Mongolian Journal of Biological Sciences 2010 Vol. 8(1): 27-39

The Relationship Between Grazing, Erosion and Adult Aquatic Insects in Streams in Mongolia.

Barbara Hayford[1] & Jon Gelhaus[2]

[1]*Wayne State College, 1111 Main Street, Wayne, NE 68787, USA, e-mail: bhayford@gmail.com*
[2]*Academy of Natural Sciences, 1900 Benjamin Franklin Parkway, Philadelphia, PA 19103*

Abstract

Overgrazing along stream channels in Mongolia may impact streams by increasing stream channel erosion and in-stream sediments, water temperature, pH, and conductivity. Grazing and erosion impacts may impair stream insects. The Mongolian Aquatic Insect Survey sampled 250 streams during summer seasons in 2003-2006 and 2008. On-site identifications of aquatic insect families mostly based on collections of adults were recorded for each site, leading us to ask whether the family-level data were useful in biological assessment related to impacts and impairment from grazing and erosion. A double dendrogram based on hierarchical cluster analysis was used to find patterns in sites and aquatic insect communities. Sites did not group by sampling period, but some sites did group by stream size and elevation. However, elevation was not a significant predictor of variation in aquatic insect metrics. Analysis of variance was used to determine whether insect metrics and water quality variables varied significantly between categories of erosion in the stream channel. Plecoptera and Diptera richness decreased with increased erosion and Percent Diptera Richness was the only aquatic insect metric to vary significantly between categories of erosion along the stream channel. Water temperature, conductivity, and pH also significantly increased with increased erosion. Multiple regression analysis was used to determine whether aquatic insect metrics could be predicted by variation in landscape, water quality and stream reach variables. Trichoptera, Ephemeroptera, and Coleoptera richness increased with increased erosion, conductivity, and pH, but not significantly. Percent Diptera Richness formed the only significant model in the multiple regression analysis, with conductivity the only significant predictor of variation in Percent Diptera Richness. Family-level data generated in the field indicated that sampling for Trichoptera and Ephemeroptera diversity would be maximized by sampling streams undergoing intermediate levels of disturbance from grazing and erosion, that sampling for the Diptera and Plecoptera diversity would be maximized by sampling streams with less erosion and grazing, and that Diptera richness was impaired by erosion related to grazing in Mongolian streams.

Key words: Mongolia, Erosion, Grazing, Aquatic Insects, Bioassessment

Introduction

Pastoralist herders in Mongolia have changed their grazing practices over the past two decades by increasing the intensity of grazing and the concentration of domesticated herbivores along stream channels. Increased grazing may directly impact riparian and stream channel condition, impacting stream quality and impairing aquatic insects. In-stream larvae will be affected by changes to water quality, substrate type and heterogeneity, and increased sedimentation. Terrestrial adults may additionally be impacted by a loss of refuge and mating habitats. The Mongolia Aquatic Insect Survey (MAIS) team made field identifications of adult aquatic insects at each collection site during summer season over five years. Data from these identifications are used here to determine whether adult family level data alone is responsive to changes in environmental gradients and if so to demonstrate the use for this data in guiding on-going surveys and biological assessments of streams in Mongolia.

Mongolia is a landlocked country characterized by grassland steppe, desert, and mountain regions which have been grazed for up to 4000 years. Domesticated grazing livestock include yaks, cattle, camels, sheep, horses, and goats; and wild rangeland grazers include gazelle, ibex, wild ass, and the critically endangered saiga antelope (Johnson *et al*. 2006).

Until recently, Mongolia exhibited less impact on rangeland health from overgrazing than surrounding central Asian countries (Fernandez-Gimenez, 2000). However, Mongolia is in transition from more traditional and collectivist pastoralist rangeland management to more centralized and intensive rangeland management (Batnasan, 2003, Batnasan *et al*., 2004, Johnson *et al*., 2006). This transition of Mongolian rangeland has already affected Mongolian pastoralist herders, making them more susceptible to economic decline and even starvation due to die off of their herds from environmental fluctuations common in the continental climate of Mongolia (Fernandez-Gimenez, 1999, 2000; Fernandez-Gimenez and Batbuyan, 2004; Johnson *et al.,* 2006). Fernandez-Gimenez & Batbuyan (2004) showed that Mongolian pastoralist herders perceived a decline in rangeland health due to the reduction of rotation of herd animals.

Grazing can have a direct impact on stream condition. In the past, herders would rotate grazers in and out of water sources, but increasingly, herders leave grazers in or near water resources sometimes resulting in unregulated concentration of grazers near and probably in water resources such as streams (Batnasan et al., 2004; Johnson *et al.,* 2006). Thus, deterioration in rangeland condition will lead to deterioration of stream condition. Over grazing, defined as loss of vegetative structure and diversity and an increase in bare ground, impacts and impairs streams in dryland ecosystems and grasslands in North America (Fitch & Adams 1998; Belsky *et al.,* 1999). Cattle can directly impact stream health by destabilizing stream banks, by defecating and urinating directly in streams, and by compacting stream bank soils. These impacts can result in increased sedimentation in the streams and increased organic enrichment and the corresponding decrease in dissolved oxygen (Belsky *et al.,* 1999; Del Rosario *et al.,* 2002). The resulting bank destabilization and sedimentation have been shown to impact macroinvertebrate communities through a decrease in frequency of certain taxa (Braccia & Voshell 2006), changes in community composition (Scrimgeour & Kendall 2003), and changes in species traits (e.g. reproductive behaviors) of macroinvertebrates (Dolédec *et al.,* 2006).

Adult aquatic insect communities may be impaired by overgrazing in two ways. First, impairment of the in-stream community will lead to reduced numbers and diversity of emerging adult insects. Second, overgrazing by domesticated herbivores removes riparian vegetation which destroys or disturbs habitat necessary for protection, dispersal, and mating of adult aquatic insects. Differing land cover has been shown to influence dispersal of adults of aquatic insects such as Chironomidae (Delettre & Morovan, 2000), Empididae and Chironomidae (Delettre *et al.,* 1992), Ephemeroptera, Plecoptera, and Trichoptera (Winterbourn *et al.,* 2007) and Ephemeroptera and Plecoptera (Petersen *et al.,* 2004). Some adults disperse great distances from their natal streams, but according to these studies most adult insect abundance decreases as a function of the perpendicular distance from the stream channel. Thus, most adult aquatic insects are concentrated either in the streams or near the streams where impacts of overgrazing by domesticated herbivores on riparian range health can impair insect communities.

