value (a value between 0 and 1). The resulting value has been dubbed SI Richness on the basis of this report. The very simple formula can be found in the *appendix 1.2.*

Figure 3.1.4 shows the values calculated by the SI Richness for each loch. The calculation provided a compromise when measuring and comparing species richness and the Simpson's D Index, for example Loch Laraig "micro" has lower species richness (by a factor of 1) than both Laraig "nano" and Loch Laraig. It also had a lower measurement of abundance (by a factor of 1 and 2 respectively), but the spread of abundance was higher than both (by factor of 0.1, which is relatively large in the Simpson's D Index) and so SI Richness calculated a value that brought it above both lochs. (*refer to appendix 4*). This compromised data for other similar lochs such as Loch an t-Sabhail Mhoine that had contrasting extremes.

In terms of SI Richness, the biodiversity of the Lochs are vary between x and y. The loch with the highest SI Richness was 10.53 for Loch "of the Great Diver", it had the highest richness of 13 species and a relatively high Simpson's D Index of 0.81. The lowest SI Richness was calculated for Loch "Case" at 3.73, it had a richness of 6 species and an Index of 0.62, both are relatively low.

4.2 TWINSPAN. For the raw TWINSPAN results output, *refer to appendix 1.3. Figure 3.2.1* illustrates the results for the TWINSPAN analysis. TWINSPAN (TWo-way INdicator SPecies ANalysis), devised by Hill, is a cluster analysis that ordinates the samples using Reciprocal Averaging (RA) and uses the RA centroid line to produce a dichotomy (in this case, one sample is the entire set of species for a loch), dividing and clustering the samples into negative and positive groups (left and right groups respectively) by taking into account the presence and absence of what it deems to be significant species based on Eigen values. Thus, lochs are clustered

together based on similarity of species content. Eigen values are representative values that indicate how likely the divisions/clustering/value on axis is likely to represent the samples in reality.

Negative indicator species (-) can only be found within clusters of samples on the negative side (or left side) of that respective level of division (not necessarily in every sample of the negative side), the same is true for positive indicator species (+).

For example, the first division groups three samples Loch "Beta", "Case" and "of the Great Diver" (Group A) away from the remaining fifteen lochs based on the presence (+) of three species: *Gyrinus caspius, Ilybius subaenus* and Dytiscid larvae (Coleopteran species), and the absence (-) of one: *Radix peregra* (Gastropod). This means that within this cluster, the three lochs collectively do not have the species *Radix peregra* but the presence of the three positive species can be found within the cluster (not necessarily in every sample). If referred to the raw baseline data at *appendix 4*, Loch "of the Great Diver" contains all three positive (+) species, Loch "Beta" shares the presence of a Dytiscid larvae while Loch "Case" shares the presence of *Ilybius subaenus,* all three samples do not contain *Radix peregra*. Using these species as biological *proxy* indicators suggests that whatever factors are necessary for a population of *Radix peregra* is not present in this cluster of lochs, while the factors necessary for the presence of the positive species should be present in the lochs that stock members of the same species. Therefore Groups B and C are the only samples that contain the species *Gammarus pulex* (a freshwater arthropod, similar to shrimps), while Group B also has the addition of the species *Pyrrhosoma nymphula* (Zygoptera).

4.3 DECORANA. For the raw DECORANA results output, *refer to appendix 1.4. Figure 3.3.1* displays a graph illustrating the results for the DECORANA analysis. DECORANA (DEtrended CORrespondence ANAlysis) was also devised by Hill (1979) and it attempts to improve on the RA. Two occurring problems with RA are known as the 'arch effect' and 'end point compression'. This underlying problem arises from the quadratic relationship between axes rather than because of any relationship between the samples. DECORANA removes this arch effect using a term called 'detrending' and expands the compressed end points. The combined analysis really could be called DECOR-TWINSPAN (DEtrended CORrespondence of a TWo-way INdicator SPecies ANalysis).

To put it simply, DECORANA was devised to improve the validity of TWINSPAN results by removing the trends imposed on the results caused by the 'arch effect'

and the 'end point compression'. Therefore, it is essential that any TWINSPAN analysis undergoes DECORANA analysis to reinforce and validate any relationships.

The results provided four axes AX1, 2, 3 and 4. AX1 had a high Eigen value of 0.706 (1 being the highest), AX2 had relatively low Eigen value of 0.259, AX3 had an even lower Eigen value of 0.174 and AX4 had very low Eigen value of 0.048 (refer to *appendix 1.4*). AX1 has a high Eigen value indicating it is significant, AX2 is not as high but AX3 and AX4 had very low Eigen values indicating that they represented low significance. The values of AX1 and AX2 have been plotted on a scatter graph for interpretation (refer to *figure 3.3.1*). If the Lochs are clustered together on the resulting graph are in the same clusters as that from the TWINSPAN output (refer to *figure 3.2.1*), without overlapping each other, then it implies that the clustering of these Lochs are significant. Indeed *figure 3.3.1* displays the same clustering which suggests there is something significant, biotic or abiotic, which is causing these Lochs to be clustered. Two samples don't fit this trend however, Loch "Sturgy" sits within the cluster of Group A, while Loch "Case" sits within the cluster of Group D. This suggests that Groups A and D, possibly even Group F, may have overlapping similarities, at least within the samples.

Overall the DECORANA reinforces the TWINSPAN clustering of the lochs suggesting that the Lochs are similar within their groups, based on the presence/absence of indicative species. It cannot however indicate what factors are affecting the species content of each sample; these analyses can only suggest that lochs may be similar in environmental variables since their share similar species.

To investigate what these factors may be AX1 and AX2 should be tested for positive correlations against the environmental factors. The variable that has a probable and relatively strong positive correlation to either AX1 or AX2 is likely to be a variable being reflected by the respective axis – note that AX1 or AX2 may each and most likely reflect a combination of environmental factors.

4.4 Environmental statistics. The list of environmental variables measured for each sample can be found in *table 3.4.1*. Few of the variables were unfit for statistical analysis based on number of measurements and variation of values. For example all the lochs had pretty much the same level of pollution – none, except one item of pollution, found at loch "of the Great Diver".

DECORANA axes correlations. The null hypothesis (H_0) for correlation analysis is that there is no correlation and the alternative hypothesis (H_A) should be accepted and the null rejected if the P-value is below α value 0.05.

AX1 and pH: Statistical analysis indicated AX1 shows a close correlation with pH. The parametric analysis provided a P-value for the correlation of 0.003 with an r value of 0.656 (*refer to table 3.5.1*). This suggests strong evidence that pH has a strong positive correlated with AX1. TWINSPAN-DECORANA clustered the samples using only the data of the presence/absence of species (essentially the biodiversity information). AX1 is the axis it produced with the most calculated influence, since pH strongly correlates with it, it suggests pH is an influence on the clustering of these lochs and since the clustering is based on biodiversity data, thus it suggests pH is probably an environmental influence on the biodiversity of the lochs in the Gairloch Hills.

AX1 and conductivity: Conductivity showed the second strongest correlation with AX1. Non-parametric analysis calculated a P-value of 0.001 indicating a strong correlation, with an r value of 0.573 suggesting a moderate positive correlation (*refer to table 3.5.2*).

This P-value does not suggest conductivity is more influential than pH although it has a more significant P-value. This is because P-values between parametric and non-parametric tests cannot be compared since the data has been transformed. Non-parametric analysis of AX1 and pH reinforce the indication that pH is AX1's strongest correlation with an r value of 0.633 (*refer to appendix 1.6*) indicating a stronger Spearman's Rank Correlation for pH over Conductivity in regards to AX1.

The correlation analysis of the environmental data shows both water pH and conductivity have the highest significant P-values and both r values are positive and relatively high. This suggests that water pH and conductivity are the primary influences on AX1, thus they may also be primary influences on the presence/absence of species affecting each Loch's biodiversity.

Bedrock geology and the surrounding land use: The bedrock geology of each loch and the surrounding land use show stronger correlations with AX1. The surrounding land use is the average percentage of what constitutes the land that encircles the lochs. Only moorland heath and exposed rock faces naturally surrounded the lochs. It is unlikely however that what lays between 250-500m away directly influences the lochs aquatic-macro-inverts. It is likely that both the geology

and surrounding land indirectly affects the lochs by altering the water pH and conductivity.

Different rocks dissolve at varied rates and produce different levels of water hardness and dissolved minerals (Harris, 1991), this would be directly reflected in pH and conductivity. Batterbee *et al.* (1985) (cited in Jeffries and Mills, 1990, p.158) studied algal and pollen remains from an acidic loch in south-west Scotland and noticed that decreases in water pH correlated with the regeneration of acidic heath in the catchment, while the influence of heathland on acidification was also ruled out by Pollen analysis, the regeneration of acidic soils in proximity to lochs seemed to decrease the loch's pH. Results from the correlation analysis do not reflect the report. Analysis for surrounding Moorland heath between 25-100m shows a positive correlation with pH (P-value: 0.010, r value: 0.589) while the presence of exposed rock faces within the same distance showed a negative correlation (P-value: 0.010, r value: -0.589). It suggests that the more moor and heathland around a loch, the higher the waters pH, thus the more alkali the water can be expected. The non-parametric correlations reinforce this analysis within the same SLU range and at catchment level.

Peat can be found throughout most of the moorland heaths of the Gairloch district, this suggests that the result should have a negative r value indicative of a negative correlation. It could be the exposed rock faces play a role, it may be that the geology of the exposed rocks increases the pH of the rain water (only bedrock geology has been distinguished and recorded), or it may be possible that the moorland heath somehow provides a pathway of increasing water pH, although this is unlikely since peat can be found throughout most of the moorlands. Nonetheless the data suggests that the pH and conductivity are correlated with the surrounding land use and may be influencing the strong correlation between SLU and AX1.

Geology does show a strong correlation with AX1 and AX2 except for the Quartzo-feldspathic orthogneisses (QFO). Since bedrock geology was not the intention of sampling, the sample of each measurement is low, hence probably insignificant. The most common geology across the lochs was QFO. Quartz is known as the most stable natural form of silica (Bennet and Siegel, 1987). This is a possible explanation for the lack of correlation it has with either of the axes.

AX2 and altitude: Altitude provided the highest positive correlation with AX2; the P-value is 0.005 with an r value of 0.468. The Spearman's rank correlation suggests altitude is a strong influence on AX2. This suggests altitude is a primary influence on

the current aquatic macro-invert biodiversity of the Gairloch Hill Lochs. This is likely since changes in altitude produce different environmental variables.

The only other correlations that were significant with AX2, adjacent water bodies (AWB) <10m and the percentage of exposed rock face within <5m and in the catchment area. These variables were not as significant, or the variables were unlikely to affect biodiversity.

Distance to the nearest town did show a positive correlation with AX2 in the non-parametric analysis but it was not reinforced by the parametric analysis. Since the parametric data is more valid, the lack of a significant relationship in the Pearson's correlations is contradictory. Another plausible explanation may exist for the non-parametric correlation.

AX1 and AX2: The correlational analysis of AX1 and AX2 indicate that the primary influences on the biodiversity of the Gairloch Hill Lochs are essentially the lochs water properties on AX1 (pH and conductivity) and their altitude on AX2. Both are likely also influenced by the geology and the surrounding land use, both alter pH and conductivity directly, but also affect factors that may influence the aquatic macro-invert biodiversity in other ways. Suitable mating environments caused by moorland heath for example may permit a higher population of specific species with aquatic larval stages, or certain surroundings may attract other predators, exposed rock faces for example may provide a suitable perch for fishing birds to observe the waters.

The presence of fish and amphibians and the biodiversity of aquatic macro-inverts: Some lochs have large predatory fish like trout present, others have sticklebacks and some have both. Species richness, abundance, Simpson's D Index and SI Richness were tested for difference between the mean populations of lochs that had the presence and absence of fish. The same was also carried out on the presence and absence of amphibians. Statistical analysis found no significance between the mean biodiversity measurements of populations with and without fish, or amphibians. An analysis that removed sticklebacks (small fish) from the equation and only differentiated between lochs with and without trout (large predatory fish) also provided the same conclusion.

The presence of fish or amphibians in the lochs does not seem to affect their biodiversity in terms of richness, abundance and proportional abundance; on the other hand, the data suggests that the presence of fish affected species

presence/absence. The presence/absence of fish seems to correlate with the TWINSPAN-DECORANA data. All the lochs of each group either have fish present or absent. *Refer to figure 3.2*. All the Lochs in Groups B, C, F and G have fish present in their waters. While Groups A, D and E do not have fish present at the time of this research. This is illustrated below in *figure 4.4.1*.
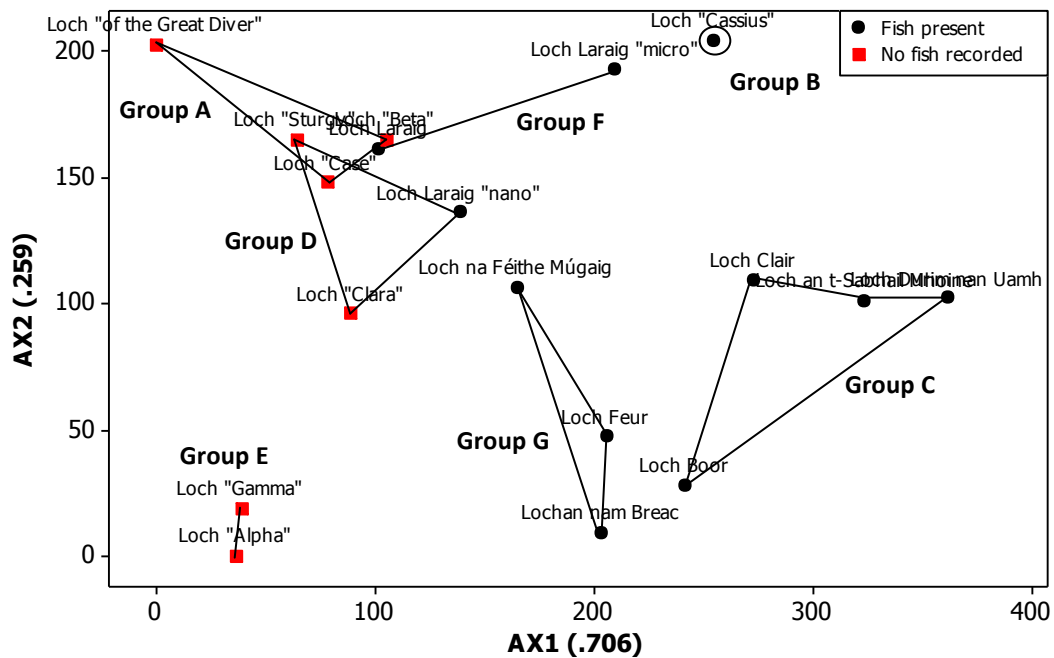
Figure 4.4.1: DECORANA analysis when grouped by the presence/absence of fish.

Only one loch seems to not fit the trend. Loch Laraig "nano" in Group D, which has fish present. It may be possible that although fish are known to enter that loch through Loch Laraig "micro", it may be that the fish do not have much influence on the aquatic macro-invert biodiversity in Laraig "nano". The plant cover for the loch had a grade 3 cover for submerged and emerged vegetation. The only loch with such high plant covers for both types of aquatic plants. This creates a complex 3D habitat in the small loch. This would make it more difficult for fish to hunt aquatic macro-inverts, possibly lessening the effect of their presence, it may provide suitable habitats for breeding or may possibly act as a food source, at least to a degree that species that normally cannot co-exist with fish are able to have populations large enough for TWINSPAN-DECORANA to cluster the loch with others based on similar species presence/absence.

Ultimately the data suggests that the presence of fish will affect which aquatic macro-invert species may be present in the loch; these effects may be reduced if there is sufficient vegetation cover to aid the survival of aquatic-macro inverts.

pH and biodiversity: The pH of the water is very important in determining biotic content of a loch. All aquatic organisms tolerate narrow ranges of pH in which they can thrive, albeit some organisms have a much larger range than others. Since the water is lentic in nature, the pH can remain more static throughout most of the loch since there isn't an overall directional flow of water flowing in from a source. Acidification of freshwaters is usually an environmental problem in many parts of the world; Jeffries and Mills (1990) wrote that some habitats are naturally acidic and support a distinct array of wildlife of their own. The Gairloch Hills are known for their peat encumbered moorland heaths which can only accumulate under acidic anaerobic conditions.

When correlated with how it affected biodiversity reflected by SI Richness, the statistics provided a P-value of 0.221 with a Pearson's correlation of -0.304. This suggests evidence for the null that there is no correlation between pH and SI Richness. General knowledge is that acidic waters typically have less species and lower abundance and biomass of aquatic-macro-inverts than waters nearer to a neutral pH (Lehigh Environmental Initiative's EnvirosciInquiry, n.d.); intriguingly, the Lochs are clustered around 7.7 and 6.7 pH (*refer to figure 4.4.2*), the Lochs were sampled with the presumption that most would be acidic due to the peat moorland. Most organisms can tolerate a range of pH which may be a confounding factor in correlation analysis; many species within this investigation can be found in closely varying levels of pH.
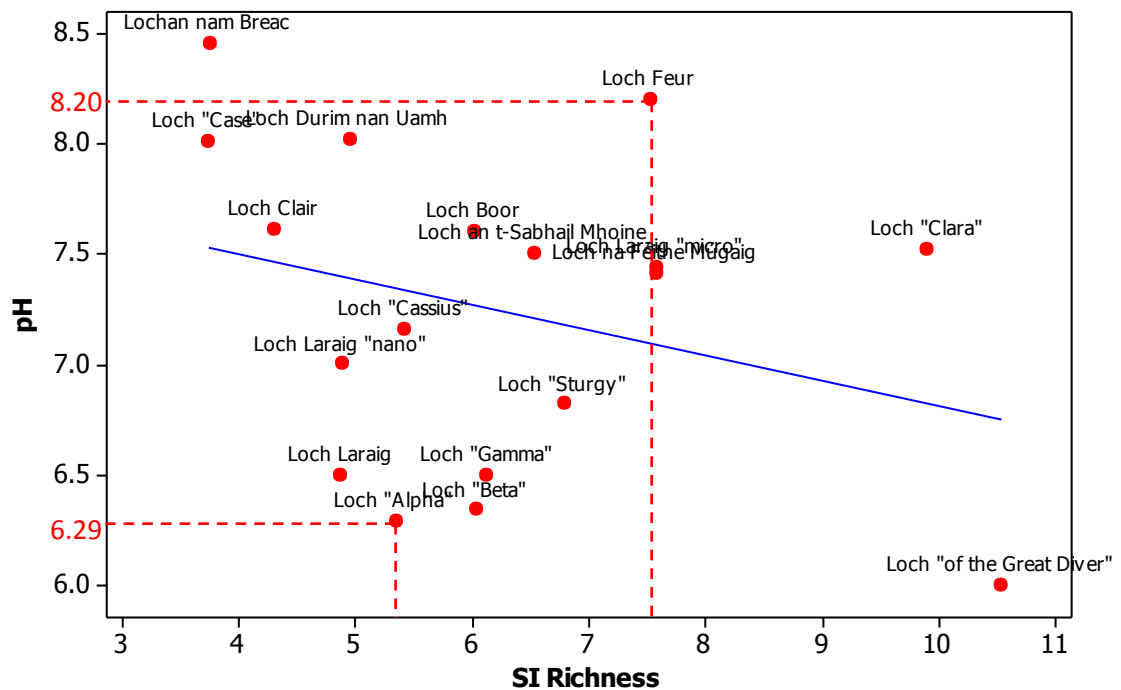
Figure 4.4.2: Scatter graph presenting pH against SI Richness.

Figure 4.4.2 shows a scatter graph of pH and SI Richness, based on visual perspective there does seem to be a weak negative correlation. All the samples seem to be in a cline range between 2pH, Loch Feur and Loch "Alpha" represent the basis of this assumption. It may be possible to infer, that if many of the aquatic macro-inverts in the region tolerate such a range, that as pH declines, so does this range by which organisms can thrive, thereby affecting the results of the statistical analysis. The TWINSPAN-DECORANA analysis reinforces the pH as a primary influence for biodiversity.

Batterbee *et al.* (1985) (cited in Jeffries and Mills, 1990, p.158) also suggested that acidification appeared to be anthropogenic. Intrigueingly, the pH showed an opposite correlation in regards to anthropogenic presence, statistical analysis suggests it has a negative correlation with the distance to nearest to town and towards the presence of roads (*refer to appendix 1.7*). According to the data, the closer the distance to anthropogenic presence the more alkali the lochs appeared to be (*refer to table 3.5.1*). However conclusions cannot be made on this alone, this requires a depth of research to validate since it contradicts existing literature. It's possible that this is an artefact from the distance to nearest town being negatively correlated with other variables, such as altitude.

Conductivity and biodiversity: The less conductive the water, the more pure it is. Water conductivity is caused by the movement of free electrons between ions and minerals. There are many elements that serve as nutrients for life which may be present in natural waters, some examples include, Nitrogen, Phosphorus, dissolved organic Carbon, Iron, all of these increase water conductivity, furthermore, differences in the levels between each element may alter species selection within communities in aquatic environments. Nitrogen in an organic usable form is rare despite it being one of the most abundant elements on Earth. The necessity for Nitrogen by insects cannot be overemphasized (Schoonhoven *et al.,* 1998); growth efficiency of many insects is closely related with plant Nitrogen content, a fundamental constituent of proteins.

Since conductivity reflects the presence of nutrients in the form of ions and minerals, it is closely related to pH since pH measures the potential for Hydrogen ions. This is supported by data in *figure 3.5.2*, with a significant P-value of 0.001 and a very strong positive correlation represented by an r value of 0.824.

Altitude and biodiversity: Altitude directly affects the aquatic environment, it influences water temperature and oxygen concentration, both is known to directly permit or prohibit aquatic species from surviving due to differences in tolerance levels. Surrounding vegetation will also change with altitude due to atmospheric temperature which will affect the surrounding biota. These are a few examples of environmental variance that occurs with difference in altitude.

4.5 Limitations and suggestions for improvement: The biggest limitation to this project is the sampling method, typically when it comes to sampling large lochs, Durim nan Uamh for example; the ability to visually gauge submerged vegetation is dependent on how far the human eye can see into water, despite the clarity of the water. It is very likely that the submerged vegetation for large lochs is not fully represented. Another problem with large lochs is the ability to reach specific micro-habitats for sampling. On Durim nan Uamh, there was floating vegetation recorded, however reaching it to sample was impossible since it was situated in the middle of the loch. The depth of the loch means that a raft is required to reach and sample the floating vegetation of lochs like Durim nan Uamh. A raft used to traverse over the lochs surface using a paddle would also allow a much more valid gauge of submerged vegetation with minimal disturbance. Funding would provide equipment to remove limitations like these and more that are associated with sampling procedures.

5. Conclusion

The biodiversity in terms of Species richness and abundance is significantly different between the Gairloch Hill Lochs. Proportional spread of abundance for each species in a loch is more similar throughout the Lochs in the sample and may be influenced by the presence of floating vegetation. Water pH, conductivity (water parameters), altitude and the presence of fish were indicated as the four primary influences on the aquatic macro-invertebrates species and biodiversity of the Gairloch Hill Lochs.

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Appendix 1 - Data, calculations and statistics
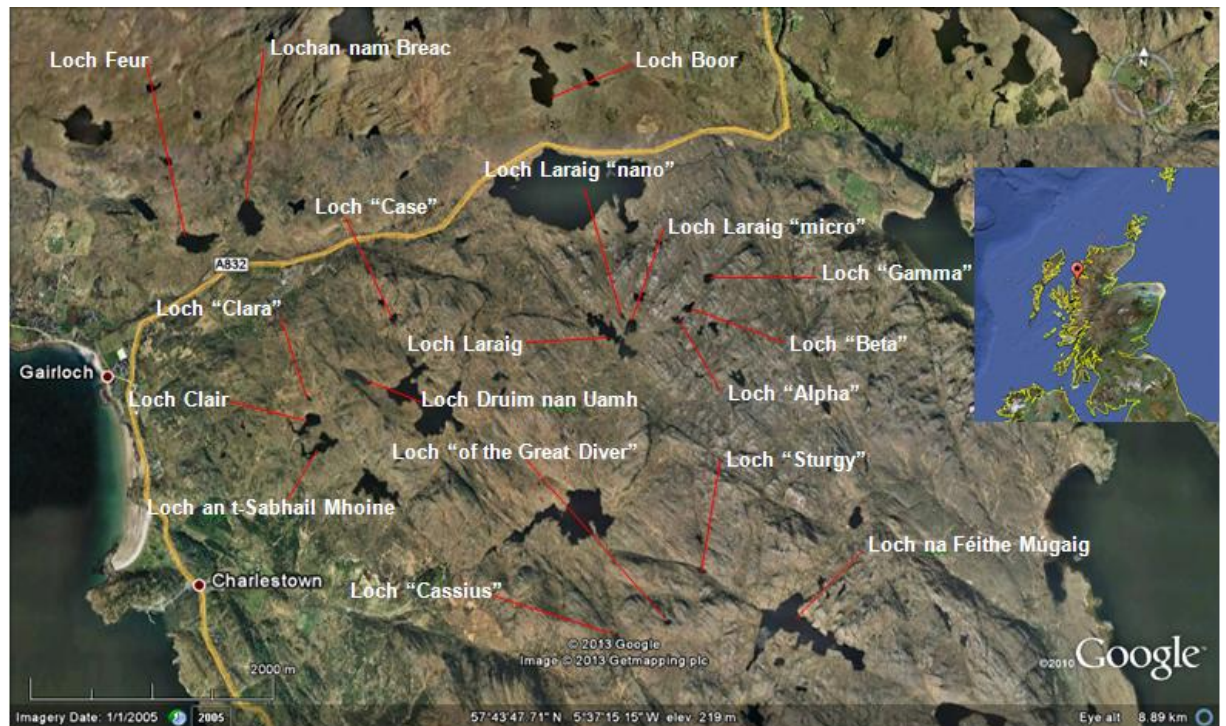
Appendix 1.0.1: Each loch location in the Sample range of Gairloch hill lochs.

Appendix 1.1: Simpson's D Index Calculation

Simpson's D Index = 1 – λ,   where **λ = ∑pi^2**

pi is the relative proportion of a species in a sample against the other species within the same sample.

pi was calculated for each species by using the formula:

pi = 1 / (total no. organisms in sample / total no. organisms in the species)

pi^2 is calculated for each species of a loch and added together to give λ for each loch sample.

Appendix 1.2: SI Richness formula

The formula proposed for: **SI Richness = Simpsons Index x Species richness**

Species richness is the number of different species within a sample.

Appendix 1.3: TWINSPAN RESULTS

```
    READING DATA MATRIX FROM DEVICE 5

  LOCHINV3.OUT

0NUMBER OF SAMPLES    18
0NUMBER OF SPECIES    48
0LENGTH OF RAW DATA ARRAY   310
        1     2000        2     2000        3     2000
    4     1000        5     1000        6     1000
       -1        2     2000        3     2000        6
  1000        7     1000        8     1000       -1
        2     2000        3     2000        6     1000
  9     1000       10     1000       11     1000
       12     3000       -1        3     4000        6
  1000       12     4000       13     9000       14
    1000       15     3000       16     1000       -1
  3     7000        8     2000       12     8000
       17     1000       18     2000       19     2000
  20     1000       21     1000       -1        2
    1000        3     3000        6     3000       12
  8000       13    11000       22     1000       23
    1000       24     2000       -1        1     8000
  3    13000        8     2000        9     3000
       12     8000       14     1000       18     1000
  22     1000       24     2000       25     1000
       26     2000       27     1000       -1        3
 15000        6     1000        8    14000       25


        ................................................
        ...............................................
        1000       32     1000       37     1000       -1
  3     1000        6     3000        8     1000
        9     2000       22     1000       -1        3
  3000        4     1000        6     9000        8
    5000       12     1000       28     1000       38
  1000       39     1000       -1        3    15000
        4     2000       12    17000       17     1000
 21     1000       22     2000       34     7000
       40    20000       41     1000       42     1000
 43     1000       44     1000       45     3000
       -1        2     5000        3     7000        4
 1000       14     1000       18     1000       28
   10000       46     5000       -1        3    41000
  5     1000        8     4000        9     1000
       10     1000       12    49000       14     1000
 26    17000       27     1000       36     1000
       -1        2     1000        3    16000        6
 2000        8     2000        9     1000       16
    3000       22     1000       26     1000       32
 1000       47     1000       48     1000       -1
0SPECIES NAMES
   1 Lest spon|   2 Pyrr nymp|   3 Chyr larv|   4 Chyr pupa|
  5 Aesh caer|   6 Radi pere|   7 Veli saul|   8 Peam usse
   9 Cord aene|  10 Enal cyan|  11 Aqua bee0|  12 Cori nymp|
  13 Isch eleg|  14 Cadd larv|  15 Hali conf|  16 Odon inst
```

```
      17 Gyri casp|  18 Coen hast|  19 Leuc iner|  20 Hydr nigr|
      21 Dyti larv|  22 Case cadd|  23 Coll woll|  24 Noto glau
      25 Wate mite|  26 Dipt larv|  27 Orth coer|  28 Gamm pule|
      29 Caen robu|  30 Caen rivu|  31 Sial luta|  32 Olig worm
      33 Cles cadd|  34 Ilyb suba|  35 Cord bolt|  36 Zygo inst|
      37 Pota depr|  38 Leuc larv|  39 Caen hora|  40 Agab arti
      41 Gyri subs|  42 Agab bipu|  43 Dyti semi|  44 Symp nigr|
      45 Siga scot|  46 Hali obli|  47 Amel inop|  48 Hair magg
 0SAMPLE NAMES
       1 Laranano |   2 Laramicr |   3 LochLara |   4 Lochalph |
       5 Lochbeta |   6 Lochgamm |   7 Lochclar |   8 LochClai
       9 Antsmhoi |  10 Durinanu |  11 Lochcase |  12 Lochfeur |
      13 Nambreac |  14 Lochboor |  15 Greadive |  16 Casssius
      17 Lochstur |  18 Nafemuga |


 DO YOU WISH TO OMIT SOME SAMPLES?
 ENTER NUMBERS (NOT NAMES) OF ITEMS TO BE OMITTED
 ONE PER LINE, ENDING LIST WITH A -1.
 OTHER NEGATIVE NUMBERS DENOTE SEQUENCES.  FOR EXAMPLE
 A 4 FOLLOWED BY A -8 OMITS ITEMS 4 THROUGH 8.
               -1
 1NOW ENTER INPUT PARAMETERS

 DO YOU WANT ALL PARAMETERS SET TO THE DEFAULTS?   <Y,N>
 ENTER NUMBER (NOT EXCEEDING 9) OF PSEUDOSPCIES CUT LEVELS
 OR TYPE -1 FOR DEFAULT CUT LEVELS, WHICH ARE 0 2 5 10 20.
 ANSWER =  1
 0NOW ENTER  1  CUT LEVELS
 0CUT LEVELS
      1.00
 0ENTER MINIMUM GROUP SIZE FOR DIVISION
  TYPE -1 FOR DEFAULT VALUE ( = 5);  OTHERWISE TYPE (INTEGER)
    VALUE REQUIRED,
  WHICH MUST NOT LIE OUTSIDE LIMITS    2 10000
  ANSWER=     5
 0ENTER MAXIMUM NUMBER OF INDICATORS PER DIVISION
  TYPE -1 FOR DEFAULT VALUE ( = 7);  OTHERWISE TYPE (INTEGER)
    VALUE REQUIRED,
  WHICH MUST NOT LIE OUTSIDE LIMITS     0    15
  ANSWER=     7
 0ENTER MAXIMUM NUMBER OF SPECIES IN FINAL TABULATION
  TYPE -1 FOR DEFAULT VALUE ( =100);  OTHERWISE TYPE (INTEGER)
    VALUE REQUIRED,
  WHICH MUST NOT LIE OUTSIDE LIMITS     0  1000
  ANSWER=    48
 0ENTER MAXIMUM LEVEL OF DIVISIONS
  TYPE -1 FOR DEFAULT VALUE ( = 6);  OTHERWISE TYPE (INTEGER)
    VALUE REQUIRED,
  WHICH MUST NOT LIE OUTSIDE LIMITS     0    15
  ANSWER=     6
 0TYPE 1 IF DIAGRAMS OF DIVISIONS ARE WANTED.
  TYPE -1 FOR DEFAULT VALUE ( = 0);  OTHERWISE TYPE (INTEGER)
    VALUE REQUIRED,
  WHICH MUST NOT LIE OUTSIDE LIMITS     0     1
  ANSWER=    -1
  VALUE SET TO    0 BY DEFAULT
```

```
0TYPE 1 IF MACHINE-READABLE COPY OF SOLUTION TO BE WRITTEN TO
   DEVICE 7
 TYPE -1 FOR DEFAULT VALUE ( =  0);  OTHERWISE TYPE (INTEGER)
   VALUE REQUIRED,
 WHICH MUST NOT LIE OUTSIDE LIMITS      0      1
 ANSWER=   -1
 VALUE SET TO    0 BY DEFAULT
0ENTER WEIGHTS FOR LEVELS OF PSEUDOSPECIES.
 FOR EXAMPLE WEIGHTS  1 2 2 2  SIGNIFY THAT PSEUDOSPECIES
 CORRESPONDING TO 3 HIGHER CUT LEVELS ARE TO BE GIVEN TWICE
 THE WEIGHT OF PSEUDOSPECIES AT THE LOWEST LEVEL.
 TYPE -1 FOR DEFAULT VALUES (I.E. IF ALL VALUES TO BE SET TO
   1)
 OR TYPE 0 IF NON-DEFAULT VALUES ARE TO BE ENTERED
 ANSWER=   -1
0ENTER INDICATOR POTENTIALS FOR CUT LEVELS.
 FOR EXAMPLE INDICATOR POTENTIALS   1 0 0 1 0   SIGNIFY
 THAT PSEUDOSPECIES AT LEVELS 1 AND 4 CAN BE USED AS
 INDICATORS, BUT THAT THOSE AT OTHER LEVELS CANNOT.
 IN THE DEFAULT CASE, ALL PSEUDOSPECIES ARE AVAILABLE
 AS INDICATORS.
 TYPE -1 FOR DEFAULT VALUES (I.E. IF ALL VALUES TO BE SET TO
   1)
 OR TYPE 0 IF NON-DEFAULT VALUES ARE TO BE ENTERED
 ANSWER=   -1
0DO YOU WISH TO OMIT SOME SPECIES FROM LIST OF
 POTENTIAL INDICATORS?  SPECIES OMITTED FROM THIS LIST
 ARE USED IN THE CALCULATION, BUT CANNOT APPEAR AS INDICATORS.
 ENTER NUMBERS (NOT NAMES) OF ITEMS TO BE OMITTED
 ONE PER LINE, ENDING LIST WITH A -1.
 OTHER NEGATIVE NUMBERS DENOTE SEQUENCES.  FOR EXAMPLE
 A 4 FOLLOWED BY A -8 OMITS ITEMS 4 THROUGH 8.
               -1


 LENGTH OF DATA ARRAY AFTER DEFINING PSEUDOSPECIES     164


 TOTAL NUMBER OF SPECIES AND PSEUDOSPECIES     48


 NUMBER OF SPECIES, EXCLUDING PSEUDOSPECIES AND ONES WITH NO
   OCCURRENCES   48
1

    ************************************************************
    ************************************************************
    **
0DIVISION    1 (N= 18)         I.E. GROUP *
 EIGENVALUE  .436 AT ITERATION   2
 INDICATORS, TOGETHER WITH THEIR SIGN
 Radi pere1(-)   Gyri casp1(+)   Dyti larv1(+)   Ilyb suba1(+)
 MAXIMUM INDICATOR SCORE FOR NEGATIVE GROUP   0     MINIMUM
   INDICATOR SCORE FOR POSITIVE GROUP    1
0ITEMS IN NEGATIVE GROUP  2 (N=  15)         I.E. GROUP *0
 Laranano  Laramicr  LochLara  Lochalph  Lochgamm  Lochclar
   LochClai  Antsmhoi  Durinanu  Lochfeur  Nambreac  Lochboor
 Casssius  Lochstur  Nafemuga
```

```
0ITEMS IN POSITIVE GROUP   3 (N=    3)          I.E. GROUP *1
 Lochbeta  Lochcase  Greadive
0NEGATIVE PREFERENTIALS
 Pyrr nymp1(  6,  0) Radi pere1( 11,  0) Peam usse1( 10,  1)
   Cord aene1(  6,  0) Cadd larv1(  4,  0) Odon inst1(  3,  0)
 Dipt larv1(  3,  0) Gamm pule1(  5,  0) Olig worm1(  3,  0)
0POSITIVE PREFERENTIALS
 Lest spon1(  2,  1) Gyri casp1(  0,  2) Coen hast1(  2,  1)
   Leuc iner1(  2,  1) Hydr nigr1(  0,  1) Dyti larv1(  0,  2)
 Ilyb suba1(  0,  2) Cord bolt1(  0,  1) Zygo inst1(  1,  1)
   Agab arti1(  0,  1) Gyri subs1(  0,  1) Agab bipu1(  0,  1)
 Dyti semi1(  0,  1) Symp nigr1(  0,  1) Siga scot1(  0,  1)
0NON-PREFERENTIALS
 Chyr larv1( 14,  3) Chyr pupa1(  4,  1) Cori nymp1(  8,  3)
   Case cadd1(  7,  1)
0   END OF LEVEL   1




    ***********************************************************
    ***********************************************************
    **
0DIVISION    2 (N=  15)          I.E. GROUP *0
 EIGENVALUE  .397  AT ITERATION    3
 INDICATORS, TOGETHER WITH THEIR SIGN
 Gamm pule1(+)
 MAXIMUM INDICATOR SCORE FOR NEGATIVE GROUP   0     MINIMUM
   INDICATOR SCORE FOR POSITIVE GROUP    1
0ITEMS IN NEGATIVE GROUP   4 (N=   10)          I.E. GROUP *00
 Laranano  Laramicr  LochLara  Lochalph  Lochgamm  Lochclar
   Lochfeur  Nambreac  Lochstur  Nafemuga
0ITEMS IN POSITIVE GROUP   5 (N=    5)          I.E. GROUP *01
 LochClai  Antsmhoi  Durinanu  Lochboor  Casssius
0NEGATIVE PREFERENTIALS
 Lest spon1(  2,  0) Pyrr nymp1(  5,  1) Aesh caer1(  2,  0)
   Cord aene1(  6,  0) Enal cyan1(  2,  0) Isch eleg1(  2,  0)
 Hali conf1(  2,  0) Noto glau1(  2,  0) Dipt larv1(  3,  0)
   Orth coer1(  2,  0)
0POSITIVE PREFERENTIALS
 Chyr pupa1(  1,  3) Coen hast1(  1,  1) Leuc iner1(  0,  2)
   Wate mite1(  1,  1) Gamm pule1(  0,  5) Caen robu1(  0,  1)
 Caen rivu1(  0,  2) Sial luta1(  0,  1) Cles cadd1(  0,  1)
   Leuc larv1(  0,  1) Caen hora1(  0,  1) Hali obli1(  0,  1)
0NON-PREFERENTIALS
 Chyr larv1( 10,  4) Radi pere1(  8,  3) Peam usse1(  6,  4)
   Cori nymp1(  6,  2) Cadd larv1(  3,  1) Odon inst1(  2,  1)
 Case cadd1(  5,  2) Olig worm1(  2,  1)

    ***********************************************************
    ***********************************************************
    **

0DIVISION    3 (N=   3)          I.E. GROUP *1
 DIVISION FAILS - THERE ARE TOO FEW ITEMS
0   END OF LEVEL   2
```

```
       ************************************************************
       ************************************************************
       **

0DIVISION    4  (N=  10)          I.E. GROUP *00
 EIGENVALUE .375 AT ITERATION   3
 INDICATORS, TOGETHER WITH THEIR SIGN
 Lest spon1(-)   Aesh caer1(-)
 MAXIMUM INDICATOR SCORE FOR NEGATIVE GROUP   -1     MINIMUM
   INDICATOR SCORE FOR POSITIVE GROUP    0
0ITEMS IN NEGATIVE GROUP   8  (N=    3)          I.E. GROUP
   *000
 Laranano  Lochclar  Lochstur
0ITEMS IN POSITIVE GROUP   9  (N=    7)          I.E. GROUP
   *001
 Laramicr  LochLara  Lochalph  Lochgamm  Lochfeur  Nambreac
   Nafemuga
0NEGATIVE PREFERENTIALS
 Lest spon1( 2,  0) Chyr pupa1( 1,  0) Aesh caer1( 2,  0)
   Enal cyan1( 1,  1) Cadd larv1( 2,  1) Coen hast1( 1,  0)
 Noto glau1( 1,  1) Wate mite1( 1,  0) Dipt larv1( 2,  1)
   Orth coer1( 2,  0) Zygo inst1( 1,  0)
0POSITIVE PREFERENTIALS
 Radi pere1( 1,  7) Isch eleg1( 0,  2) Hali conf1( 0,  2)
   Odon inst1( 0,  2) Olig worm1( 0,  2)
0NON-PREFERENTIALS
 Pyrr nymp1( 1,  4) Chyr larv1( 3,  7) Peam usse1( 2,  4)
   Cord aene1( 2,  4) Cori nymp1( 2,  4) Case cadd1( 1,  4)

       ************************************************************
       ************************************************************
       **

0DIVISION    5  (N=   5)          I.E. GROUP *01
 EIGENVALUE .625 AT ITERATION   1
 INDICATORS, TOGETHER WITH THEIR SIGN
 Pyrr nymp1(+)
 MAXIMUM INDICATOR SCORE FOR NEGATIVE GROUP    0     MINIMUM
   INDICATOR SCORE FOR POSITIVE GROUP    1
0ITEMS IN NEGATIVE GROUP  10  (N=    4)          I.E. GROUP
   *010
 LochClai  Antsmhoi  Durinanu  Lochboor
0ITEMS IN POSITIVE GROUP  11  (N=    1)          I.E. GROUP
   *011
 Casssius
0NEGATIVE PREFERENTIALS
 Radi pere1( 3,  0) Peam usse1( 4,  0) Cori nymp1( 2,  0)
   Odon inst1( 1,  0) Leuc iner1( 2,  0) Case cadd1( 2,  0)
 Wate mite1( 1,  0) Caen robu1( 1,  0) Caen rivu1( 2,  0)
   Sial luta1( 1,  0) Olig worm1( 1,  0) Cles cadd1( 1,  0)
 Leuc larv1( 1,  0) Caen hora1( 1,  0)
0POSITIVE PREFERENTIALS
 Pyrr nymp1( 0,  1) Chyr pupa1( 2,  1) Cadd larv1( 0,  1)
   Coen hast1( 0,  1) Hali obli1( 0,  1)
0NON-PREFERENTIALS
 Chyr larv1( 3,  1) Gamm pule1( 4,  1)
0   END OF LEVEL   3
```

```
      * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      * *

0DIVISION    8  (N=   3)         I.E. GROUP *000
 DIVISION FAILS - THERE ARE TOO FEW ITEMS


      * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      * *

0DIVISION    9  (N=   7)         I.E. GROUP *001
 EIGENVALUE  .387  AT ITERATION    2
 INDICATORS, TOGETHER WITH THEIR SIGN
 Isch eleg1(+)
 MAXIMUM INDICATOR SCORE FOR NEGATIVE GROUP    0      MINIMUM
    INDICATOR SCORE FOR POSITIVE GROUP    1
0ITEMS IN NEGATIVE GROUP 18  (N=    5)           I.E. GROUP
    *0010
 Laramicr  LochLara  Lochfeur  Nambreac  Nafemuga
0ITEMS IN POSITIVE GROUP 19  (N=    2)           I.E. GROUP
    *0011
 Lochalph  Lochgamm
0NEGATIVE PREFERENTIALS
 Veli saul1(  1,  0) Peam usse1(  4,  0) Cord aene1(  4,  0)
   Enal cyan1(  1,  0) Aqua bee01(  1,  0) Dipt larv1(  1,  0)
 Olig worm1(  2,  0) Pota depr1(  1,  0) Amel inop1(  1,  0)
   Hair magg1(  1,  0)
0POSITIVE PREFERENTIALS
 Cori nymp1(  2,  2) Isch eleg1(  0,  2) Cadd larv1(  0,  1)
   Hali conf1(  1,  1) Odon inst1(  1,  1) Coll woll1(  0,  1)
 Noto glau1(  0,  1)
0NON-PREFERENTIALS
 Pyrr nymp1(  3,  1) Chyr larv1(  5,  2) Radi pere1(  5,  2)
   Case cadd1(  3,  1)


      * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      * *

0DIVISION   10  (N=   4)         I.E. GROUP *010
 DIVISION FAILS - THERE ARE TOO FEW ITEMS


      * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      * *

0DIVISION   11  (N=   1)         I.E. GROUP *011
 DIVISION FAILS - THERE ARE TOO FEW ITEMS
0    END OF LEVEL    4


 * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
      * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

