EFFECT OF HABITAT STRUCTURE ON ODONATE SPECIES RICHNESS IN STREAMS OF KALAKKAD MUNDANTHURAI TIGER RESERVE IN TAMIL NADU, INDIA

In partial fulfilment of Master's Degree in Wildlife Science from Saurashtra University, Rajkot.

Submitted By

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CERTIFICATE

This is to certify that Ms. Anilitty A.S has carried out original research titled "**Effect of habitat structure on Odonate species richness in streams of Kalakkad Mundanthurai Tiger Reserve in Tamil Nadu, India**", in partial fulfilment of Master's Degree in Wildlife Science from Saurashtra University, Rajkot. The study was carried out under our supervision from December 2012 to June 2013. We hereby certify that this work has not been submitted for any other degree to any other university.

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Summary

This study aimed at the responses of species richness of Odonates toward the habitat structure in Kalakkad Mundanthurai Tiger Reserve(KMTR) in Tamil Nadu, India. KMTR lies between latitudes 8^{o} 25' to 8^{o} 53' N and longitudes 77^{o}10' to 77^{o} 35' E with altitude ranging from 50 meters to 1868 meters. Intensive study areas were confined to three beats in Mundanthurai and Kalakkad ranges of KMTR namely Kodamadi, Kannikatti and Sengaltheri. We sampled vegetation and stream structural parameters along with altitude and time of sampling from three drainages, River Thamiraparni, River Servalar and River Kil Manimuthar. Only the second, third and fourth order streams were sampled. Thirty six belt transects were laid and each transect was walked trice. A total of thirty six species were found during the study period. Species richness was calculated using Software Estimate S version 0.8 and used to do GLM(Generalized Linear Model) in Software R version 3.0.1. Altitude was found to be the most influencing factor on species richness. A second GLM was carried out for the altitude-wise stratified data incorporating temporal replicates for each transect. Tree height and stream width were found to be the most influencing factors in this model with p values 0.00007 and 0.001 respectively.

1. Introduction

The Odonata is an Order under the Class Insecta comprising three sub orders Anisoptera (Dragonflies) Zygoptera (damselflies) and Anisozygoptera (Relict dragonflies). The Sub order Anisozygoptera contains only two species. Globally 5740 species are present of which 470 are present in India. Odonate adults are terrestrial and larvae are aquatic and most of them are highly specific to aquatic habitats. This habitat specificity makes them an ideal group to study the integrity of water bodies (Subramanian 2009)

The adult flies are large conspicuous winged flies which are usually active during day around water bodies. They show incomplete metamorphosis and life cycle includes egg, larval stage (Nymph) and ultimately adult. Female lays eggs "exophytically" which is basically laying eggs upon water plants or other suitable surfaces. Certain dragonflies are "Endophytic" and they normally place eggs inside living plant tissue thus preventing the thin layered eggs from desiccation. Eggs of many tropical and temperate species show direct development and usually hatch after 5-40 days, whereas those of certain other temperate species hatch after 80-230 days due to delay in egg development which is an after effect of extreme cold winter. The Nymphs are aquatic forms with specialized organs for an aquatic life (Corbet 1980)
The study area, Kalkad Mundanthurai Tiger Reserve has eight major forest types which can again be classified into sub classes. Odonates, being top predators in terrestrial and aquatic habitats largely feed upon both herbivorous and carnivorous insects and vegetation plays a significant role in supporting a variety of prey species for them. Apart from harbouring large number of insects, vegetation is an essential part of Odonate life by being cover, perching sites, hatching site, substratum for egg laying, mating, sun basking, roosting etc. But unfortunately habitat alteration is one of the greatest threats to insects in centres of endemism like the Western Ghats.

The dependency of most of the Odonates on riparian vegetation calls for the conservation of riparian vegetation and adjoining habitats since some Odonates are extremely sensitive towards the changes in adjoining vegetation and the territory size.

1.1. Literature review

Odonates use a wide range of running and stagnant water bodies to complete their life cycle. Even though most of the species are highly specific to pristine habitats, some are adapted to live in man-made or polluted water bodies. The latter tend to be widespread generalists and the former tend to be habitat specialists with narrow distribution. Even within a habitat there exists micro climate specificity (Fraser and FC 1934). Odonates being predators both at larval and adult stages play an important role in aquatic ecosystem functions. They can also act as a biological control agent of some of the most harming insects like mosquitoes and other blood sucking flies. In addition to their role as a predator their value as an indicator of integrity of wetland is widely recognized (Nair 2011).

The composition of the dragonfly and damselfly communities is determined by hydrological connectivity, the habitat heterogeneity, the quality and quantity of aquatic and semi aquatic vegetation, shoreline structures and sun exposure. Some dragonflies and damselflies may decline when their natural environment is changed and they are sensitive to the impact of afforestation and other landscape alterations (Samways and Steytler 1996, Chovanec and Waringer 2001). The Odonate larvae are very sensitive to aquatic habitat structures, such as bottom substrate, water clarity and stream width and depth, while adult habitat selection is strongly dependent on structural characteristics, like canopy openness and vegetation structure openness (Kinvig and Samways 2000). It has been proved that, Odonate assemblages in rainforests are controlled by shading, water speed and water permanence along with the factors mentioned above (Oppel 2005).

Many studies have correlated the structural and physiological characteristics of plants to the number of insects. Herbivore insects are more abundant on plants with high structural complexity, i.e. a combination of size, growth form and the variations in the above ground structures of the plant. Vegetated areas of aquatic ecosystem support more or sometimes many magnitudes greater species diversity than open areas. Macrophytes provide more food resources to herbivore insects and thereby increase the number of their predators (Crowder *et al* 1998). According to Heck and Wetstone (1977) the abundance and diversity of macro invertebrate species increases with the increase in vegetation biomass and density. Macrophytes of more complex structure should support high abundance and diversity. Plants considered structurally complex can provide more efficient refuge for both preys and predators (Edgar 1983).

1.2. Objectives

2. To understand the influence of habitat structural components on species richness of Odonates in their natural habitats.
3. To examine the variation in species richness along different altitudinal gradients.