MAIS has sampled adult aquatic insects in, along, and near stream sites in Mongolia for seven summer seasons. The objective of the MAIS project has been to discover and document diversity of aquatic macroinvertebrates in Mongolia. Although the project has sampled all stages of aquatic insects at nearly all sites, most project scientists have concentrated their efforts in collecting and identifying adult aquatic insects as these can be identified to species level. However, with over 300,000 specimens collected, intensive species level identifications in all groups lag behind field work by years. To date, the MAIS team has increased the known diversity of aquatic insects from the Selenge River watershed resulting from collections made during July sampling in 2003-2006 to over 1300 species with 32% of these new records for the country (Gelhaus, 2010), This is documented through publications on Tipuloidea (Gelhaus and Podenas, 2006; Podeniene *et al.,* 2006; Gelhaus *et al.,* 2007), Chironomidae (Hayford, 2005), Ephemeroptera (Enkhtaivan & Soldan, 2008), Trichoptera (Chuluunbat & Morse, 2007; Morse & Chuluunbat, 2007), and Coleoptera (Shaverdo & Fery, 2006; Short and Kanda, 2006).

Publications on other aquatic insects collected through the MAIS project are either submitted or in preparation.

These publications are enriching our understanding of the diversity and biogeography of Mongolian aquatic insects, but the lag time between collection and publication of species identification in peer-reviewed journals impacts the second objective of the MAIS project, which is to establish baseline data for biological assessment at stream sites. To meet this objective, the team has collected benthic samples and water quality, landscape, land cover, land use, and habitat data from stream sites. On one hand, identification of benthic specimens to genus or species level in conjunction with species level identifications of adults will produce valuable data for assessing stream condition across gradients of environmental stressors such as grazing intensity and erosion (Lenat & Resh, 2001). On the other hand, the goals of understanding diversity and community dynamics of aquatic insects differ from those of understanding response of benthos to impact or impairment. Biological assessments may successfully use family or order level data, particularly if they are conducted as part of volunteer assessment efforts (Bailey *et al.,* 2001). Researchers and volunteers may not be able to identify taxa beyond the family and order level due to the impediments caused by lack of taxonomic resources and time necessary to identify benthic macroinvertebrates to species in biological assessments (Bailey *et al.,* 2001; Lenat & Resh, 2001; Bouchard *et al*., 2005). Given the quandary between lag time in identifications and the two goals of the MAIS project, project participants decided to bridge the gap by identifying adult insects in the field to family level for use in broad scale biological assessment of the sites with the goal of helping guide future research,

Identification of adult insects in the field can produce valuable information on their presence and absence and are a link to the larvae which inhabit streams. Morse et al. (1980, 1983) showed that adult insects could be useful in characterizing the community structure and functional feeding structure of Upper Three Runs Creek, South Carolina. Furthermore, there is a link between land use, land cover, and condition of the riparian zone, habitat for adult insects, and in-stream diversity (e.g. Delettre & Morovan, 2000). This link means that community data for in-stream larvae should reflect the condition of the riparian one and watershed (e.g. Dolédec *et al*., 2006; Mazor *et al*., 2006,) and that the in-stream responses should be reflected by adult community dynamics.

The present study is the first in which family-level data from adult aquatic insects is used in biological assessment across a large region. The objective of this study is to determine whether adult insect communities and metrics are related to the environmental gradients of grazing and erosion. To achieve this objective we first classified sites and aquatic insect communities to determine whether patterns in sites were attributed to timing of adult insect activity (phenological phenomena) or to landscape and land use characteristics. Second, we compared adult aquatic insect metrics and water quality variables between categories of stream side erosion. Third, we determined which landscape, habitat, and water quality variables contributed most to variation in aquatic insect metrics across the study sites.

Methods and Materials

Study Sites

The Mongolian Aquatic Insect Survey, formerly known as the Selenge River Project, has sampled seven summer seasons from 2003-2006 and 2008-2010 (MAIS, 2010). The dataset for this study is derived from sampling over 250 sites during the five sampling seosons in 2003-2006 and 2008. Each sampling season occurred during July, with some sampling dates in late June. Sites were sampled to document diversity of aquatic invertebrates and to establish baseline aquatic ecology data and diversity of benthic specimens. Sites were determined before field work by examining topographic and detailed road atlas maps. Overnight camping sites were selected using a stratified random method in which the expedition travelled along a stratum such as a stream basin and randomly selected a site based on its proximity during the time camp selection was made. Forty-five of the 250 total MAIS sampling sites were selected for this study based on the following criteria: 1) each had to have field estimates of family level diversity of aquatic insects associated with it;

Figure 1. Google Earth map of Mongolia showing the sampling site field codes. Field code data can be found at http://clade.ansp.org/entomology/mongolia/mais_research.html).

2) sites had to be exhaustively surveyed over several hours; 3) sites had to be exclusively lotic, with no associated lentic habitat; 4) sites had to have water quality and habitat variables associated with them. Sites sampled in 2003 were excluded because they did not have family level identifications associated with them. Only camp sites sampled in 2004-2006 and 2008 were sampled exhaustively of which only 45 sites were devoid of associated lentic habitat (Figure 1).

Sampling methods

Family-level identifications were used because the combined expertise of the international team of scientists who participated in the MAIS expeditions would incur only a small chance of error in their field identifications at the family level (see http://clade.ansp.org/entomology/mongolia/mais_expedition.html). A list of identifications was compiled in the field at each site upon completion of sampling. Sampling methods consisted of aerial netting, vegetation beating, picking off of and through substrate, Malaise trapping, white and UV light trapping, and yellow pan trapping. Most adult insects emerge during a narrow period of time in Mongolia, typically being active during July. The team has experienced snow during late June sampling and cold rain during early August travel in Mongolia. This narrow window of emergence reduces the phenological variation between communities collected during different times, but this may be examined via a classification of sites based on the aquatic insect community.

Water quality variables were measured following methods modified from the U.S. Environmental Protection Agency's Rapid Bioassessment Protocol (Barbour *et al.*, 1999). Modifications consisted of shortening the sampling reach to 50 m to ensure that the protocol could be completed in the amount of time allotted to each site, which was about one hour on average. Water samples were collected or directly measured in the center of flow. Water temperature, conductivity, dissolved oxygen (DO), pH, and nitrates have been shown to change relative to grazing in the riparian zone along streams (Belsky *et al.*, 1999) and so these variables were used in the analyses described below. Other water quality variables measured by the MAIS team were not included because they were not available for enough sites for analyses. A Hach Drel 2000 portable water quality lab was used to measure conductivity for all years. An Oakton ® 310 portable DO meter and probe was used to measure DO in 2004 and 2005. A Horriba ®, U-10 multimetric water quality checker was additionally used to collect DO, conductivity, and pH in 2004. A YSI ® DO meter and probe was used to measure dissolved oxygen in 2006 and 2008. The instrument used to measure DO was also the instrument used to measure water temperature.