```
0DIVISION  18  (N=   5)        I.E. GROUP *0010
 EIGENVALUE  .412  AT ITERATION   1
 INDICATORS, TOGETHER WITH THEIR SIGN
 Case cadd1(-)
 MAXIMUM INDICATOR SCORE FOR NEGATIVE GROUP   -1    MINIMUM
   INDICATOR SCORE FOR POSITIVE GROUP    0
0ITEMS IN NEGATIVE GROUP 36  (N=    3)       I.E. GROUP
   *00100
 Lochfeur  Nambreac  Nafemuga
0ITEMS IN POSITIVE GROUP 37  (N=    2)       I.E. GROUP
   *00101
 Laramicr  LochLara
0NEGATIVE PREFERENTIALS
 Peam usse1( 3, 1) Cord aene1( 3, 1) Hali conf1( 1, 0)
   Odon inst1( 1, 0) Case cadd1( 3, 0) Dipt larv1( 1, 0)
 Olig worm1( 2, 0) Pota depr1( 1, 0) Amel inop1( 1, 0)
   Hair magg1( 1, 0)
0POSITIVE PREFERENTIALS
 Pyrr nymp1( 1, 2) Veli saul1( 0, 1) Enal cyan1( 0, 1)
   Aqua bee01( 0, 1)
0NON-PREFERENTIALS
 Chyr larv1( 3, 2) Radi pere1( 3, 2) Cori nymp1( 1, 1)

   ************************************************************
   ************************************************************
   **

0DIVISION  19  (N=   2)        I.E. GROUP *0011
 DIVISION FAILS - THERE ARE TOO FEW ITEMS
0    END OF LEVEL   5



   ************************************************************
   ************************************************************
   **

0DIVISION  36  (N=   3)        I.E. GROUP *00100
 DIVISION FAILS - THERE ARE TOO FEW ITEMS

   ************************************************************
   ************************************************************
   **

0DIVISION  37  (N=   2)        I.E. GROUP *00101
 DIVISION FAILS - THERE ARE TOO FEW ITEMS
0THIS IS THE END OF THE DIVISIONS REQUESTED

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   ************************************************************
   **

1

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   **
```

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0DIVISION    1 (N=  48)        I.E. GROUP *
 EIGENVALUE .698 AT ITERATION    2
0ITEMS IN NEGATIVE GROUP   2 (N=   33)        I.E. GROUP *0
  Pyrr nymp  Chyr larv  Chyr pupa  Aesh caer  Radi pere  Veli
  saul  Peam usse  Cord aene  Enal cyan  Aqua bee0  Cori nymp
  Isch eleg  Cadd larv  Hali conf  Odon inst  Case cadd  Coll
  woll  Noto glau  Wate mite  Dipt larv  Orth coer  Gamm pule
  Caen robu  Caen rivu  Sial luta  Olig worm  Cles cadd  Pota
  depr  Leuc larv  Caen hora  Hali obli  Amel inop  Hair magg
0ITEMS IN POSITIVE GROUP   3 (N=   15)        I.E. GROUP *1
  Lest spon  Gyri casp  Coen hast  Leuc iner  Hydr nigr  Dyti
  larv  Ilyb suba  Cord bolt  Zygo inst  Agab arti  Gyri subs
  Agab bipu  Dyti semi  Symp nigr  Siga scot
0   END OF LEVEL   1


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0DIVISION    2 (N=  33)        I.E. GROUP *0
 EIGENVALUE .338 AT ITERATION    2
0ITEMS IN NEGATIVE GROUP   4 (N=   29)        I.E. GROUP *00
  Pyrr nymp  Aesh caer  Radi pere  Veli saul  Peam usse  Cord
  aene  Enal cyan  Aqua bee0  Isch eleg  Cadd larv  Hali conf
  Odon inst  Coll woll  Noto glau  Wate mite  Dipt larv  Orth
  coer  Gamm pule  Caen robu  Caen rivu  Sial luta  Olig worm
  Cles cadd  Pota depr  Leuc larv  Caen hora  Hali obli  Amel
  inop  Hair magg
0ITEMS IN POSITIVE GROUP   5 (N=    4)        I.E. GROUP *01
  Chyr larv  Chyr pupa  Cori nymp  Case cadd

  *************************************************************
  *************************************************************
  **

0DIVISION    3 (N=  15)        I.E. GROUP *1
 EIGENVALUE .489 AT ITERATION    1
0ITEMS IN NEGATIVE GROUP   6 (N=    4)        I.E. GROUP *10
  Lest spon  Coen hast  Leuc iner  Zygo inst
0ITEMS IN POSITIVE GROUP   7 (N=   11)        I.E. GROUP *11
  Gyri casp  Hydr nigr  Dyti larv  Ilyb suba  Cord bolt  Agab
  arti  Gyri subs  Agab bipu  Dyti semi  Symp nigr  Siga scot
0   END OF LEVEL   2


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 ***************************************************************

0DIVISION    4 (N=  29)        I.E. GROUP *00
 EIGENVALUE .224 AT ITERATION    1
0ITEMS IN NEGATIVE GROUP   8 (N=   18)        I.E. GROUP
   *000
  Pyrr nymp  Aesh caer  Radi pere  Veli saul  Cord aene  Enal
  cyan  Aqua bee0  Isch eleg  Cadd larv  Hali conf  Coll woll
  Noto glau  Dipt larv  Orth coer  Olig worm  Pota depr  Amel
  inop  Hair magg
0ITEMS IN POSITIVE GROUP   9 (N=   11)        I.E. GROUP
   *001
```

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     Peam usse  Odon inst  Wate mite  Gamm pule  Caen robu  Caen
     rivu  Sial luta  Cles cadd  Leuc larv  Caen hora  Hali obli


     ************************************************************
     ************************************************************
     **
0DIVISION    5 (N=   4)        I.E. GROUP *01
 DIVISION FAILS - THERE ARE TOO FEW ITEMS


     ************************************************************
     ************************************************************
     **
0DIVISION    6 (N=   4)        I.E. GROUP *10
 DIVISION FAILS - THERE ARE TOO FEW ITEMS


     ************************************************************
     ************************************************************
     **
0DIVISION    7 (N=  11)        I.E. GROUP *11
0    END OF LEVEL   3




     ************************************************************
     ************************************************************
     **
0DIVISION    8 (N=  18)        I.E. GROUP *000
 EIGENVALUE  .100  AT ITERATION   1
0ITEMS IN NEGATIVE GROUP 16 (N=   14)         I.E. GROUP
    *0000
  Aesh caer  Veli saul  Cord aene  Enal cyan  Aqua bee0  Isch
   eleg  Hali conf  Coll woll  Noto glau  Dipt larv  Orth coer
   Pota depr  Amel inop  Hair magg
0ITEMS IN POSITIVE GROUP 17 (N=    4)         I.E. GROUP
    *0001
  Pyrr nymp  Radi pere  Cadd larv  Olig worm


     ************************************************************
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     **
0DIVISION    9 (N=  11)        I.E. GROUP *001
 EIGENVALUE  .264  AT ITERATION   1
0ITEMS IN NEGATIVE GROUP 18 (N=   10)         I.E. GROUP
    *0010
  Odon inst  Wate mite  Gamm pule  Caen robu  Caen rivu  Sial
   luta  Cles cadd  Leuc larv  Caen hora  Hali obli
0ITEMS IN POSITIVE GROUP 19 (N=    1)         I.E. GROUP
    *0011
  Peam usse
0    END OF LEVEL   4




     ************************************************************
     ************************************************************
     **
0DIVISION   16 (N=  14)        I.E. GROUP *0000
 EIGENVALUE  .079  AT ITERATION   1
```

43

```
0ITEMS IN NEGATIVE GROUP 32  (N=    8)          I.E. GROUP
   *00000
 Veli saul  Aqua bee0  Isch eleg  Hali conf  Coll woll  Pota
 depr  Amel inop  Hair magg
0ITEMS IN POSITIVE GROUP 33  (N=    6)          I.E. GROUP
   *00001
 Aesh caer  Cord aene  Enal cyan  Noto glau  Dipt larv  Orth
 coer


   ************************************************************
   ************************************************************
   **
0DIVISION   17  (N=   4)         I.E. GROUP *0001
 DIVISION FAILS - THERE ARE TOO FEW ITEMS

   ************************************************************
   ************************************************************
   **
0DIVISION   18  (N=  10)         I.E. GROUP *0010
 EIGENVALUE  .182  AT ITERATION   1
0ITEMS IN NEGATIVE GROUP 36  (N=    1)          I.E. GROUP
   *00100
 Odon inst
0ITEMS IN POSITIVE GROUP 37  (N=    9)          I.E. GROUP
   *00101
 Wate mite  Gamm pule  Caen robu  Caen rivu  Sial luta  Cles
 cadd  Leuc larv  Caen hora  Hali obli


   ************************************************************
   ************************************************************
   **
0DIVISION   19  (N=   1)         I.E. GROUP *0011
 DIVISION FAILS - THERE ARE TOO FEW ITEMS
0    END OF LEVEL   5



   ************************************************************
   ************************************************************
   **
0DIVISION   32  (N=   8)         I.E. GROUP *00000
 EIGENVALUE  .037  AT ITERATION   1
0ITEMS IN NEGATIVE GROUP 64  (N=    5)          I.E. GROUP
   *000000
 Veli saul  Aqua bee0  Pota depr  Amel inop  Hair magg
0ITEMS IN POSITIVE GROUP 65  (N=    3)          I.E. GROUP
   *000001
 Isch eleg  Hali conf  Coll woll


   ************************************************************
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   **
0DIVISION   33  (N=   6)         I.E. GROUP *00001
 EIGENVALUE  .062  AT ITERATION   1
0ITEMS IN NEGATIVE GROUP 66  (N=    4)          I.E. GROUP
   *000010
 Aesh caer  Noto glau  Dipt larv  Orth coer
```

44

```
0ITEMS IN POSITIVE GROUP  67  (N=    2)          I.E. GROUP
   *000011
  Cord aene  Enal cyan


   **********************************************************
   **********************************************************
   **


0DIVISION   36  (N=   1)         I.E. GROUP *00100
 DIVISION FAILS - THERE ARE TOO FEW ITEMS


   **********************************************************
   **********************************************************
   **


0DIVISION   37  (N=   9)         I.E. GROUP *00101
 EIGENVALUE  .087  AT ITERATION   1
0ITEMS IN NEGATIVE GROUP  74  (N=    8)          I.E. GROUP
   *001010
  Gamm pule  Caen robu  Caen rivu  Sial luta  Cles cadd  Leuc
   larv  Caen hora  Hali obli
0ITEMS IN POSITIVE GROUP  75  (N=    1)          I.E. GROUP
   *001011
  Wate mite
0    END OF LEVEL   6


0THIS IS THE END OF THE DIVISIONS REQUESTED


   **********************************************************
   **********************************************************
   **


 ORDER OF SPECIES INCLUDING RARER ONES
    7 Veli saul| 11 Aqua bee0| 37 Pota depr| 47 Amel inop|
   48 Hair magg| 13 Isch eleg| 15 Hali conf| 23 Coll woll
    5 Aesh caer| 24 Noto glau| 26 Dipt larv| 27 Orth coer|
   9 Cord aene| 10 Enal cyan|  2 Pyrr nymp|  6 Radi pere
   14 Cadd larv| 32 Olig worm| 16 Odon inst| 28 Gamm pule|
   29 Caen robu| 30 Caen rivu| 31 Sial luta| 33 Cles cadd
   38 Leuc larv| 39 Caen hora| 46 Hali obli| 25 Wate mite|
   8 Peam usse|  3 Chyr larv|  4 Chyr pupa| 12 Cori nymp
   22 Case cadd|  1 Lest spon| 18 Coen hast| 19 Leuc iner|
   36 Zygo inst| 17 Gyri casp| 20 Hydr nigr| 21 Dyti larv
   34 Ilyb suba| 35 Cord bolt| 40 Agab arti| 41 Gyri subs|
   42 Agab bipu| 43 Dyti semi| 44 Symp nigr| 45 Siga scot


 ORDER OF SAMPLES
    1 Laranano |  7 Lochclar | 17 Lochstur | 12 Lochfeur |
   13 Nambreac | 18 Nafemuga |  2 Laramicr |  3 LochLara
    4 Lochalph |  6 Lochgamm |  8 LochClai |  9 Antsmhoi |
   10 Durinanu | 14 Lochboor | 16 Casssius |  5 Lochbeta
   11 Lochcase | 15 Greadive |
1
```

```
                         1111      111 11
                         177238234689046515

    7 Veli saul   ------1-----------   000000
   11 Aqua bee0   -------1----------   000000
   37 Pota depr   ---1-------------   000000
   47 Amel inop   -----1-----------   000000
   48 Hair magg   -----1-----------   000000
   13 Isch eleg   --------11--------   000001
   15 Hali conf   ---1----1---------   000001
   23 Coll woll   ---------1--------   000001
    5 Aesh caer   1-1--------------   000010
   24 Noto glau   -1-------1-------   000010
   26 Dipt larv   -11--1-----------   000010
   27 Orth coer   -11--------------   000010
    9 Cord aene   -11111-1----------   000011
   10 Enal cyan   --1----1----------   000011
    2 Pyrr nymp   1----111-1----1---   0001
    6 Radi pere   1--11111111-11----   0001
   14 Cadd larv   -11-----1-----1---   0001
   32 Olig worm   ---1-1-----1------   0001
   16 Odon inst   -----1--1--1------   00100
   28 Gamm pule   ----------11111---   001010
   29 Caen robu   ----------1-------   001010
   30 Caen rivu   -----------11-----   001010
   31 Sial luta   -----------1------   001010
   33 Cles cadd   ------------1-----   001010
   38 Leuc larv   -------------1----   001010
   39 Caen hora   -------------1----   001010
   46 Hali obli   --------------1---   001010
   25 Wate mite   -1--------1-------   001011
    8 Peam usse   -111111---1111-1--   0011
    3 Chyr larv   111111111111-11111   01
    4 Chyr pupa   1-----------111--1   01
   12 Cori nymp   -111---111-1-1-111   01
   22 Case cadd   -1-111---1-11----1   01
    1 Lest spon   11-------------1-   10
   18 Coen hast   -1------------11--   10
   19 Leuc iner   -----------11--1--   10
   36 Zygo inst   --1-------------1-   10
   17 Gyri casp   ---------------1-1   11
   20 Hydr nigr   ---------------1--   11
   21 Dyti larv   ---------------1-1   11
   34 Ilyb suba   ----------------11   11
   35 Cord bolt   ---------------1-   11
   40 Agab arti   ----------------1   11
   41 Gyri subs   ----------------1   11
   42 Agab bipu   ----------------1   11
   43 Dyti semi   ----------------1   11
   44 Symp nigr   ----------------1   11
   45 Siga scot   ----------------1   11


                    00000000000000000111
                    000000000011111
                    000111111100001
                       0000011
                        00011
```

Appendix 1.4: DECORANA RESULTS/RAW OUTPUT

```
ENTER TRANSFORMATION IN FREE FORMAT
 A NEGATIVE ENTRY TERMINATES TRANSFORMATION DATA
 IF NO TRANSFORMATION DESIRED, MERELY TYPE -1 0
    .00  -1.00
 NO TRANSFORMATION OF DATA WILL BE MADE
 PARAMETERS SET TO DEFAULTS:
   NO DOWN WEIGHTING OF RARE SPECIES
   AXES RESCALED 4 TIMES
   DETRENDED CORRESPONDENCE ANALYSIS (NOT RA)
   26 SEGMENTS
   RESCALING THRESHOLD = 0, I.E., ALL AXES WILL BE RESCALED
   NO MACHINE READABLE OUTPUT

 READING DATA MATRIX FROM DEVICE 5

 LOCHINV3.OUT

 ENTER NUMBERS (NOT NAMES) OF SAMPLES TO BE OMITTED
 ONE AT A TIME, ENDING LIST WITH A ZERO
       0

 NO DOWNWEIGHTING

 AXES ARE RESCALED

 RESIDUAL  .254011    AT ITERATION  0
 RESIDUAL  .018200    AT ITERATION  1
 RESIDUAL  .000622    AT ITERATION  2
 RESIDUAL  .000012    AT ITERATION  3
 EIGENVALUE  .70573

 LENGTH OF GRADIENT    3.427
 LENGTH OF SEGMENTS  .23  .23  .23  .23  .23  .23  .22  .20  .18  .17
 LENGTH OF SEGMENTS  .16  .15  .14  .14  .14  .16  .19  .20
 LENGTH OF GRADIENT    3.576

 LENGTH OF GRADIENT    3.621
 LENGTH OF SEGMENTS  .18  .19  .19  .20  .20  .20  .20  .21  .21  .20
 LENGTH OF SEGMENTS  .19  .19  .18  .17  .16  .16  .18  .21  .22
 LENGTH OF GRADIENT    3.623

 RESIDUAL  .107648    AT ITERATION  0
 RESIDUAL  .004194    AT ITERATION  1
 RESIDUAL  .000506    AT ITERATION  2
 RESIDUAL  .000384    AT ITERATION  3
 RESIDUAL  .000052    AT ITERATION  4
 EIGENVALUE  .25923

 LENGTH OF GRADIENT    2.264
 LENGTH OF SEGMENTS  .10  .11  .12  .16  .20  .23  .27  .28  .26  .22
 LENGTH OF SEGMENTS  .17  .14
 LENGTH OF GRADIENT    2.231

 LENGTH OF GRADIENT    2.101
 LENGTH OF SEGMENTS  .16  .16  .17  .19  .22  .22  .22  .21  .20  .18
 LENGTH OF SEGMENTS  .17
 LENGTH OF GRADIENT    2.042

 RESIDUAL  .040375    AT ITERATION  0
 RESIDUAL  .026893    AT ITERATION  1
 RESIDUAL  .001570    AT ITERATION  2
 RESIDUAL  .000072    AT ITERATION  3
 EIGENVALUE  .17361

 LENGTH OF GRADIENT    1.584
 LENGTH OF SEGMENTS  .20  .22  .24  .23  .20  .16  .13  .09  .07  .06
 LENGTH OF GRADIENT    1.982

 LENGTH OF GRADIENT    2.008
 LENGTH OF SEGMENTS  .14  .18  .22  .23  .22  .21  .20  .18  .16  .14
 LENGTH OF SEGMENTS  .13
 LENGTH OF GRADIENT    1.958
```

```
RESIDUAL   .015131   AT ITERATION  0
RESIDUAL   .001252   AT ITERATION  1
RESIDUAL   .000884   AT ITERATION  2
RESIDUAL   .000018   AT ITERATION  3
EIGENVALUE   .04757

LENGTH OF GRADIENT    1.343
LENGTH OF SEGMENTS  .14  .15  .17  .18  .18  .18  .14  .09  .06  .05
LENGTH OF GRADIENT    1.756

LENGTH OF GRADIENT    1.844
LENGTH OF SEGMENTS  .15  .15  .17  .21  .23  .22  .20  .19  .17  .15
LENGTH OF GRADIENT    1.884
1
LOCHINV3.OUT
 DECORANA OPTIONS -- DOWNWEIGHTING 0  RESCALING 4  ANALYSIS 0  SEGMENTS 26  THRESHOLD
.00
 TRANSFORMATION      .00    .00
```
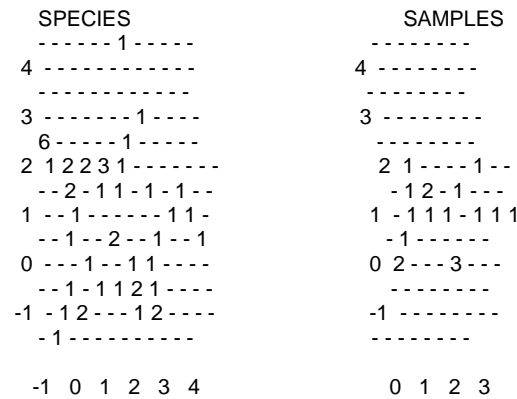
SPECIES SCORES

N	NAME	AX1	AX2	AX3	AX4	RANKED 1 EIG= .706	RANKED 2 EIG= .259	RANKED 3 EIG= .174	RANKED 4 EIG= .048
1	Lest spon	44	-1	129	-131	33 Cles cadd 476	7 Veli saul 470	11 Aqua bee0 427	7 Veli saul 447
2	Pyrr nymp	207	277	291	250	30 Caen rivu 417	46 Hali obli 329	10 Enal cyan 335	35 Cord bolt 284
3	Chyr larv	130	162	39	141	31 Sial luta 398	2 Pyrr nymp 277	2 Pyrr nymp 291	20 Hydr nigr 279
4	Chyr pupa	198	193	175	8	28 Gamm pule 393	40 Agab arti 254	7 Veli saul 283	11 Aqua bee0 268
5	Aesh caer	52	211	226	-45	8 Peam usse 335	41 Gyri subs 254	46 Hali obli 272	36 Zygo inst 262
6	Radi pere	237	-51	144	17	29 Caen robu 291	42 Agab bipu 254	9 Cord aene 257	2 Pyrr nymp 250
7	Veli saul	229	470	283	447	19 Leuc iner 277	43 Dyti semi 254	23 Coll woll 249	15 Hali conf 249
8	Peam usse	335	54	17	69	46 Hali obli 272	44 Symp nigr 254	24 Noto glau 235	10 Enal cyan 242
9	Cord aene	120	-2	257	-117	38 Leuc larv 264	45 Siga scot 254	5 Aesh caer 226	17 Gyri casp 241
10	Enal cyan	27	229	335	242	39 Caen hora 264	34 Ilyb suba 244	14 Cadd larv 223	21 Dyti larv 241
11	Aqua bee0	51	226	427	268	32 Olig worm 263	17 Gyri casp 230	13 Isch eleg 212	19 Leuc iner 235
12	Cori nymp	6	164	108	138	37 Pota depr 245	21 Dyti larv 230	27 Orth coer 201	16 Odon inst 207
13	Isch eleg	-33	-104	212	204	6 Radi pere 237	10 Enal cyan 229	26 Dipt larv 190	13 Isch eleg 204
14	Cadd larv	87	13	223	14	7 Veli saul 229	11 Aqua bee0 226	4 Chyr pupa 175	46 Hali obli 202
15	Hali conf	32	-98	-31	249	25 Wate mite 223	26 Dipt larv 218	28 Gamm pule 163	47 Amel inop 185
16	Odon inst	196	-28	37	207	22 Case cadd 216	18 Coen hast 216	33 Cles cadd 147	48 Hair magg 185
17	Gyri casp	-8	230	-170	241	2 Pyrr nymp 207	5 Aesh caer 211	6 Radi pere 144	18 Coen hast 170
18	Coen hast	140	216	-129	170	4 Chyr pupa 198	20 Hydr nigr 200	1 Lest spon 129	33 Cles cadd 164
19	Leuc iner	277	159	-132	235	16 Odon inst 196	4 Chyr pupa 193	22 Case cadd 127	3 Chyr larv 141
20	Hydr nigr	80	200	-316	279	47 Amel inop 161	36 Zygo inst 180	30 Caen rivu 119	12 Cori nymp 138
21	Dyti larv	-8	230	-170	241	48 Hair magg 161	12 Cori nymp 164	31 Sial luta 109	34 Ilyb suba 134
22	Case cadd	216	15	127	-27	18 Coen hast 140	3 Chyr larv 162	12 Cori nymp 108	28 Gamm pule 105
23	Coll woll	-31	-90	249	0	3 Chyr larv 130	19 Leuc iner 159	47 Amel inop 59	32 Olig worm 98
24	Noto glau	2	-61	235	-130	9 Cord aene 120	28 Gamm pule 153	48 Hair magg 59	30 Caen rivu 73
25	Wate mite	223	-17	28	-129	14 Cadd larv 87	27 Orth coer 115	3 Chyr larv 39	8 Peam usse 69
26	Dipt larv	15	218	190	37	20 Hydr nigr 80	31 Sial luta 109	16 Odon inst 37	31 Sial luta 45

```
  27 Orth coer   22 115 201 -103 |   5 Aesh caer   52 |  30 Caen rivu  106 |  25 Wate mite   28 |  37 Pota depr
44 |
  28 Gamm pule  393 153 163 105 |  11 Aqua bee0   51 |  33 Cles cadd   96 |   8 Peam usse   17 |  26 Dipt
larv   37 |
  29 Caen robu  291  -4 -53   4 |   1 Lest spon   44 |  35 Cord bolt   96 |  32 Olig worm   15 |  40 Agab arti   37
|
  30 Caen rivu  417 106 119  73 |  15 Hali conf   32 |  47 Amel inop   73 |  40 Agab arti    4 |  41 Gyri subs   37
|
  31 Sial luta  398 109 109  45 |  10 Enal cyan   27 |  48 Hair magg   73 |  41 Gyri subs    4 |  42 Agab bipu
37 |
  32 Olig worm  263  35  15  98 |  27 Orth coer   22 |   8 Peam usse   54 |  42 Agab bipu    4 |  43 Dyti semi
37 |
  33 Cles cadd  476  96 147 164 |  26 Dipt larv   15 |  32 Olig worm   35 |  43 Dyti semi    4 |  44 Symp nigr
37 |
  34 Ilyb suba  -74 244 -25 134 |  35 Cord bolt   15 |  22 Case cadd   15 |  44 Symp nigr    4 |  45 Siga scot
37 |
  35 Cord bolt   15  96 -98 284 |  36 Zygo inst   12 |  14 Cadd larv   13 |  45 Siga scot    4 |   6 Radi pere   17 |
  36 Zygo inst   12 180 -64 262 |  12 Cori nymp    6 |   1 Lest spon   -1 |  34 Ilyb suba  -25 |  14 Cadd larv   14
|
  37 Pota depr  245 -12 -35  44 |  24 Noto glau    2 |   9 Cord aene   -2 |  15 Hali conf  -31 |   4 Chyr pupa    8 |
  38 Leuc larv  264 -92 -96   6 |  17 Gyri casp   -8 |  29 Caen robu   -4 |  37 Pota depr  -35 |  38 Leuc larv    6 |
  39 Caen hora  264 -92 -96   6 |  21 Dyti larv   -8 |  37 Pota depr  -12 |  29 Caen robu  -53 |  39 Caen hora
6 |
  40 Agab arti  -86 254   4  37 |  23 Coll woll  -31 |  25 Wate mite  -17 |  36 Zygo inst  -64 |  29 Caen robu    4 |
  41 Gyri subs  -86 254   4  37 |  13 Isch eleg  -33 |  16 Odon inst  -28 |  38 Leuc larv  -96 |  23 Coll woll    0 |
  42 Agab bipu  -86 254   4  37 |  34 Ilyb suba  -74 |   6 Radi pere  -51 |  39 Caen hora  -96 |  22 Case cadd  -
27 |
  43 Dyti semi  -86 254   4  37 |  40 Agab arti  -86 |  24 Noto glau  -61 |  35 Cord bolt  -98 |   5 Aesh caer  -45
|
  44 Symp nigr  -86 254   4  37 |  41 Gyri subs  -86 |  23 Coll woll  -90 |  18 Coen hast -129 |  27 Orth coer  -
103 |
  45 Siga scot  -86 254   4  37 |  42 Agab bipu  -86 |  38 Leuc larv  -92 |  19 Leuc iner -132 |   9 Cord aene  -
117 |
  46 Hali obli  272 329 272 202 |  43 Dyti semi  -86 |  39 Caen hora  -92 |  17 Gyri casp -170 |  25 Wate mite  -
129 |
  47 Amel inop  161  73  59 185 |  44 Symp nigr  -86 |  15 Hali conf  -98 |  21 Dyti larv -170 |  24 Noto glau  -
130 |
  48 Hair magg  161  73  59 185 |  45 Siga scot  -86 |  13 Isch eleg -104 |  20 Hydr nigr -316 |   1 Lest spon  -
131 |
1
 LOCHINV3.OUT
 DECORANA OPTIONS -- DOWNWEIGHTING 0   RESCALING  4   ANALYSIS 0   SEGMENTS 26   THRESHOLD
.00
 TRANSFORMATION        .00    .00
```
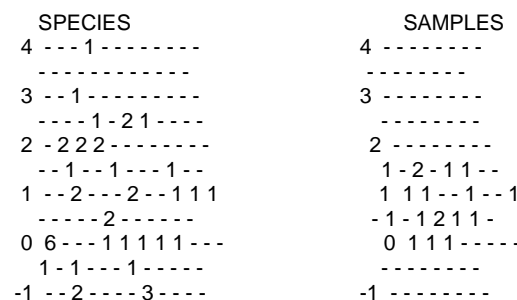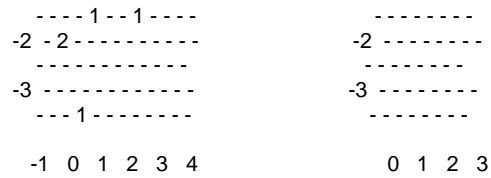
SAMPLE SCORES - WHICH ARE WEIGHTED MEAN SPECIES SCORES

N	NAME	AX1	AX2	AX3	AX4	RANKED 1 EIG= .706	RANKED 2 EIG= .259	RANKED 3 EIG= .174	RANKED 4 EIG= .048
1	Laranano	139	136	163	55	10 Durinanu 362	16 Casssius 204	3 LochLara 195	2 Laramicr 188
2	Laramicr	210	193	158	188	9 Antsmhoi 324	15 Greadive 203	16 Casssius 166	4 Lochalph 171
3	LochLara	102	161	195	146	8 LochClai 273	2 Laramicr 193	1 Laranano 163	5 Lochbeta 158
4	Lochalph	37	0	122	171	16 Casssius 255	5 Lochbeta 165	6 Lochgamm 163	16 Casssius 150
5	Lochbeta	105	165	0	158	14 Lochboor 242	17 Lochstur 165	2 Laramicr 158	3 LochLara 146
6	Lochgamm	39	19	163	126	2 Laramicr 210	3 LochLara 161	13 Nambreac 141	6 Lochgamm 126
7	Lochclar	89	96	105	33	12 Lochfeur 206	11 Lochcase 148	4 Lochalph 122	11 Lochcase 126
8	LochClai	273	109	61	94	13 Nambreac 204	1 Laranano 136	7 Lochclar 105	18 Nafemuga 122
9	Antsmhoi	324	101	68	93	18 Nafemuga 165	8 LochClai 109	10 Durinanu 101	17 Lochstur 117
10	Durinanu	362	102	101	88	1 Laranano 139	18 Nafemuga 106	17 Lochstur 97	15 Greadive 95
11	Lochcase	78	148	48	126	5 Lochbeta 105	10 Durinanu 102	14 Lochboor 80	8 LochClai 94
12	Lochfeur	206	47	62	74	3 LochLara 102	9 Antsmhoi 101	18 Nafemuga 69	9 Antsmhoi 93
13	Nambreac	204	9	141	0	7 Lochclar 89	7 Lochclar 96	9 Antsmhoi 68	10 Durinanu 88
14	Lochboor	242	28	80	54	11 Lochcase 78	12 Lochfeur 47	12 Lochfeur 62	12 Lochfeur 74
15	Greadive	0	203	36	95	17 Lochstur 64	14 Lochboor 28	8 LochClai 61	1 Laranano 55
16	Casssius	255	204	166	150	6 Lochgamm 39	6 Lochgamm 19	11 Lochcase 48	14 Lochboor 54
17	Lochstur	64	165	97	117	4 Lochalph 37	13 Nambreac 9	15 Greadive 36	7 Lochclar 33
18	Nafemuga	165	106	69	122	15 Greadive 0	4 Lochalph 0	5 Lochbeta 0	13 Nambreac 0

1

SCATTER DIAGRAM OF ORDINATION, AXES   1   2