2. Study Area

2.1 The Western Ghats

The Western Ghats is a global biodiversity hotspot (Olson and Dinerstein 1998), and also recognised as one of the UNESCO's World heritage site. The mountain range has an exceptionally high level of biodiversity. Because of concentration of endemic species it is recognized as one of the world's eight "hottest hotspots" of biological diversity (Myers 1990). The endemism can be accounted to the latitudinal length of dry season gradient and temperature elevation gradient (Ramesh *et.al* 1997).

There are four major forest types in the Western Ghats: evergreen, semi-evergreen, moist deciduous, and dry deciduous. The moist type vegetation type has the largest forest area of which the majority is in Kerala and Karnataka accounting for 80 percent of the evergreen forest and 66percent of the moist deciduous forests in the Western Ghats (IIRS 2002).Since the area is embedded in human dominated landscape, many human activities have caused major fragmentation of these forests (Nair 1991) and of the approximately 180,000-square-kilometer area in the Western Ghats region, only one-third is under natural vegetationAt least 325 globally threatened (IUCN Red Data List) species occur in the Western Ghats. The Western Ghats harbours more than 5000 species of angiosperms, 140 species of mammals, 508 species of birds, 140 species of amphibians, 240 species of reptiles and 290 species of fresh water fishes (Nameer et al 2001, Kumar et al 2002). The Western Ghats ranges north to south across the states of Goa, Maharashtra, Karnataka, Tamil Nadu and Kerala.

2.2 Kalakkad Mundanthurai Tiger Reserve (KMTR)

Kalakkad Mundanthurai Tiger Reserve(KMTR) is located in the tip of southern Western Ghats in Tirunelveli District of Tamil Nadu. This reserve comprises of two wildlife sanctuaries namely, Kalakkad and Mundanthurai covering about 841 km^2 area. It lies between latitudes 8^o 25' to 8^o 53' N and longitudes 77^o10' to 77^o 35' E with altitude ranging from 50 m to the highest point Pothikai malai peak reaching 1868 m. This area represents diverse vegetation types and the core zone of the reserve is considered as one of the important rainforest area in the country. The rich and dense forest types are important watershed area for many streams and rivers, which joined to form a perennial east flowing river system called Tamiraparani (Fig.1).

2.2.1 Biodiversity

Floral diversity: KMTR forming part of the southern Western Ghats includes part of the Agasthiarmalai biosphere Reserve which is recognized as one of the five important centers of Plant species diversity in India and as one of the 24 Micro centers of endemism in India. It bears a large contiguous tract of about 400 sq.kms of wet evergreen forests located away from the equatorial region and it exhibits high endemicity in Vascular plants. The major endemic species of the reserve include: *Hopea utilis, Bentickia condappana, Gluta travancorica, Humboldtia unijuga* (var. *unijuga* and *trijuga)Eugenia singampattiana, Popowia beddomeana, Palaquium bourdilloni, Psychotria beddomei, Symplocos marcrocarpa,* and *S. macrophylla* to name a few. 79 genera and 161 species of pteridophyta have been reported from this reserve(Johnsingh 2001).

Faunal diversity: This tiger reserve also supports a large number of mammalian fauna. All the 5 primates of Peninsular India are found in KMTR. All the 14 endemic mammals of Western Ghats are found in KMTR. Out of 19 endemic birds of Western Ghats, 15 are found in KMTR. The major threatened species include the Lion Tailed Macaque (*Macaca silenus)*, Nilgiri Langur (*Presbytis johnii*), Nilgiri Marten (*Martes gwatkinsi* sub sp.,), Brown Palm Civet (*Paradoxurus jerdoni*), and Nilgiri Tahr (*Hemitragus hylocrius*). Fifteen bird species that are endemic to WGs are reported from KMTR viz., Nilgiri Pipit (*Anthus nilghiriensis*), Travancore White Breasted Laughing Thrush (*Garrulax jerdoni*), Grey Headed Bulbul (*Pycnonotus priocephalus*), Blue Winged Parakeet (*Psittacula columboides*), Nilgiri Wood Pigeon (*Columba elphinstonii*), Rufous Babbler (*Turdoides subrufus*), Malabar Grey Hombill (*Tockus griseus*) and Black and Rufous Flycatcher (*Muscic apa nigrorufa*). The reserve has a very diverse fish fauna, 45 species of fishes were reported from this reserve out of this 5 species of fishes are endemic to KMTR. Herpetofaunal assemblage is high with many endemic and rare species such as *Dasia haliana* , *Calotes anda manensis* and the Black Microhylid Frog, *Melanobatrachus indicus* (Johnsingh 2001).

2.2.2 Intensive study area

Our intensive study areas were confined to three beats in Mundanthurai and Kalakkad ranges of KMTR namely Kodamadi, Kannikatti and Sengaltheri. Three major rivers - Thamiraparni, Servalar and Kil Manimuthar flow through these beats. Study areas were selected based on the accessibility to those areas. By doing a pilot survey in these areas we selected suitable second order to fourth order streams for laying transects (Fig.2). Only those streams which are devoid of any kind of disturbance were selected for sampling. Intensive study area lies between an altitude range of 200-1350 meters. Kodamadi beat has riparian vegetation along the banks of River Servalar with semi evergreen and evergreen forest matrix whereas in Kannikatti the matrices are evergreen and wet evergreen at high altitudes. In Sengalthery the only forest type is wet evergreen with almost closed canopy.

2.2.3 Climate and rainfall

KMTR has three distinct seasons, South -West monsoon (June-September), North-East monsoon (October –January) and Dry season (February – May). The intensive sampling sites receive around 2000 mm rainfall per year(Mudappa *et al* 2001).

2.3. Study Design

In the beginning a pilot survey was carried out covering streams/ rivers in KMTR. Based on the preliminary survey, thirty six belt transects were laid along the headwater streams of three drainages namely Servalar, Tamiraparani and Kil Manimuthar. The transects were walked thrice from December 2012 to April 2013.

3. Methodology

3.1 Odonate Sampling

3.1.1 . Belt Transects

Odonates were sampled using belt transects of 70 meters length and 10 meters width. Width of the transect was 5 meter over water (stream) and 5 meter on bank. Belt transects were chosen as they give more detections in field and hence effectively cover more area in the same time as compared to other methods (Buckland *et al* 1993).