Percent estimates and categorization of substrate followed protocols in Barbour *et al.*, (1999). Land cover in the stream channel for the left and right descending banks was estimated as a percent of land cover in grasslands, forest, forbs, shrubs, or other. Each site was also categorized based on the amount of erosion along the stream channel. Erosion along stream channels increases as riparian cover is removed and as cattle hooves either compact or cut into stream banks. Other land uses which typically cause erosion (e.g. row crow, urban development) were not evident in most watersheds. Sites which were impacted and impaired by gold mining activities were not used in this analysis. Categories for erosion in the stream channel were: 0 for no erosion; 1 for slight erosion with few to no bare earth along the stream channel and banks; 2 for moderate erosion with some patches of erosion present in the stream channel and occasional eroded banks and a deeper stream cross section; 3 for heavy mixed erosion with eroded banks and a deeper U-shaped stream cross section.

Analytical methods

Taxa were treated in two ways. First, taxa were collected as presence/absence data. The MAIS team sampled adult aquatic insects exhaustively and thus, absence of a taxon was interpreted to mean that that taxon was not present rather than not collected. Insects which were exclusively aquatic were used in this analysis, with the exception of some families of brachyceran Diptera and Tipuloidea which were included if they were observed as having aquatic species present at a site. Second, the taxonomic data were converted to the following commonly used metrics in biological assessments: total Taxonomic Richness; Percent Ephemeroptera Richness; Percent Plecoptera Richness; Percent Trichoptera Richness; Percent Coleoptera Richness; and Percent Diptera Richness (Table 1).

Table 1. Variables recorded by the MAIS team for 45 stream sites in Mongolia that have met assumptions necessary for ANOVA or multiple regression analysis.

Variable	Transformation for Multiple Regression and ANOVA
Elevation	Raw
% Cobble (diameter: 64-256 mm)	Raw
% Gravel (diameter: 2-64 mm)	Raw
% Sand (diameter: 0.06-2 mm)	Square Root
Water temperature (° C)	Raw
Conductivity (µS/cm)	Natural Log
Dissolved Oxygen (mg/L)	Square Root
Nitrate (NO3-N) mg/L	Square Root
pH (IU)	Square Root
Percent Ephemeroptera Richness	Raw
Percent Plecoptera Richness	Square Root
Percent Trichoptera Richness	Raw
Percent Diptera Richness	Square Root
Percent Coleoptera Richness	Raw
Percent EPT Richness	Raw
Total Taxonomic Richness	Raw

Trichoptera and Plecoptera identifications had been completed in the laboratory for a subset of 27 of the 45 sites. Pearson product correlation was used to determine how closely field and laboratory identifications matched for each family. Mean and median difference was calculated between the percent richness metrics based on field identification and metrics based on laboratory identifications.

Stream sites were classified based on family-level community structure to determine whether annual and temporal or phenological variation in the insects would affect subsequent analyses. This was a concern because sites were sampled over several weeks and over several years. Site codes were created by giving each site a number for the year in which it was collected: 4 for 2004, 5 for 2005, 6 for 2006, and 8 for 2008. Next each code received one of four temporal categories denoting sampling period: B for the last week of June through the first week of July, M for the second week of July, L for the third week of July, and E for the fourth week of July. Next, site codes were given a category based on whether they were collected in a river (R), a site which was too large to wade across safely or whether they were collected in a stream (S). Most stream sites were third to fifth order wadable streams. Next the code contained three numbers corresponding to the categories of stream channel erosion listed above (see Sampling Methods). Presence/absence data for taxa were used to construct a classification of stream sites using hierarchical cluster analysis. Common families showed little variation, being present at all sites, and thus were not informative in searching for pattern in sites. Thus, we used less common and rare taxa in the analysis. Taxa present at 42% or less of the sites were used in the analysis, based on an obvious discontinuity between taxa present at 42% of the sites and 47% of the sites. The classification of sites based on the aquatic insect community was visualized on a double dendrogram to allow comparison of community classes and site classes. Unweighted group pair averages were used to link sites based on Euclidian distances of taxa treated as symmetrical binary data. A cophenetic correlation coefficient of 0.75 or greater was used as a goodness of fit metric for selection of a dendrogram (Hintz 2007). Number Crunching Statistical Software ® (NCSS version 7.18) was used to perform the hierarchical cluster analysis.

The stratified random site selection method allowed for random selection of camp sites during the MAIS expeditions. Variables which did not meet assumptions of normality were transformed or removed from analysis if they still did not meet the assumptions of normality after transformation. A one-way, general linear model ANOVA for unequal sample size was used to determine whether taxonomic metric and water quality variables varied significantly between categories of erosion along the stream channel.

Prior to running the multiple regression analysis the macroinvertebrate metrics were individually regressed on the independent variables to determine whether the variables met assumptions of heteroscedasticity (modified Levine Test) and linearity (Linear Fit Test). Variables which did not meet these assumptions were removed from the analysis. All possible regressions analysis (Hintz, 2007) was used to select the best combination of predictor variables, with a Mallow's Cp statistic of $p+1$ (with p=number of independent variables), high R^2, and low square root of the mean square error used to select the best model. *A postieri* multicollinearity tests were run on the variables and those with a high degree of colinearity were removed from the analyses. Culling of the data and model selection resulted in the use of elevation, conductivity, pH, nitrate, cobble, gravel, and sand as predictor variables for variation in the macroinvertebrate metrics except for Percent Plecoptera Richness.

Statistical significance for the ANOVA and multiple regression analysis was set at $p < 0.05$. All statistical analyses were done using NCSS (version 7.18).

Results

Seventy-four families of aquatic insects were identified at forty-five stream sites in Mongolia during the 2004-2006 and 2008 expeditions (Table 2). Diptera were dominant in terms of overall diversity at each site with Chironomidae and Limoniidae present at all sites and Tipulidae present at 93% of the sites. Other common Diptera included Culicidae, Simuliidae, Dolichopodidae, Empididae, and Ephydridae. Common Ephemeroptera families included Baetidae, Ephemerellidae, and Heptageniidae (Table 2). Nemouridae was the most common Plecoptera present and common Trichoptera included Brachycentridae, Glossosomatidae, and Limnephilidae (Table 2). Dytiscidae, Helophoridae, and Hydrophilidae were commonly collected Coleoptera (Table 2).