```
   SPECIES                       SAMPLES
   - - - - - - 1 - - - - -        - - - - - - - -
 4 - - - - - - - - - - - -      4 - - - - - - - -
   - - - - - - - - - - - - -      - - - - - - - -
 3 - - - - - - - 1 - - - -      3 - - - - - - - -
   6 - - - - - 1 - - - - -        - - - - - - - -
 2 1 2 2 3 1 - - - - - - -      2 1 - - - - 1 - -
   - - 2 - 1 1 - 1 - 1 - -        - 1 2 - 1 - - -
 1 - - 1 - - - - - - 1 1 -      1 - 1 1 1 - 1 1 1
   - - 1 - - 2 - - 1 - - 1        - 1 - - - - - -
 0 - - - 1 - - 1 1 - - - -      0 2 - - - 3 - - -
   - - 1 - 1 1 2 1 - - - -        - - - - - - - -
-1 - 1 2 - - - 1 2 - - - -     -1 - - - - - - - -
   - 1 - - - - - - - - - -        - - - - - - - -

  -1  0  1  2  3  4              0  1  2  3
```

SCATTER DIAGRAM OF ORDINATION, AXES   1   3

```
   SPECIES                       SAMPLES
 4 - - - 1 - - - - - - - -      4 - - - - - - - -
   - - - - - - - - - - - - -      - - - - - - - -
 3 - - 1 - - - - - - - -        3 - - - - - - - -
   - - - - 1 - 2 1 - - - -        - - - - - - - -
 2 - 2 2 2 - - - - - - - -      2 - - - - - - - -
   - - 1 - - 1 - - - 1 - -        1 - 2 - 1 1 - -
 1 - - 2 - - - 2 - - 1 1 1      1 1 1 - - 1 - - 1
   - - - - - 2 - - - - - -        - 1 - 1 2 1 1 -
 0 6 - - - 1 1 1 1 1 - - -      0 1 1 1 - - - - -
   1 - 1 - - - 1 - - - - -        - - - - - - - -
-1 - - 2 - - - - 3 - - - -     -1 - - - - - - - -
```

```
   - - - - 1 - - 1 - - - -          - - - - - - - -
-2 - 2 - 2 - - - - - - - - - -   -2 - - - - - - - -
   - - - - - - - - - - - -          - - - - - - -
-3 - - - - - - - - - - - -       -3 - - - - - - - -
   - - - 1 - - - - - - - -          - - - - - - - -

   -1  0  1  2  3  4               0  1  2  3
```

1

SCATTER DIAGRAM OF ORDINATION, AXES   1   4

```
    SPECIES                       SAMPLES
 4 - - - - - - 1 - - - - -       4 - - - - - - - -
    - - - - - - - - - - - -          - - - - - - - -
 3 - - - - - - - - - - - -       3 - - - - - - - -
    - - 2 2 - - 1 - - - - -          - - - - - - - -
 2 - 3 2 - - 1 - 2 - - - -       2 - - - - - - - -
    - - - - 1 2 - - - - - 1       1 - 1 - 1 1 - -
 1 1 - 1 - 1 - - - - 1 - -       1 1 2 1 1 - - - -
    - - - - - - - 1 1 - 1 -       1 - 1 - 2 1 1 1
 0 6 1 1 1 - 1 2 3 - 1 - -       0 - 1 - - 1 - - -
    - - - 1 - - 1 - - - - -          - - - - - - - -
-1 - - - - - - - - - - - - -     -1 - - - - - - - -
    - - 3 - 1 - 1 - - - - -          - - - - - - - -

   -1  0  1  2  3  4               0  1  2  3
```


SCATTER DIAGRAM OF ORDINATION, AXES   2   3

```
    SPECIES                       SAMPLES
 4 - - - - - - - 1 - - - - -     4 - - - - -
    - - - - - - - - - - - - -        - - - - -
 3 - - - - - - - 1 - - - - -     3 - - - - -
    - - 1 - - - - - 1 1 - - 1        - - - - -
 2 1 2 - 1 - 1 - 1 - - - - -     2 - - - - -
    - - - - - - 2 1 - - - - -     1 - 1 2 1
 1 - 1 1 1 1 2 1 - - - - - -       1 2 1 1 - -
    - - - - 2 - - - - - - - -     2 - 3 1 -
 0 - - 2 1 1 - 1 - 6 - - - -       0 - - 1 1 1
    - 1 1 - - - - 1 - - - - -        - - - - -
-1 - 2 1 - 1 - 1 - - - - - -     -1 - - - - -
    - - - - - - 1 1 - - - - -        - - - - -
-2 - - - - - - - 2 - - - - -     -2 - - - - -
    - - - - - - - - - - - - -        - - - - -
-3 - - - - - - - - - - - - -     -3 - - - - -
    - - - - - - - 1 - - - - -        - - - - -

   -1  0  1  2  3  4               0  1  2
```
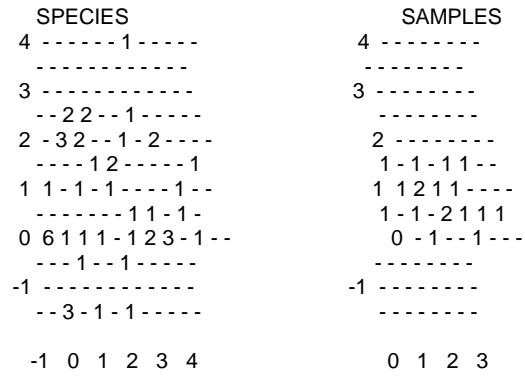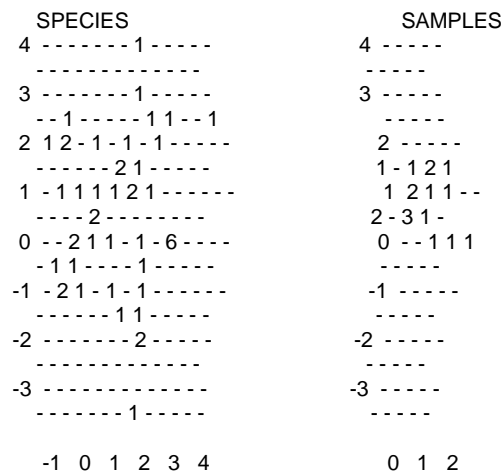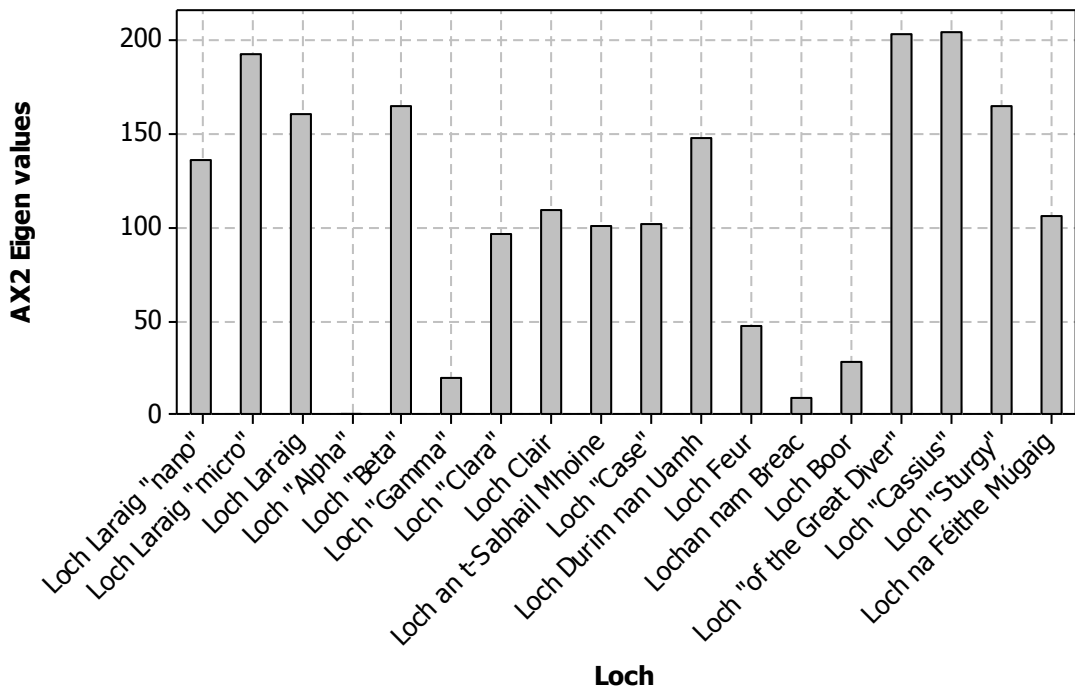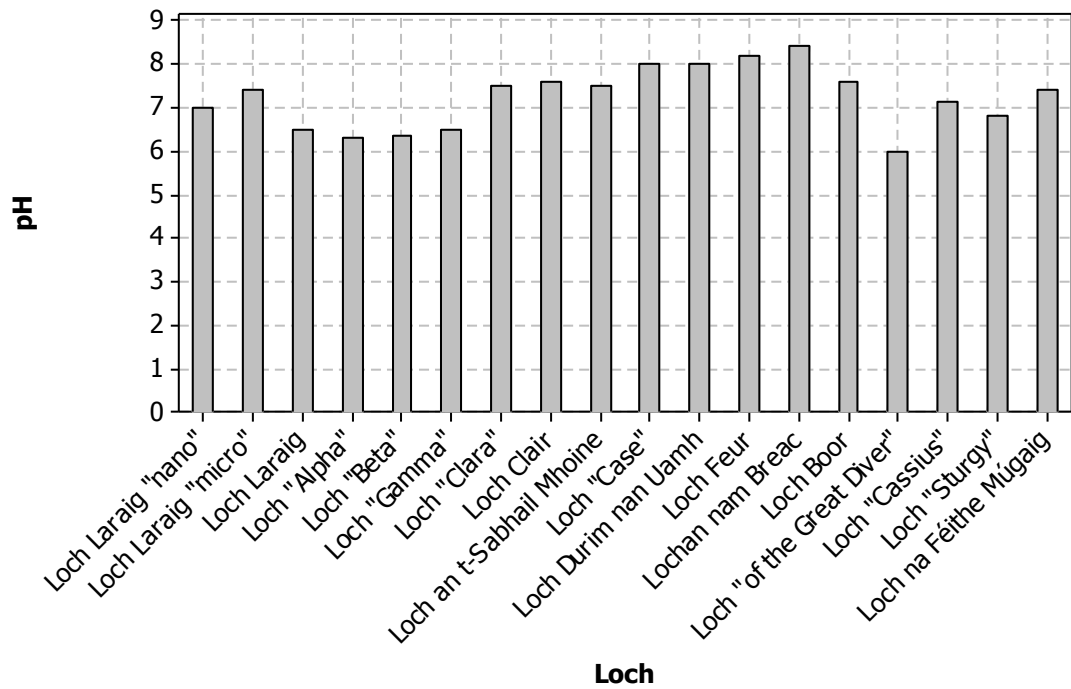
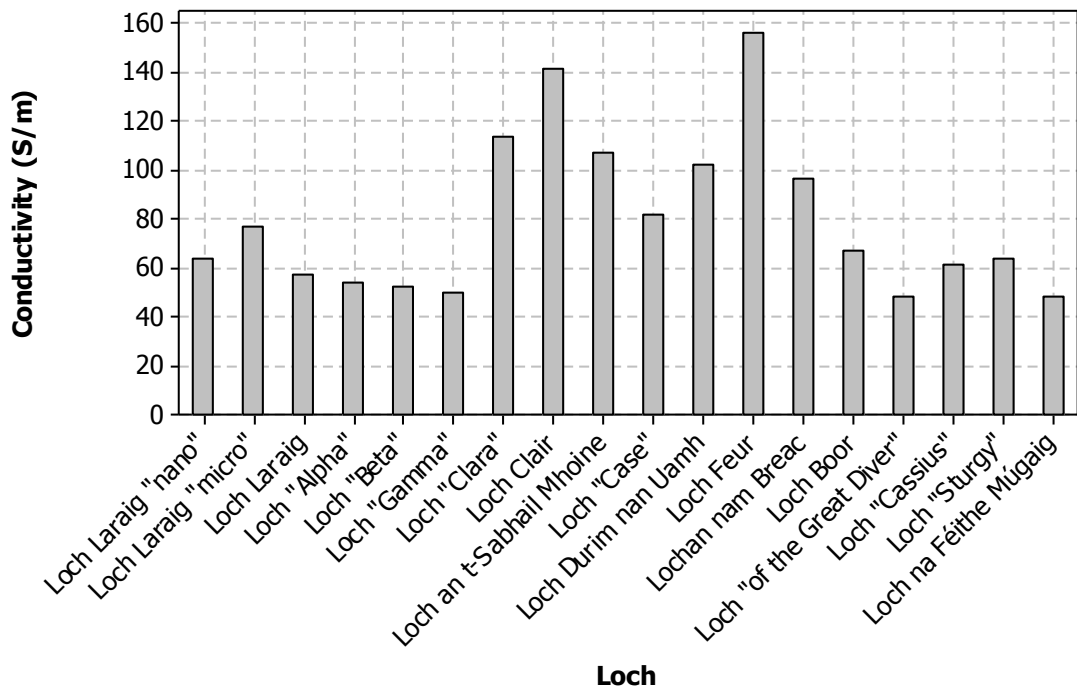**Appendix 1.5: Column graphs of the Gairloch Hill Loch data**
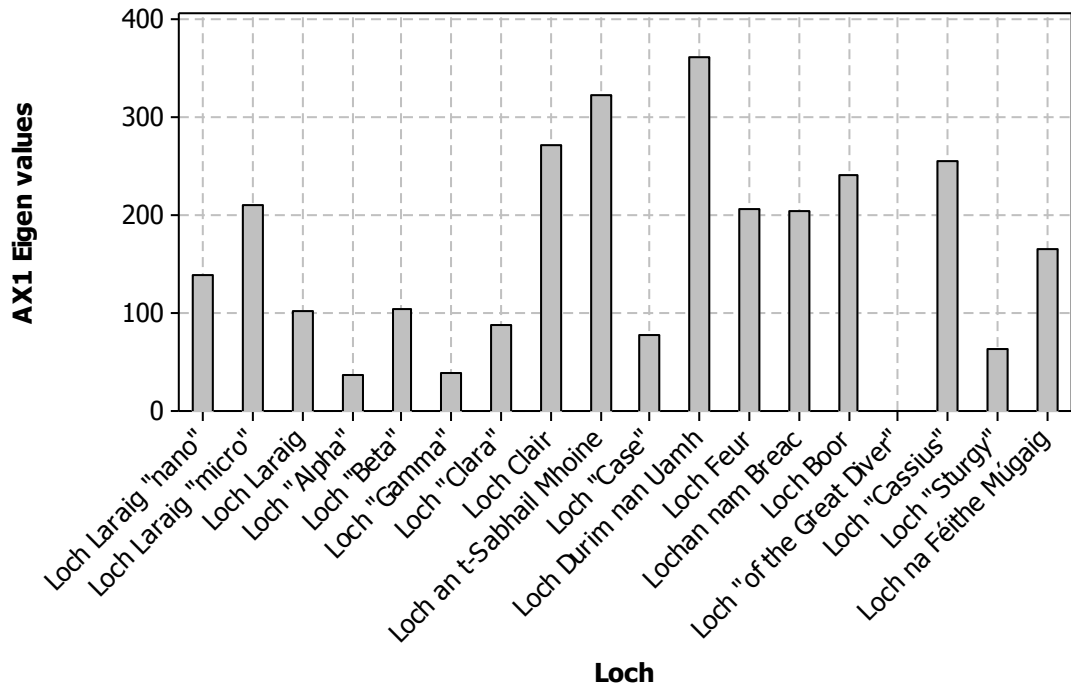
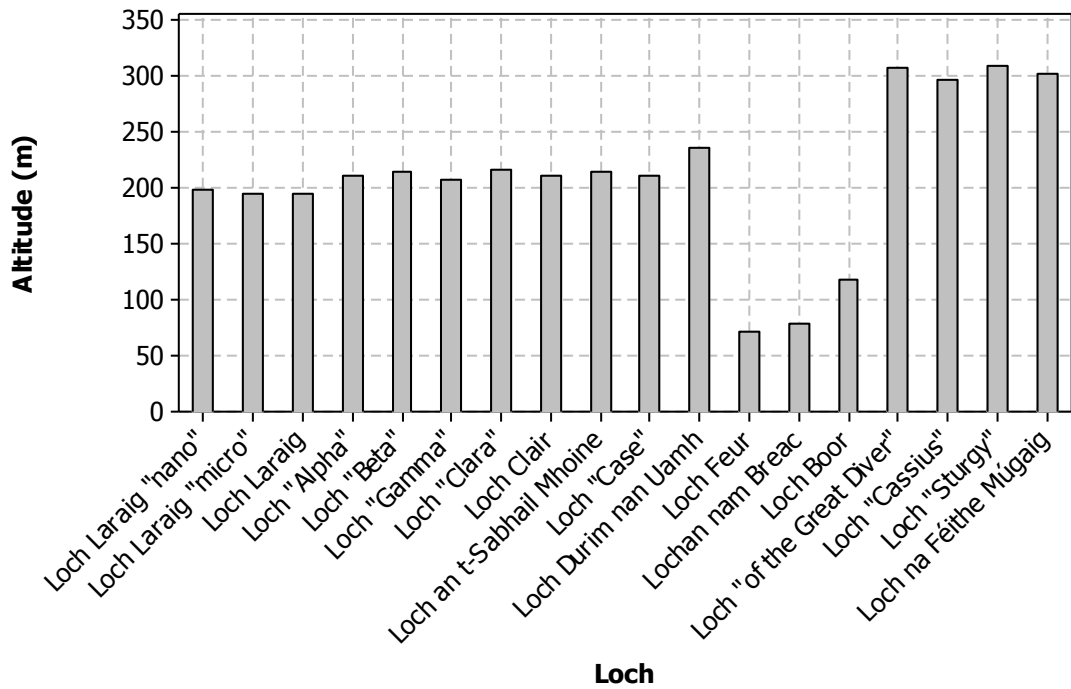**Appendix 1.5.1:** Eigen values of AX1 from DECORANA output (AX1, EIG= .706).

Appendix 1.5.2: Eigen values of AX1 from DECORANA output (AX2= .259).
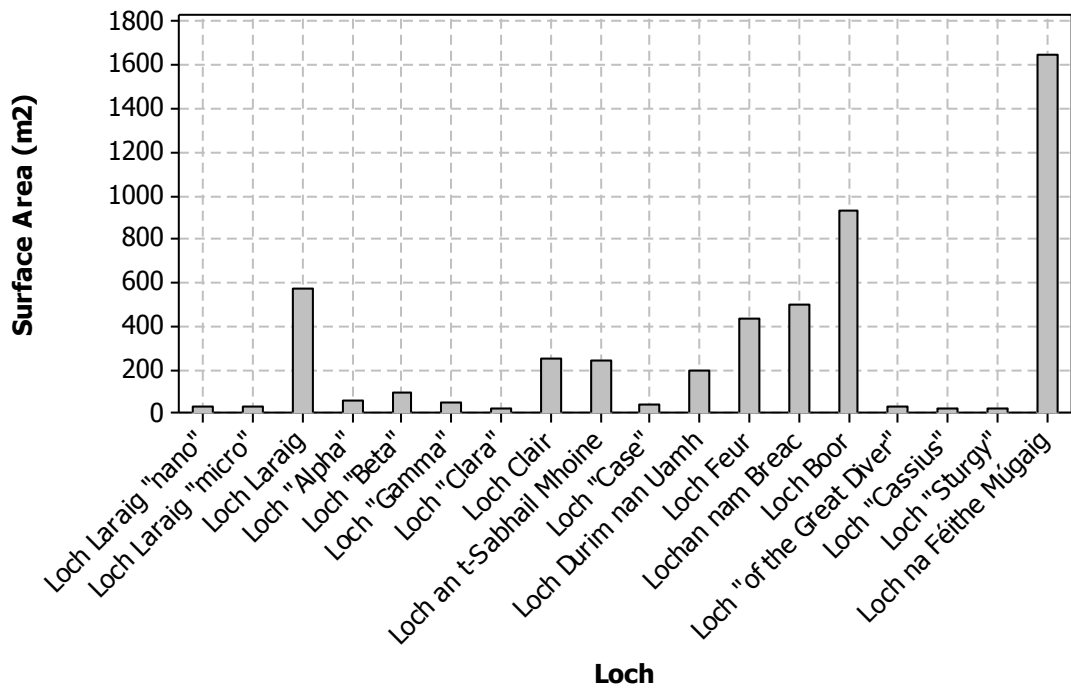
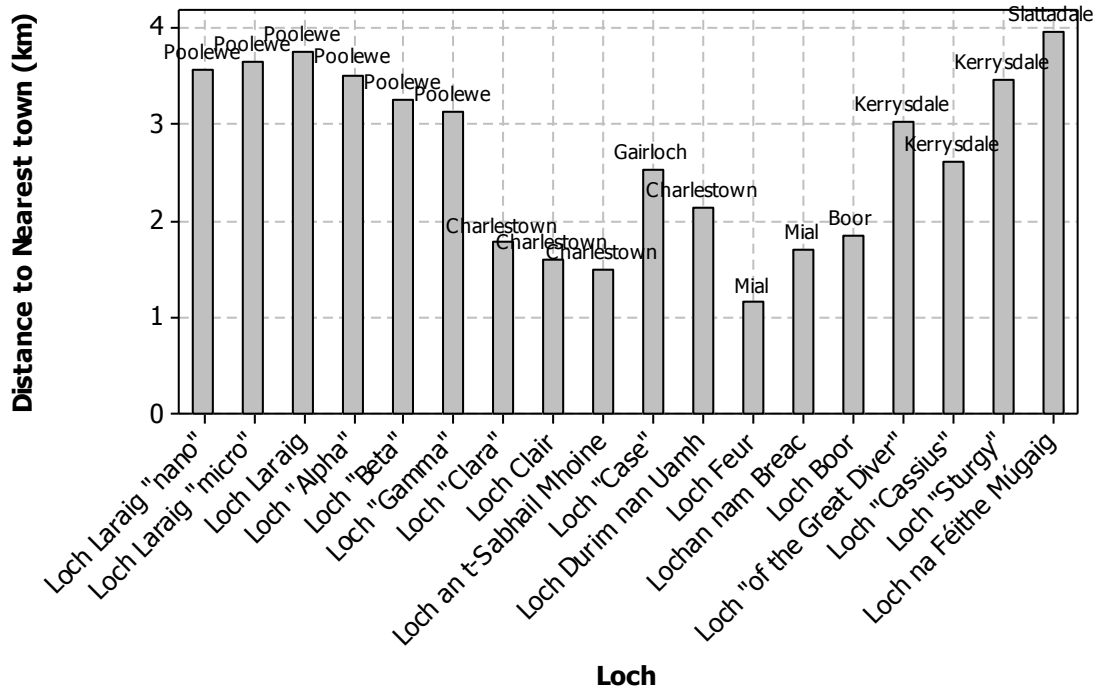**Appendix 1.5.3:** Water pH levels across the samples of Loch.

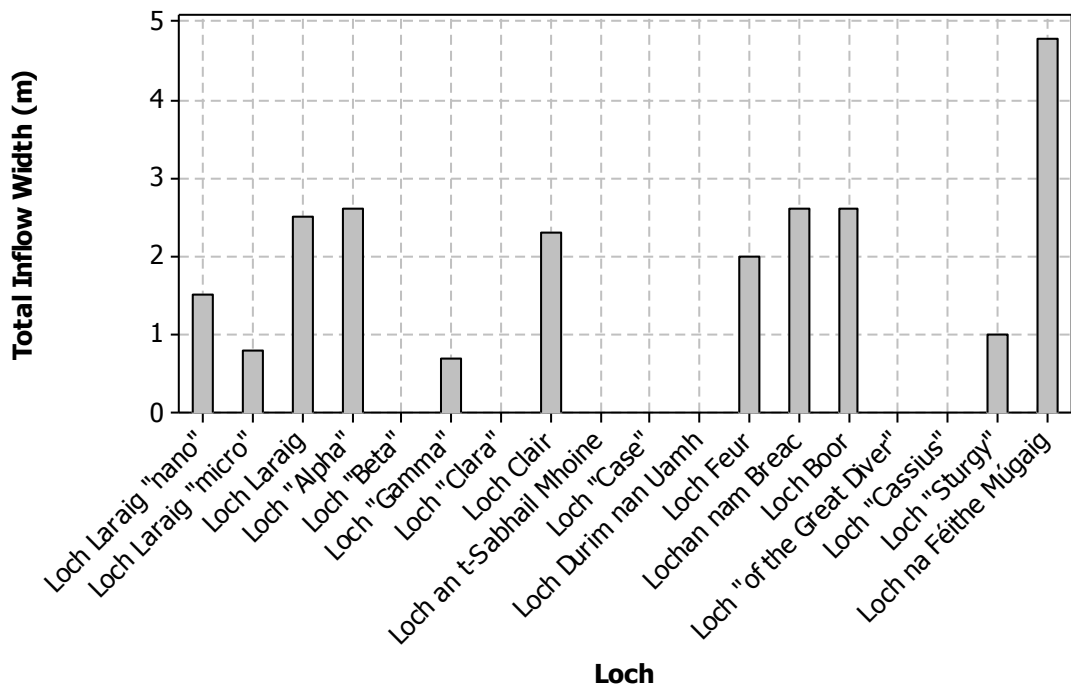**Appendix 1.5.4:** Level of water conductivity in each of the Lochs.

Appendix 1.5.5: Altitude of each loch above sea level.

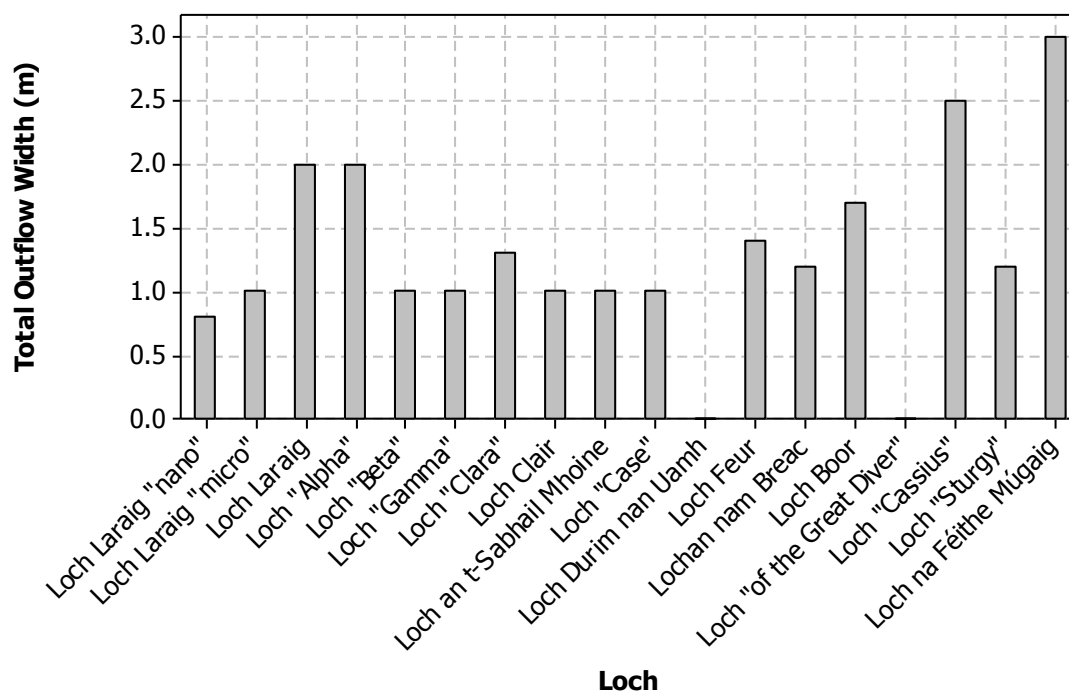**Appendix 1.5.6:** Approximate surface area for each loch.

Appendix 1.5.7: Distance to the nearest town for each loch.

Appendix 1.5.8: Total inflow width of each loch.

Appendix 1.5.9: Total outflow width for each loch.

Appendix 1.6: Pearson's Correlations for parametric data: Species rich, Simpons Inde, SI Richness, AX1 (.706), …

N = 16	Species richness	Simpons Index	SI Richness
Simpons Index	-0.092		
	0.717		
SI Richness	0.825	0.419	
	1.360	0.083	
AX1 (.706)	-0.249	-0.276	-0.314
	0.319	0.268	0.204
AX2 (.259)	0.099	0.114	0.233
	0.696	0.654	0.352
pH	-0.260	-0.263	-0.304
	0.297	0.292	0.221
Distance to near	-0.069	0.187	0.054
	0.786	0.458	0.830
Total Outflow Wi	-0.065	0.080	-0.097
	0.796	0.752	0.703
Geology UD (%)	0.577	-0.175	0.457
	0.423	0.825	0.543
Geology SP (%)	1.000	-1.000	1.000
	*	*	*
Geology GB (%)	-1.000	-1.000	-1.000
	*	*	*
SLU <5m ERF (%)	0.077	-0.138	0.004
	0.856	0.745	0.992
SLU 5-25m ERF (%	-0.179	0.223	0.087
	0.599	0.511	0.799
SLU 25-100m MLH	0.055	-0.010	-0.006
	0.827	0.969	0.981
SLU 25-100m ERF	-0.055	0.010	0.006
	0.827	0.969	0.981
AWB <10m	-0.500	0.482	0.496
	0.667	0.680	0.670
AWB 250-500m	-0.233	0.314	-0.054
	0.353	0.205	0.833

	AX1 (.706)	AX2 (.259)	pH
AX2 (.259)	-0.071		
	0.779		
pH	0.656	-0.304	
	0.003	0.221	
Distance to near	-0.544	0.389	-0.674
	0.020	0.110	0.002
Total Outflow Wi	-0.020	-0.134	-0.011
	0.939	0.595	0.966
Geology UD (%)	0.842	-0.309	0.525

```
                                   0.158            0.691            0.475

Geology SP (%)                     1.000           -1.000           -1.000
                                     *                *                *

Geology GB (%)                    -1.000           -1.000            1.000
                                     *                *                *

SLU <5m ERF (%)                    0.451            0.459            0.298
                                   0.262            0.253            0.473

SLU 5-25m ERF (%                  -0.004            0.195            0.282
                                   0.990            0.566            0.402

SLU 25-100m MLH                    0.682           -0.387            0.589
                                   0.002            0.113            0.010

SLU 25-100m ERF                   -0.682            0.387           -0.589
                                   0.002            0.113            0.010

AWB <10m                           0.179            0.828           -0.037
                                   0.886            0.378            0.977

AWB 250-500m                      -0.299           -0.023           -0.558
                                   0.228            0.927            0.016


                       Distance to near  Total Outflow Width  Geology UD (%)
Total Outflow Wi                   0.246
                                   0.324

Geology UD (%)                    -0.843           -0.720
                                   0.157            0.280

Geology SP (%)                    -1.000              *                *
                                     *                *                *

Geology GB (%)                     1.000           -1.000           -1.000
                                     *                *                *

SLU <5m ERF (%)                    0.140           -0.104              *
                                   0.741            0.806              *

SLU 5-25m ERF (%                   0.310           -0.406              *
                                   0.353            0.216              *

SLU 25-100m MLH                   -0.757           -0.026            0.778
                                   0.000            0.918            0.222

SLU 25-100m ERF                    0.757            0.026           -0.778
                                   0.000            0.918            0.222

AWB <10m                           0.801            0.629              *
                                   0.409            0.567              *

AWB 250-500m                       0.619            0.107           -0.751
                                   0.006            0.672            0.249


                        Geology SP (%)   Geology GB (%)   SLU <5m ERF (%)
Geology GB (%)                       *
                                     *

SLU <5m ERF (%)                      *                *
                                     *                *

SLU 5-25m ERF (%                     *                *              0.711
                                     *                *              0.048
```

```
SLU 25-100m MLH              -1.000                 *              -0.140
                                 *                  *               0.740

SLU 25-100m ERF               1.000                 *               0.140
                                 *                  *               0.740

AWB <10m                         *                  *              -0.945
                                 *                  *               0.212

AWB 250-500m                     *              1.000               0.301
                                 *                  *               0.469


                   SLU 5-25m ERF (%)  SLU 25-100m MLH  SLU 25-100m ERF
SLU 25-100m MLH              -0.465
                             0.150

SLU 25-100m ERF              0.465            -1.000
                             0.150                *

AWB <10m                    -0.500            -0.500            0.500
                             0.667             0.667            0.667

AWB 250-500m                 0.306            -0.513            0.513
                             0.360             0.030            0.030