70x10 meters transects were laid and minimum 300 m distance was maintained between each transect. All transects were walked thrice from December 15th of 2012 to April 4th of 2013. Since almost all the Odontes are diurnal and are mostly active from morning to noon I fixed my sampling time between 9:00 AM to 2:00 PM, after that no sampling was performed. In each walk presence of species and all the micro habitat variables were recorded along with the time of sampling and altitude. Only the individuals actually using that habitat were recorded since there are certain species of dragonflies such as *Pantala favescens* those migrate in swarms and just pass through the site. I encountered swarms of this species few times and they were not recorded unless they display any kind of reproductive behaviour. Many of the species were identified in the field itself, unidentified and female individuals were caught using a sweep net to take photographs for later identification. Since there were different age classes and colour variations among individuals in many species that I could not identify on field, total number of individuals were not recorded. Fauna of British India for Odonata (Fraser 1934) was used for identifying species.

3.2. Vegetation Sampling

Circular plots were laid within the belt transects to sample vegetation structural components. There were two 10 meter radius circular plots for trees and related structural attributes in each belt transect one in the beginning and the other at the end. Within those circular plots one circular plot of 5 meter radius for shrubs and another circular plot of 1 meter radius for herbs were laid.

The following habitat attributes were quantified as covariates to explain the influence of vegetation structure on Odonates.

1. **Tree density**: Number of live trees was counted. All the trees which had more than 30 cm diameter were counted
2. **Canopy cover**: Canopy cover was measured using a densiometer in four sites within 10 meter radius circular plots.
3. **Number of tree species**: Number of tree Species encountered in each plot was recorded.
4. **Average height of trees**: Height of trees was recorded in meters using a clinometer and took the average.
5. **Number of vertical stratum**: The vegetation was stratified (ground layer, herb layer, shrub layer, and canopy) by visual perception.
6. **Foliage density**: Foliage density was recorded inside all the 5 meter radius circular plots in four sites using Nudds cover board (Nudds 1977).

3.3. Stream structure sampling

Quantification of habitat characteristics and stream inventory were followed by the methods described in Johnson and Arunachalam (2010). Each transect was quantified for depth, flow, instream cover (tree cover over the stream) and substrate characteristics. Depth, water velocity and dominant substrates were measured/ estimated at 1 to 2 meter intervals across the transect. Substrate was classified as Bedrock (>512mm diameter), boulder (128-512mm), cobble (64-128), gravel (16-64mm), sand (1-16) and leaf litters. From this data mean depth, flow and width of the streams were calculated. Percentage of in stream cover was estimated using densitometer.

3.4. Analysis

3.4.1. Odonate species richness

Software PAST was used to calculate number of species present per transacts.

Software ESTIMATE S 8.0 (Colwell 2006) was used to estimate Odonate species richness. The JACK 2 estimator which uses incidence or abundance data was used in all estimations. This species richness was used to plot Rarefaction curve.

In order to calculate species richness for different altitudinal gradients, I stratified altitude in to three and calculated estimated species richness for each. Software ESTIMATE S 8.0 was used to calculate richness and the rarefaction curves were drawn in Microsoft Excel 2007.

3.4.2. Vegetation Structure and Stream Structure

Structural attributes of the vegetation were calculated using the data from the circular plots. Stream habitat variables were calculated using the data obtained from within the belt transects. The Shannon index was calculated for stream substratum diversity for each transect using software PAST. This diversity index was used in further analysis instead of using the entire substratum separately. All the structural attributes were normalized using Z transformation since there was huge variation in the range of each variable.

Pearson correlation matrix was generated in NCSS.8. Variables which were highly correlated with each other were removed to do GLM (Generalised Linear Model). Canopy cover, average tree height and foliage density were highly correlated and the canopy cover and foliage density were removed for analysis

Altitude was used along with both stream and vegetation structural components. Highly correlated variables were removed for Generalised Linear Model (GLM) in software R version 3.0.1. GLM was carried out using Poisson family Different models were built with all the combinations of variables. A null model was used to compare AICc (Akaike information criterion) values of other models.

Another GLM with Gaussian family was carried out using altitude-wise stratified data incorporating temporal replicates for each transect to see the difference in species richness in different gradients of altitudes. Stratification was based on major vegetation types present there. Major vegetation types in my sampling sites were Mid-elevation wet evergreen forests, evergreen forests and semi evergreen forests. Since all the rivers which I sampled had evergreen riparian forest along the banks I considered major vegetation matrix for stratification. Form 200 meters to 600 meters the major matrix was semi evergreen forests, 600 meters to 900 was evergreen and 900 meters to 1350 meters was wet evergreen forests.

One way Anova was done in software R version 3.0.1 and box plots were plotted to examine the variation in each variable in different altitudinal ranges. Height of trees, stream width, number of vertical stratum and shrub density were the most significant variables which used to compare between altitudinal ranges using box plots.

4. Results

4.1. Species richness

A total of ten families, twenty seven genera and thirty six species were found in thirty six transects. Most of the species were categorised as least concerned in IUCN and few were data deficient (Table.5). All the data deficient species were rare and found at higher altitudes.

The number of transects in X axis then plotted against this estimated species richness in Y axis (Fig.3). Species richness reaches asymptote at 20th transect and there is no increase in richness further, instead it decreases slightly from 30th transect till 36th. Standard deviation was taken to plot. The actual number of observed species in thirty six transects was thirty six and Jack 2 estimator estimated 42 species, which is six species more than the observed.

4.2. Vegetation and stream structure

Highly correlated variables in person correlation matrix were removed for GLM (table.1). Height of trees, foliage density and canopy cover were correlated each other and canopy cover was removed for GLM.

Model 5 was selected as the most parsimonious model with altitude as the most influencing factor on species richness with a p value of 0.01 and an AICc value of 174.06(Table.2).

Second GLM with altitude wise stratified data shows influence of habitat structural components on species richness (Table.3). The best fit model was model 11 with Average height of trees, No. Of vertical stratum, Shrub density, Altitude and Stream width as the best predictors for difference in species richness. Average height of trees and altitude negatively influences the species richness. Average height of trees and stream width were found to be the most influencing factors in this model with p values 0.00007 and 0.0014 respectively (Table.4).

4.3. Rarefaction curves for altitudinal strata

By using species richness which was generated in software Estimate S three rarefaction curves were plotted in the same scatter plot for comparison. The first two strata do not differ much but the highest one which is 900-1350 meters shows an entirely different trend in richness (Figure.4).