Correlations between family-level field and laboratory identifications of Plecoptera and Trichoptera ranged from 0.71 to 1, with a mean correlation of 0.86 and a median correlation of 0.88. Differences between percent richness metrics for Trichoptera based on field and laboratory identifications ranged from 0-38%, with a mean difference of 6% and a median difference of 5%. Differences between percent richness metrics for Plecoptera based on field and laboratory identifications ranged from 0-15%, with a mean and median difference of 3%.

Communities of aquatic insects did not cluster based on the time of month in which they were collected (Figure 2). Distinct communities of aquatic insects based on stream size and elevation are evident. Six large rivers collected in 2005 formed a group based on a diagnostic community composed of Psychomyiidae, Hydroptilidae, Polymitarcidae, Caenidae, and Coenagrionidae, another community composed of Siphlonuridae, Perlidae, and Leptoceridae, and including Perlodidae and Ephemerellidae, two taxa that were commonly collected from many study sites (Fig. 2, Group 1). Twelve sites, mostly from high elevations and collected mostly in 2008 were characterized by the absence of many of the taxa and the presence of Rhyacophilidae, Blephariceridae, Goeridae and taxa such as Stratiomyidae, Pediciidae, Apataniidae, Ptychopteridae, and Leptoceridae (Fig. 2, Group 2). A small group of

Table 2. Families of aquatic insects collected from study sites in Mongolia (Numbers of familes for each order are in parentheses behind each order).

Taxon	% of total sites*	Taxon	% of total sites*
Odonata (5)		Trichoptera	
Aeshnidae	0.09	Goeridae	0.33
Coenagrionidae	0.13	Hydropsychidae	0.47
Gomphidae	0.09	Hydroptilidae	0.16
Libellulidae	0.09	Lepidostomatidae	0.11
Lestidae	0.13	Leptoceridae	0.33
Ephemeroptera (15)		Limnephilidae	0.69
Acanthemetropodidiae	0.07	Philopotamidae	0.02
Ameletidae	0.09	Phryganeidae	0.07
Baetidae	0.73	Polycentropodidae	0.02
Caenidae	0.18	Psychomyiidae	0.2
Ephemeriidae	0.13	Rhyacophilidae	0.38
Ephemerellidae	0.78	Diptera: Nematocera (14)	
Heptageniidae	0.78	Blephariceridae	0.27
Isonychidae	0.04	Ceratopogonidae	0.31
Leptophlebiidae	0.16	Chironomidae	1
Metropodidae	0.07	Culicidae	0.62
Oligoneuridae	0.02	Cylindrotomidae	0.02
Polymitarcidae	0.16	Dixidae	0.16
Potomanthidae	0.07	Deuterophlebiidae	0.09
Siphlonuridae	0.4	Limoniidae	1
Tricorythidae	0.02	Pediciidae	0.29
Plecoptera (8)		Psychodidae	0.22
Capniidae	0.11	Ptychopteridae	0.16
Chloroperlidae	0.49	Simuliidae	0.64
Leuctridae	0.09	Tanyderidae	0.02
Nemouridae	0.53	Tipulidae	0.93
Perlidae	0.36	Diptera: Brachycera (4)	
Perlodidae	0.6	Dolichopodidae	0.84
Pteronarcyidae	0.07	Empididae	0.78
Taeniopterygidae	0.09	Ephydridae	0.71
Hemiptera (6)		Stratiomyidae	0.31
Corixidae	0.11	Coleoptera (8)	
Gerridae	0.16	Dryopidae	0.04
Nepidae	0.02	Dytiscidae	0.76
Notonectidae	0.02	Elmidae	0.04
Saldidae	0.27	Gyrinidae	0.02
Veliidae	0.02	Haliplidae	0.42
Trichoptera (14)		Helophoridae	0.67
Apataniidae	0.36	Hydraenidae	0.13
Brachycentridae	0.69	Hydrophilidae	0.53
Glossosomatidae	0.51	*% of streams where taxa are present	

Table 3. Variation of mean (standard error) aquatic insect metrics and water quality variables by category of erosion in the stream channel.

Category	0	1	2	3
Percent Ephemeroptera Richness*	0.12 (0.04)	0.13 (0.02)	0.17 (0.02)	0.19 (0.02)
Percent Plecoptera Richness*	0.14 (0.03)	0.12 (0.03)	0.10 (0.02)	0.08 (0.01)
Percent Trichoptera Richness*	0.17 (0.02)	0.16 (0.02)	0.19 (0.02)	0.21 (0.02)
Percent EPT Richness*	0.43 (0.05)	0.41 (0.04)	0.47 (0.03)	0.49 (0.04)
Percent Diptera Richness*	0.48 (0.05)^{3}	0.44 (0.03)	0.37 (0.04)	0.32 (0.01)^{0}
Percent Coleoptera Richness*	0.06 (0.03)	0.12 (0.02)	0.13 (0.02)	0.12 (0.03)
Total Richness	21.00 (2.27)	20.73 (1.74)	21.85 (2.49)	26.45 (2.29)
Water Temperature	12.90 (2.47)	13.21 (1.04)^{3}	14.08 (1.46)	18.22 (0.95)^{1}
Conductivity	118.40 (26.45)	85.56 (11.44)^{3}	140.01 (16.70)	168.20 (10.98)^{1}
DO	10.46 (1.02)	11.05 (0.81)	10.20 (.080)	9.92 (0.30)
Nitrate	0.11 (0.02)	0.13 (0.03)	0.24 (0.06)	0.14 (0.03)
pH	7.52 (0.47)	7.80 (.016)	7.54 (0.25)^{3}	8.49 (0.26)^{2}

*Percents given as proportion data.
Significance ($P \leq 0$) is denoted by a superfix for the categories in which means vary significantly.

3 sites collected in 2004 from different weeks, elevations, streams and rivers, and which were characterized by different categories of erosion were based on the presence of Siphlonuridae, Hydraenidae, Psychodidae, and Ptychopteridae (Fig. 2, Group 3).

Percent Diptera Richness was the only taxonomic metric to vary significantly between categories of erosion along the stream channel, but variation in Percent Ephemeroptera Richness between categories of erosion in the stream channel was close to significant (*P* = 0.06). Percent Diptera Richness decreased significantly between erosion categories 0 and 3, indicating decreased dipteran diversity in streams with greater erosion (Table 3). Percent Ephemeroptera and Trichoptera Richness tended to increase with increased erosion along the stream channel; but Percent Plecoptera Richness decreased with increased erosion. Thus the standard metric, Percent EPT Richness showed no clear pattern in response to changes in erosion along the stream channel (Table 3). Percent Coleoptera Richness and Total Taxonomic Richness showed a general trend in increasing with erosion (Table 3). Water temperature and pH increased with increased erosion in the stream channel. Mean water temperature increased significantly between categories 1 and 3 and mean pH increased significantly between categories 2 and 3 (Table 3). Conductivity increased with increased erosion, increasing significantly between categories 1 and 3 (Table 3). Nitrate showed a trend of increasing in concentration with increased erosion before decreasing between categories 2 and 3.