                        AWB <10m
AWB 250-500m            -0.500
                         0.667

Cell Contents: Pearson correlation

* NOTE * Not enough data in column
* NOTE * All values in column are identical.
```

Appendix 1.7: Spearman's Rank Correlations for non-parametric data: Species Rich, Total no. of, Simpsons D I, SI Richness , …

N = 39	Species Richness	Total no. of org	Simpsons D Index
Total no. of org	0.648		
Simpsons D Index	-0.089	-0.579	
SI Richness rk	0.745	0.245	0.380
AX1 (.706) rk	-0.214	0.035	-0.226
AX2 (.259) rk	-0.020	0.124	0.132
pH rk	-0.227	-0.048	-0.264
Conductivity rk	-0.166	0.081	-0.068
Surface Area rk	-0.071	-0.254	-0.273
Altitude rk	0.603	0.778	-0.374
Distance to near	-0.140	-0.316	0.197
Geology QFO (%)	0.280	0.231	-0.268
Geology Amp (%)	-0.672	-0.452	0.160
Geology All (%)	*	*	*
Geology UD (%) r	0.549	0.698	-0.076
Geology SP (%) r	1.000	1.000	-1.000
Geology Peat (%)	*	*	*
Geology GB (%) r	-1.000	-1.000	-1.000
Geology CZ (%) r	*	*	*
Inflows rk	0.326	-0.062	-0.251
Total Inflow Wid	-0.270	-0.513	0.048
Outflows rk	-0.115	-0.228	0.068
Total Outflow Wi	0.043	-0.293	0.140
SLU <5m MLH (%)	0.043	0.369	-0.372
SLU <5m ERF (%)	0.085	-0.051	-0.104
SLU 5-25m MLH (%	0.226	0.321	-0.238
SLU 5-25m ERF (%	-0.340	-0.481	0.217
SLU 25-100m MLH	-0.009	0.026	-0.028
SLU 25-100m ERF	0.009	-0.026	0.028
SLU Catchment ML	-0.042	-0.097	0.047
SLU Catchment ER	-0.054	-0.115	0.056
SLU Catchment Ro	0.553	0.551	-0.621
AWB <10m rk	-0.500	-0.866	0.277
AWB 10-250m rk	-0.122	-0.374	0.122
AWB 250-500m rk	-0.260	-0.353	0.273
Margin Overhang	*	*	*
Pond Overhang rk	*	*	*
Emergent PC rk	-0.125	0.066	0.074
Floating PC rk	0.166	-0.212	0.351
Submerged PC rk	-0.354	-0.515	0.295

	SI Richness rk	AX1 (.706) rk	AX2 (.259) rk
AX1 (.706) rk	-0.196		
AX2 (.259) rk	0.164	-0.015	
pH rk	-0.296	0.633	-0.353
Conductivity rk	-0.198	0.573	-0.276
Surface Area rk	-0.224	0.327	-0.471
Altitude rk	0.371	-0.185	0.468
Distance to near	0.102	-0.434	0.380
Geology QFO (%)	-0.023	-0.111	0.026
Geology Amp (%)	-0.439	0.365	-0.047
Geology All (%)	*	*	*
Geology UD (%) r	0.489	0.883	-0.303
Geology SP (%) r	1.000	1.000	-1.000
Geology Peat (%)	*	*	*
Geology GB (%) r	-1.000	-1.000	-1.000
Geology CZ (%) r	*	*	*
Inflows rk	0.073	-0.129	-0.160
Total Inflow Wid	-0.200	-0.005	-0.457
Outflows rk	-0.011	0.136	0.045
Total Outflow Wi	0.048	-0.021	-0.203
SLU <5m MLH (%)	-0.222	0.385	-0.291
SLU <5m ERF (%)	0.088	0.525	0.518
SLU 5-25m MLH (%	-0.060	0.480	-0.538

SLU 5-25m ERF (%	-0.018	0.152	0.177
SLU 25-100m MLH	-0.097	0.664	-0.356
SLU 25-100m ERF	0.097	-0.664	0.356
SLU Catchment ML	-0.095	0.686	-0.540
SLU Catchment ER	0.051	-0.739	0.430
SLU Catchment Ro	-0.183	0.380	-0.933
AWB <10m rk	0.430	0.189	0.803
AWB 10-250m rk	-0.158	-0.226	-0.298
AWB 250-500m rk	0.016	-0.209	0.013
Margin Overhang	*	*	*
Pond Overhang rk	*	*	*
Emergent PC rk	-0.009	-0.284	-0.090
Floating PC rk	0.210	0.117	-0.210
Submerged PC rk	-0.086	-0.247	0.070

	pH rk	Conductivity rk	Surface Area rk
Conductivity rk	0.824		
Surface Area rk	0.329	0.071	
Altitude rk	-0.391	-0.355	-0.439
Distance to near	-0.670	-0.759	-0.135
Geology QFO (%)	-0.117	-0.177	0.009
Geology Amp (%)	0.135	-0.007	-0.335
Geology All (%)	*	*	*
Geology UD (%) r	0.674	0.974	-0.949
Geology SP (%) r	-1.000	-1.000	-1.000
Geology Peat (%)	*	*	*
Geology GB (%) r	1.000	-1.000	1.000
Geology CZ (%) r	*	*	*
Inflows rk	-0.327	-0.581	0.591
Total Inflow Wid	0.088	-0.105	0.629
Outflows rk	0.000	-0.159	0.057
Total Outflow Wi	-0.014	-0.136	0.285
SLU <5m MLH (%)	0.682	0.710	0.020
SLU <5m ERF (%)	0.269	0.128	-0.106
SLU 5-25m MLH (%	0.558	0.617	0.300
SLU 5-25m ERF (%	0.372	0.337	0.125
SLU 25-100m MLH	0.680	0.714	0.326
SLU 25-100m ERF	-0.680	-0.714	-0.326
SLU Catchment ML	0.673	0.674	0.413
SLU Catchment ER	-0.521	-0.561	-0.321
SLU Catchment Ro	0.886	0.583	0.979
AWB <10m rk	0.052	0.000	0.596
AWB 10-250m rk	-0.349	-0.375	0.431
AWB 250-500m rk	-0.578	-0.518	0.039
Margin Overhang	*	*	*
Pond Overhang rk	*	*	*
Emergent PC rk	-0.151	0.161	-0.300
Floating PC rk	0.351	0.398	0.211
Submerged PC rk	-0.213	-0.088	0.057

	Altitude rk	Distance to near	Geology QFO (%)
Distance to near	0.205		
Geology QFO (%)	0.316	0.167	
Geology Amp (%)	-0.475	0.247	-0.994
Geology All (%)	*	*	*
Geology UD (%) r	0.172	-0.879	-1.000
Geology SP (%) r	1.000	-1.000	*
Geology Peat (%)	*	*	*
Geology GB (%) r	1.000	1.000	*
Geology CZ (%) r	*	*	*
Inflows rk	0.223	0.432	0.600
Total Inflow Wid	-0.457	0.238	0.151
Outflows rk	0.000	0.227	0.179
Total Outflow Wi	-0.096	0.162	0.164
SLU <5m MLH (%)	-0.060	-0.773	-0.137
SLU <5m ERF (%)	0.316	0.154	0.479
SLU 5-25m MLH (%	-0.119	-0.802	-0.270
SLU 5-25m ERF (%	-0.394	0.272	0.294

```
SLU 25-100m MLH          -0.315          -0.662          -0.204
SLU 25-100m ERF           0.315           0.662           0.204
SLU Catchment ML         -0.426          -0.709          -0.355
SLU Catchment ER          0.221           0.594           0.068
SLU Catchment Ro         -0.896          -0.963          -0.110
AWB <10m rk              -1.000           0.866          -0.993
AWB 10-250m rk           -0.203           0.372           0.118
AWB 250-500m rk          -0.062           0.592          -0.152
Margin Overhang              *               *               *
Pond Overhang rk             *               *               *
Emergent PC rk           -0.159           0.051          -0.075
Floating PC rk           -0.398          -0.397               *
Submerged PC rk          -0.336           0.303           0.016
```

	Geology Amp (%)	Geology All (%)	Geology UD (%) r
Geology All (%)	*		
Geology UD (%) r	*	*	
Geology SP (%) r	*	*	*
Geology Peat (%)	*	*	*
Geology GB (%) r	*	*	-1.000
Geology CZ (%) r	*	*	*
Inflows rk	*	*	-0.816
Total Inflow Wid	0.470	*	-0.637
Outflows rk	0.812	*	*
Total Outflow Wi	0.663	*	-0.638
SLU <5m MLH (%)	0.298	*	0.816
SLU <5m ERF (%)	-0.573	*	*
SLU 5-25m MLH (%	0.054	*	0.816
SLU 5-25m ERF (%	-0.561	*	*
SLU 25-100m MLH	0.130	*	0.816
SLU 25-100m ERF	-0.130	*	-0.816
SLU Catchment ML	0.217	*	0.674
SLU Catchment ER	-0.247	*	-1.000
SLU Catchment Ro	*	*	*
AWB <10m rk	*	*	*
AWB 10-250m rk	0.053	*	*
AWB 250-500m rk	0.041	*	-0.715
Margin Overhang	*	*	*
Pond Overhang rk	*	*	*
Emergent PC rk	0.421	*	0.729
Floating PC rk	*	*	0.544
Submerged PC rk	0.000	*	-0.236

	Geology SP (%) r	Geology Peat (%)	Geology GB (%) r
Geology Peat (%)	*		
Geology GB (%) r	*	*	
Geology CZ (%) r	*	*	*
Inflows rk	*	*	*
Total Inflow Wid	-1.000	*	1.000
Outflows rk	*	*	*
Total Outflow Wi	*	*	-1.000
SLU <5m MLH (%)	*	*	*
SLU <5m ERF (%)	*	*	*
SLU 5-25m MLH (%	*	*	*
SLU 5-25m ERF (%	*	*	*
SLU 25-100m MLH	-1.000	*	*
SLU 25-100m ERF	1.000	*	*
SLU Catchment ML	*	*	*
SLU Catchment ER	*	*	*
SLU Catchment Ro	*	*	*
AWB <10m rk	*	*	*
AWB 10-250m rk	-1.000	*	*
AWB 250-500m rk	*	*	1.000
Margin Overhang	*	*	*
Pond Overhang rk	*	*	*
Emergent PC rk	*	*	-1.000
Floating PC rk	*	*	-1.000
Submerged PC rk	*	*	-1.000

	Geology CZ (%) r	Inflows rk	Total Inflow Wid
Inflows rk	*		
Total Inflow Wid	*	0.753	
Outflows rk	*	0.586	0.328
Total Outflow Wi	*	0.830	0.547
SLU <5m MLH (%)	*	-0.308	-0.131
SLU <5m ERF (%)	*	-0.026	-0.181
SLU 5-25m MLH (%	*	-0.128	0.052
SLU 5-25m ERF (%	*	-0.125	-0.006
SLU 25-100m MLH	*	-0.256	0.276
SLU 25-100m ERF	*	0.256	-0.276
SLU Catchment ML	*	-0.182	0.183
SLU Catchment ER	*	-0.190	-0.060
SLU Catchment Ro	*	0.408	0.821
AWB <10m rk	*	0.500	0.115
AWB 10-250m rk	*	0.376	0.550
AWB 250-500m rk	*	0.167	0.179
Margin Overhang	*	*	*
Pond Overhang rk	*	*	*
Emergent PC rk	*	-0.600	-0.044
Floating PC rk	*	-0.235	0.121
Submerged PC rk	*	0.164	0.066

	Outflows rk	Total Outflow Wi	SLU <5m MLH (%)
Total Outflow Wi	0.742		
SLU <5m MLH (%)	-0.037	0.130	
SLU <5m ERF (%)	0.167	-0.276	-1.000
SLU 5-25m MLH (%	-0.094	0.175	0.793
SLU 5-25m ERF (%	-0.283	-0.536	-0.562
SLU 25-100m MLH	0.011	0.178	0.655
SLU 25-100m ERF	-0.011	-0.178	-0.655
SLU Catchment ML	0.036	0.171	0.522
SLU Catchment ER	-0.057	-0.140	-0.444
SLU Catchment Ro	*	0.922	0.983
AWB <10m rk	*	0.716	0.918
AWB 10-250m rk	0.300	0.277	-0.579
AWB 250-500m rk	0.092	-0.096	-0.828
Margin Overhang	*	*	*
Pond Overhang rk	*	*	*
Emergent PC rk	0.000	-0.197	0.008
Floating PC rk	0.000	0.167	0.206
Submerged PC rk	0.000	0.145	-0.345

	SLU <5m ERF (%)	SLU 5-25m MLH (%	SLU 5-25m ERF (%
SLU 5-25m MLH (%	-0.755		
SLU 5-25m ERF (%	0.755	-1.000	
SLU 25-100m MLH	0.057	0.828	-0.350
SLU 25-100m ERF	-0.057	-0.828	0.350
SLU Catchment ML	0.000	0.830	-0.286
SLU Catchment ER	0.000	-0.798	0.286
SLU Catchment Ro	*	1.000	*
AWB <10m rk	-0.918	0.500	-0.500
AWB 10-250m rk	0.130	-0.239	0.000
AWB 250-500m rk	0.281	-0.527	0.300
Margin Overhang	*	*	*
Pond Overhang rk	*	*	*
Emergent PC rk	-0.415	-0.175	-0.017
Floating PC rk	*	0.266	*
Submerged PC rk	-0.089	-0.430	0.288

	SLU 25-100m MLH	SLU 25-100m ERF	SLU Catchment ML
SLU 25-100m ERF	-1.000		
SLU Catchment ML	0.866	-0.866	
SLU Catchment ER	-0.830	0.830	-0.992
SLU Catchment Ro	0.990	-0.990	0.963
AWB <10m rk	-0.500	0.500	*
AWB 10-250m rk	-0.272	0.272	-0.044

```
AWB 250-500m rk                 -0.500              0.500              -0.245
Margin Overhang                     *                  *                  *
Pond Overhang rk                    *                  *                  *
Emergent PC rk                  -0.214              0.214              -0.285
Floating PC rk                   0.331             -0.331               0.390
Submerged PC rk                 -0.466              0.466              -0.261


                     SLU Catchment ER  SLU Catchment Ro      AWB <10m rk
SLU Catchment Ro                -1.000
AWB <10m rk                         *                  *
AWB 10-250m rk                   0.145              0.000              -0.500
AWB 250-500m rk                  0.166             -0.898              -0.500
Margin Overhang                     *                  *                  *
Pond Overhang rk                    *                  *                  *
Emergent PC rk                   0.334             -0.667              -0.500
Floating PC rk                      *               0.408                  *
Submerged PC rk                  0.373             -0.281               0.971


                      AWB 10-250m rk   AWB 250-500m rk  Margin Overhang
AWB 250-500m rk                  0.650
Margin Overhang                     *                  *
Pond Overhang rk                    *                  *                  *
Emergent PC rk                   0.139              0.103                  *
Floating PC rk                   0.169             -0.332                  *
Submerged PC rk                  0.377              0.365                  *


                     Pond Overhang rk   Emergent PC rk    Floating PC rk
Emergent PC rk                      *
Floating PC rk                      *               0.172
Submerged PC rk                     *               0.264               0.251


Cell Contents: Pearson correlation

* NOTE * Not enough data in column
* NOTE * All values in column are identical.
```

Appendix 1.8: Testing for difference in biodiversity levels in the presence and absence of Amphibians

Descriptive Statistics: Species ichness_Amphibia, Species ichness_No amphi

```
Variable                        N   N*    Mean  SE Mean  StDev  Minimum      Q1
Median
Species  ichness_Amphibia  13   0   8.000    0.679  2.449    5.000   6.000
8.000
Species  ichness_No amphi   5   0   8.20     1.07   2.39     5.00    6.00
8.00

Variable                      Q3  Maximum
Species  ichness_Amphibia  9.500   13.000
Species  ichness_No amphi  10.50    11.00
```


Mean	8
StDev	2.449
N	13
AD	0.566
P-Value	0.115
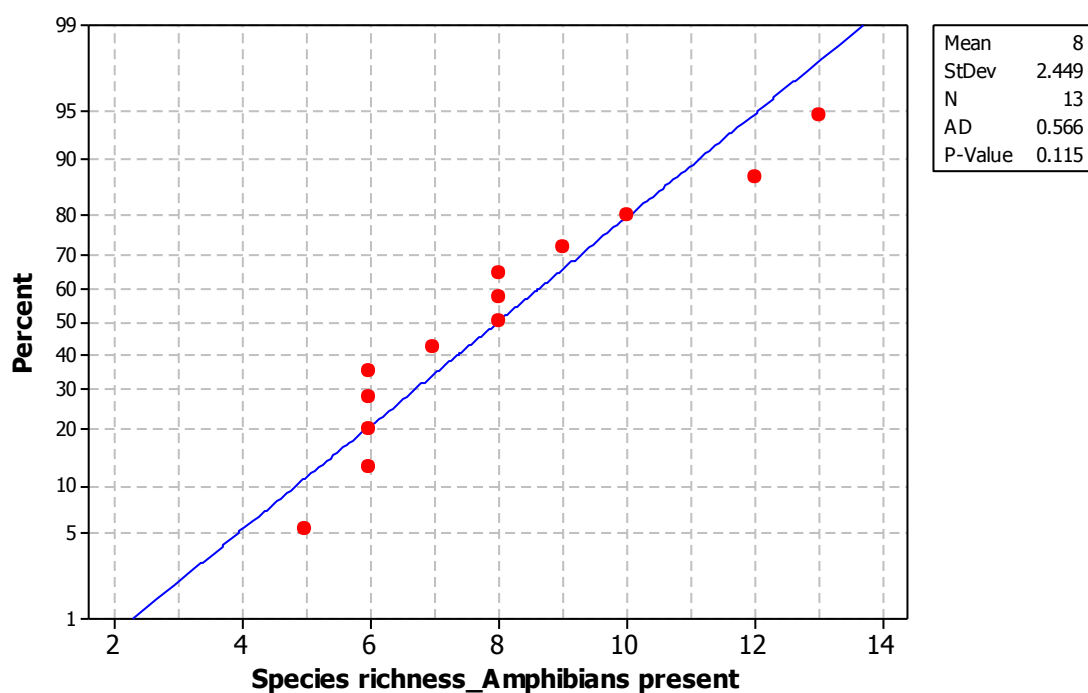
Appendix 1.8.1: Normality test of species richness for the lochs where amphibians are present.

Mean	8.2
StDev	2.387
N	5
AD	0.170
P-Value	0.860
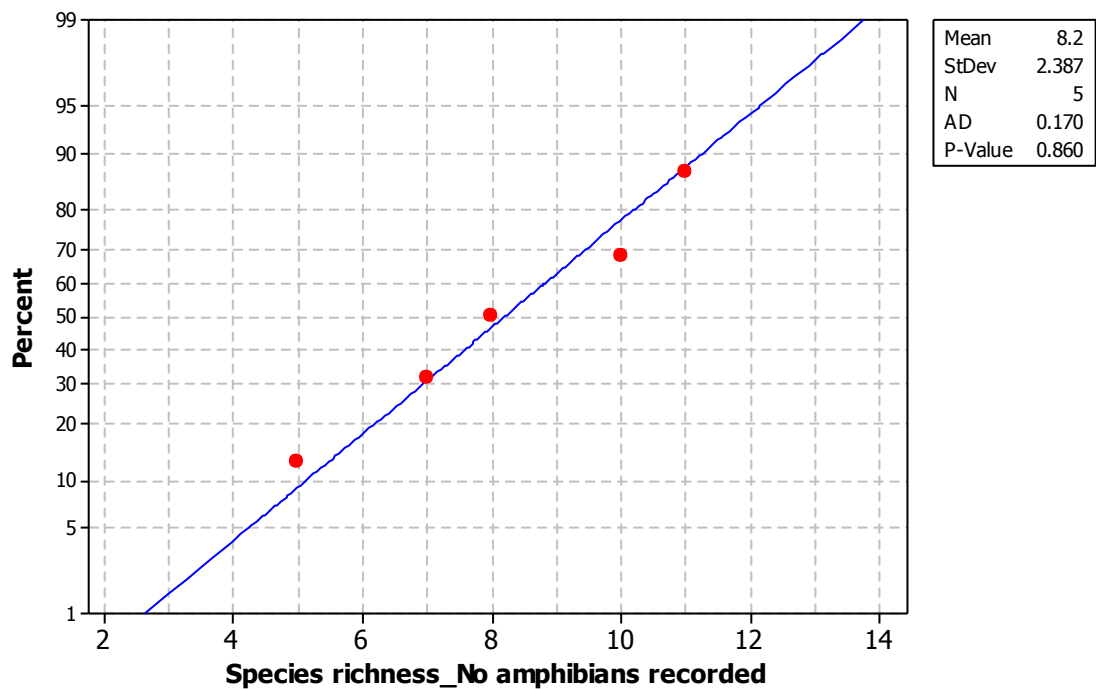
Appendix 1.8.2: Normality test of species richness for the lochs where amphibians were not visible.

Test and CI for Two Variances: Species richnes_, Species richnes_

```
Null hypothesis           Sigma(Species richnes_Amphibians pres) /
Sigma(Species richnes_No amphibians r) = 1
Alternative hypothesis  Sigma(Species richnes_Amphibians pres) /
Sigma(Species richnes_No amphibians r) not = 1
Significance level      Alpha = 0.05


Statistics

Variable                          N  StDev  Variance
Species richnes_Amphibians pres  13  2.449     6.000
Species richnes_No amphibians r   5  2.387     5.700

Ratio of standard deviations = 1.026
Ratio of variances = 1.053

95% Confidence Intervals
                              CI for
Distribution    CI for StDev    Variance
of Data           Ratio          Ratio
Normal         (0.347, 2.083)  (0.120, 4.338)
Continuous     (0.206, 2.245)  (0.042, 5.042)

Tests
                                       Test
Method                     DF1  DF2  Statistic  P-Value
F Test (normal)             12    4     1.05      0.938
Levene's Test (any continuous)  1   16     0.00      0.953
```
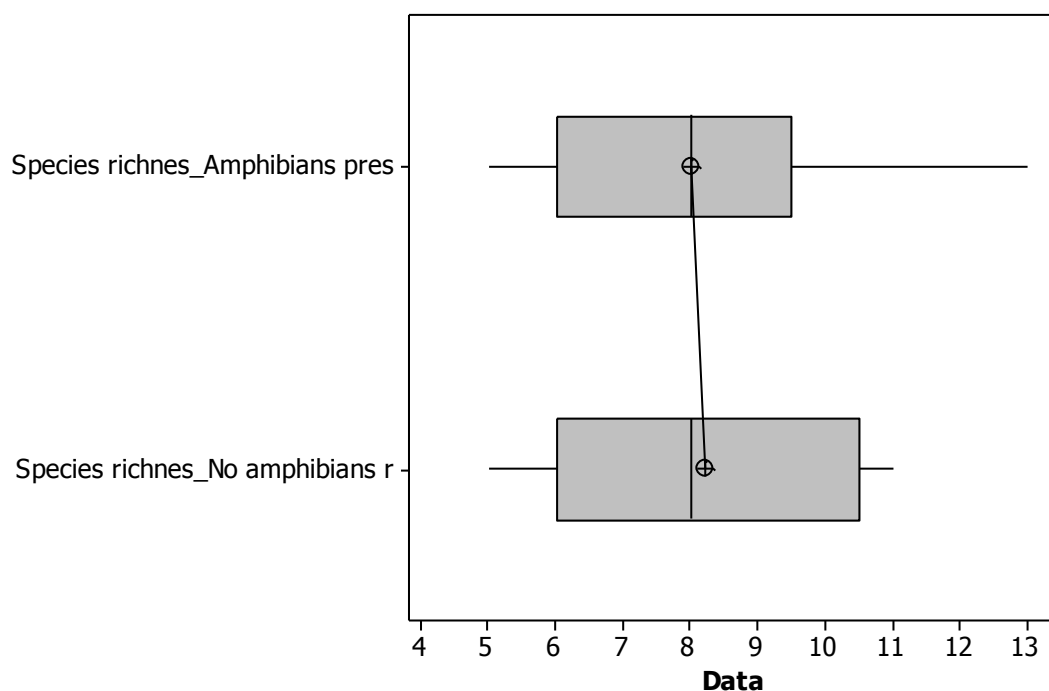
Appendix 1.8.3: Boxplot of species richness between lochs with and without the presence of amphibians.

Two-Sample T-Test and CI: Species richnes_Amphibia, Species richnes_No amphi

```
Two-sample T for Species richnes_Amphibians pres vs Species richnes_No
    amphibians r
                            N    Mean  StDev  SE Mean
Species richnes_Amphibia   13   8.00   2.45     0.68
Species richnes_No amphi    5   8.20   2.39      1.1

Difference = mu (Species richnes_Amphibians pres) - mu (Species richnes_No
    amphibians r)
Estimate for difference:  -0.20
95% CI for difference:  (-3.19, 2.79)
T-Test of difference = 0 (vs not =): T-Value = -0.16  P-Value = 0.879  DF =
7
```

Descriptive Statistics: Total no. of Inverts_Amphibia, Total no. of or_No amphi

```
Variable                   N   N*    Mean  SE Mean  StDev  Minimum      Q1
Median
Total no. of In_Amphibia  13    0   39.92     9.63  34.71     7.00   12.50
30.00
Total no. of In_No amphi   5    0    41.4     19.3   43.2      8.0    15.0
30.0

Variable                    Q3  Maximum
Total no. of In_Amphibia  58.00   123.00
Total no. of In_No amphi   73.5   117.0
```

Mean	39.92
StDev	34.71
N	13
AD	0.760
P-Value	0.035
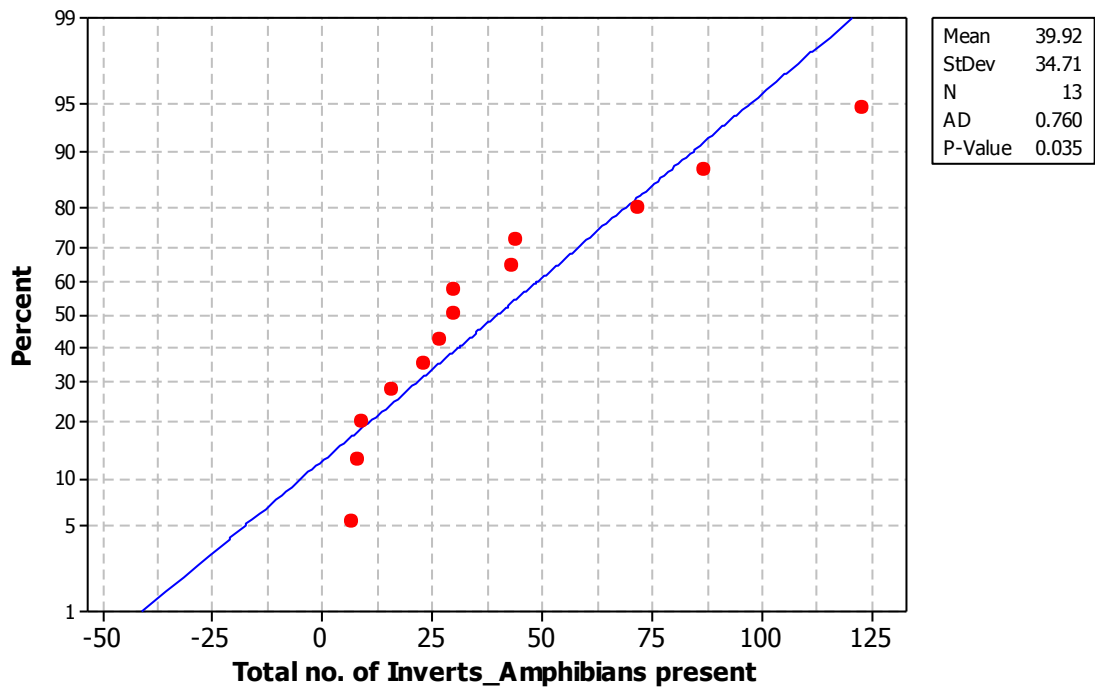
Appendix 1.8.4: Normality test abundance for the lochs where amphibians were present.

Mean	41.4
StDev	43.21
N	5
AD	0.722
P-Value	0.022
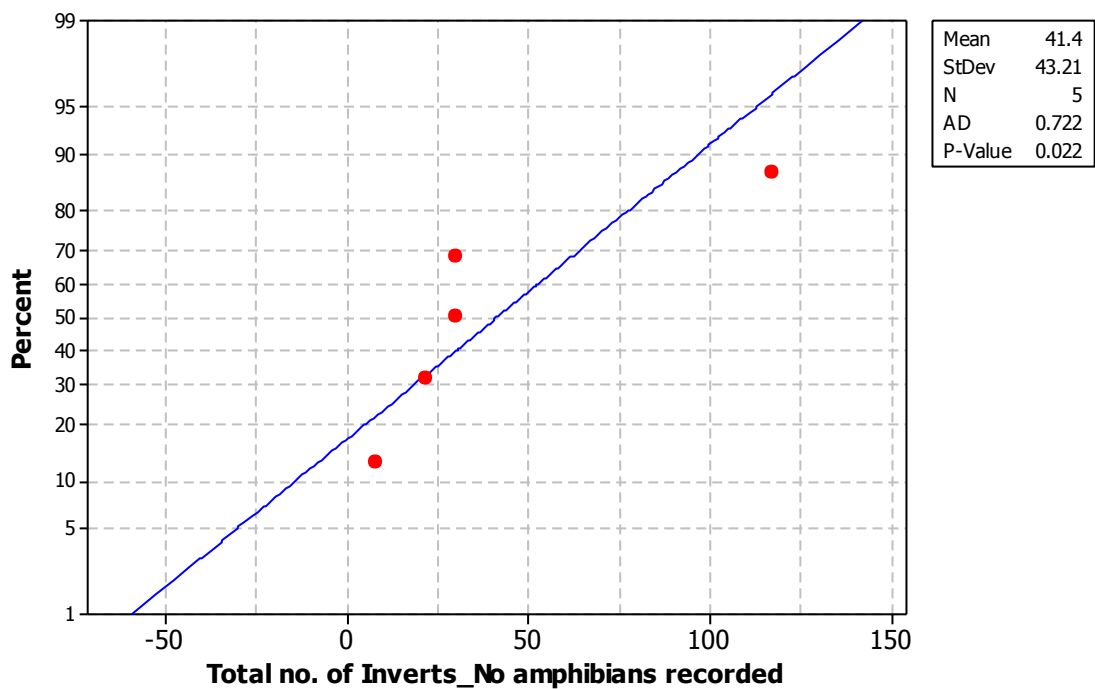
Appendix 1.8.5: Normality test abundance for the lochs where amphibians were not visible.

Test and CI for Two Variances: Total no. of In_, Total no. of In_

```
Null hypothesis          Sigma(Total no. of In_Amphibians pres) / Sigma(Total
no. of In_No amphibians r) = 1
```

```
Alternative hypothesis  Sigma(Total no. of In_Amphibians pres) / Sigma(Total
no. of In_No amphibians r) not = 1
Significance level      Alpha = 0.05


Statistics

Variable                          N    StDev  Variance
Total no. of In_Amphibians pres  13   34.707  1204.577
Total no. of In_No amphibians r   5   43.206  1866.800

Ratio of standard deviations = 0.803
Ratio of variances = 0.645

95% Confidence Intervals
                             CI for
Distribution   CI for StDev     Variance
of Data          Ratio          Ratio
Normal        (0.272, 1.631)  (0.074,  2.659)
Continuous    (    *, 8.691)  (    *, 75.525)

Tests
                                        Test
Method                       DF1  DF2  Statistic  P-Value
F Test (normal)               12    4     0.65     0.500
Levene's Test (any continuous) 1   16     0.00     0.981
```
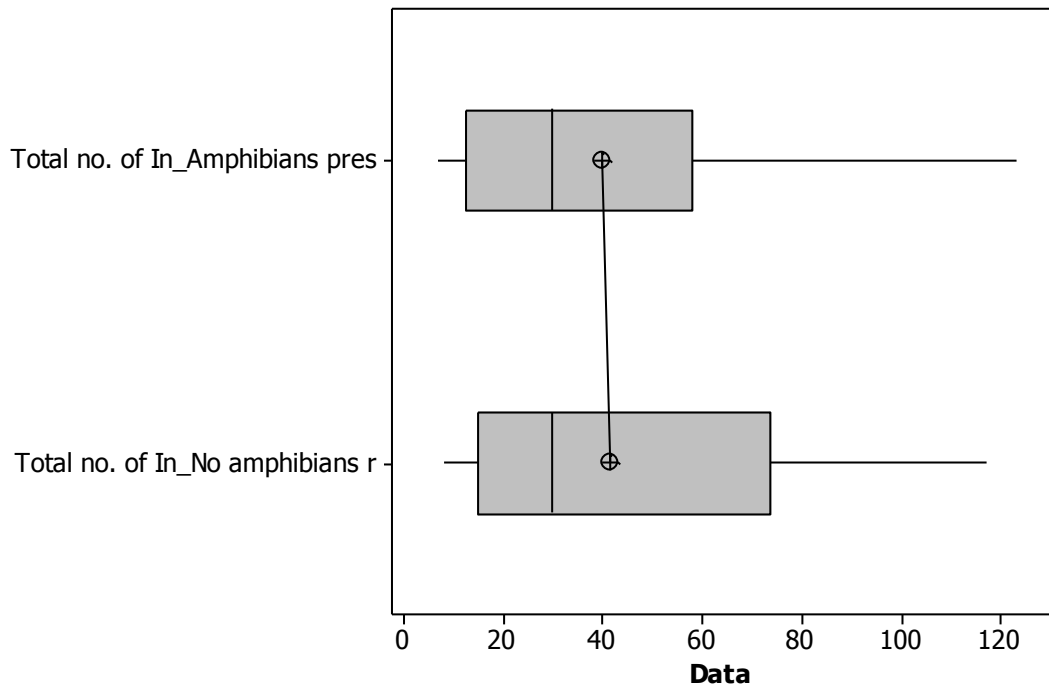

Appendix 1.8.6: Boxplot of invertebrate abundance between lochs with and without
the presence of amphibians.

Mann-Whitney Test and CI: Total no. of In_, Total no. of In_

```
                                  N  Median
Total no. of In_Amphibians pres  13   30.00
Total no. of In_No amphibians r   5   30.00


Point estimate for ETA1-ETA2 is -0.00
95.1 Percent CI for ETA1-ETA2 is (-23.00,36.03)
W = 124.5
```

69

```
Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at 0.9607
The test is significant at 0.9605 (adjusted for ties)
```

Descriptive Statistics: Simpsons D Inde_Amphibia, Simpsons D Inde_No amphi

```
Variable                     N   N*    Mean  SE Mean   StDev  Minimum      Q1
Simpsons D Inde_Amphibia    13   0   0.7619   0.0244  0.0881   0.6188  0.6851
Simpsons D Inde_No amphi     5   0   0.7291   0.0190  0.0425   0.6791  0.6840

Variable                  Median     Q3  Maximum
Simpsons D Inde_Amphibia  0.7667  0.8201   0.9106
Simpsons D Inde_No amphi  0.7500  0.7638   0.7756
```
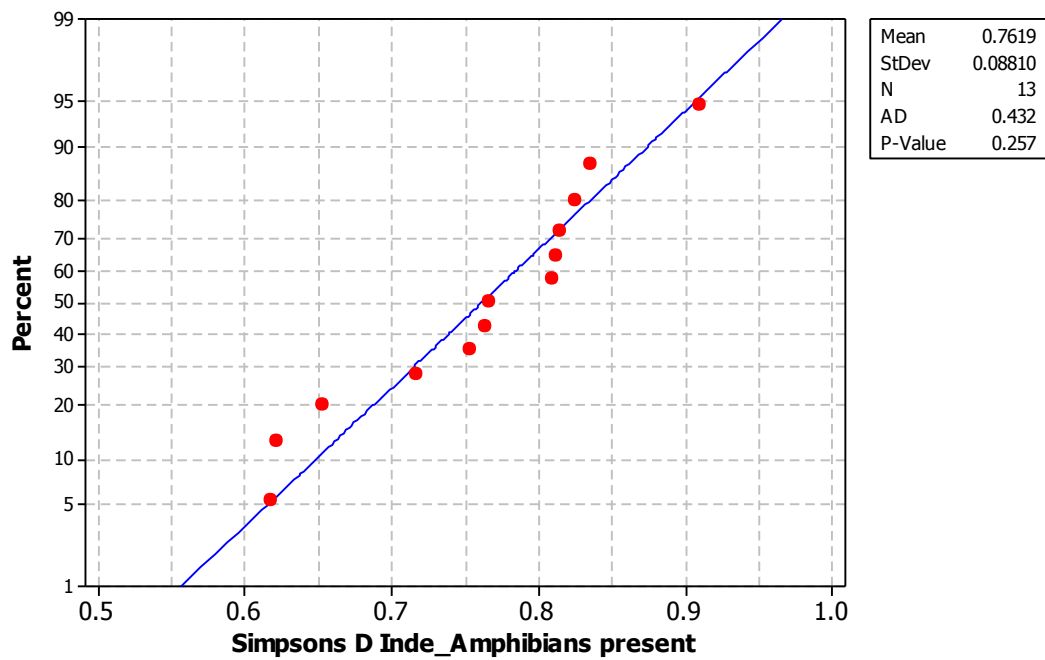

Appendix 1.8.7: Normality test of Simpson's D Index for the lochs where amphibians were present.

Mean	0.7291
StDev	0.04255
N	5
AD	0.398
P-Value	0.216
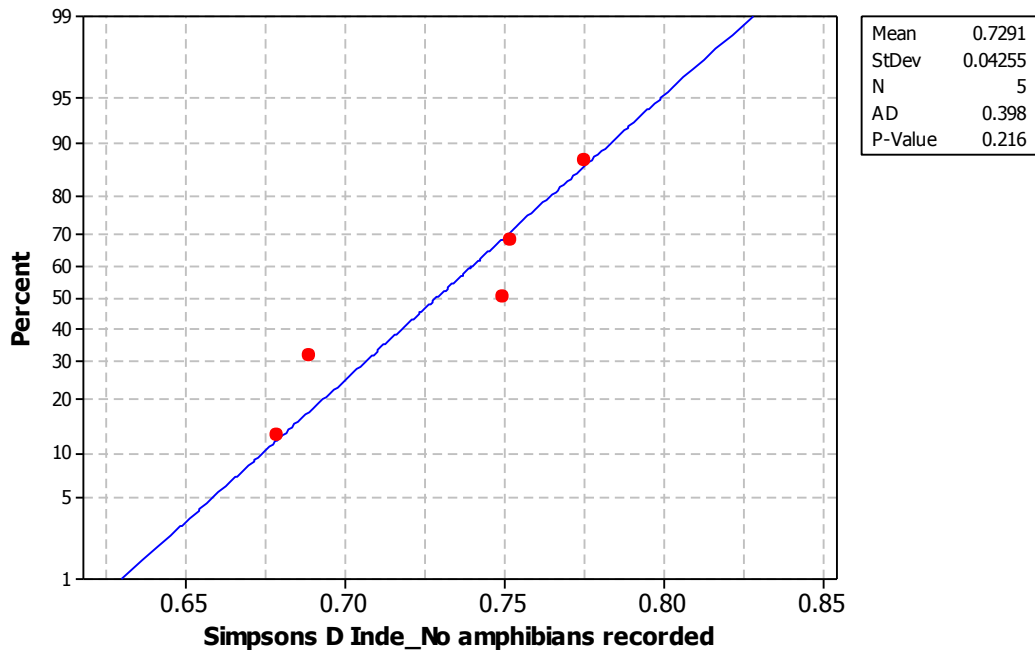
Appendix 1.8.8: Normality test of Simpson's D Index for the lochs where amphibians were not recorded.

Test and CI for Two Variances: Simpsons D Inde_, Simpsons D Inde_