.Comparison between rarefaction curves drawn using Jack 2 estimator and the observed species richness show that the highest stratum differs in a large scale from the first two. The first two strata reach asymptote (Figure.5 & 6) but not the third one. It shows a linear relation between species richness and transects (Figure.6)

4.4. One Way Anova for significant variables in three altitudinal ranges

Among all the variables used in one way Anova (fig.8, 9, 10 &10), Height of trees and stream width were found to be significantly different in three altitudinal ranges. P value of tree height was 0.001and that of stream width was 0.01. Height of trees and stream width were negatively correlated with altitude and the box plots did not explain this trend (fig.8&10).

5. Discussion

Most studies on Odonates have shown that human modified habitats support less number of species compared to natural habitats. But within natural habitats there are high variations in preferences. A number of studies have been conducted on influence of habitat structure on many insect groups, mostly herbivorous insects. This study demonstrates how natural habitats with different structure influence the species richness and composition of Odonates.

For this study I sampled thirty six transects from different forest types in different altitudes. In certain areas with high canopy cover both dragon flies and damsel files tend to be very elusive and it is very difficult to detect them. In order to make sure that I sampled most of the species found there it is essential to plot a rarefaction curve with cumulative species richness. The rarefaction curve (Fig.3) shows that sampling has reached asymptote.

Despite widespread recognition of relationship between habitat structure and insect communities, understanding of the ecological mechanisms underlying these relationships is limited. Alterations in the natural habitats may alter insect communities by directly influencing food resources for phytophagous and detritivorous species, and thereby indirectly influencing food resources for predaceous and parasitic species (Schowalter 1985).

Vegetation characteristics such as species diversity, biomass (Knops *et al* 1999), species richness (Haddad *et al* 2001), structural complexity (Araujo *et al* 2006, Oppel 2005) and composition (Schowalter *et al* 1986) influence insect communities. In our study we found similar trends which can be further related to abiotic factors as well. The results indicate that habitat structural variables like height of trees, Number of vertical stratum, Shrub density, and Stream width influence species richness. The first GLM with altitude as the main influencing factor can be explained by the altitude range of sampling. The sampling was from an altitude of 200 to 1350 meters. The other structural variables did not have much variance among them as in altitude. There may be a masking effect of altitude over other variables without altitudinal stratification as is evident in the rarefaction curves without altitudinal stratification and with stratification. Few transects in high altitude with relatively low species richness and large altitude range made

difference in the two GLMs. From the results we got transects which were in lower altitude had much high species richness and less variation in altitude among them. According to Lawton, 1976 and Hodkinson, 2005, decline in species richness with altitude is typical of many groups of insects. Altitude was positively correlated with canopy cover in this study. Canopy cover can influence species richness by reducing sunlight penetration (Kinvig and Samways 2000), which is very crucial for Odonates. Species richness was found to be positively correlated with stream width and it can be related to the larval preferences of Odonates. The Odonate larvae are very sensitive to aquatic habitat structures, such as bottom substrate, water clarity and stream width and depth, while adult habitat selection is strongly dependent on structural characteristics, like canopy openness and vegetation structure openness(Kinvig and Samways 2000).
A comparison of altitude-wise stratified transects is good to represent how the species richness differ in different altitudinal gradients. The three rarefaction curves plotted after stratifying transects into three altitudinal categories can explain trend in different altitudes. In high altitudes the canopy cover, number of tree species and other structural parameters like foliage density, shrub density increase thus the chances of missing a species increases. Transects above 900 meters had few species but many are very rare in nature. Most of the species form family Platystictidae(Reedtails) were found only above 800 meters where the vegetation type was wet evergreen. All the species that we found in this family except one were considered as Data Deficient in IUCN red list (Table.5 List of Species with IUCN status).

The one way ANOVA shows that the variance between strata is significant for two variables, height of trees and stream width (fig.8&10) but they do not explain the trend in species richness in those altitudinal strata.

6. Conclusion

This study shows that altitude plays an important role in species richness of Odonates. Canopy cover increases as altitude increases within the first two altitudinal strata, i.e., from 200-800 meters. But it does not explain the increasing trend of species richness in these strata. Height of trees, number of vertical stratum, Shrub density and Stream width are significant in determining species richness in lower altitudes i.e., 200- 800 meters.

Being one of the least disturbed protected areas in Western Ghats, studies on natural composition of fauna or flora of KMTR can be used as a conservation management tool in other protected areas of Western Ghats. Since Odonate species richness differ in different altitudes and most of them are sensitive to habitat alterations they can be used in monitoring habitat quality of those protected areas which have reservoirs or hydro-electric projects which can change the face of natural vegetation and stream structure. If we consider the habitat preferences of this group of insects in management of protected areas many of the other groups of insects both terrestrial and aquatic, insectivorous birds and mammals would be benefitted.

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Appendix I- Tables

Table.1. Pearson correlation matrix for habitat structural variables

	Canopy cover	**Avg.height of trees**	**No.of vertical stratum**	**Tree density**	**Shrub density**	**Herb density**
Canopy cover	1	**0.72**	0.50	0.67	0.239467	-0.60956
Avg.height of trees	0.72	1	0.42	0.60	0.060508	-0.48152
No.of vertical stratum	0.50	0.42	1	0.47	0.301886	-0.35287
Tree density	0.65	0.60	0.47	1	0.268084	-0.54148
Shrub Density	0.23	0.06	0.30	0.26	1	-0.23055
Herb density	-0.6	-0.48	-0.35287	-0.54	-0.23055	1
Average height of shrubs	0.40	0.57	0.286525	0.146084	-0.03076	-0.00343
Foliage density	**0.716888**	0.620978	0.605406	0.640951	0.344114	-0.49916
Tree species richness	**0.700823**	0.561258	0.467999	0.895629	0.302295	-0.51931
Altitude	0.499645	0.401655	0.303581	0.369238	0.306259	-0.42685

Stream Order	-0.40567	-0.08448	-0.0108	-0.32998	-0.1677	0.357493
Stream depth	-0.17757	0.149071	0.003949	-0.08254	0.04259	-0.12159
Stream width	-0.57904	-0.43466	-0.19657	-0.41391	-0.24138	0.402315
Bed rock	0.185435	0.222244	0.215293	0.264877	0.25131	-0.2357
Bolder	-0.226	-0.03293	-0.1664	-0.3666	-0.23214	0.07562
Coble	-0.24627	-0.28483	-0.31023	-0.16373	-0.13642	0.259859
Gravel	0.155589	0.071419	0.20778	0.23839	-0.01244	-0.02378
Silt	0.171413	-0.01656	0.068149	0.107651	0.017368	0.05515
Leaf litter	0.198634	-0.0842	0.141535	0.156898	0.116644	-0.05172
Tree cover	0.514329	0.417895	-0.01525	0.540529	0.119063	-0.30021