Table 4. Results of the Multiple Regression Analysis

	Regression Coefficient	R^2	*F*	*p*
Intercept	4.0261			
Model		0.407	4.118	0.003*
Elevation	0.0001	0.033	2	0.1658
% Cobble	-0.0031	0.0278	1.691	0.2018
% Gravel	-0.0009	0.0011	0.067	0.7977
% Sand	0.0398	0.0484	2.939	0.095
Conductivity	-0.1635	0.0909	5.517	0.0244*
Nitrate	0.1168	0.0037	0.224	0.6391

Percent Diptera Richness regressed on elevation, conductivity, concentration of nitrate, percent cobble, percent gravel, and percent sand produced the only significant model, with an R^2 of 0.41, a Mallow Cp statistic (for six independent variables) of 7, and mean of mean square error of 0.2510. The model indicated that the strongest and only statistically significant predictor of Percent Diptera Richness was conductivity, with increasing conductivity driving decreasing richness in Diptera (Table 4). The second strongest predictor was percent sand, with increased sand driving an increase in Diptera richness (Table 4).

Discussion

Field and laboratory identifications were highly correlated and for some sites perfectly correlated. However, identifications from a few sites were different, particularly for Trichoptera. These differences probably result from collections made of Trichoptera by members of the MAIS team who were not experts in the order. Each team member collected specimens in their target group, but if they also collected taxa in the other groups, then they later shared those taxa with the expert, who may not have seen the specimens until in the lab. This exchange of specimens was done for all the families of aquatic insects, but it was probably more common for Trichoptera because they could be very abundant at some sites and were large and obvious to pick out of nets. We wanted to know whether the differences between field and laboratory identifications for families of Trichoptera and Plecoptera would affect calculation of the metrics. On average there was only a 3% difference for Plecoptera and a 6% difference for Tricoptera between percent metrics calculated based on field and laboratory identifications. In most cases these difference were due to additional families identified in the laboratory which were not seen in the field. Thus, estimates of field percent richness of Plecoptera and Diptera were underestimated by a few percent.

Two of the three distinct groups of stream study sites were classified based on elevation and stream size rather than on the week during which they were collected. The third group classified was not based on any of the temporal, spatial, elevational or erosional attributes of the streams. Thus, we can conclude that the timing of adult aquatic insect activity due to phenological variation did not affect the analysis of the family-level metric data. These results confirm our field observations which show that most insects are active during mid summer in Mongolia. However, lack of phenological pattern may also be due to lack of taxonomic resolution at the

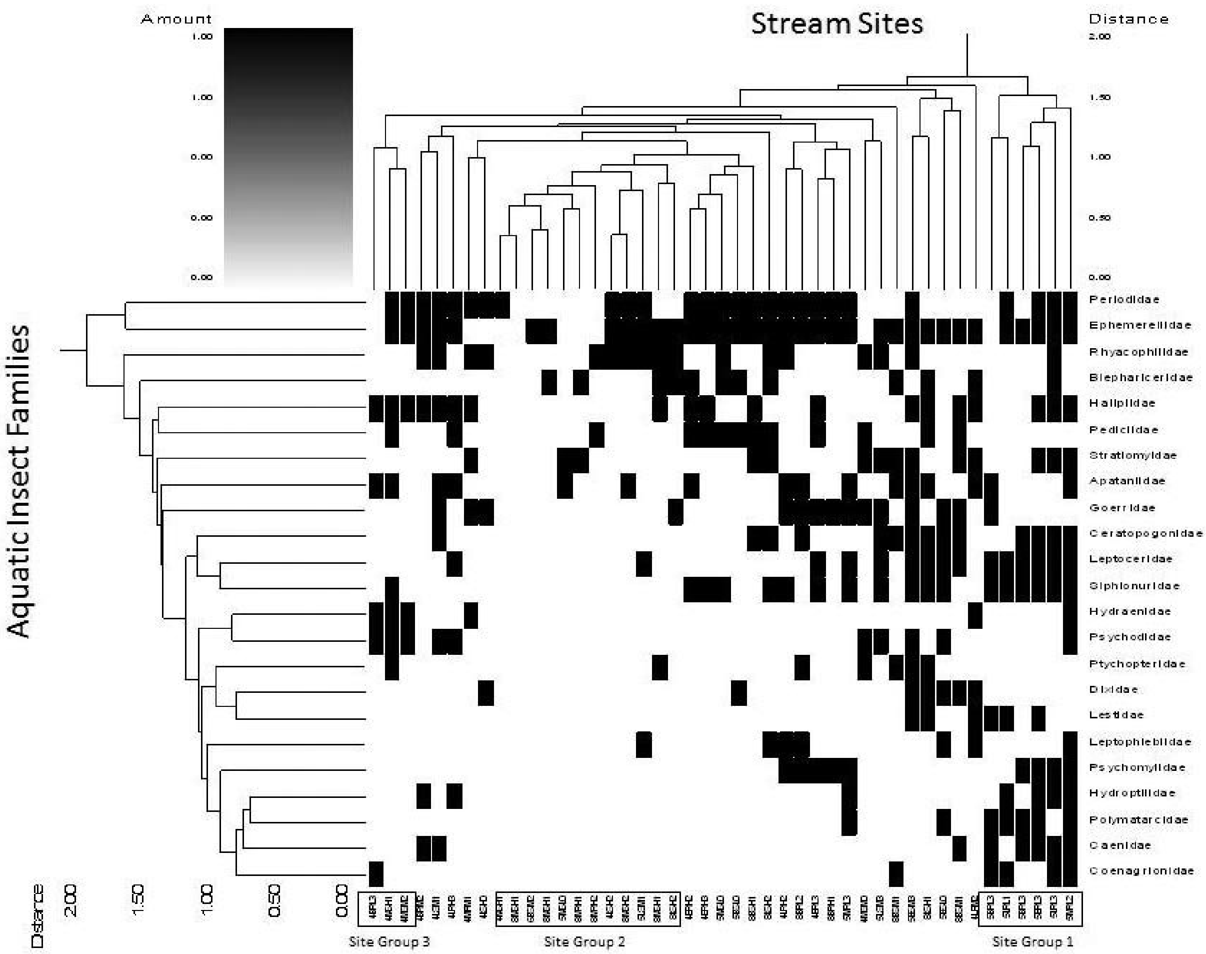

Figure 2. Double dendrogram of stream study sites and aquatic insects.

family level.