```
Null hypothesis         Sigma(Simpsons D Inde_Amphibians pres) /
Sigma(Simpsons D Inde_No amphibians r) = 1
Alternative hypothesis  Sigma(Simpsons D Inde_Amphibians pres) /
Sigma(Simpsons D Inde_No amphibians r) not = 1
Significance level      Alpha = 0.05


Statistics

Variable                         N  StDev  Variance
Simpsons D Inde_Amphibians pres 13  0.088     0.008
Simpsons D Inde_No amphibians r  5  0.043     0.002

Ratio of standard deviations = 2.071
Ratio of variances = 4.288


95% Confidence Intervals
                           CI for
Distribution   CI for StDev      Variance
of Data          Ratio            Ratio
Normal       (0.700, 4.204)  (0.490, 17.670)
Continuous   (0.486, 5.837)  (0.236, 34.075)


Tests
                                   Test
Method                     DF1 DF2 Statistic  P-Value
F Test (normal)             12   4    4.29     0.171
Levene's Test (any continuous)  1  16    1.93     0.184
```

71
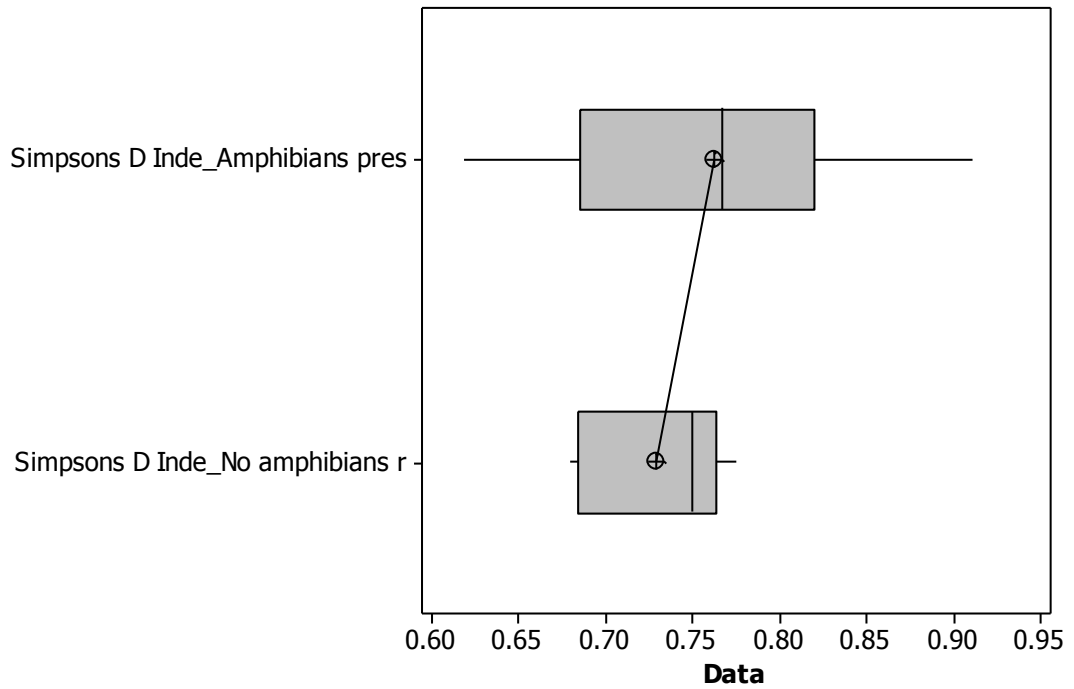
Appendix 1.8.9: Boxplot of the Simpson's D Index between lochs with and without the presence of amphibians.

Two-Sample T-Test and CI: Simpsons D Inde_Amphibia, Simpsons D Inde_No amphi

```
Two-sample T for Simpsons D Inde_Amphibians pres vs Simpsons D Inde_No
     amphibians r
                          N     Mean    StDev   SE Mean
Simpsons D Inde_Amphibia  13   0.7619   0.0881    0.024
Simpsons D Inde_No amphi   5   0.7291   0.0425    0.019


Difference = mu (Simpsons D Inde_Amphibians pres) - mu (Simpsons D Inde_No
     amphibians r)
Estimate for difference:  0.0328
95% CI for difference:  (-0.0336, 0.0992)
T-Test of difference = 0 (vs not =): T-Value = 1.06  P-Value = 0.307  DF =
14
```

Descriptive Statistics: SI Richness in the presence and absence of Amphibians

```
Variable                  N   N*   Mean  SE Mean  StDev  Minimum      Q1
Median
SI Richness_Amphibians p  13   0   6.333   0.574  2.071    3.733   4.882
6.036
SI Richness_No amphibian   5   0   5.913   0.651  1.455    3.750   4.589
6.017

Variable                   Q3  Maximum
SI Richness_Amphibians p  7.551   10.527
SI Richness_No amphibian  7.184    7.578
```

72
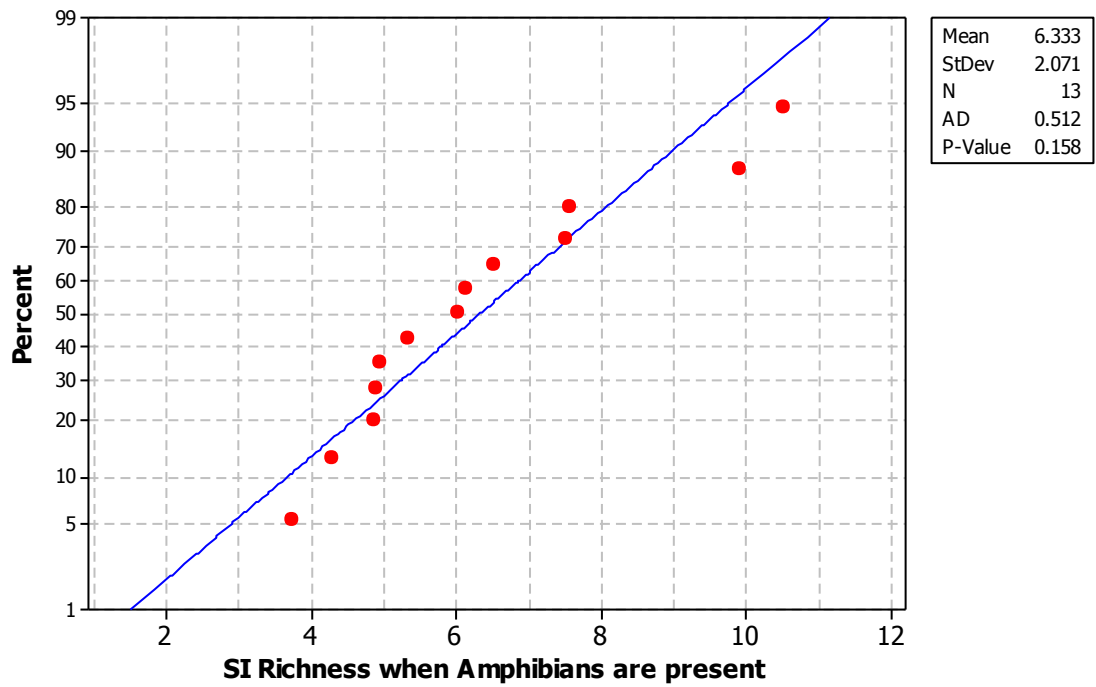
Appendix 1.8.10: Normality test for the SI Richness of lochs where amphibians were present.
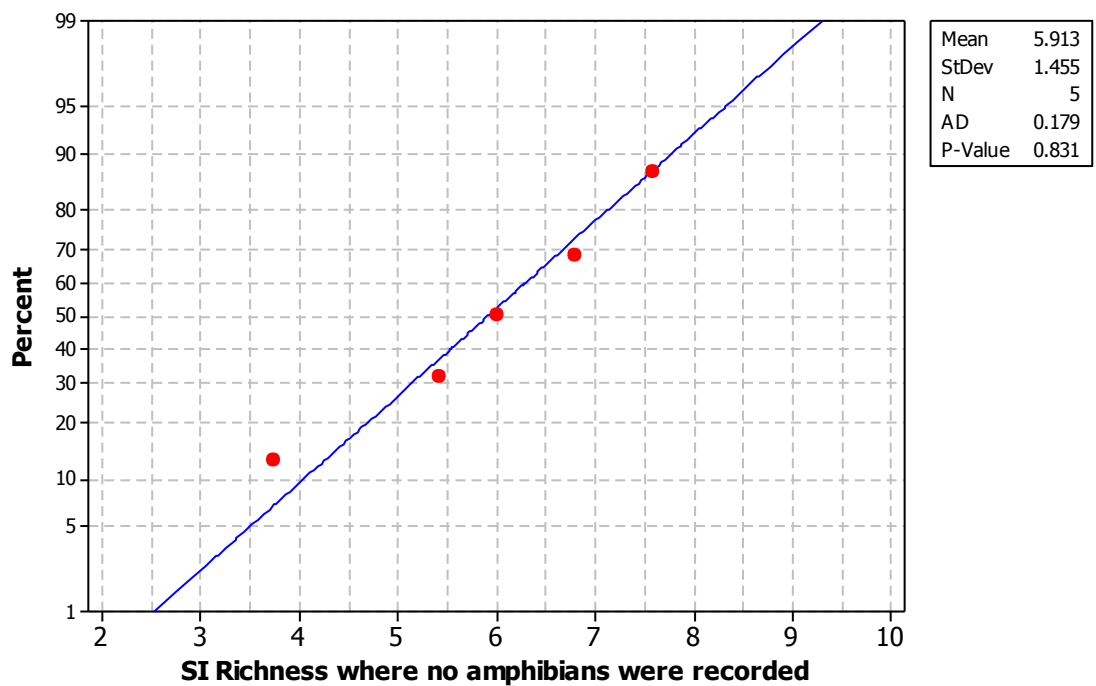
Appendix 1.8.11: Normality test for the SI Richness of lochs where amphibians were not recorded.

Test and CI for Two Variances: SI Richness in the presence and absence of Amphibians

```
Null hypothesis          Sigma(SI Richness_Amphibians present) / Sigma(SI
Richness_No amphibians recor) = 1
Alternative hypothesis   Sigma(SI Richness_Amphibians present) / Sigma(SI
Richness_No amphibians recor) not = 1
Significance level       Alpha = 0.05


Statistics

Variable                          N  StDev  Variance
SI Richness_Amphibians present   13  2.071     4.288
SI Richness_No amphibians recor   5  1.455     2.116

Ratio of standard deviations = 1.423
Ratio of variances = 2.026

95% Confidence Intervals
                                  CI for
Distribution   CI for StDev      Variance
of Data          Ratio            Ratio
Normal        (0.481, 2.890)  (0.232,  8.350)
Continuous    (0.238, 3.612)  (0.057, 13.050)

Tests
                                        Test
Method                       DF1  DF2  Statistic  P-Value
F Test (normal)               12    4      2.03    0.518
Levene's Test (any continuous) 1   16      0.61    0.448
```
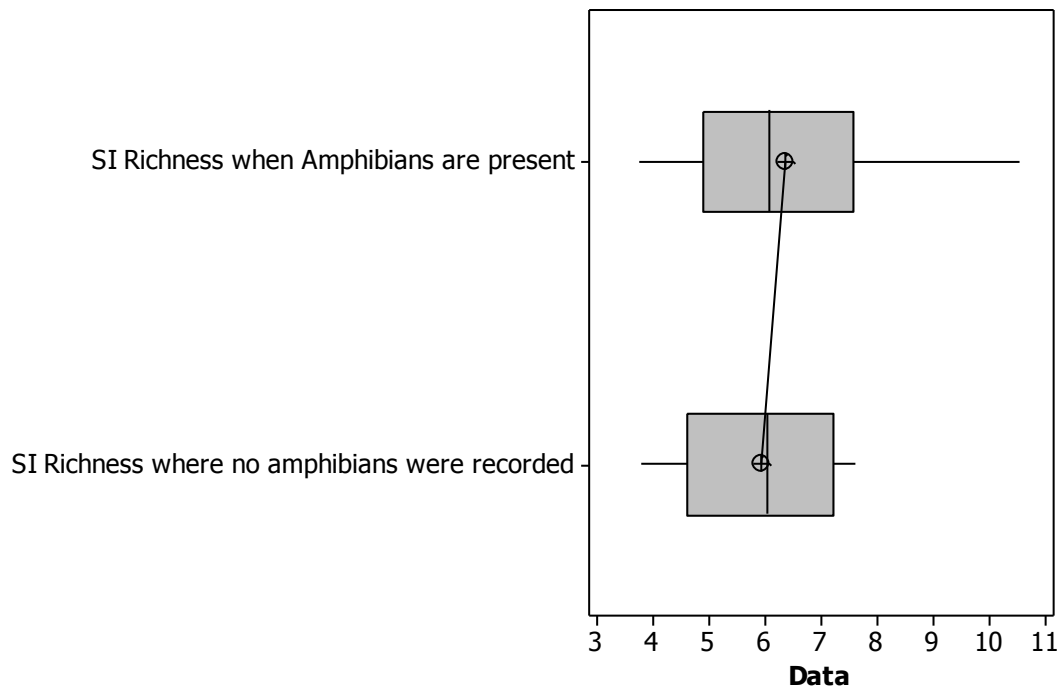

Appendix 1.8.12: Boxplot of the SI Richness between lochs with and without the presence of amphibians.

Two-Sample T-Test and CI: SI Richness in the presence and absence of Amphibians

```
Two-sample T for SI Richness_Amphibians present vs SI Richness_No amphibians
    recor
```

74

```
                          N   Mean   StDev  SE Mean
SI Richness_Amphibians p  13  6.33   2.07    0.57
SI Richness_No amphibian   5  5.91   1.45    0.65


Difference = mu (SI Richness_Amphibians present) - mu (SI Richness_No
    amphibians recor)
Estimate for difference:  0.420
95% CI for difference:  (-1.513, 2.354)
T-Test of difference = 0 (vs not =): T-Value = 0.48  P-Value = 0.639  DF =
10
```
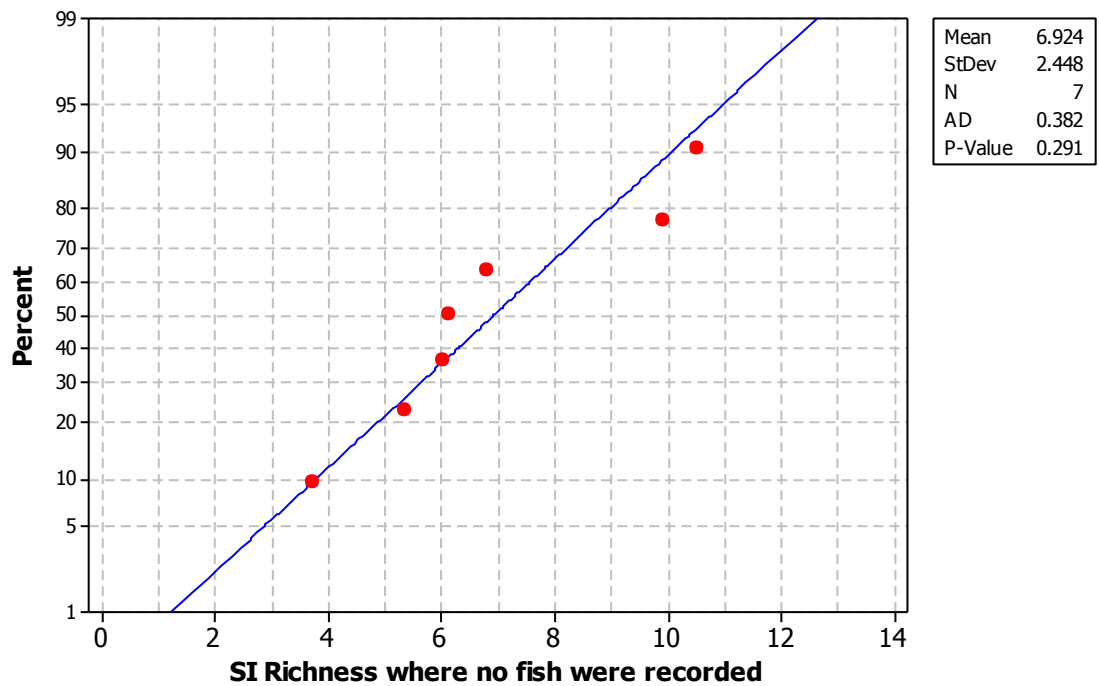
```
                          N   Mean   StDev  SE Mean
SI Richness_Amphibians p  13  6.33   2.07    0.57
SI Richness_No amphibian   5  5.91   1.45    0.65
```

Appendix 1.9: Testing for difference in biodiversity levels in the presence and absence of Fish

Descriptive Statistics: Species richness_Fish pr, Species richnes_No fish

```
Variable                     N  N*   Mean  SE Mean  StDev  Minimum     Q1
Median
Species richness_Fish pr  11   0  7.364    0.607  2.014    5.000  6.000
7.000
Species richnes_No fish    7   0  9.143    0.986  2.610    6.000  7.000
8.000

Variable                     Q3  Maximum
Species richness_Fish pr  9.000   11.000
Species richnes_No fish  12.000   13.000
```


Appendix 1.9.1: Normality test of Species richness for the lochs where fish were present.

Mean	9.143
StDev	2.610
N	7
AD	0.292
P-Value	0.505

Appendix 1.9.2: Normality test of Species richness for the lochs where fish were not recorded.

Test and CI for Two Variances: Species richness, Species richnes_

```
Null hypothesis          Sigma(Species richness_Fish present) / Sigma(Species
richnes_No fish recorde) = 1
Alternative hypothesis  Sigma(Species richness_Fish present) / Sigma(Species
richnes_No fish recorde) not = 1
Significance level      Alpha = 0.05


Statistics

Variable                          N  StDev  Variance
Species richness_Fish present    11  2.014     4.055
Species richnes_No fish recorde   7  2.610     6.810


Ratio of standard deviations = 0.772
Ratio of variances = 0.595


95% Confidence Intervals
                               CI for
Distribution   CI for StDev   Variance
of Data          Ratio          Ratio
Normal        (0.330, 1.557)  (0.109, 2.425)
Continuous    (0.324, 2.237)  (0.105, 5.004)


Tests
                                            Test
Method                       DF1  DF2  Statistic  P-Value
F Test (normal)               10    6       0.60    0.447
Levene's Test (any continuous)  1   16       0.26    0.616
```
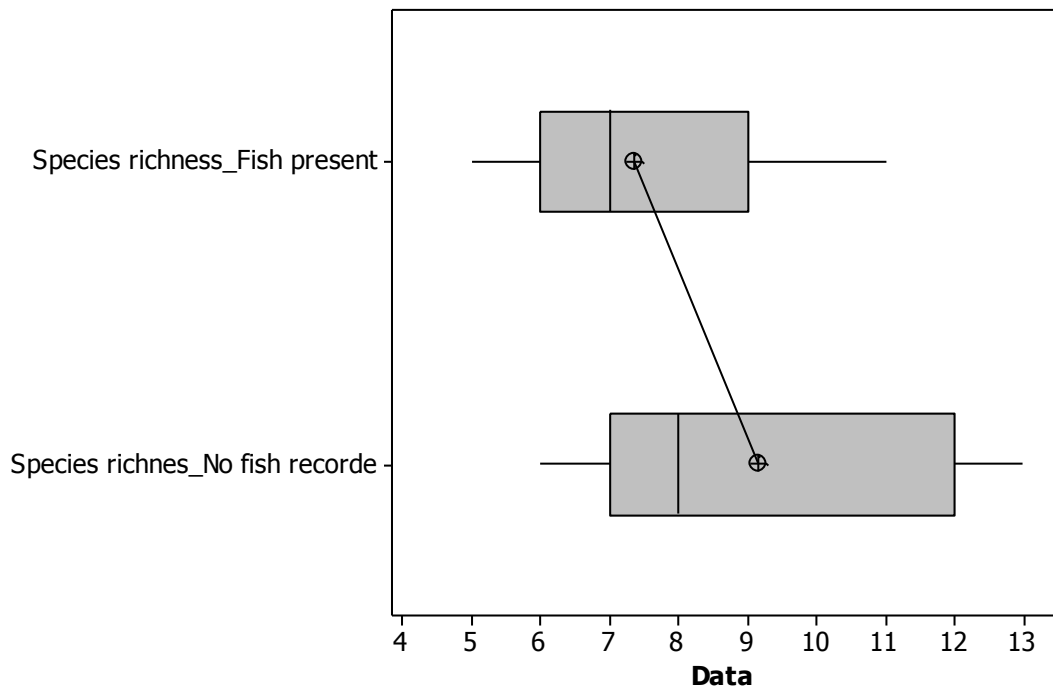
Appendix 1.9.3: Boxplot of the Species richness between lochs with and without the presence of fish.

Two-Sample T-Test and CI: Species richness_Fish pr, Species richnes_No fish

```
Two-sample T for Species richness_Fish present vs Species richnes_No fish
    recorde
                          N  Mean  StDev  SE Mean
Species richness_Fish pr  11  7.36  2.01     0.61
Species richnes_No fish    7  9.14  2.61     0.99

Difference = mu (Species richness_Fish present) - mu (Species richnes_No
fish
    recorde)
Estimate for difference:  -1.78
95% CI for difference:  (-4.36, 0.80)
T-Test of difference = 0 (vs not =): T-Value = -1.54  P-Value = 0.155  DF =
10
```

Descriptive Statistics: Total no. of Inverts_Fish , Total no. of or_No fish

```
Variable                    N  N*  Mean  SE Mean  StDev  Minimum    Q1
Median
Total no. of Inver_Fish    11   0  34.9     11.3   37.5      7.0   8.0
22.0
Total no. of In_No fish     7   0  48.9     13.0   34.3     23.0  27.0
30.0

Variable                   Q3  Maximum
Total no. of Inver_Fish  44.0    123.0
Total no. of In_No fish  72.0    117.0
```

78
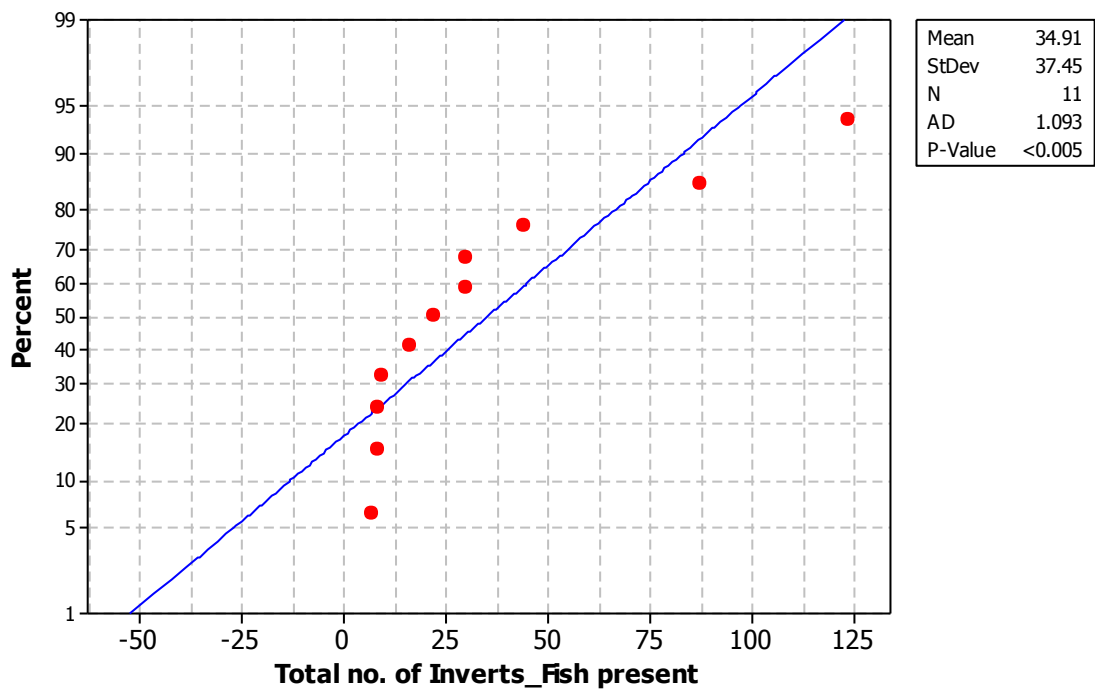
Appendix 1.9.4: Normality test of the abundance of inverts for the lochs where fish
were present.
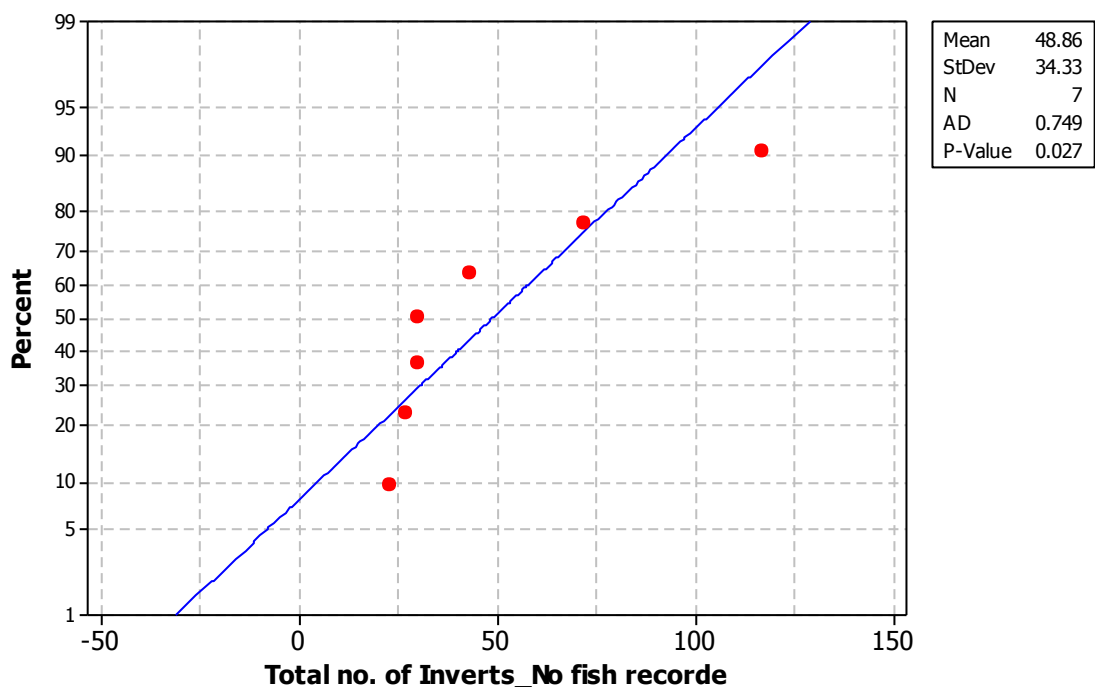
Appendix 1.9.5: Normality test of invertebrate abundance for the lochs where fish
were not recorded.

Test and CI for Two Variances: Total no. of Invert, Total no. of or_

```
Null hypothesis          Sigma(Total no. of Inver_Fish present) / Sigma(Total
no. of In_No fish recorde) = 1
```

```
Alternative hypothesis  Sigma(Total no. of Inver_Fish present) / Sigma(Total
no. of In_No fish recorde) not = 1
Significance level      Alpha = 0.05


Statistics

Variable                         N   StDev   Variance
Total no. of Inver_Fish present  11  37.453  1402.691
Total no. of In_No fish recorde   7  34.329  1178.476


Ratio of standard deviations = 1.091
Ratio of variances = 1.190

95% Confidence Intervals

Distribution    CI for StDev       CI for
of Data            Ratio        Variance Ratio
Normal         (0.467,  2.202)  (0.218,    4.847)
Continuous     (    *, 17.385)  (    *, 302.225)

Tests
                                          Test
Method                        DF1  DF2  Statistic  P-Value
F Test (normal)                10    6     1.19      0.867
Levene's Test (any continuous)  1   16     0.03      0.873
```
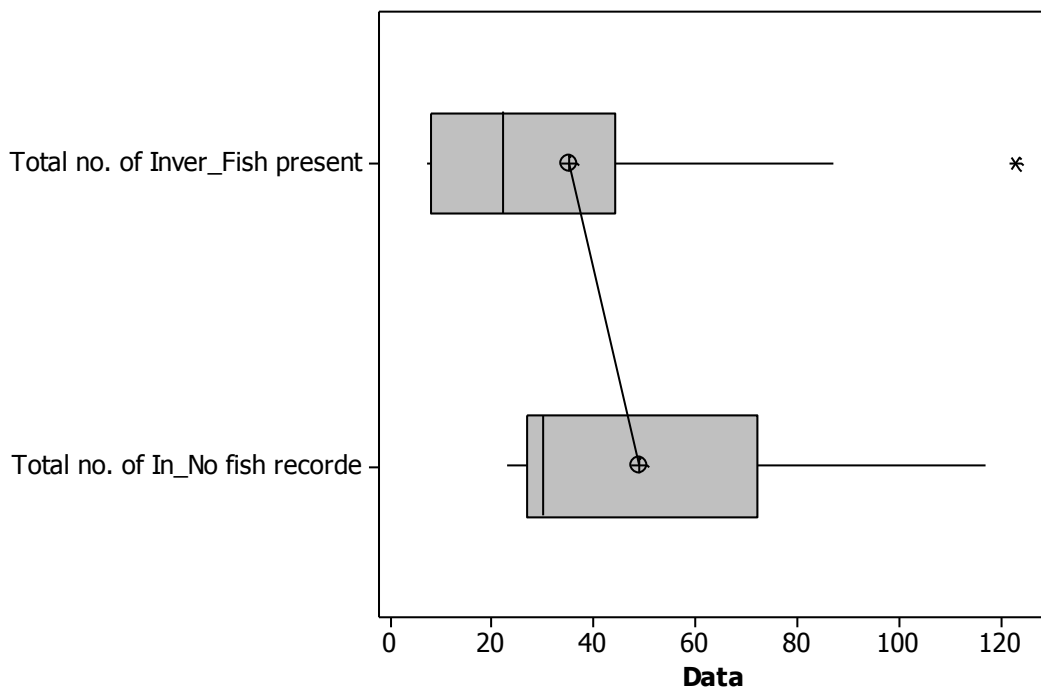

Appendix 1.9.6: Boxplot of the abundance of invertebrates Index between lochs
with and without the presence of fish.

Mann-Whitney Test and CI: Total no. of Inverts, Total no. of In_

```
                                  N   Median
Total no. of Inver_Fish present  11   22.00
Total no. of In_No fish recorde   7   30.00


Point estimate for ETA1-ETA2 is -15.00
95.4 Percent CI for ETA1-ETA2 is (-42.01,6.98)
W = 90.0
```

Test of ETA1 = ETA2 vs ETA1 not = ETA2 is significant at **0.2048**
The test is significant at **0.2022** (adjusted for ties)

Descriptive Statistics: Simpsons D Index_Fish pr, Simpsons D Inde_No fish

```
Variable                    N   N*    Mean  SE Mean   StDev  Minimum      Q1
Simpsons D Index_Fish pr   11   0   0.7572   0.0257  0.0853   0.6188  0.6889
Simpsons D Inde_No fish     7   0   0.7459   0.0272  0.0718   0.6222  0.6791

Variable                  Median      Q3  Maximum
Simpsons D Index_Fish pr  0.7521  0.8148   0.9106
Simpsons D Inde_No fish   0.7637  0.8098   0.8253
```
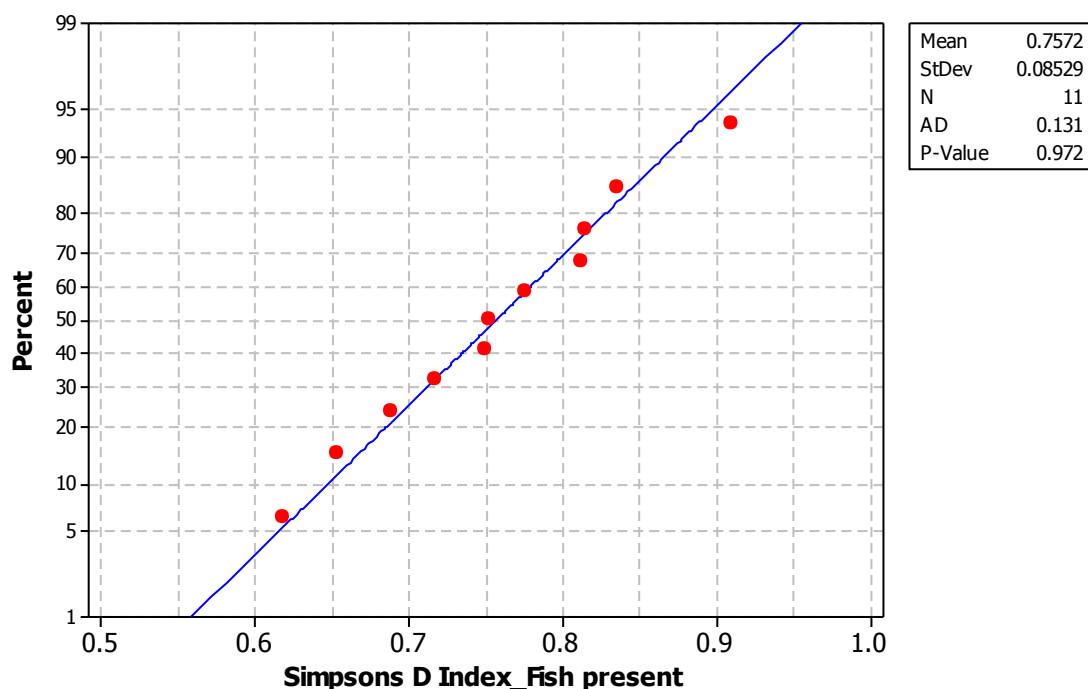

Appendix 1.9.7: Normality test of the Simpson's D Index for the lochs where fish
were present.
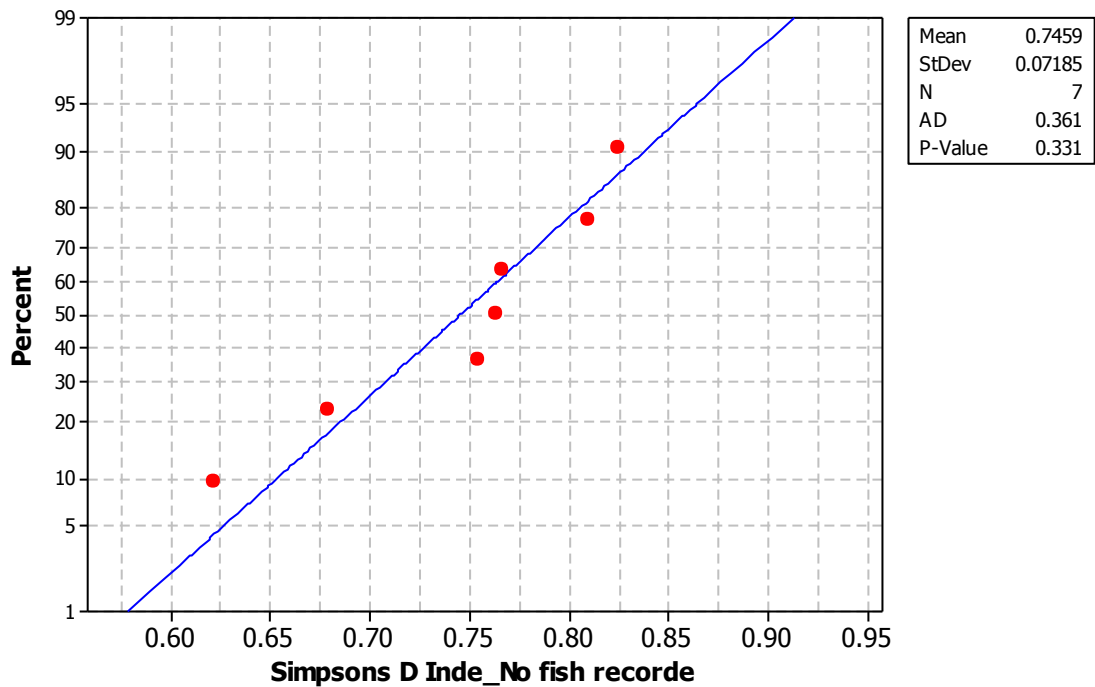
Appendix 1.9.8: Normality test of the Simpson's D Index for the lochs where fish were not recorded.

Test and CI for Two Variances: Simpsons D Index, Simpsons D Inde_