	Average height of shrubs	**Foliage density**	**Tree species richness**	**altitude**	**Stream order**
Canopy cover	0.40	**0.716888**	**0.700823**	0.499645	-0.40567
Avg.height of trees	0.57	0.620978	0.561258	0.401655	-0.08448
No.of vertical stratum	0.28	0.605406	0.467999	0.303581	-0.0108

Tree density	0.14	0.640951	**0.895629**	0.369238	-0.32998
Shrub Density	-0.03	0.344114	0.302295	0.306259	-0.1677
Herb density	-0.003	-0.49916	-0.51931	-0.42685	0.357493
Average height of shrubs	1	0.231987	0.13326	0.202168	0.166566
Foliage density	0.23	1	0.615106	0.445362	-0.25075
Tree species richness	0.13	0.615106	1	0.424181	-0.41124
Altitude	0.38	0.431784	0.543036	0.582258	-0.39188
Stream Order	0.16	-0.25075	-0.41124	-0.44685	1
Stream depth	0.05	-0.16669	-0.12509	-0.14094	0.557795
Stream width	-0.14	-0.33901	-0.49176	-0.48492	0.624748
Bed rock	0.15	-0.05133	0.290283	0.156103	0.099803
Bolder	0.01	-0.14949	-0.35274	0.145008	0.215211
Coble	-0.19	-0.07416	-0.2184	-0.26073	-0.12281
Gravel	0.124283	0.198729	0.149159	-0.10553	-0.00772
Silt	-0.07007	0.182626	0.14391	-0.21922	-0.25057
Leaf litter	-0.16544	0.332446	0.194466	0.029064	-0.38309

	Stream depth	Stream width	Bed rock	bolder	coble	gravel
Canopy cover	-0.17757	-0.57904	0.185435	-0.226	-0.24627	0.155589
Avg.height of trees	0.149071	-0.43466	0.222244	-0.03293	-0.28483	0.071419
No.of vertical stratum	0.003949	-0.19657	0.215293	-0.1664	-0.31023	0.20778
Tree density	-0.08254	-0.41391	0.264877	-0.3666	-0.16373	0.23839
Shrub Density	0.04259	-0.24138	0.25131	-0.23214	-0.13642	-0.01244
Herb density	-0.12159	0.402315	-0.2357	0.07562	0.259859	-0.02378
Average height of shrubs	0.055382	-0.14033	0.152381	0.014239	-0.19905	0.124283
Foliage density	-0.16	-0.33901	-0.05133	-0.14949	-0.07416	0.198729
Tree species richness	-0.12	-0.49176	0.290283	-0.35274	-0.2184	0.149159
Altitude	-0.14	-0.48492	0.156103	0.145008	-0.26073	-0.10553
Stream Order	0.55	0.624748	0.099803	0.215211	-0.12281	-0.00772
Stream depth	1	0.275639	0.262011	0.316327	-0.31373	-0.22333
Stream width	0.27	1	-0.10983	0.341274	0.053943	-0.17233
Bed rock	0.26	-0.10983	1	-0.29898	-0.54614	-0.21254

Bolder	0.31	0.341274	-0.29898	1	-0.18253	-0.48208
Coble	-0.31	0.053943	-0.54614	-0.18253	1	-0.09623
Gravel	-0.22	-0.17233	-0.21254	-0.48208	-0.09623	1
Silt	-0.39	-0.20875	-0.49767	-0.46977	0.186461	0.562447
Leaf litter	-0.38	-0.31828	-0.44772	-0.40242	0.061077	0.572533
Tree cover	-0.40	-0.56344	-0.07159	-0.27061	0.18723	-0.00312

	Silt	**Leaf litter**	**Tree cover**
Canopy cover	0.17	0.198634	0.514329
Avg.height of trees	-0.01	-0.0842	0.417895
No.of vertical stratum	0.06	0.141535	-0.01525
Tree density	0.10	0.156898	0.540529
Shrub Density	0.017368	0.116644	0.119063
Herb density	0.05515	-0.05172	-0.30
Average height of shrubs	-0.07007	-0.16544	0.10
Foliage density	0.182626	0.332446	0.36
Tree species richness	0.14391	0.194466	0.60
Altitude	-0.21922	0.029064	0.27
Stream Order	-0.25057	-0.38309	-0.69
Stream depth	-0.39225	-0.38306	-0.40
Stream width	-0.20875	-0.31828	-0.56
Bed rock	-0.49767	-0.44772	-0.07
Bolder	-0.46977	-0.40242	-0.2

Coble	0.186461	0.061077	0.18
Gravel	0.562447	0.572533	-0.003
Silt	1	0.747785	0.29
Leaf litter	**0.747785**	1	0.24
Tree cover	0.296709	0.243983	1

Table .2 .Generalised Linear Model Result Using number of species per transect as response variable. Model 15 is the Null model. All the models those had higher AICc values than Null model were removed from the table.

Model	K	AICc	Delta_AICc	p	Response variable	Predictor Variable/s
model 5	2	174.06	0	0.0141	No. of species/ transect	Altitude
model 13	3	175.81	1.74		No. of species/ transect	Altitude, Stream order
model 14	3	176.44	2.37		No. of species/ transect	Altitude, tree cover
model 2	2	177.54	3.47		No. of species/ transect	Average height of trees
model 12	4	177.62	3.55		No. of species/ transect	Altitude, Stream order, tree cover
model 15	1	178.44	4.37		No. of species/ transect	null model

Table.3 .Generalised Linear Model Result using altitude vice stratified data. All the transects above 900 meters were omitted. The number of species per transect was calculated for the remaining transects and used as response variable. Model 15 is the Null model. All the models those had higher AICc values than null model were removed from the table.