Two of the three clusters were grouped by elevation and stream size and consequently year. A group of small streams at high elevations were collected from the Altai Mountains during 2008 and a group of large rivers at low elevations were collected from the central Mongolian steppes during 2005. The variation in aquatic insect communities between these two years is most likely due to differences in stream order and elevation rather than due to interannual variation. Aquatic macroinvertebrate communities differ based on stream order (Vanotte *et al.* 1980, Heino *et al.* 2006). The community of aquatic insects which formed the group of low elevation river sites was composed of common taxa in the study; families which were found at a wide variety of sites. The community of aquatic insects which formed the group of high elevation stream sites was composed of few taxa, some of which were present at other sites (Figure 2). Together, these two groups comprise 27% of all sites in the study and the variables of elevation and stream order may drive variation in aquatic insect metrics.

Stream order often varies by elevation, with headwater streams at higher elevation and large order rivers at lower elevation. Stream order did not meet the assumptions necessitated by the multiple regression, thus was not included in the analysis. Elevation did meet the assumptions and can be used to approximate variation in stream order as well. Each metric was regressed individually on elevation to test for evidence of heteroscedasticity and the assumptions of linearity. Elevation did not form statistically significant relationships with any of the metrics, indicating that despite the pattern in the stream sites, elevation, and by approximation stream order, did not confound the results of the multiple regression analysis.

The number of Diptera families decreased with increased conductivity (Table 4), indicating that Diptera was impaired by increased concentration of particles in the water. Percent Diptera Richness also decreased significantly in streams categorized with greater amounts of streamside erosion (Table 3). We attributed increased erosion to grazing which has been related to increased concentration of sediment particles in streams (Belsky *et al.*, 1999). Diptera Richness is predicted to decrease with increased impairment (Barbour *et al.*, 1999). Thus, it is likely that overgrazing is impairing dipteran communities in Mongolia. Interestingly, the metrics most commonly used in biological assessments, those associated with Ephemeroptera, Plecoptera, and Trichoptera (EPT), did not produce significant models nor did they vary significantly between categories of erosion (Tables 3 and 4). First, Percent Plecoptera Richness did not meet all the assumptions to be used in the multiple regression analysis. The models for Trichoptera percent richness may not have been significant because richness was underestimated on average. Percent EPT Richness and Total Richness were probably not significant because Percent Ephemeroptera Richness and Percent Trichoptera Richness increased with increases in the predictor variables of elevation and conductivity, whereas Percent Plecoptera Richness decreased. Thus the combined metrics initially increased with increased disturbance and then decreased, counter to the pattern of general increase in the predictor variables.

The general trend in increased Ephemeroptera, Trichoptera, and Coleoptera richness with increased levels of disturbance (Table 3) supports field observations. Ephemeroptera, in particular, were observed to increase in diversity and abundance in streams with elevated sedimentation, indicating an increase associated with minor to medium levels of disturbance as would be expected under the intermediate disturbance hypothesis (Townsend *et al.*, 1997). We can conclude from this that most communities of adult aquatic insects in Mongolia are not yet strongly impacted by grazing and erosion, but that some taxa such as Diptera are responding significantly to changes in stream condition related to grazing. Studies on streams in desert and Great Basin grasslands in western North America show that there is an impact on aquatic insects by improperly managed grazing along riparian zones (Fitch & Adams, 1998; Belsky *et al.*, 1999). Grazing by domesticated herbivores is a relatively recent practice in North America, whereas grazing has been managed by nomadic herders for at least 4000 years in Mongolia (Johnson *et al.*, 2006), thus the response of streams to improperly managed grazing in Mongolia may be very different than it is in North America. Until the last few decades, common Mongolian grazing management strategies included rotating herds in and out of stream channels. Now some herders allow domesticated grazers unlimited access to streams (Batnasan *et al*., 2004, Johnson *et al*., 2006). Perhaps range health and stream condition have been recently disrupted by current trends in overgrazing. Fernandez-Gimenez & Allen-Diaz (1999) showed that steppe and mountain steppe rangeland in Mongolia responds directly to increasing pressures in grazing. Our results indicate that as improper grazing practices increase grazing pressure they are causing intermediate levels of disturbance in the streams, driving increases in Ephemerptera and Trichoptera, and driving stronger impacts on the riparian range health, impairing Diptera diversity.

Family-level data is not informative in determining whether impact to the stream from grazing and erosion will impact frequency of certain genus or species level taxa (Braccia & Voshell, 2006) and changes in species traits (e.g. reproductive behaviors) of macroinvertebrates (Dolédec *et al*., 2006). However, the data we generated from field identification of adult aquatic insects, particularly for Diptera and to a lesser extent Ephemeroptera, did respond to variation in erosion and conductivity. One way this data may be useful is in pointing out where future surveys of aquatic insects in Mongolia should focus their sampling for specific taxa. For example, understanding of diversity in Ephemeroptera would be maximized by sampling streams with medium levels of grazing and erosion. Understanding of diversity in Diptera would be maximized by concentrating on smaller, more pristine streams.

Volunteer stream sampling has been initiated in Mongolia, in an effort to connect Mongolians to their local streams and stream health, to help them monitor the impact of gold mining on streams, and to engage them in proactive protection of water quality and biodiversity (Anonymous, 2008). Family-level identifications of adult aquatic insects may be useful in these volunteer biological assessment efforts and may help Mongolian volunteers target specific stream sites for sampling. Our results show that a group of experts dedicated to specific taxa can generate data immediately for use in their own project and we suggest that this data can be used by volunteers and government agencies in other biological assessment efforts particularly if used in conjunction with more traditional benthic analysis.