```
Null hypothesis           Sigma(Simpsons D Index_Fish present) /
Sigma(Simpsons D Inde_No fish recorde) = 1
Alternative hypothesis   Sigma(Simpsons D Index_Fish present) /
Sigma(Simpsons D Inde_No fish recorde) not = 1
Significance level       Alpha = 0.05


Statistics

Variable                          N  StDev   Variance
Simpsons D Index_Fish present    11  0.085      0.007
Simpsons D Inde_No fish recorde   7  0.072      0.005

Ratio of standard deviations = 1.187
Ratio of variances = 1.409

95% Confidence Intervals
                               CI for
Distribution    CI for StDev    Variance
of Data          Ratio           Ratio
Normal        (0.508, 2.396)  (0.258,  5.739)
Continuous    (0.445, 4.229)  (0.198, 17.887)

Tests
                                          Test
Method                      DF1  DF2  Statistic  P-Value
F Test (normal)              10    6      1.41    0.700
Levene's Test (any continuous) 1   16      0.43    0.523
```

82
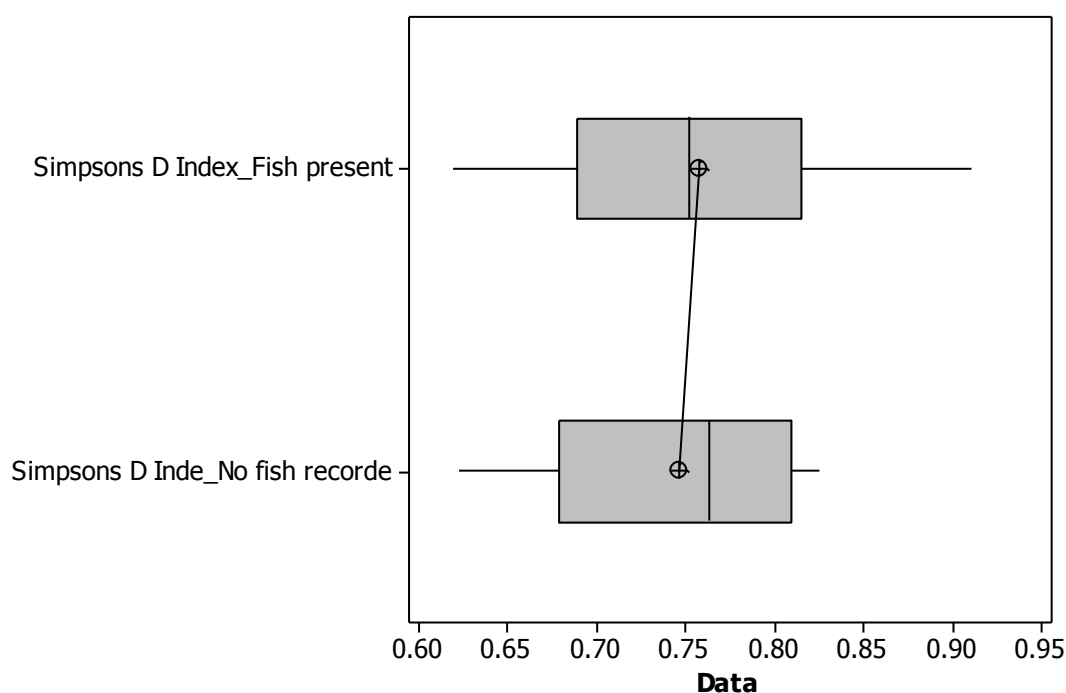
Appendix 1.9.9: Boxplot of the Simpson's D Index between lochs with and without
the presence of fish.

Two-Sample T-Test and CI: Simpsons D Index_Fish pr, Simpsons D Inde_No fish

```
Two-sample T for Simpsons D Index_Fish present vs Simpsons D Inde_No fish
     recorde
                          N     Mean    StDev   SE Mean
Simpsons D Index_Fish pr  11  0.7572  0.0853    0.026
Simpsons D Inde_No fish    7  0.7459  0.0718    0.027

Difference = mu (Simpsons D Index_Fish present) – mu (Simpsons D Inde_No
fish
     recorde)
Estimate for difference:  0.0113
95% CI for difference:  (-0.0689, 0.0915)
T-Test of difference = 0 (vs not =): T-Value = 0.30  P-Value = 0.766  DF =
14
```

Descriptive Statistics: SI Richness in the presence and absence of Fish

```
Variable                    N   N*   Mean  SE Mean  StDev  Minimum    Q1
Median
SI Richness_Fish present   11    0  5.766    0.414  1.373    3.750  4.875
5.429
SI Richness_No fish reco    7    0  6.924    0.925  2.448    3.733  5.346
6.133

Variable                     Q3  Maximum
SI Richness_Fish present  7.523    7.578
SI Richness_No fish reco  9.904   10.527
```

Mean	5.766
StDev	1.373
N	11
AD	0.418
P-Value	0.269
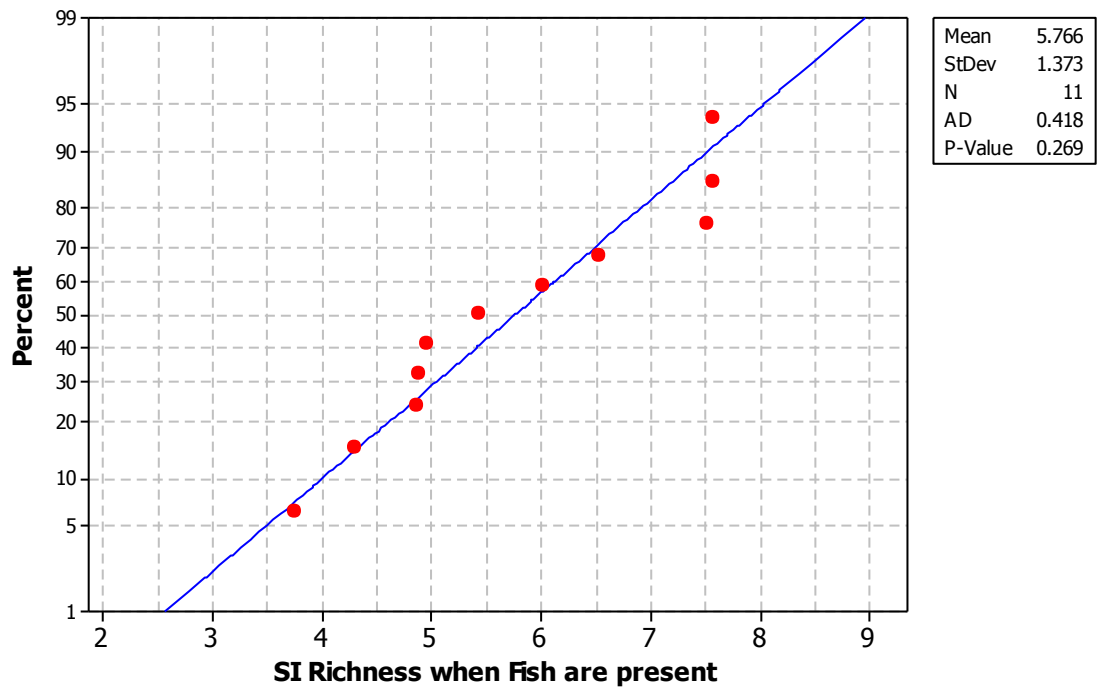
Appendix 1.9.10: Normality test of SI Richness for the lochs where fish were present.

Mean	6.924
StDev	2.448
N	7
AD	0.382
P-Value	0.291

Appendix 1.9.11: Normality test of SI Richness for the lochs where fish were not recorded.

Test and CI for Two Variances: SI Richness in the presence and absence of Fish

```
Null hypothesis          Sigma(SI Richness_Fish present) / Sigma(SI
Richness_No fish recorded) = 1
Alternative hypothesis  Sigma(SI Richness_Fish present) / Sigma(SI
Richness_No fish recorded) not = 1
Significance level      Alpha = 0.05


Statistics


Variable                      N  StDev  Variance
SI Richness_Fish present      11  1.373    1.886
SI Richness_No fish recorded   7  2.448    5.994


Ratio of standard deviations = 0.561
Ratio of variances = 0.315


95% Confidence Intervals
                              CI for
Distribution   CI for StDev    Variance
of Data           Ratio          Ratio
Normal        (0.240, 1.132)  (0.058, 1.281)
Continuous    (0.256, 2.026)  (0.066, 4.105)


Tests
                                        Test
Method                      DF1  DF2  Statistic  P-Value
F Test (normal)             10    6      0.31     0.103
Levene's Test (any continuous)  1   16      0.96     0.342
```
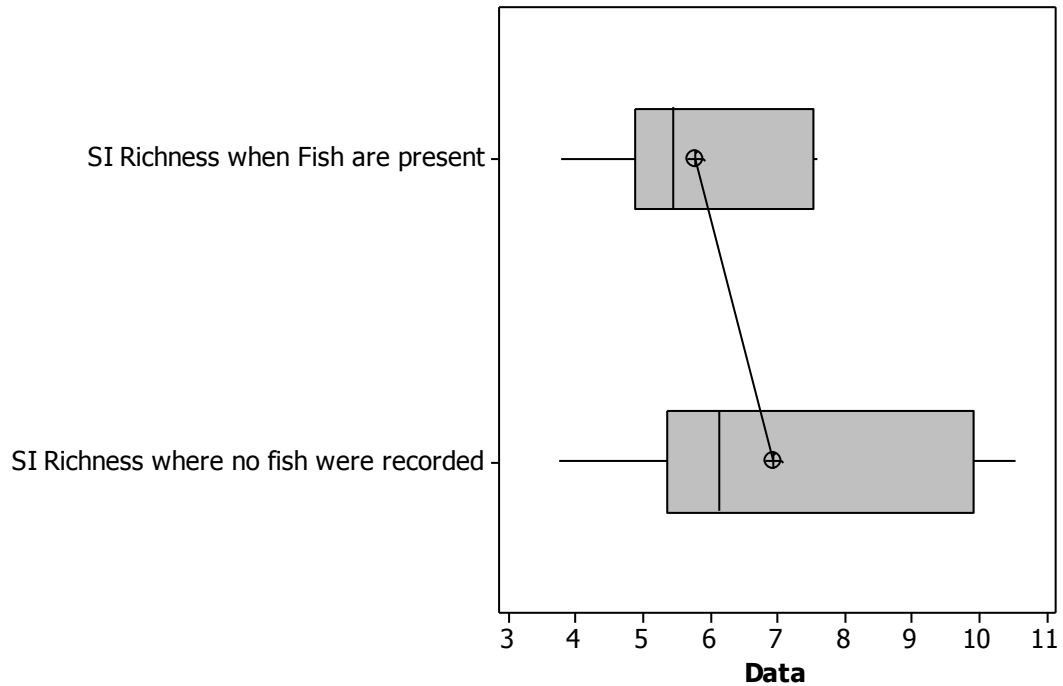

Appendix 1.9.12: Boxplot of the SI Richness between lochs with and without the presence of fish.

Two-Sample T-Test and CI: SI Richness in the presence and absence of Fish

```
Two-sample T for SI Richness_Fish present vs SI Richness_No fish recorded

                           N  Mean  StDev  SE Mean
SI Richness_Fish present  11  5.77   1.37     0.41
SI Richness_No fish reco   7  6.92   2.45     0.93
```

85

```
Difference = mu (SI Richness_Fish present) - mu (SI Richness_No fish
recorded)
Estimate for difference:  -1.16
95% CI for difference:  (-3.50, 1.18)
T-Test of difference = 0 (vs not =): T-Value = -1.14  P-Value = 0.286  DF =
8
```