Model	AICc	Delta_AICc	AICc weight
Average height of trees, no. Of vertical stratum, Shrub density, Altitude, Stream width	67.58	0	0.54
Average height of trees, no. Of vertical stratum, Shrub density, Altitude, Stream width, Stream depth	70.8	3.21	0.1
Average height of trees, Stream width, shrub density	71.17	3.58	0.09
Average height of trees, Stream width, shrub density, no. Of vertical stratum	71.39	3.81	0.08
Average height of trees, Stream width, shrub density, Canopy cover, Altitude	71.48	3.9	0.07
Average height of trees, Stream width, shrub density, no. Of vertical stratum, Altitude	71.86	4.27	0.06
Canopy cover, Average height of trees, no. Of vertical stratum, Shrub density, Altitude, Stream width, Stream depth, Tree cover	74.38	6.79	0.01
Average height of trees, Stream width	77.07	9.49	0.004
Canopy cover, Average height of trees, no. Of vertical stratum, Shrub density, Altitude, Stream width, mean depth, tree cover, substratum diversity	78.38	10.79	0.002
Null	85.74	18.15	0

Table.4. Significance of predictor variables of best model from Table.3

Response variable	**Predictor variables**	**Estimate**
No. of species/ transect	**Average height of trees**	**-1.015**
	No. Of vertical stratum	**0.41**
	Shrub density	**0.39**
	Stream width	**-0.55**
	Altitude	**0.62**

Table.5 List of Species with IUCN status

No.	**Common Name**	**Scientific Name**	**Family**	**IUCN Status**
1	blue darner	*Anax immaculifrons*	Aeshnidae	LC
2	stream glory	*Neurobasis chinensis*	Calopterygidae	LC
3	black tipped forest glory	*Vestalis apicalis*	Calopterygidae	LC
4	clear winged forest glory	*Vestalis gracilis*	Calopterygidae	LC
5	stream ruby	*Rhinocypha bisignata*	Chlorocyphidae	LC
6	rever heliodor	*Libellago lineata*	Chlorocyphidae	LC
7	Saffron - Faced Blue Dart	*Pseudagrion rubriceps*	Coenagrionidae	LC
8	black marsh dart	*Onychargia atrocyana*	Coenagrionidae	LC

9	travancore torrent dart	*Euphaea cardinalis*	Euphaeidae	LC
10	black torrent dart	*Dysphaea ethela*	Euphaeidae	**DD**
11	Common Clubtail	*Ictinogomphus rapax*	Gomphidae	LC
12	Clubtail	*Gomphidia kodaguensis*	Gomphidae	**DD**
13	Crimson Marsh Glider	*Trithemis aurora*	Libellulidae	LC
14	Crimson -Tailed march glider	*Orthetrum pruinosum*	Libellulidae	LC
15	granite ghost	*Bradinopyga geminata*	Libellulidae	LC
16	blue marsh hawk	*Orthetrum glaucum*	Libellulidae	LC
17	Black Stream Glider	*Trithemis festiva*	Libellulidae	LC
18	brown backed red marsh hawk	*Orthetrum chrysis*	Libellulidae	LC
19	pigmy skimmer	*Tetrathemis platyptera*	Libellulidae	LC
20	wandering glider	*Pantala flavescens*	Libellulidae	LC
21	Ground Skimmer	*Diplacodes trivialis*	Libellulidae	LC
22	scarlet rock glider	*Trithemis kirbyi*	Libellulidae	LC
23	blue tailed forest hawk	*Orthetrum triangulare*	Libellulidae	LC
24	iridescent stream glider	*Zygonyx iris*	Libellulidae	LC
25	green marsh hawk	*Orthetrum sabina*	Libellulidae	LC
26	emerald banded skimmer	*Cratilla lineata*	Libellulidae	LC
27	ditch jewel	*Brachythemis contaminata*	Libellulidae	LC
28	yellow tailed ashy skimmer	*Potamarcha congener*	Libellulidae	LC
29	greater crimson glider	*Urothemis signata*	Libellulidae	LC
30	stetitte river hawk	*Onychothemis testacea*	Libellulidae	LC
31	yellow bush dart	*Copera marginiceps*	Platycnemididae	LC
32	blue bush dart	*Copera vittata*	Platycnemididae	LC
33	Anamalai reed tail	*Protosticta davenporti*	Platystictidae	LC
34	red spot reed tail	*Protosticta sanguinostigma*	Platystictidae	**VU**
35	Reed tail	*Coconeura.sps*	Platystictidae	**DD**
36	travancore bamboo tail	*Esme mudiensis*	Protoneuridae	**DD**