Acknowledgments

We gratefully acknowledge the generous support of the US National Science Foundation (DEB-BSI #0206674, "Survey and Inventory of the Aquatic Macroinvertebrates of the Selenge River, Mongolia" to J. Gelhaus, J. Morse, B. Hayford), (DEB-BSI #0743732, "Survey and Inventory of the Aquatic Macroinvertebrates of the Altai and Hangai Mountain drainages, Mongolia", to J. Gelhaus, J. Morse, C. R. Nelson), and (DEB-BS&I #0816910, "An Ecological Guild-Based Biodiversity Inventory and Survey of the Aquatic Non-biting Midges (Diptera: Chironomidae) of the Altai and Hangai Mountain Drainages, Mongolia" to B. Hayford). Studies were conducted under the auspices of the Academy of Natural Sciences, Philadelphia, Clemson University, Brigham Young University, and Wayne State College. We would like to thank Sanaa Enkhtaivan (Ephemeroptera), Monkjargal Gotov (Chironomidae), John Morse (Trichoptera), C. Riley Nelson (Plecoptera), Sigitas Podenas (Tipuloidea), Virginija Podeniene (Tipuloidea), Andrew Short (Coleoptera), Ignac Sivec (Plecoptera), Tomas Soldan (Ephmeroptera), Chuluunbat Suvdtsetseg (Trichoptera), Enkhnasan Davaadorj (Coleoptera) for their field identifications and the entire MAIS team for their hard work and dedication to this project.

References

Anonymous, 2008. Community Manual: Water Quality Monitoring in Rivers. A Methods Manual for Citizen Volunteers in Mongolia. The Asia Foundation, Ulaanbaatar, 192 pp. (available as pdf download from http://www.mongolianriverresources.mn/)

Bailey, R., R. Norris & T. Reynoldson. 2001. Taxonomic resolution of benthic macroinvertebrate communities in bio-assessments. *Journal of the North American Benthological Society*. 20: 280-286.

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. *Rapid Bioassessment Protocols for Use in Streams and*

Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.

Batnasan, N. 2003. Freshwater issues in Mongolia. *Proceedings of the National Seminar on IRBM in Mongolia,* 24-25 Sept. 2003, Ulaanbaatar, p.53-61.

Batnasan, N., Davaa, G., Erdenebayar, Y., Tumersukh, D. & Zagas, B. 2004. Water resources of the Great Lakes Basin, 15-27, In: Batima, P., Batnasan, N. and B. Lerner, eds., *Freshwater systems of the Great Lakes Basin, Mongolia: Opportunities and challenges in the face of climate change.* WWF Mongolia Programme Office, Ulaanbaatar.

Belsky, A., Matzke, J. & Uselman, S. 1999. Survey of livestock influences on strea and riparian ecosystems in the western United States. *Journal of Soil and Water Conservation* 54: 419-431.

Bouchard, Jr. R. W., Huggins, D.G. & Kriz, J. 2005. *A Review of the Issues Related to Taxonomic Resolution in Biological Monitoring of Aquatic Ecosystems with an Emphasis on Macroinvertebrates.* Open-file Report No. 133. Biological Survey, Lawrence, KS. 38 pp.

Braccia, A & Voshell, J. R. 2006. Benthic Macroinvertebrate Fauna in Small Streams Used by Cattle in the Blue Ridge Mountains, Virginia. *Northeastern Naturalist*. 13(2):269-286.

Chuluunbat, S., & Morse, J.C. 2007. Caddisflies (Insecta: Trichoptera) of Selenge River Basin, Mongolia. Pp. 51-57 in J. Bueno-Soria, R. Narba-Alvarez, and B. Armitage, editors, Proceedings of the XIIth International Symposium on Trichoptera, June 18-22, 2006, The Caddis Press, Columbus, Ohio. xii + 378 pp.

Delettre, Y., Trehen, P. & Grootaert, P. 1992. Space heterogeneity, space use and short range dispersal in Diptera: A case study. *Landscape Ecology* 6: 175-181.

Delettre, Y.R. & Morvan, N. 2000. Dispersal of adult aquatic Chironomidae (Diptera) in agricultural landscapes. *Freshwater Biology*, 44, 399-411.

Del Rosario, R. B., Betts, E. A. & Resh, V. H. 2002. Cow manure in headwater streams: Tracing aquatic insect responses to organic enrichment. J. N. Am. Benthol. Soc. 21: 278–289.

Dolédec, S., Phillips, N., Scarsbrook, M., Riley, R., Townsend, C. 2006. Comparison of structural and functional approaches to determining landuse effects on grassland stream invertebrate communities. *Journal of the North American Benthological Society* 2006, 25(1):44–60.

Enkhtaivan, S. & Soldan, T. 2008. "Mayflies (Ephemeroptera) of the Lake Hovsgol Region, Mongolia" pp. 103-115 *In:* F. R. Hauer, J. A. Stanford, and R. L. Newell (eds.) *International Advances in the Ecology, Zoogeography and Systematics of Mayflies and Stoneflies* Univ. California Publ. Entomology no 128.

Fernandez-Gimenez, M. 1999. Reconsidering the Role of Absentee Herd Owners: A View from Mongolia. *Human Ecology* 27: 1-27.

Fernandez-Gimenez, M. 2000. The Role of Mongolian Nomadic Pastoralists' Ecological Knowledge in Rangeland Management. *Ecological Applications* 10: 1318-1326.

Fernandez-Gimenez, M. E. & Allen-Diaz, B. 1999. Testing a non-equilibrium model of rangeland vegetation dynamics in Mongolia. *Journal of Applied Ecology* 36: 871-885.

Fernandez-Gimenez, M. & Batbuyan, B. 2004. Law and Disorder: Local Implementation of Mongolia's Land Law. *Development and Change* 35: 141-165.

Fitch, L. & B. W. Adams. 1998. Can cows and fish co-exist? *Canadian Journal of Plant Science* 78: 191-198.

Gelhaus, J. 2010. The census of aquatic biodiversity in Mongolia: Results from the Mongolian Aquatic Insect Survey 2002-2010. Abstract,, pg. 37. First International Conference "Survey of Mongolian aquatic ecosystems in a changing climate: Results, new approaches and future outlook. 7-10 April 2010. Ulaanbaatar, Mongolia" Water Research Center, National University of Mongolia, Ulaanbaatar.

Gelhaus, J., Podenas, S. & Brodo, F. 2000. New or poorly known long palped crane flies from Mongolia (Diptera: Tipuloidea: Tipulidae). *Proceedings of the Academy of Natural Sciences* 150: 145-157.

Gelhaus, J., Hayford, B., Morse, J., Nelson, C.

R., Suvdtsetseg, Ch., Oyunchuluun, Y., Sanaa, E. 2008. The Mongolian Aquatic Insect Survey (MAIS): Progress and future projects, pp. 53-60 *IN* B. Boldgiv, ed. Proceedings of the International Conference, Fundamental and Applied Issues of Ecology and Evolutionary Biology. National University, Ulaanbaatar, Mongolia

Hayford, B. 2005. New records of Chironomidae (Insecta: Diptera) from Mongolia with review of distribution and biogeography of Mongolian Chironomidae. *Journal of the Kansans Entomological Society* 78: 192-200.