```
Difference = mu (SI Richness_Fish present) - mu (SI Richness_No fish
recorded)
Estimate for difference:  -1.16
95% CI for difference:  (-3.50, 1.18)
T-Test of difference = 0 (vs not =): T-Value = -1.14  P-Value = 0.286  DF =
8
```

Appendix 1.10: Normality tests for all Environmental data sets

Biological data:

Mean	8.056
StDev	2.363
N	18
AD	0.467
P-Value	0.221
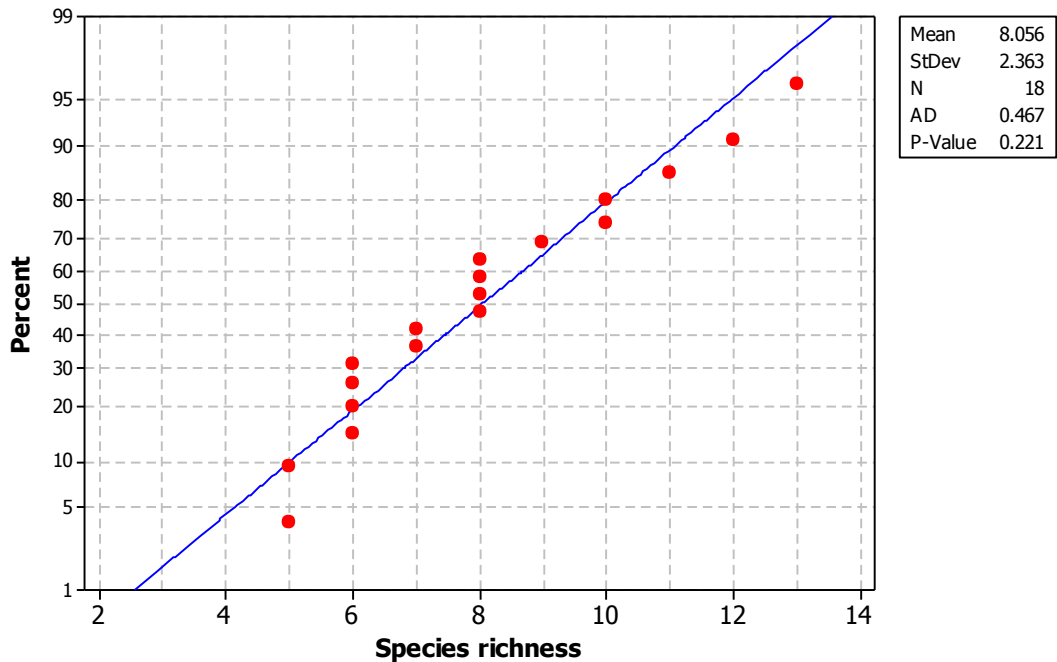
Appendix 1.10.1: Probability plot of Species richness for the Lochs, it shows the species richness data is normally distributed.

Mean	40.33
StDev	35.92
N	18
AD	1.396
P-Value	<0.005
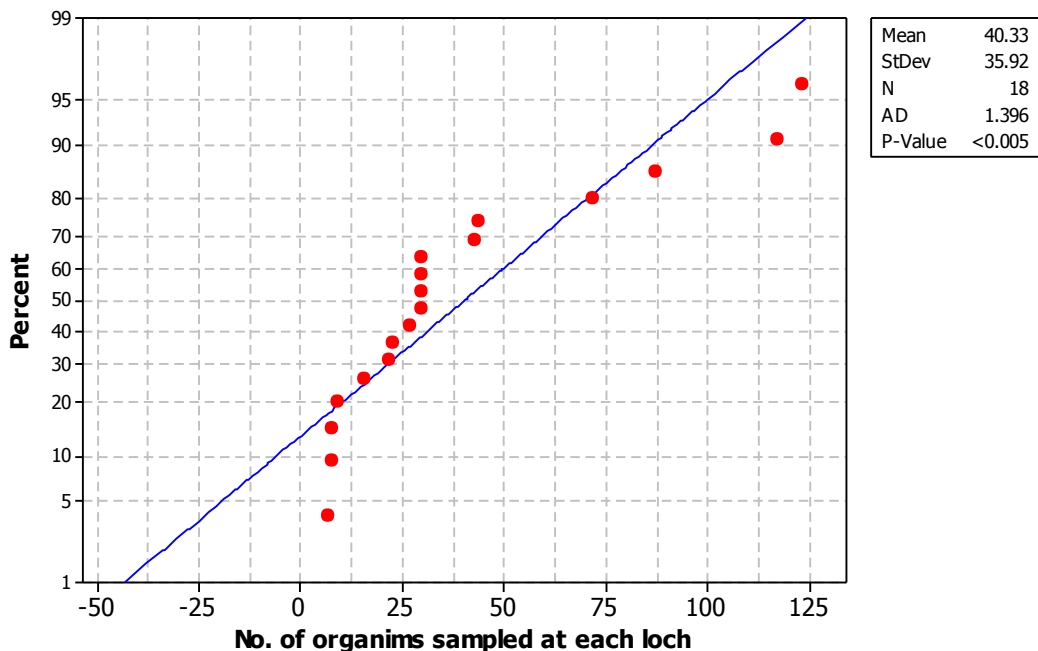
Appendix 1.10.2: Probability plot of the number of organisms sampled at each Loch, the results indicate the abundance of organisms at each loch is not normal and can vary greatly.
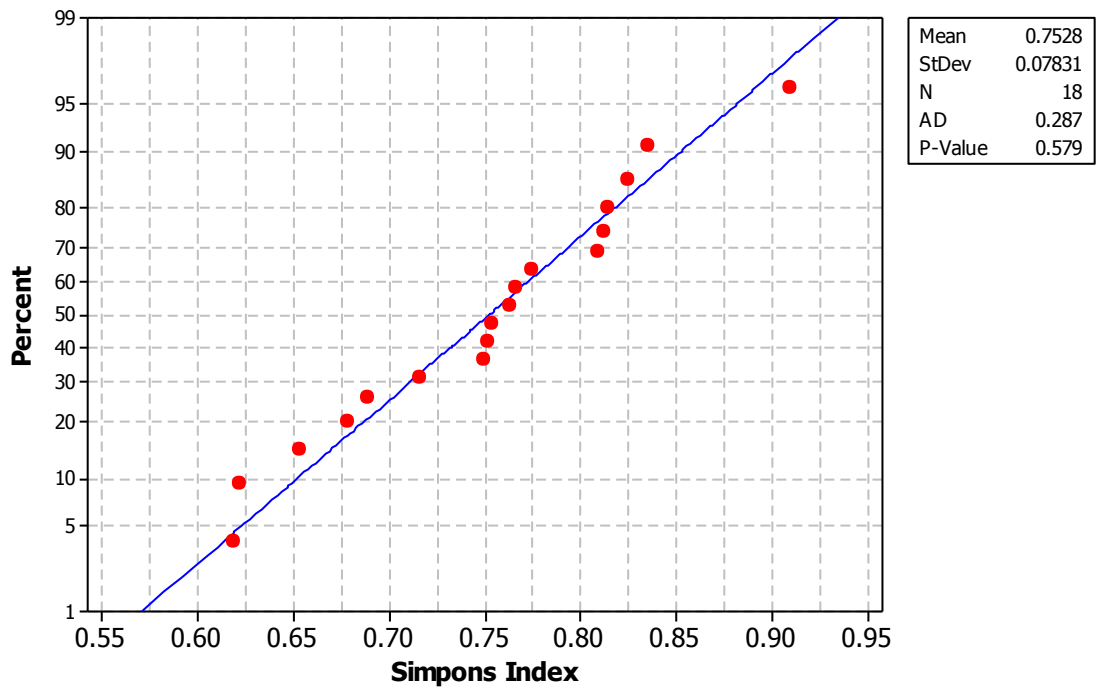
Appendix 1.10.3: Probability plot displaying a normal distribution of the Simpson's
D Index for all lochs.
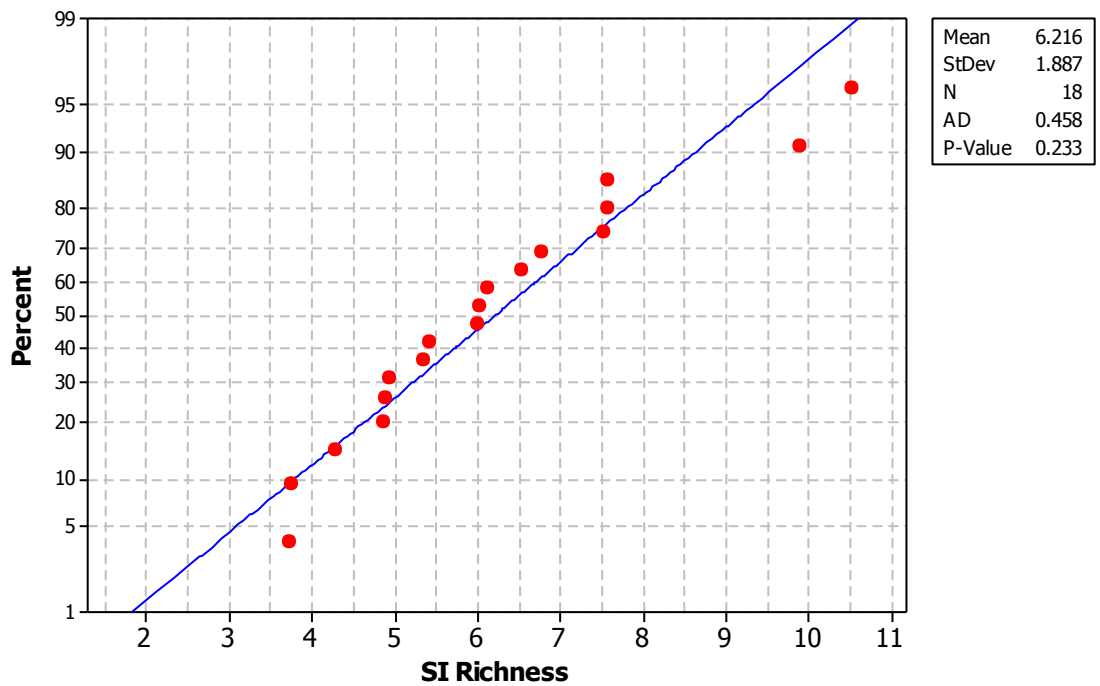
Appendix 1.10.4: Normality test result for SI Richness for each loch, indicating
normal distribution for SI Richness between the Lochs.

DECORANA axis values:

Mean	160.8
StDev	104.6
N	18
AD	0.264
P-Value	0.654
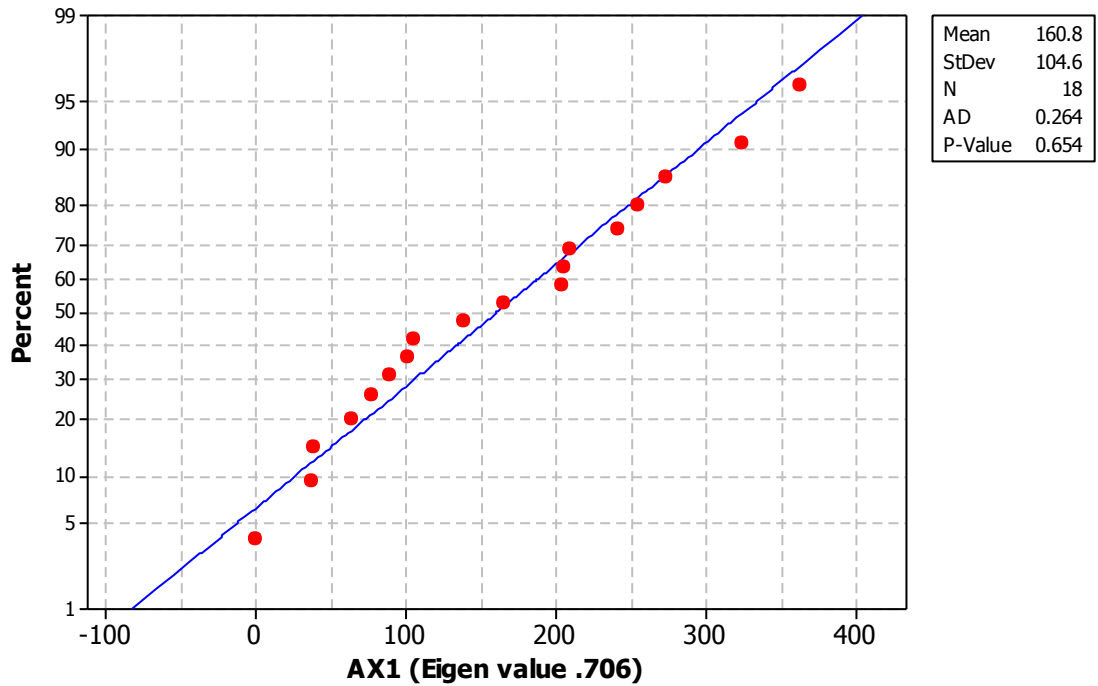
Appendix 1.10.5: Normality test results showing a normal distribution for AX1 values.

Mean	110.7
StDev	67.20
N	18
AD	0.428
P-Value	0.277
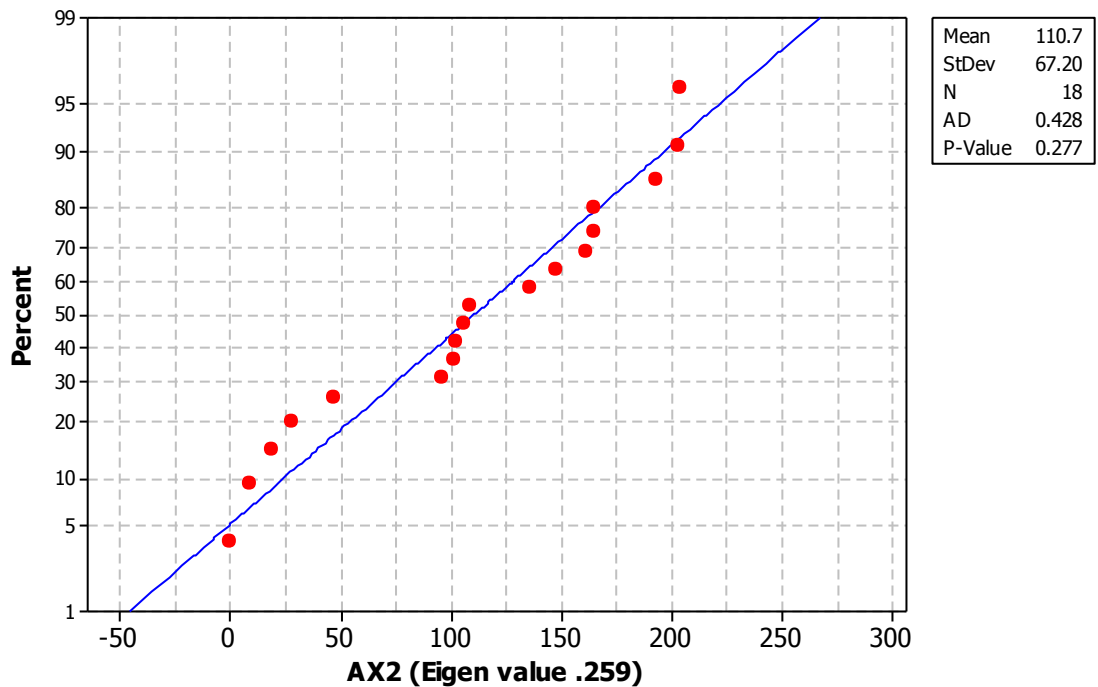
Appendix 1.10.6: Normality test results showing a normal distribution for AX2 values.

Loch water properties:
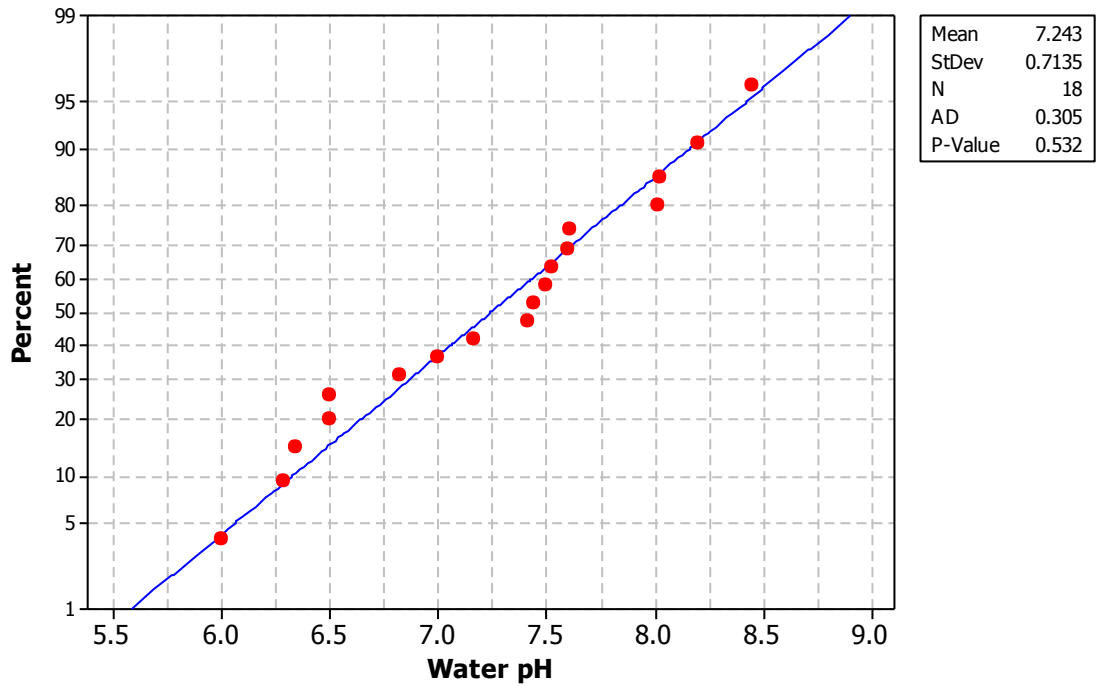
Appendix 1.10.7: Probability plot showing the pH readings for each loch indicating
the distribution of pH variability between the samples is normal.
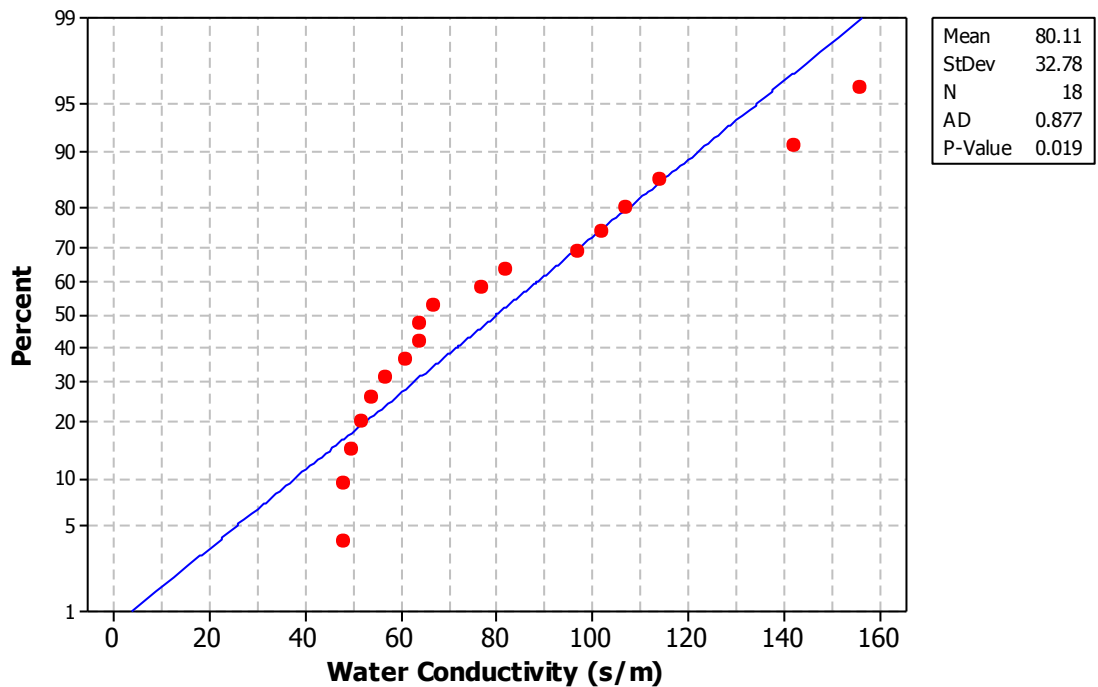
Appendix 1.10.8: Probability plot indicating that the samples do not have a normal
distribution of water conductivity levels.

Loch properties:
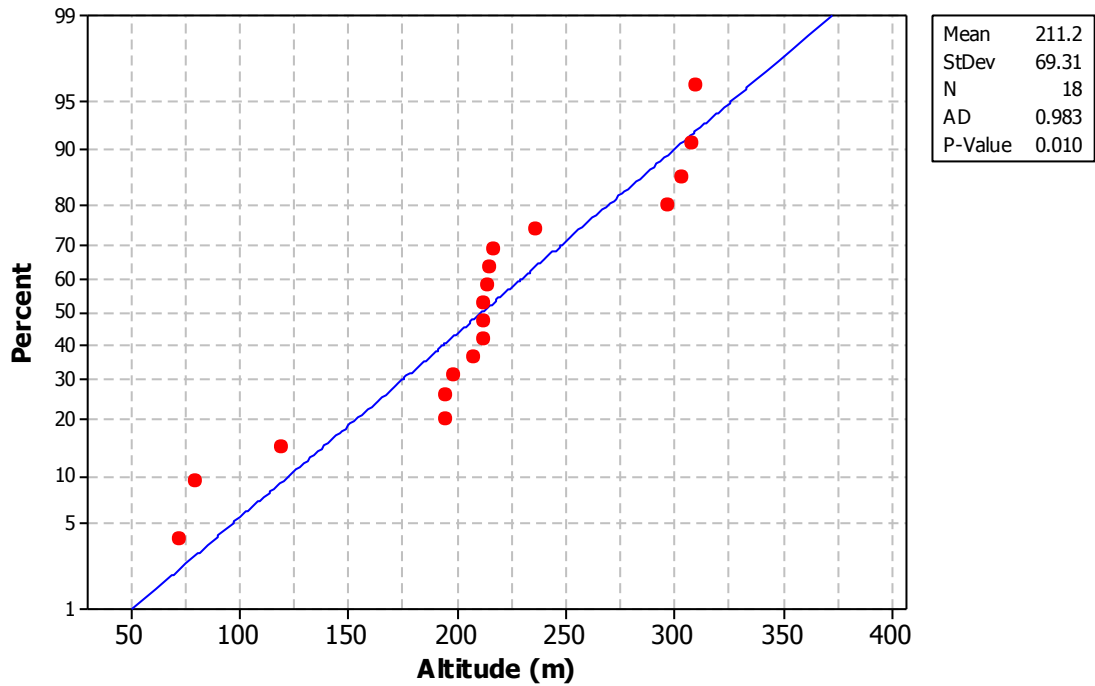
Appendix 1.10.9: Probability plot of altitude, the distribution of the loch altitudes is not normal.
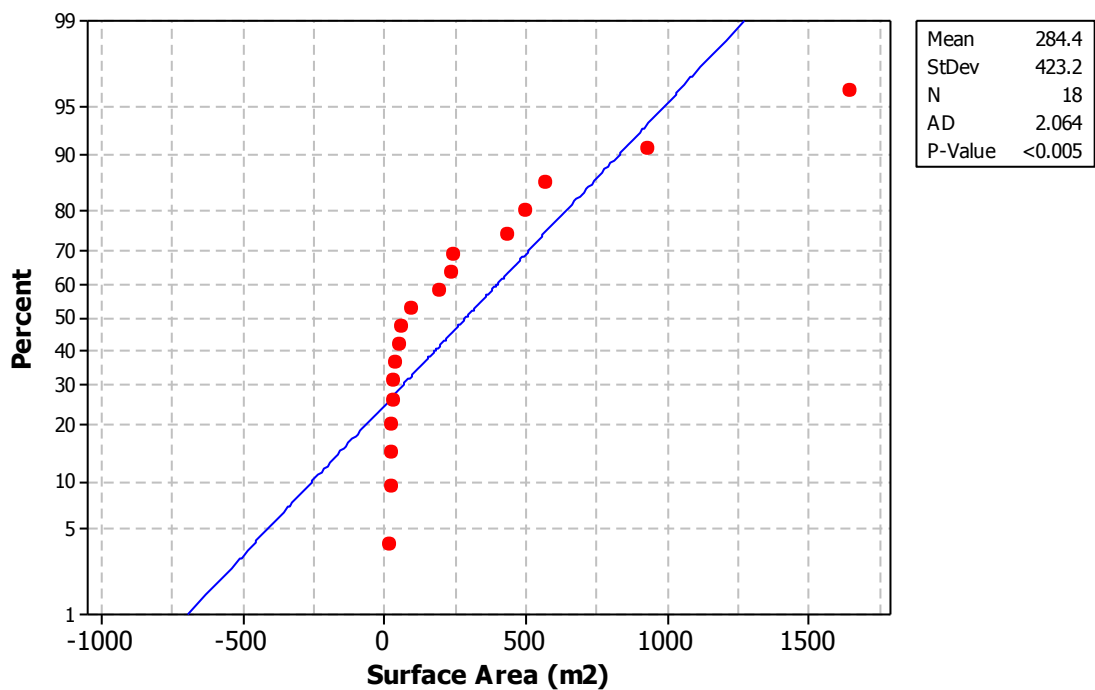
Appendix 1.10.10: Probability plot of each Loch's water surface area, the graph shows the variability between the lochs sizes is not normal.
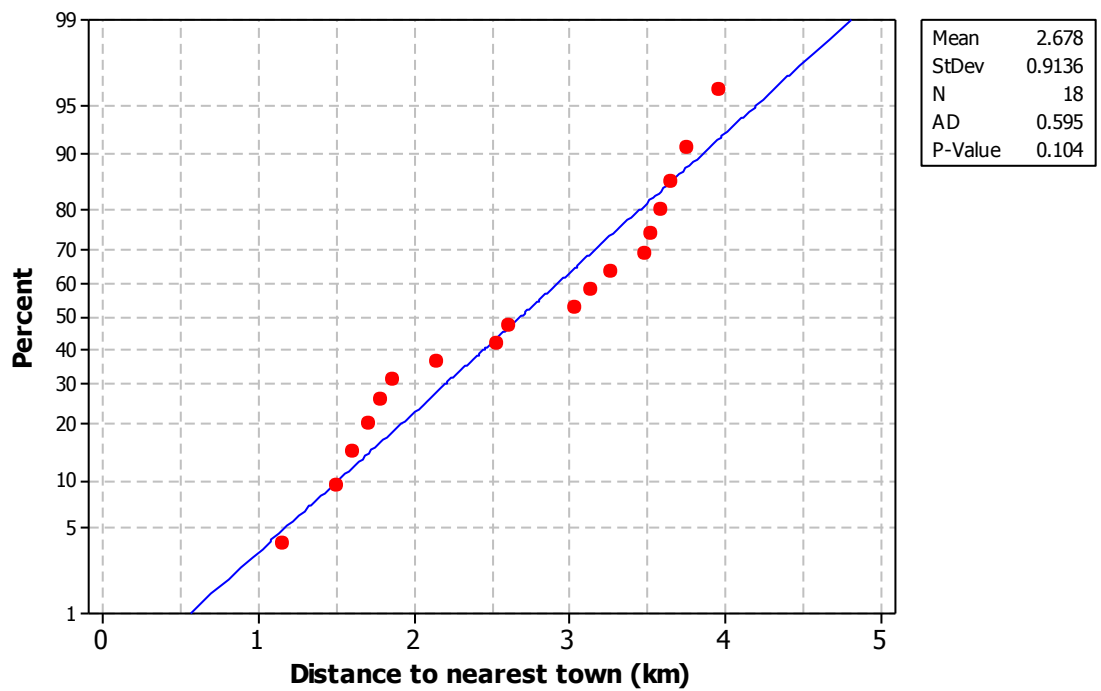
Appendix 1.10.11: Probability plot showing the distance to the nearest town for each loch is normally distributed.
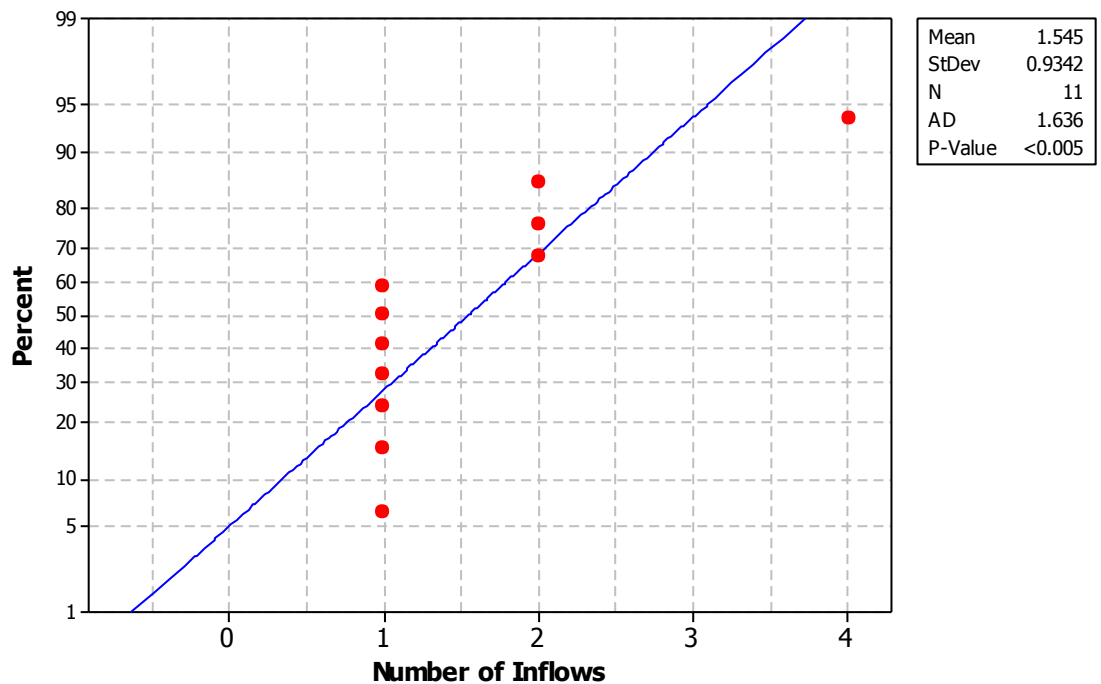
Appendix 1.10.12: Probability plot of the number of Inflows, it indicates that inflow distribution within the sample of lochs is not normal.
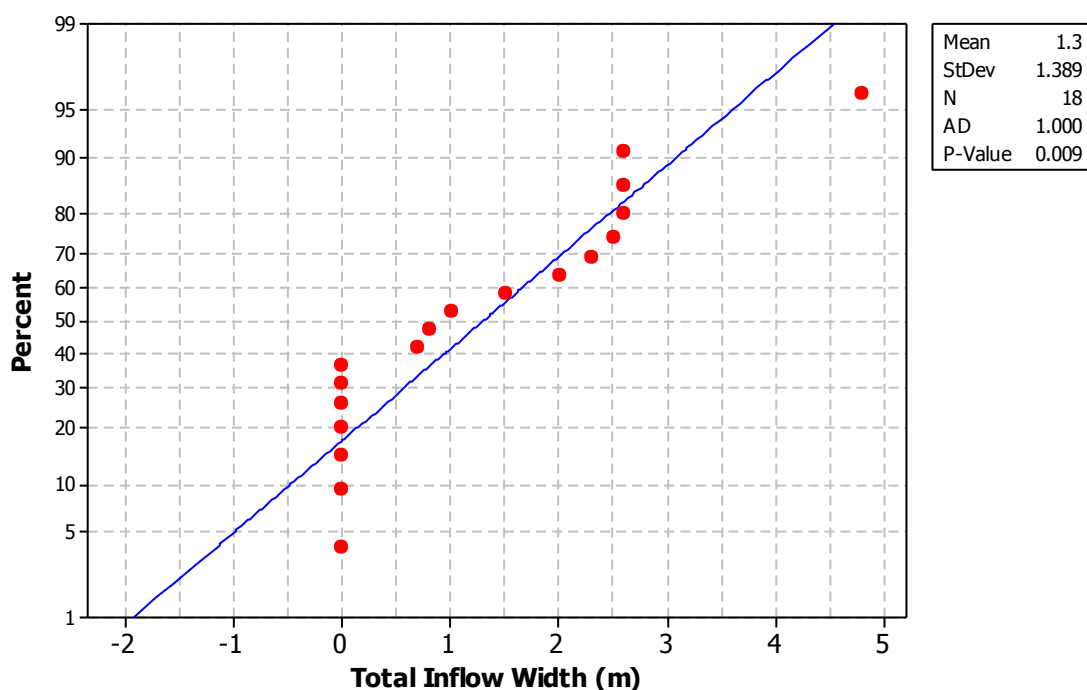
Appendix 1.10.13: Probability plot of Total Inflow Width indicating that inflow width
distribution within the sample of lochs is not normal.
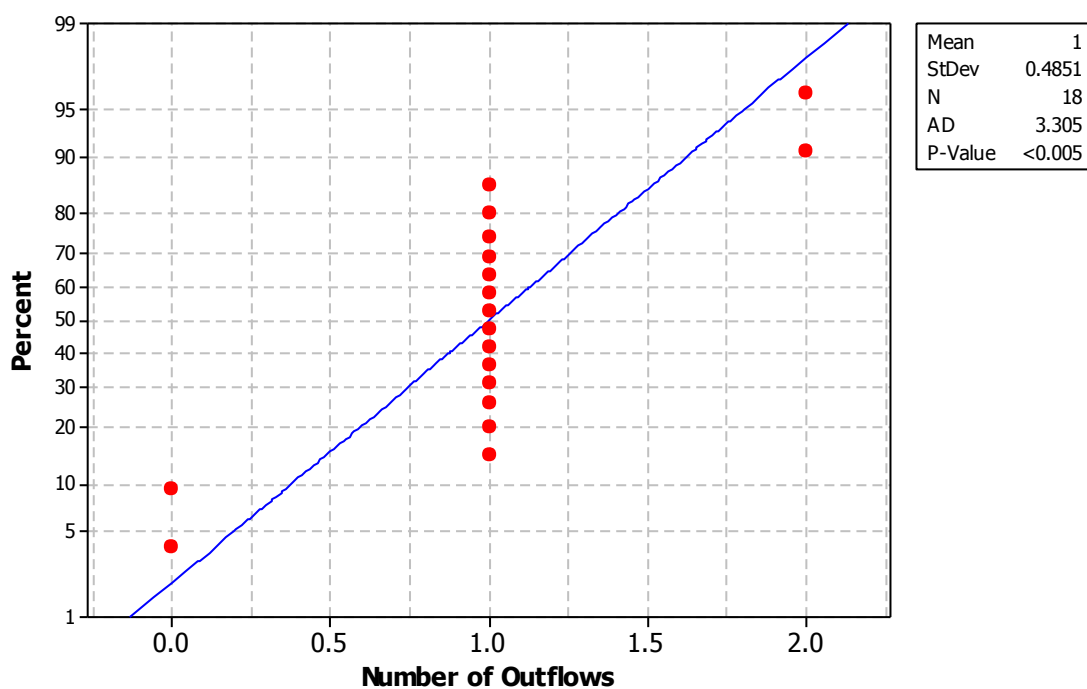
Appendix 1.10.14: Probability plot of Outflows, the distribution is highly abnormal
with almost all the values on 1.0.
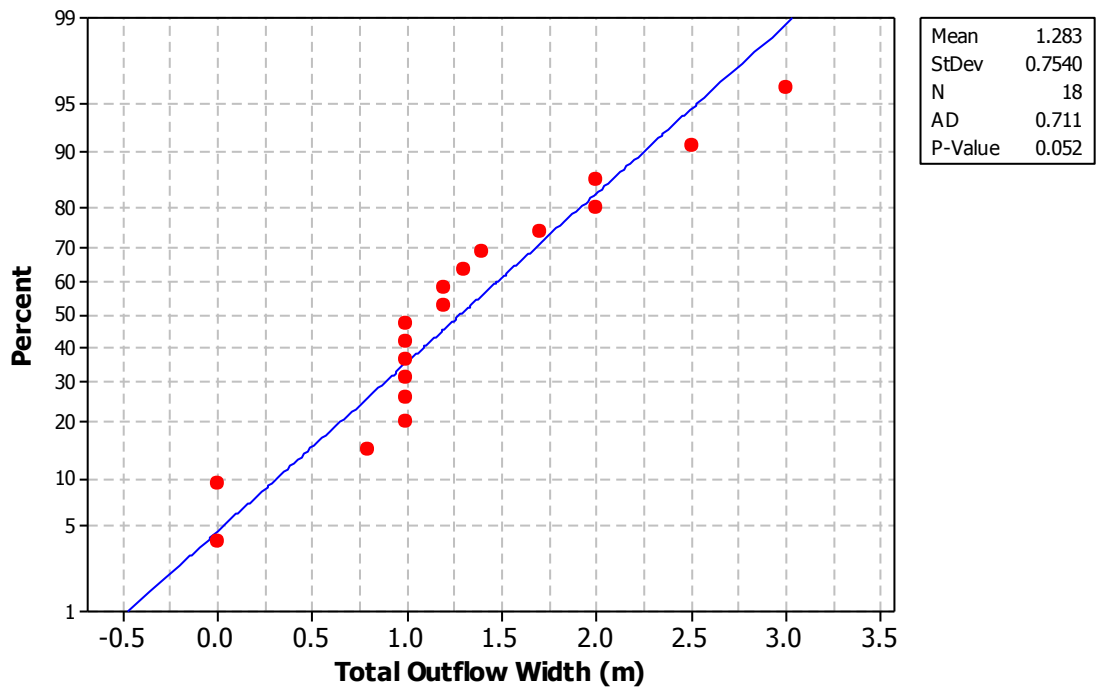
Appendix 1.10.15: Probability plot of Total Outflow Width indicating that the distribution is not normal, although the P-value is border line for significance.

Bedrock geology:
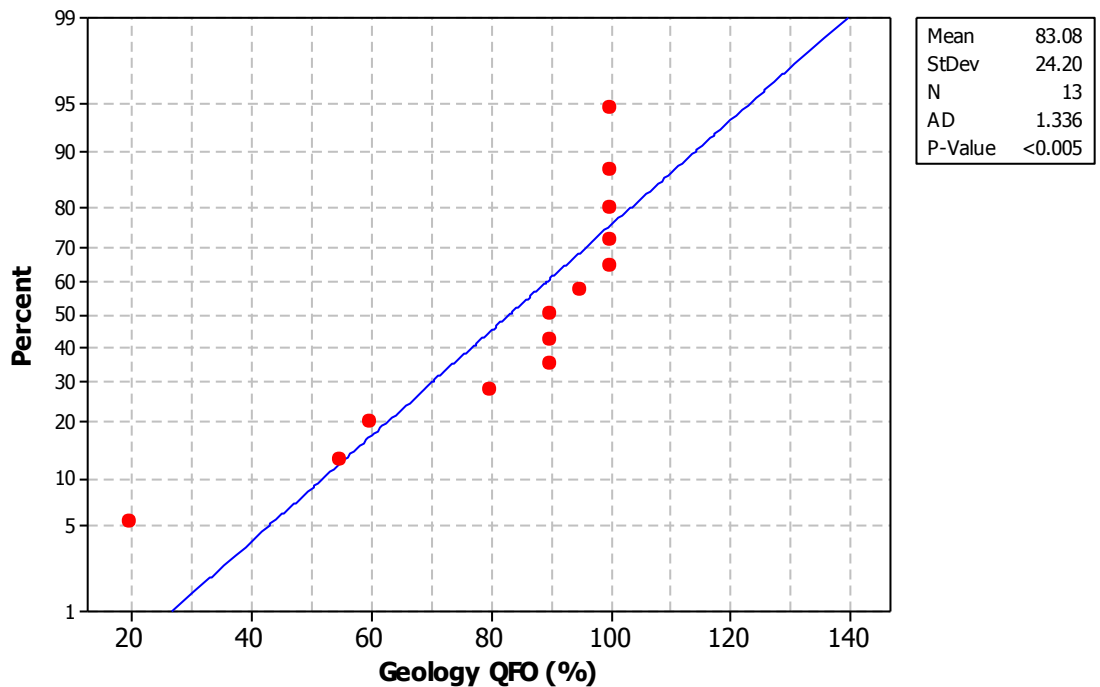
Appendix 1.10.16: Probability plot of the bedrock geology in terms of Quartzo-feldspathic orthogneisses showing abnormal distribution between the Lochs.
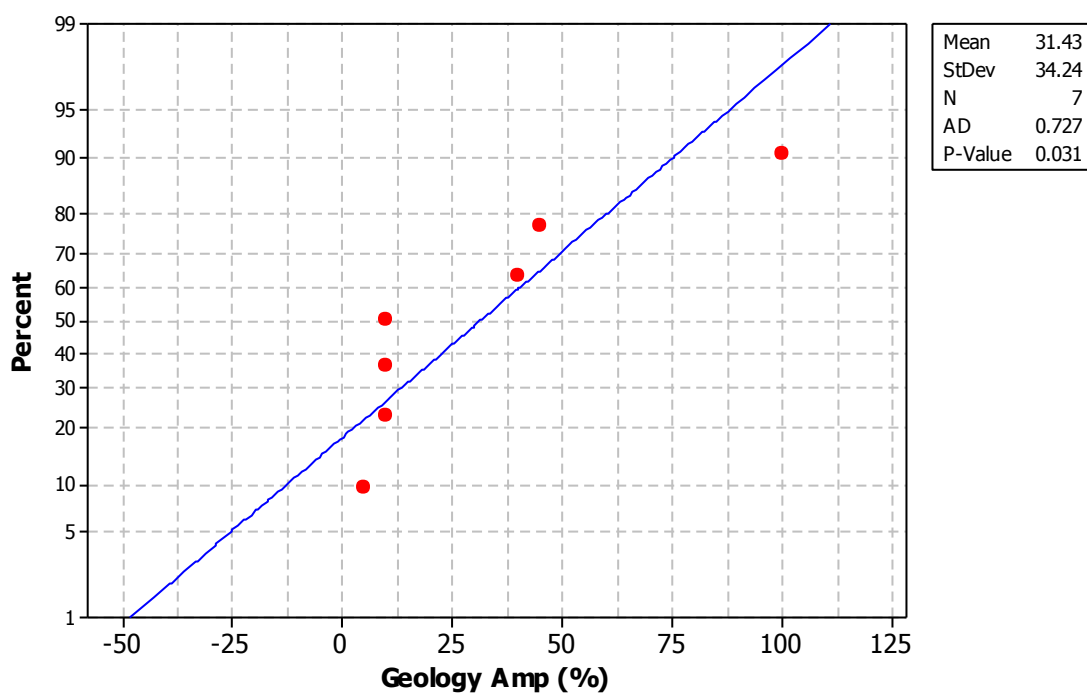
Appendix 1.10.17: Probability plot of the bedrock geology in terms of Amphibolite showing abnormal distribution between the Lochs.
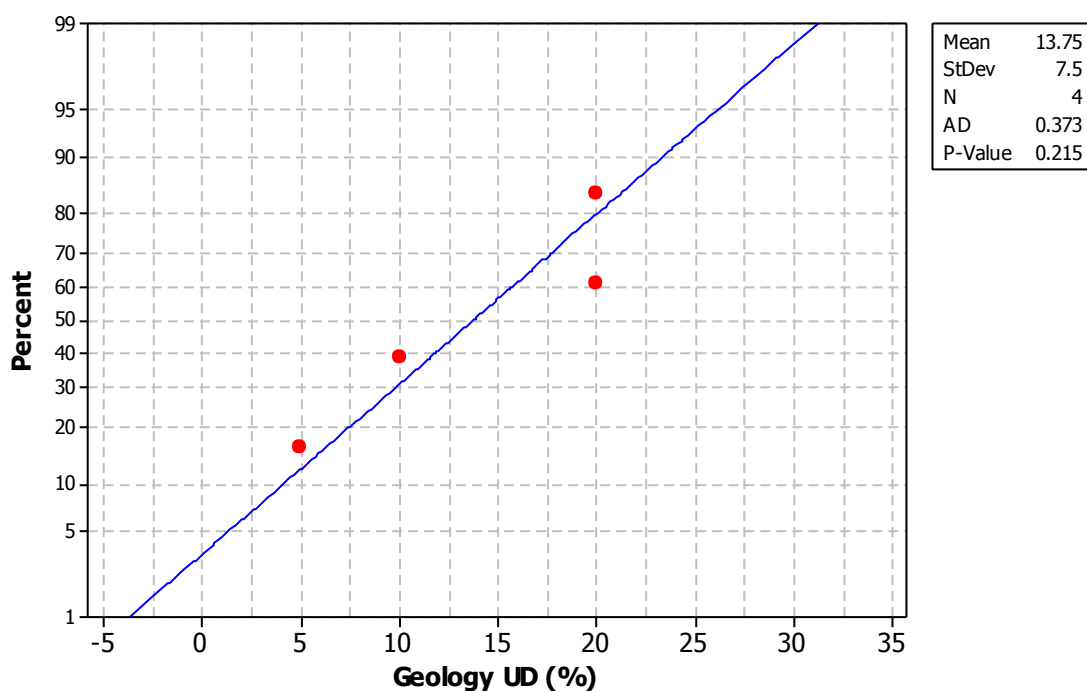
Appendix 1.10.18: Probability plot of the bedrock geology in terms of undifferentiated drift showing normal distribution between the Lochs.
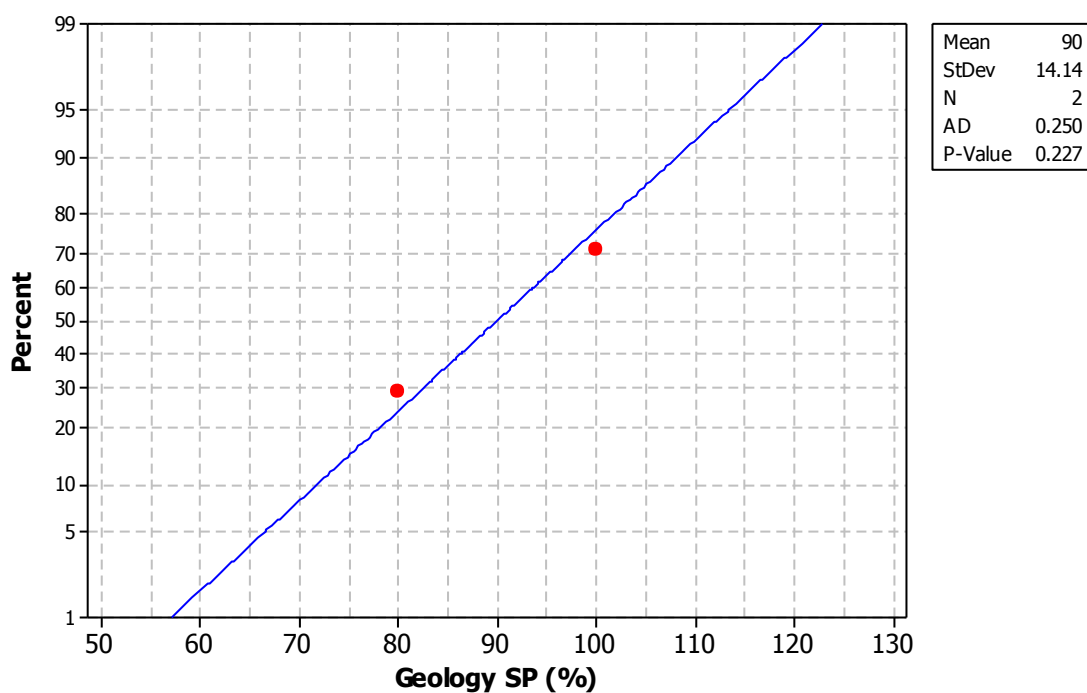
Appendix 1.10.19: Probability plot of the bedrock geology in terms of Semipelite showing a normal distribution between the Lochs.
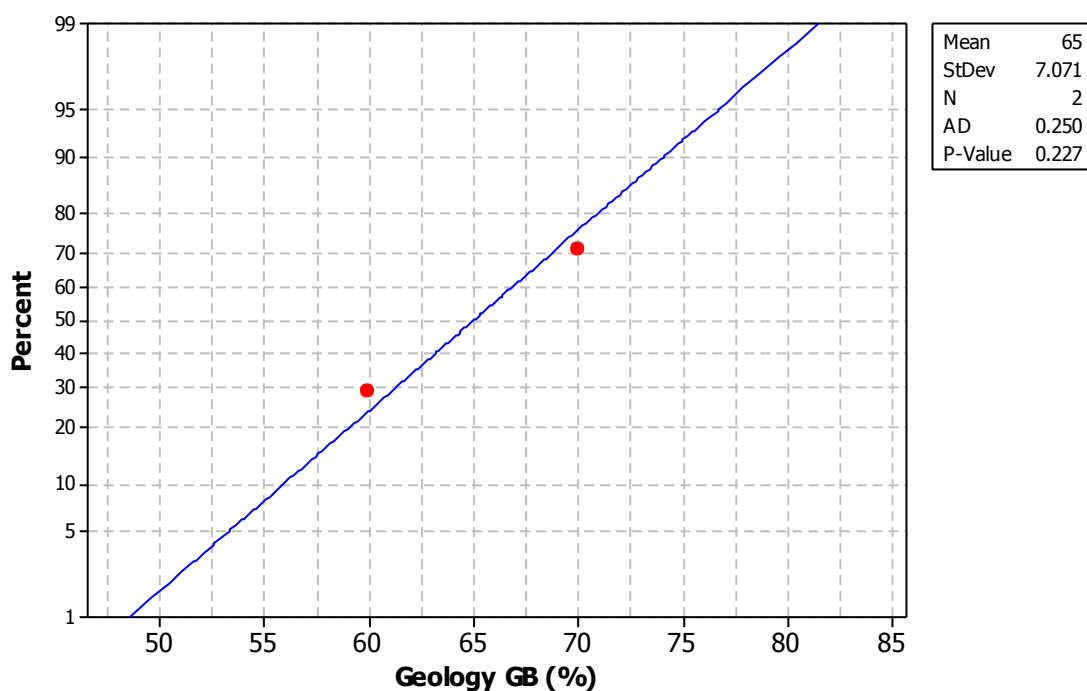
Appendix 1.10.20: Probability plot of the bedrock geology in terms of Gneiss-breccia showing normal distribution between the Lochs.

Surrounding land use:

Mean	90.28
StDev	14.19
N	18
AD	2.113
P-Value	<0.005
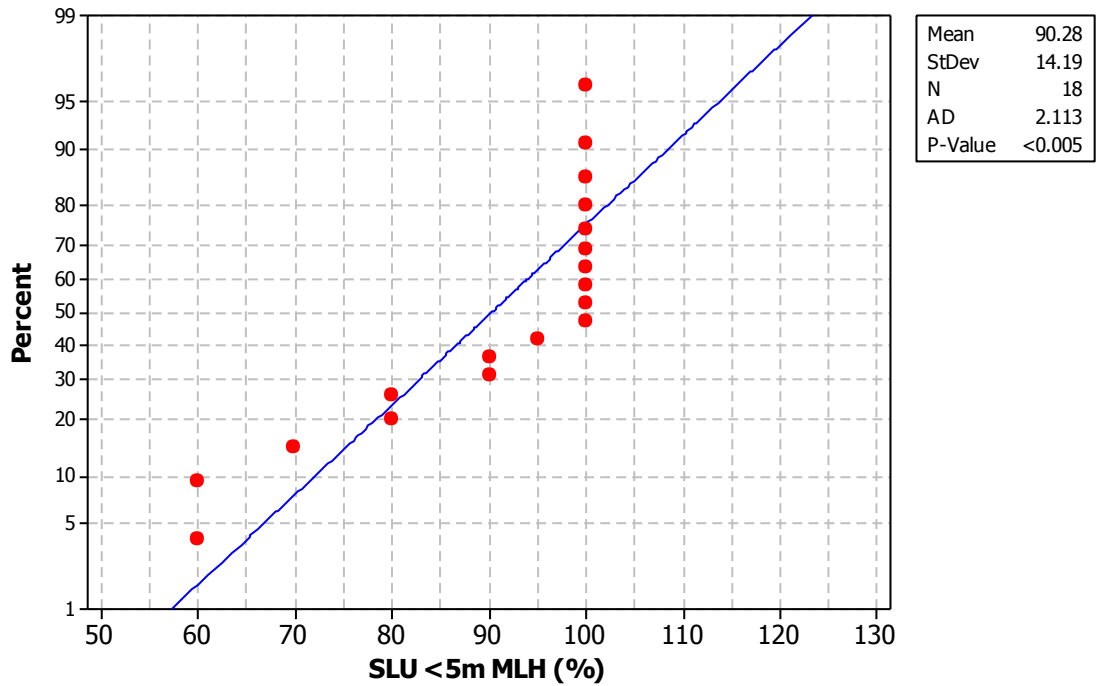
Appendix 1.10.21: Probability plot of the surrounding land use in terms of
Moorland heath showing abnormal distribution between the Lochs.

Mean	21.88
StDev	13.61
N	8
AD	0.360
P-Value	0.350
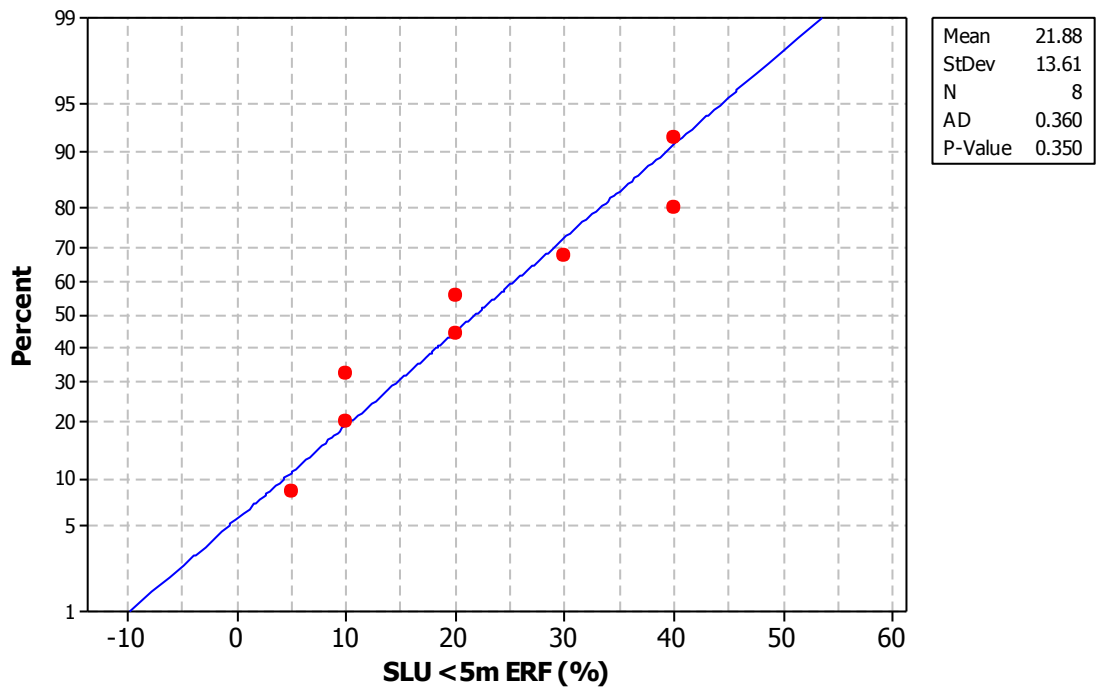
Appendix 1.10.22: Probability plot of the surrounding land use in terms of exposed
rock face showing normal distribution between the Lochs.
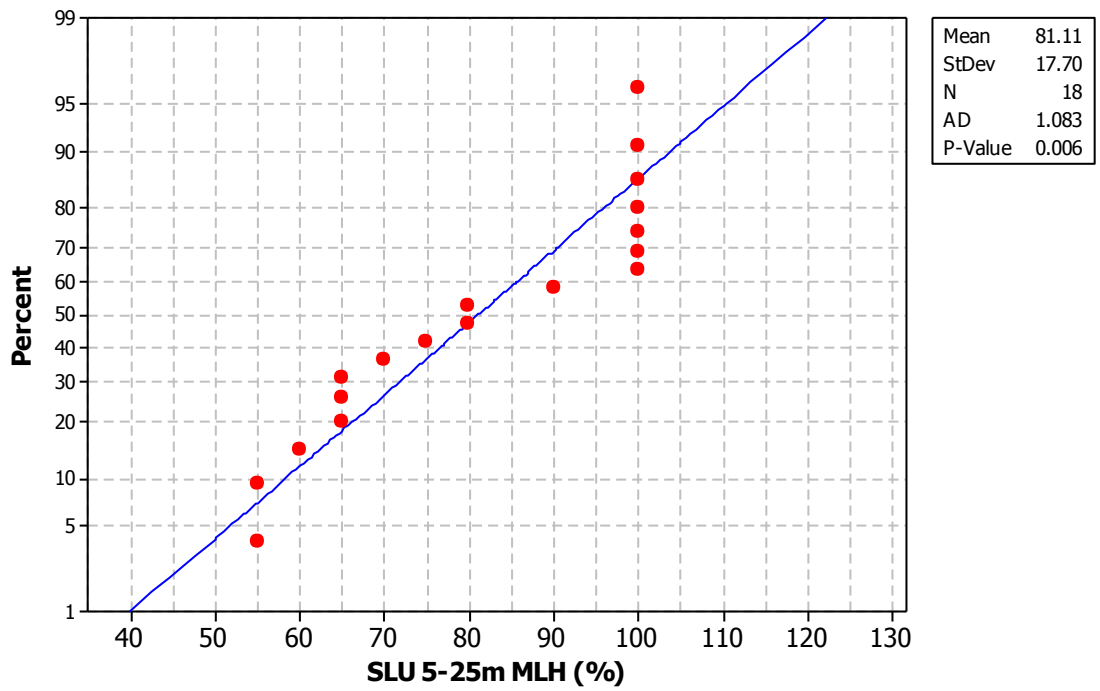
Appendix 1.10.23: Probability plot of the surrounding land use in terms of
Moorland heath showing abnormal distribution between the Lochs.
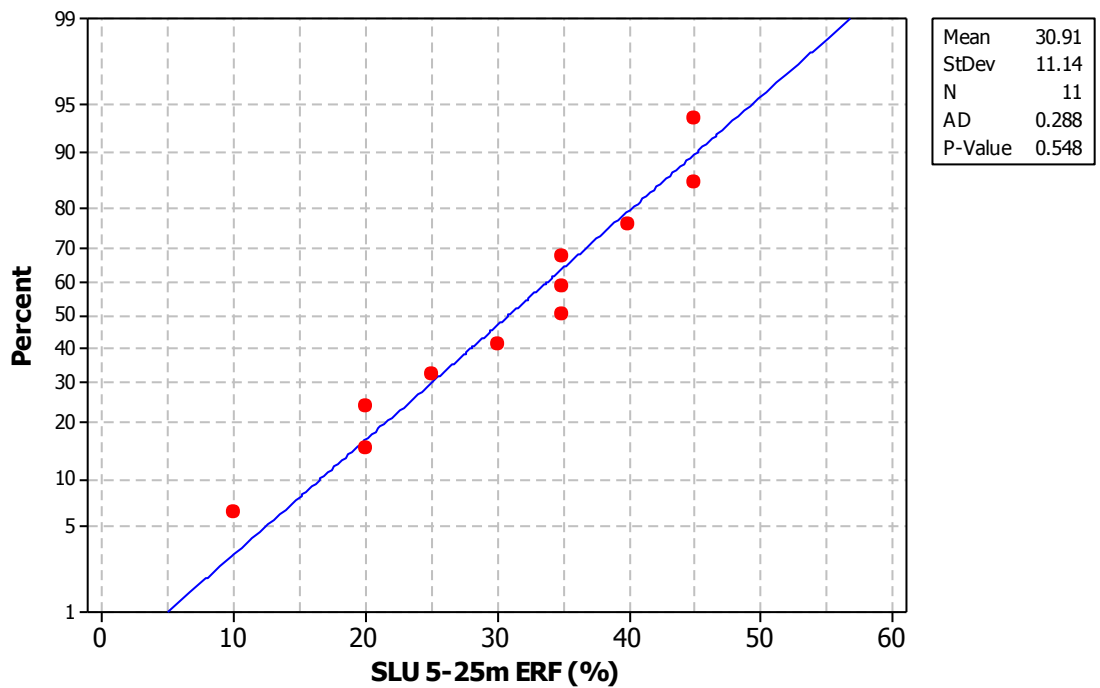
Appendix 1.10.24: Probability plot of the surrounding land use in terms of exposed
rock face showing normal distribution between the Lochs.
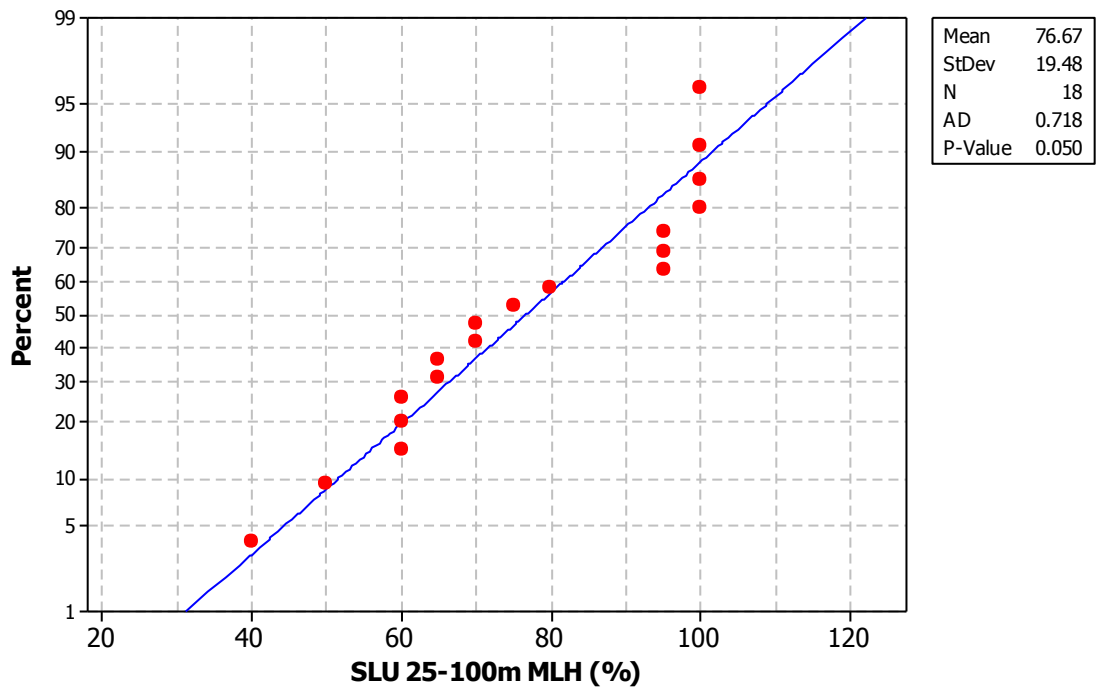
Appendix 1.10.25: Probability plot of the surrounding land use in terms of
Moorland heath showing normal distribution between the Lochs.
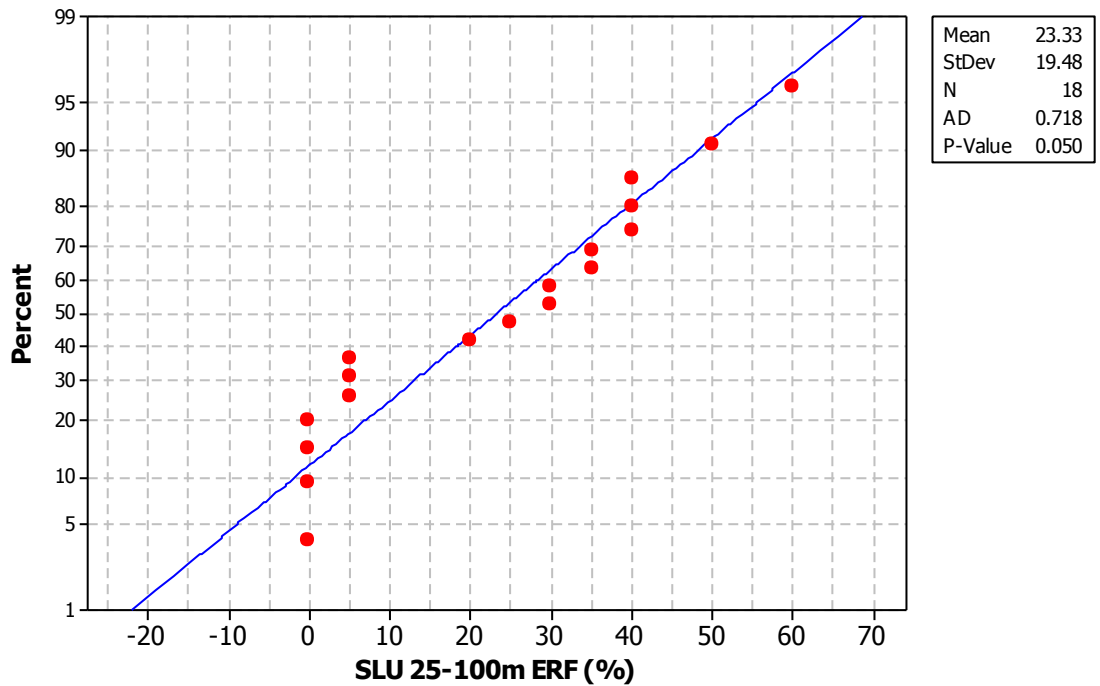
Appendix 1.10.26: Probability plot of the surrounding land use in terms of exposed
rock face showing normal distribution between the Lochs.
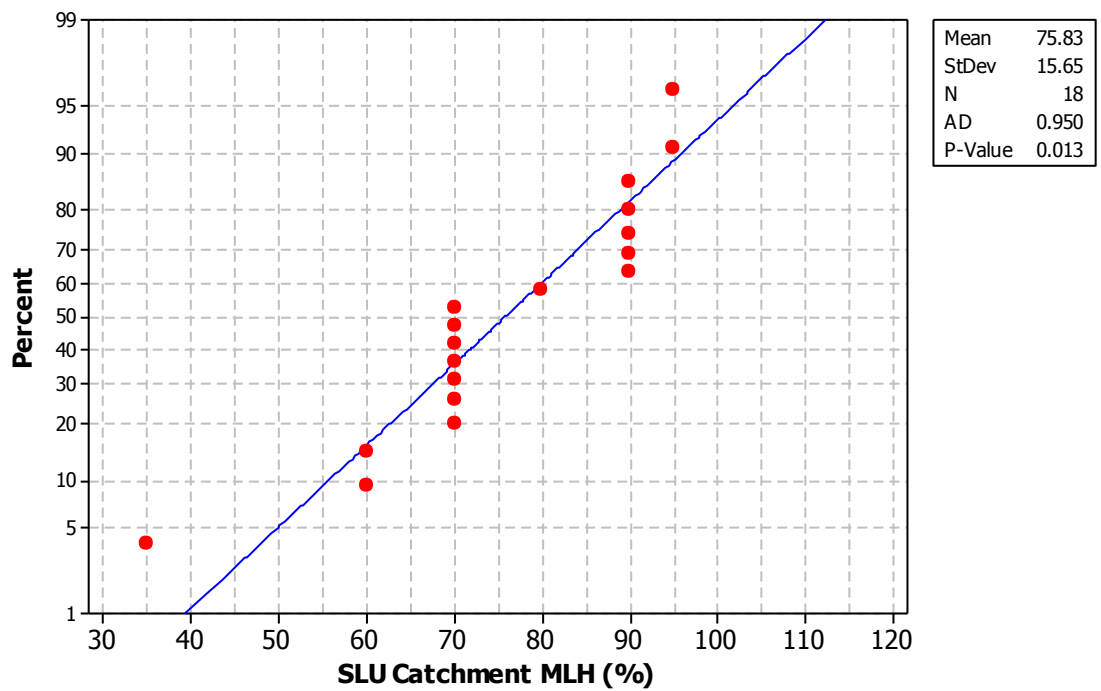
Appendix 1.10.27: Probability plot of the surrounding land use in terms of
Moorland heath showing abnormal distribution between the Lochs.
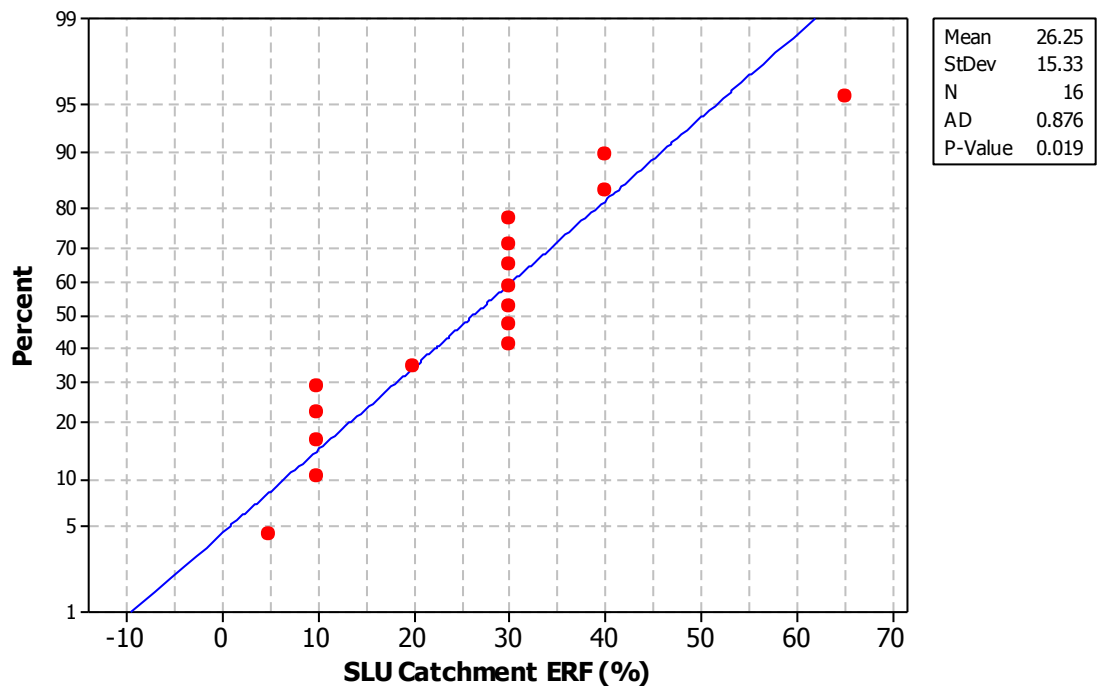
Appendix 1.10.28: Probability plot of the surrounding land use in terms of exposed
rock face showing abnormal distribution between the Lochs.

Mean	3
StDev	2.739
N	5
AD	0.800
P-Value	0.013
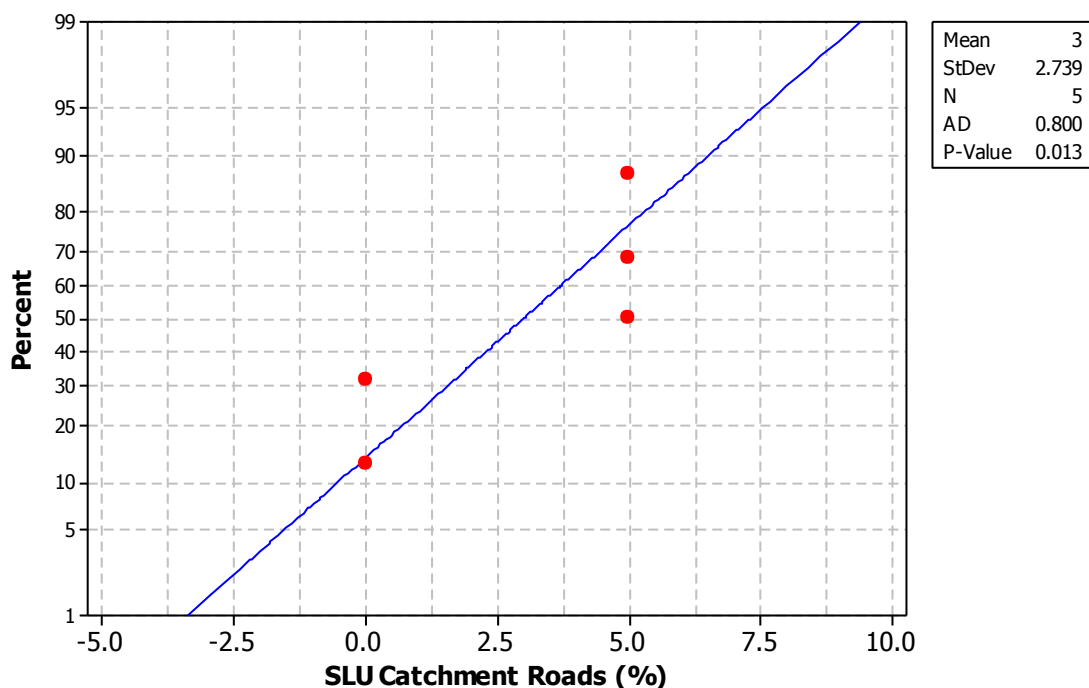
Appendix 1.10.29: Probability plot of the surrounding land use in terms of exposed roads showing abnormal distribution between the Lochs.

Number of adjacent water bodies:

Mean	1.667
StDev	0.5774
N	3
AD	0.488
P-Value	0.057
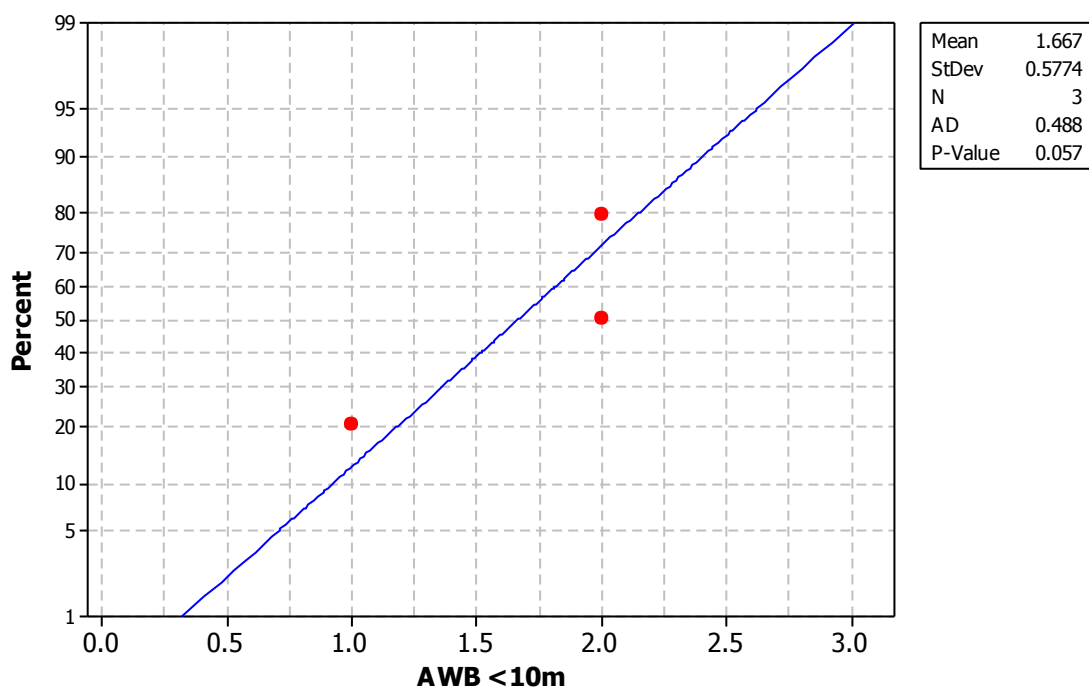
Appendix 1.10.30: Probability plot of the number of adjacent water bodies within a range of <10m, the results indicate an normal distribution. Results may be invalid due to sample size.
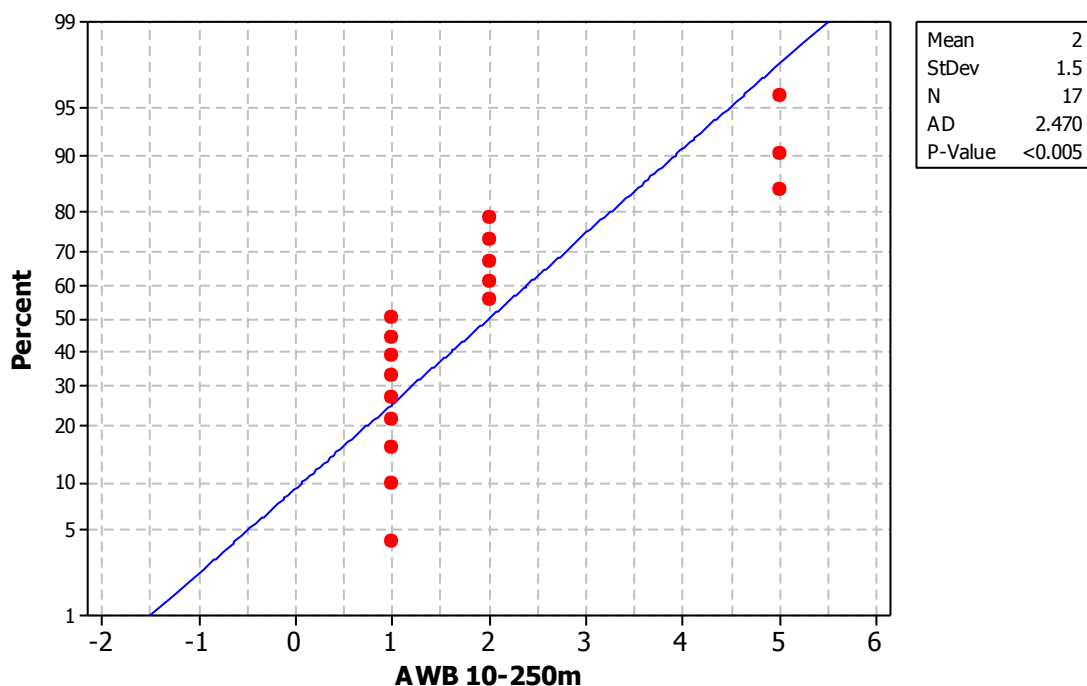
Appendix 1.10.31: Probability plot of the number of adjacent water bodies within a range between 10-250m, the results indicate an abnormal distribution.