Appendix II- Figures

Figure.1. Study area map with major rivers

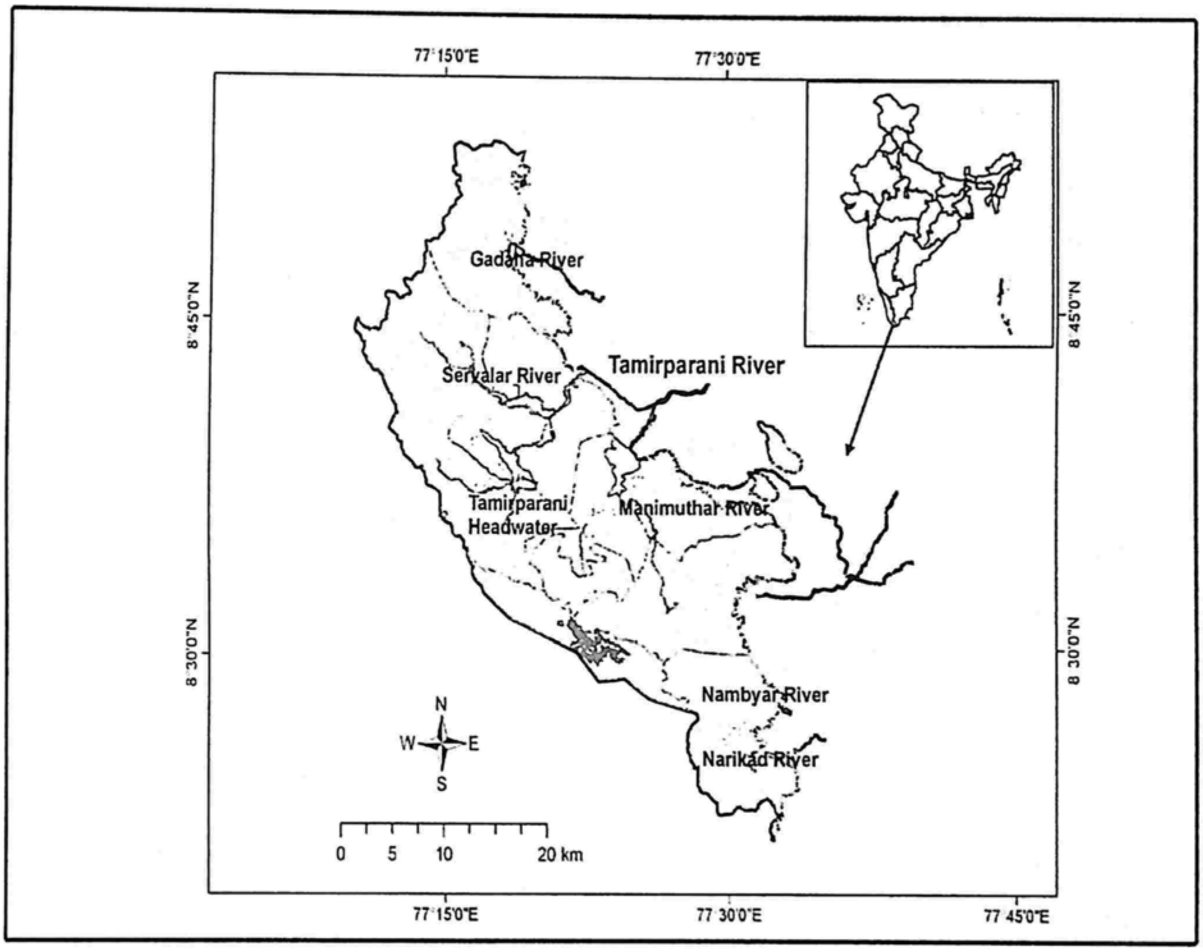


Figure.2.Intensive study area

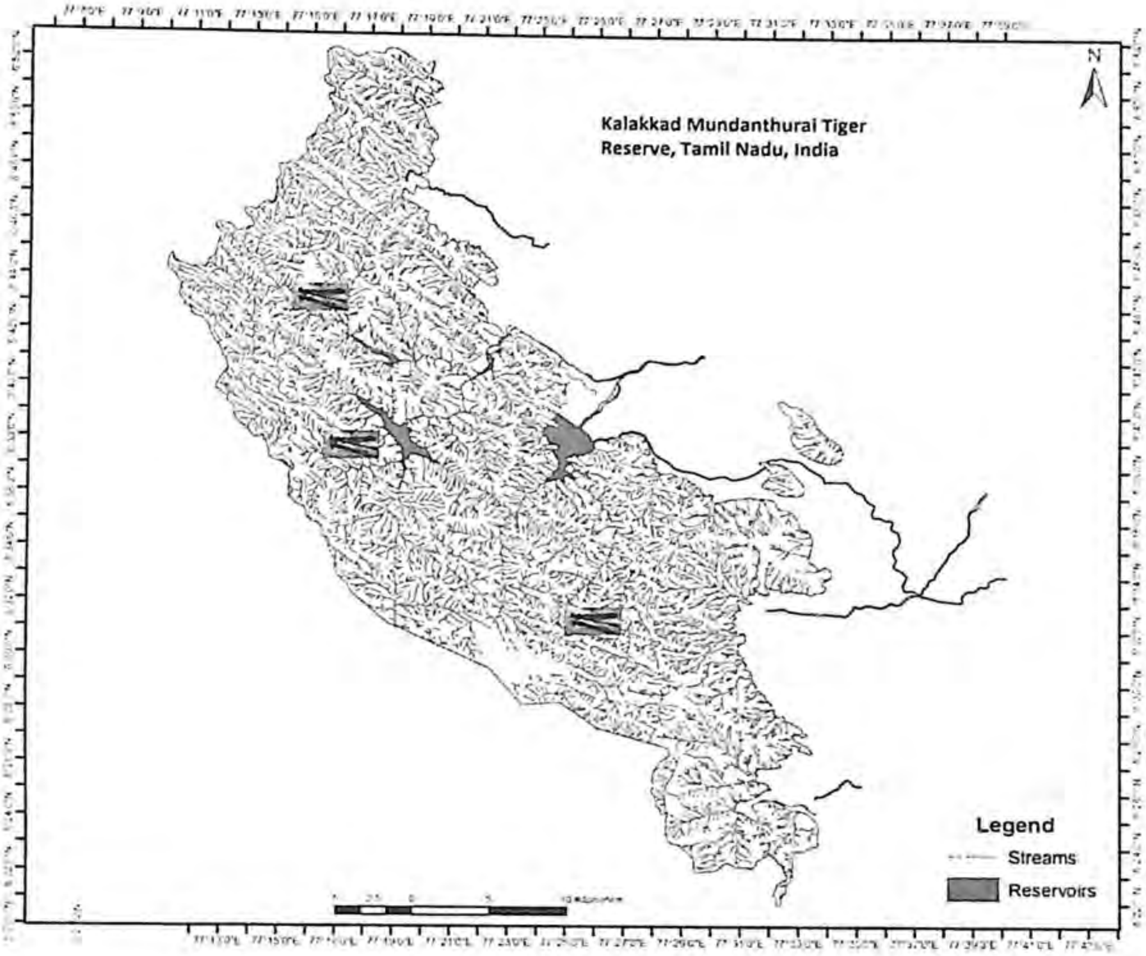


Figure.3. Rarefaction curve for species richness with standard deviation. Jack 2 estimator was used to calculate species richness.