Hintze, J. L. 2007. Number Cruncher Statistical System: Product 7.18—Advanced Statistics. Dr. Jerry L. Hintze, Kaysville, Utah.

Johnson, D., Sheehy, D., Miller, D. & Damiran, D. 2006. Mongolian rangelands in transition. *Secheresse* 17: 133-141.

Lenat, D. R. and V. H. Resh. 2001. Taxonomy and stream ecology—the benefits of genus- and species-level identifications. *Journal of the North American Benthological Society* 20(2): 287-298.

Morse, J.C., & Chuluunbat, S. 2007. Skating caddisflies of Mongolia. Pp. 219-227 in J. Bueno-Soria, R. Narba-Alvarez, and B. Armitage, editors, Proceedings of the XIIth International Symposium on Trichoptera, June 18-22, 2006, The Caddis Press, Columbus, Ohio. xii + 378 pp. Photographs and videos.

Morse, J., Chapin, J., Herlong, D. & Harvey, R. 1983. Aquatic insects of the Upper Three Runs Creek, Savannah River Plant, South Carolina Part II: Diptera. *Journal of the Georgia Entomological Society* 18: 300-303.

Morse, J., Chapin, J., Herlong, D., & Harvey, R. 1980. Aquatic insects of the Upper Three Runs Creek, Savannah River Plant, South Carolina Part I: Orders other than Diptera. *Journal of the Georgia Entomological Society* 15: 69-73.

Petersen, I., Masters, Z., Hildrew, A., and S. Ormerod, A. 2004. Dispersal of adult aquatic insects in catchments of differing land use. *Journal of Applied Ecology.* 41: 934-950.

Podeniene, V., Gelhaus, J. & Oyunchuluun, Y. 2006. The last instar larvae and pupae of *Tipula (Arctotipula*) (Diptera, Tipulidae) from Mongolia. *Proceedings of the Academy of Natural Sciences*. 155: 79-105.

Scrimgeour, G. J. & Kendall, S. 2003. Effects of livestock grazing on benthic invertebrates from a native grassland ecosystem. *Freshwater Biology* 48: 347–362.

Shaverdo, H. & Fery, H. 2006. *Oreodytes shorti*, sp.n. from Mongolia (Coleoptera: Dytiscidae) *Koleopterologische Rundschau* 76: 35-42

Short, A. E. Z. & Kanda, K. 2006. The water scavenger beetles of Mongolia with new records from the Selenge River Basin (Coleoptera: Hydrophilidae). *Proceedings of the Academy of Natural Sciences* 155: 9-12.

Sovell, L. A., Vondracek, B., Frost, J. A. & Mumford, K. G. 2000. Impacts of Rotational Grazing and Riparian Buffers on Physicochemical and Biological Characteristics of Southeastern Minnesota, USA, Streams. *Environmental Management* 26: 629–641.

Townsend, C., Scarsbrook, M. & Dolédec, S. 1997. The intermediate disturbance hypothesis, refugia, and biodiversity in streams. *Limnology and Oceanography* 42: 938-949.

Vannot, R., Minshall, G., Cummins, K., Sedell, J. & Cushing, C. (1980). The River Continuum Concept. *Journal of Fisheries and Aquatic Sciences, 30,* 130-137.

Winterbourn, M., Chadderton, W., Entrekin, S., Tank, J. & Harding, J. 2007. Distribution and dispersal of adult stream insects in a heterogeneous montane environment. *Archiv Fur Hydrobiologie* 168: 127-135.

Хураангуй

Монгол орны гол горхийн сав дагуух бэлчээрийн талхигдал нь тухайн гол горхийн сувгийн элэгдэл, ёроолын хурдас, усны температур, pH, цахилгаан дамжуулах чанар зэрэгт нөлөөлөх боломжтой. Мал бэлчээрлэлт ба элэгдэл эвдрэл зэрэг нь усны шавьжийн бүлгэмдэлд ч нөлөөлж болох юм. Бид усны шавьжийг хээрийн нөхцөлд овгийн түвшин хүртэл тодорхойлж, түүнд үндэслэн бэлчээрийн талхигдал ба орчны элэгдэл эвдрэлийг илэрхийлэх биологийн индикатор болох боломжтой эсэхийг судалсан юм. Судалгаанд хамрагдсан гол горхинууд нь дээж цуглуулсан хугацаанаас хамаарч усны шавьжийн бүлгэмдлээрээ ялгаатай байгаагүй боловч зарим гол горхи хэмжээ

болон өндөршлийн байрлалаасаа хамааран нэг нэгнээсээ ялгагдаж байв. Гэвч өндөршил нь усны шавьжийн бүлгэмдэл өөр байхад төдийлөн нөлөөтэй биш байв. Голын сав газрын элэгдэл эвдрэл нэмэгдэхийн хэрээр хаварч ба хос далавчтаны олон янз байдал буурч байсан бөгөөд голын сав газрын элэгдэл эвдрэлийн хэмжээнээс хамаарч хос далавчтаны олон янз байдал ихээхэн өрчлөгдөж буй нь тогтоогдов. Түүнчлэн голын сав газрын элэгдэл эвдрэл нэмэгдэхийн хэрээр усны температур, цахилгаан дамжуулах чанар, pH зэрэг үзүүлэлт эрс нэмэгдэж байв. Хоовгон, мөхөөлж, шулуун далавчтан зэрэг шавьжийн баялаг буюу олон янз байдал нь элэгдэл эвдрэл, усны цахилгаан дамжуулах чанар, pH нэмэгдэхэд мөн нэмэгдэж байв. Хос далавчтаны харьцангуй баялаг нь регрессийн анализ хийхэд чухал загвар болсон юм. Хээрийн нөхцөлд бий болсон усны шавьжийн овгийн түвшний мэдээлэл нь хоовгоно, мөхөөлж зэрэг шавьжийн олон янз байдлыг илрүүлэхийн тулд бэлчээрийн нөлөө, элэгдэл эврэлд дунд зэрэг өртсөн гол горхийг илүүтэй сонгож, хос далавчтан, хаварчийн олон янз байдлыг илрүүлэхийн тулд элэгдэл эвдрэл, бэлчээрийн талхигдалд бага өртсөн гол горхийг, харин хос далавчтаны олон янз байдлыг илрүүлэхэд бэлчээрийн талхигдлаас үүдэлтэй элэгдэл эвдрэлд өртсөн гол горхийг сонгож судлах нь зүйтэй болохыг илэрхийлж байна.

Received: 25 June 2010
Accepted: 08 September 2010