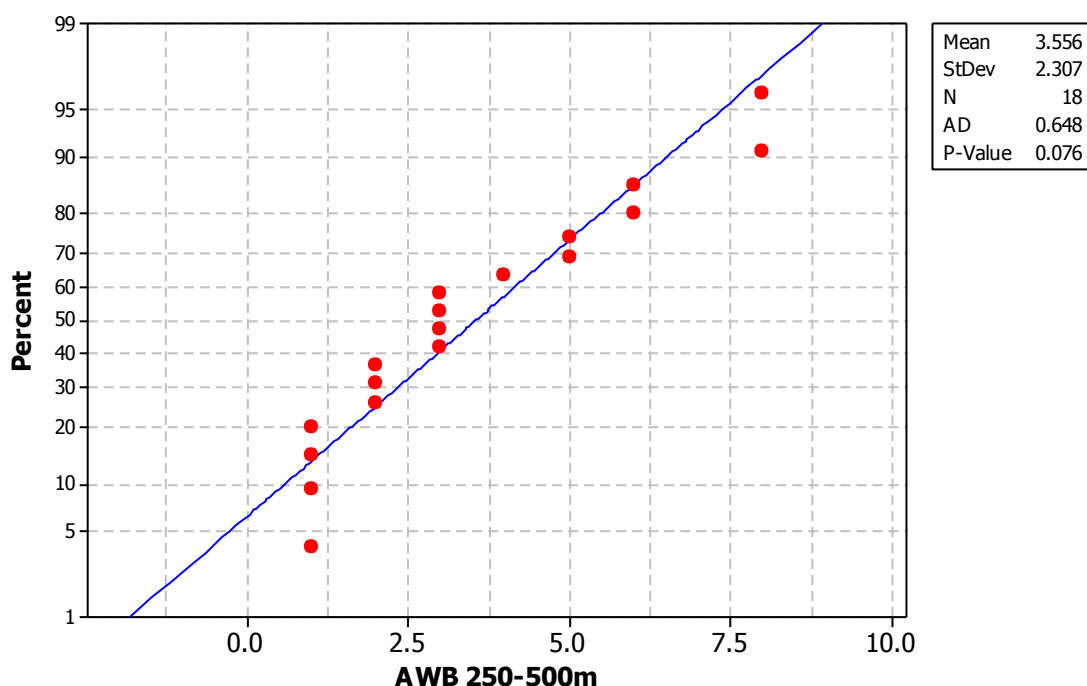
Appendix 1.10.32: Probability plot of the number of adjacent water bodies within a range between 250-500m, the results indicate a normal distribution.

Plant cover:
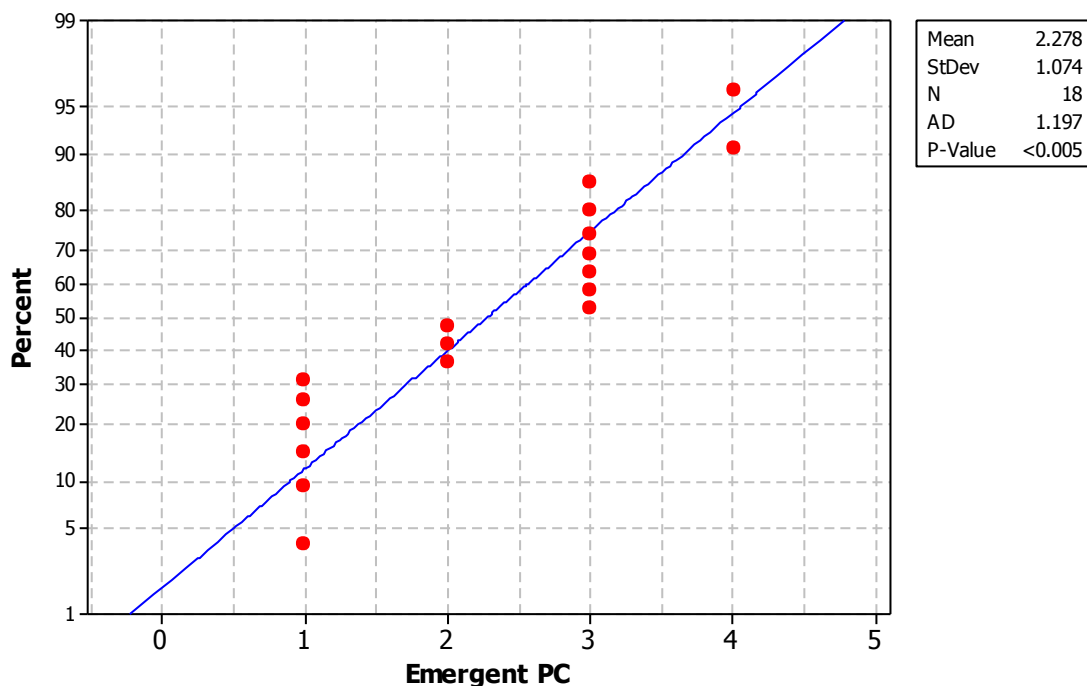
Appendix 1.10.33: Probability plot indicating that the grade of emergent plant cover is abnormal.
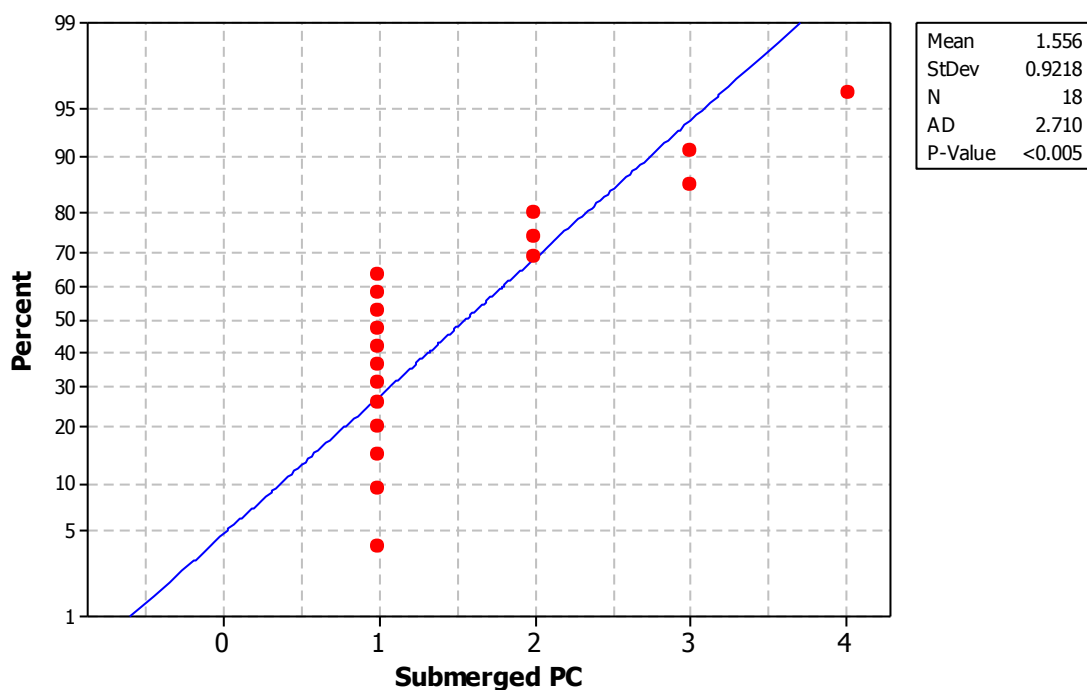
Appendix 1.10.34: Probability plot indicating that the grade of submerged plant cover is abnormal.

Mean	1.056
StDev	0.2357
N	18
AD	6.389
P-Value	<0.005
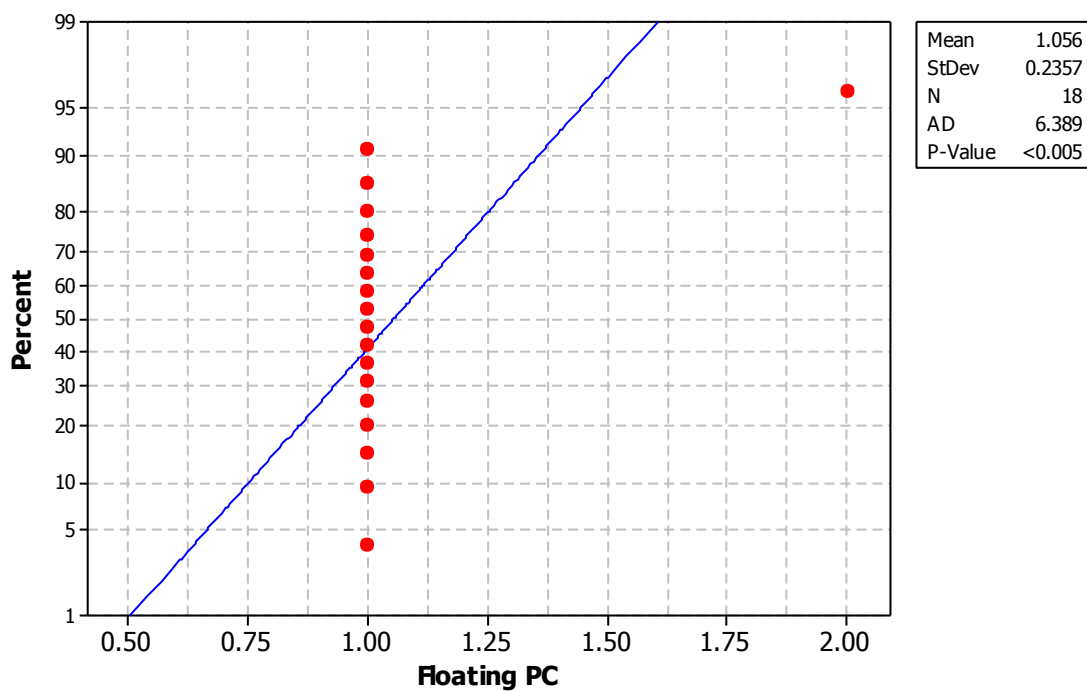
Appendix 1.10.35: Probability plot indicating that the grade of floating plant cover is abnormal.

Appendix 1.11: Calculating the Surface Area of each Loch

Appendix 2

Middlesex University London
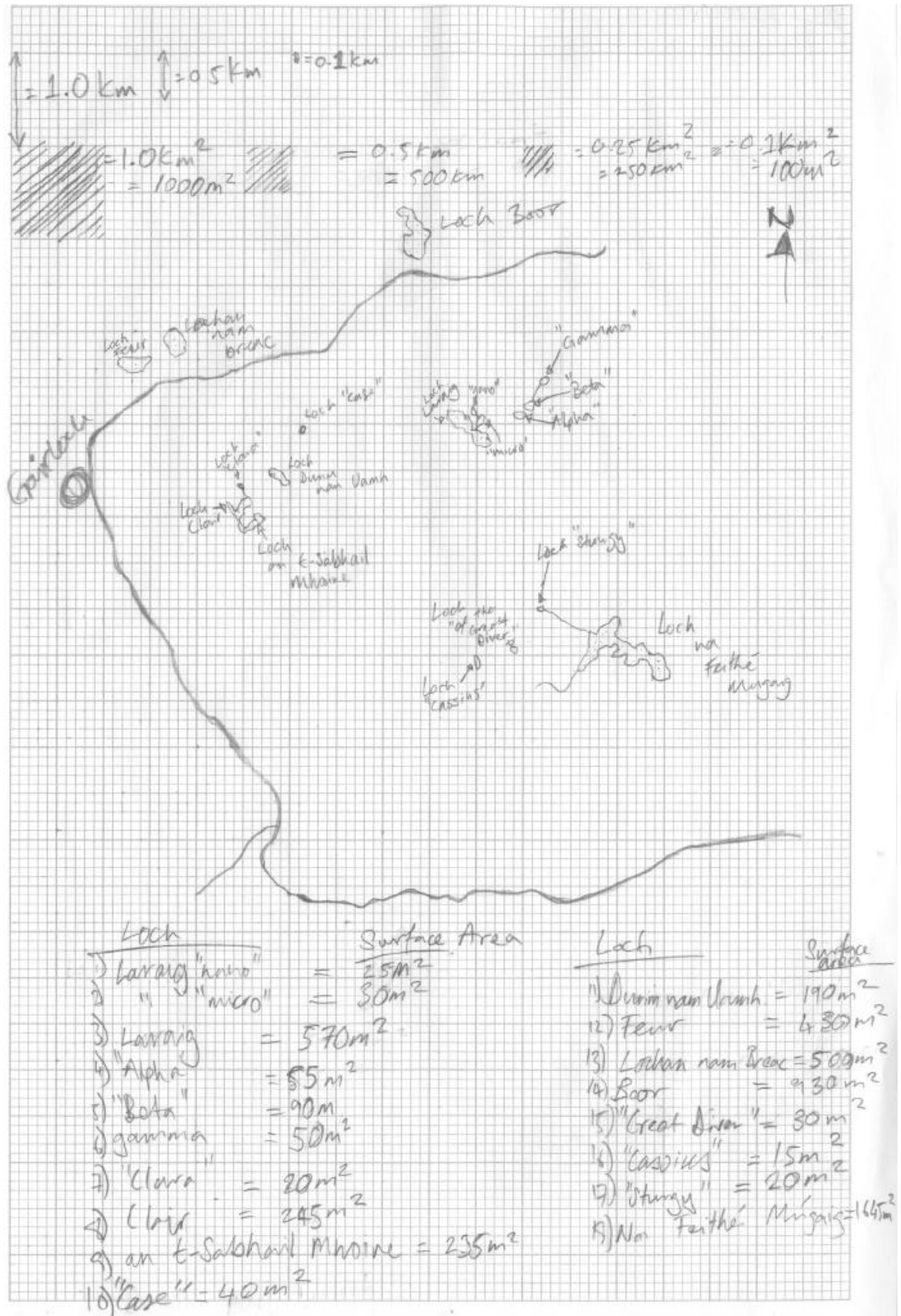
School of Science and
Technology
Department of Natural
Sciences
Hendon Campus
The Burroughs
Hendon
NW4 4BT

To: Vu Dang

Date: 13/11/12

Dear Vu

Re: **1015** "Effects of biotic and abiotic environmental variables upon the macroinvertebrate faunae of hill lochs."

Thank you for the above application which was presented to the Natural Sciences Ethics sub-Committee. On behalf of the committee, I am pleased to give your project its final approval. Please note that the committee must be informed if any changes in the protocol need to be made at any stage.

I wish you all the very best with your project. The committee will be delighted to receive a copy of the final report.

Yours sincerely
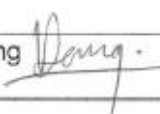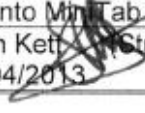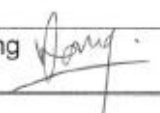
**Adam Choonara
Chair of the Natural Sciences Ethics sub-Committee**

Appendix 3

Learning Log

Topic and Focus of Study: (Initial Meeting)	Date: 10/04/2012

Initial idea of studying biodiversity in lotic environments was changed to studying biodiversity in lentic environments, namely aquatic macro-invertebrates of hill lochs in Gairloch, Wester Ross, Scotland.

Brief Outline of Intent:

Discuss potential areas of study with specific interests in aquatic ecology and biodiversity.

Agreed Objectives:
- Complete ethics form.
- Complete associated risk assessments.
- Familiarise knowledge bank with the Gairloch region in terms of geographic distribution of the sample locations and how to reach the sample area.
- Understand the national pond survey, its standard method and what kind of investigations it can permit.

Signatures (Supervisor): Dr. Stephen Kett   (Student): Vu H. Dang
Date and Time for next meeting: 03/06/2012

Meeting 1	Date: 03/06/2012
Comments	

Finalised the method of use for sampling.
Received some tools required for research from supervisor: i.e. Ordinance Survey (OS) map of the Gairloch region.
Discuss required equipment for investigation.
Discuss required safety equipment necessary for expedition.
Arrange date for volunteer work expedition.

Agreed Objectives
- Obtain required equipment need for sampling and safety.
- Investigate modes of analysis for potential data.
- Contact T. Denning to arrange lab sessions.
- Arrange travel to Gairloch, Scotland.

Signatures (Supervisor): Dr. Stephen Kett   (Student): Vu H. Dang
Date and Time for next meeting: 10/08/2012

Meeting 2	Date: 10/08/2012
Comments	

Meeting held at a laboratory in the Hatchcroft building.
Lab induction instructed my technician Thomas Denning.
Instructed and supervised by supervisor during lab based identification process necessary for valid taxonomic classification down to at least genus taxonomic level; use of correct equipment and taxonomic key outlined.

Agreed Objectives
- Practice identification skills.
- Revise taxonomic hierarchy to fully understand the necessity of identification and to ease the remembrance of invertebrate hierarchical groups.
- Identify all organisms across all samples before the next academic year begins.

Signatures (Supervisor): Dr. Stephen Kett   (Student): Vu H. Dang
Date and Time for next meeting: 06/10/2012

Meeting 3	Date: 06/10/2012

Comments
Double-checked identification of species with interest with supervisor.
Outlined the process of obtaining further geological and geographical data by using geology maps and Google Earth™.
Discussed the use of TWINSPAN and DECORANA as cluster analysis method.
Considered different indices to measure biodiversity.

Agreed Objectives

- Gather all geological and geographical data to compile with other environmental data obtained on site.
- Investigate TWINSPAN and DECORANA as a form of cluster analysis and provide TWINSPAN data input.
- Research indices used to measure biodiversity.

Signatures (Supervisor): Dr. Stephen Kett (Student): Vu H. Dang
Date and Time for next meeting: 28/01/2013

Meeting 4   **Date: 28/01/2013**

Comments
Provided supervisor with TWINSPAN data input derived from identification data obtained in summer lab sessions.
Overviewed the compiled environmental data and explored possible data analysis using MiniTab.
Decided on a simplified version of the Simpson's D Index as measurement of biodiversity for each sample.

Agreed Objectives

- Research Simpson's D Index as a measurement of biodiversity.
- Ordinate environmental data into MiniTab for analytical use.

Signatures (Supervisor): Dr. Stephen Kett (Student): Vu H. Dang
Date and Time for next meeting: 10/02/2013

Meeting 5   **Date: 10/02/2013**

Comments
Received TWINSPAN and DECORANA output results.
Discuss possible analysis of results in relation to baseline environmental data.

Agreed Objectives

- Research Simpson's D Index as a measurement of biodiversity.
- Ordinate environmental data into MiniTab for analytical use.

Signatures (Supervisor): Dr. Stephen Kett (Student): Vu H. Dang
Date and Time for next meeting: 18/04/2013

Meeting 6 (Final meeting)   **Date: 18/04/2013**

Comments
Discuss appropriate format and structure of dissertation.
Read over introduction section and was advised to focus it more on the Gairloch region in particular.
Proposed SI Richness as a compromise measurement of biodiversity.
Statistical analysis overviewed, with suggestions to analysing non-parametric data.

Agreed Objectives

- Focus introduction.
- Continue statistical analysis in relation to the non-parametric data.
- Finish dissertation.

Signatures (Supervisor): Dr. Stephen Kett (Student): Vu H. Dang
Date and Time for next meeting: N/A