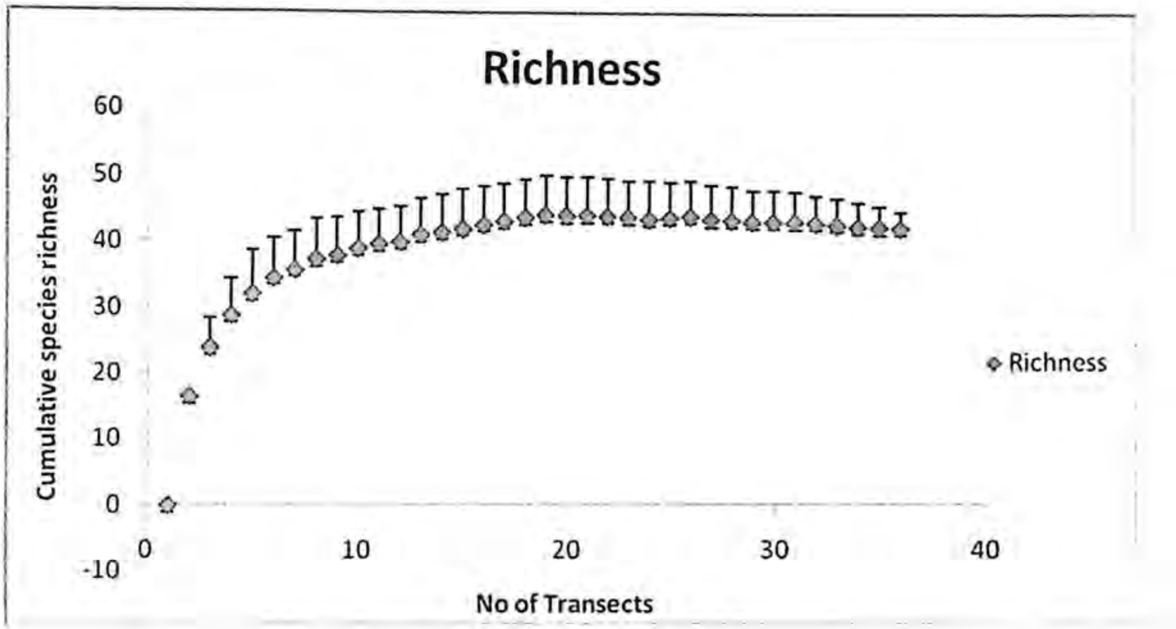


Figure.4. Rarefaction curves based on altitude vice stratified transects versus observed species richness.

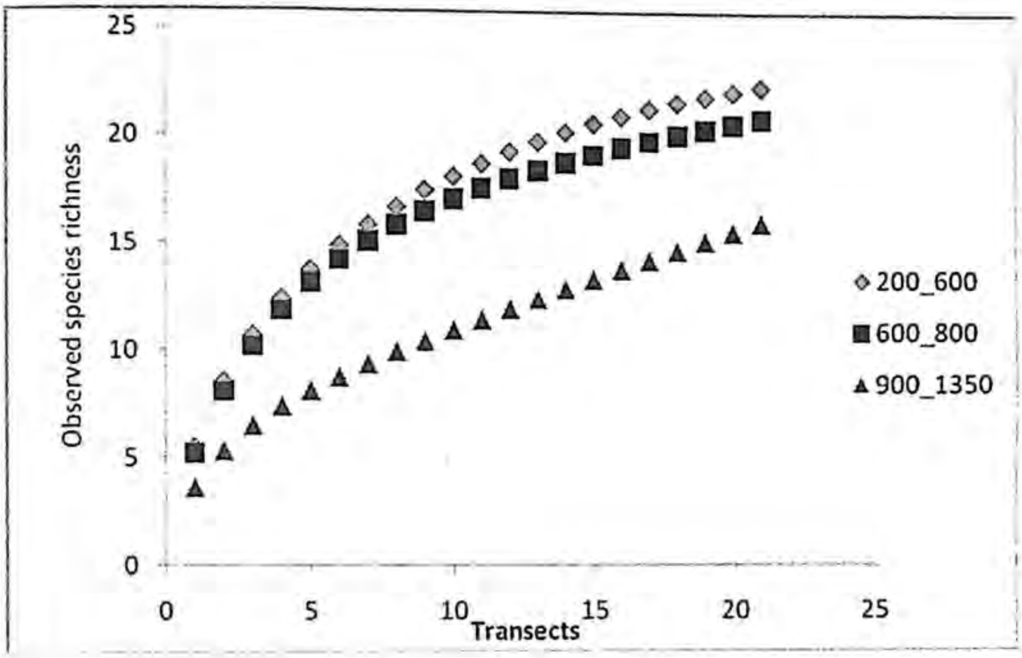


Figure.5. Graph with Jack 2 estimator species richness and observed species richness for altitude range 200-600 meters

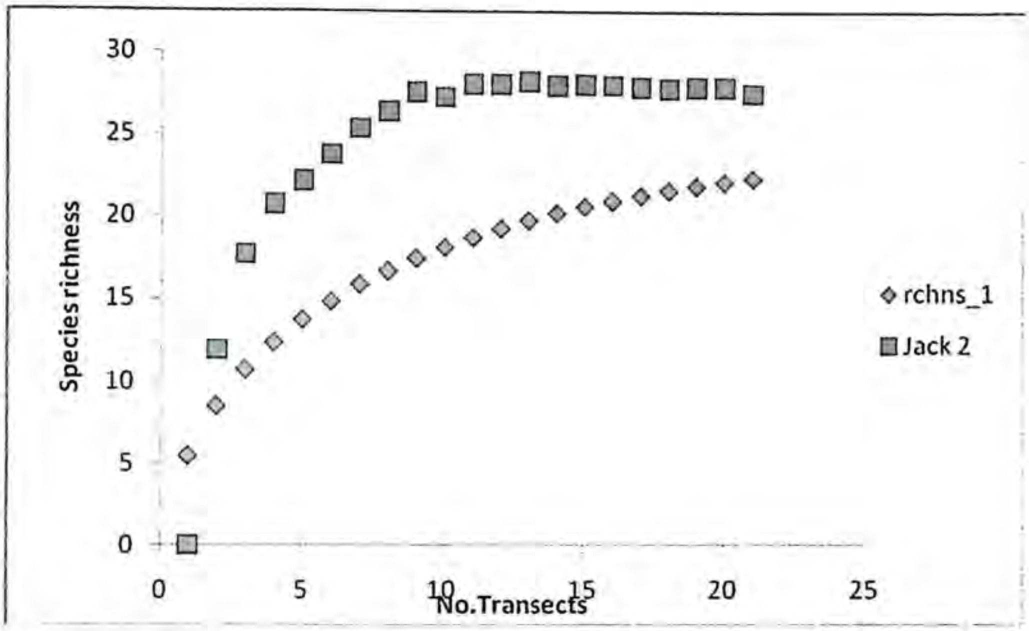


Figure.6. Graph with Jack 2 estimator species richness and observed species richness for altitude range 600-900 meters

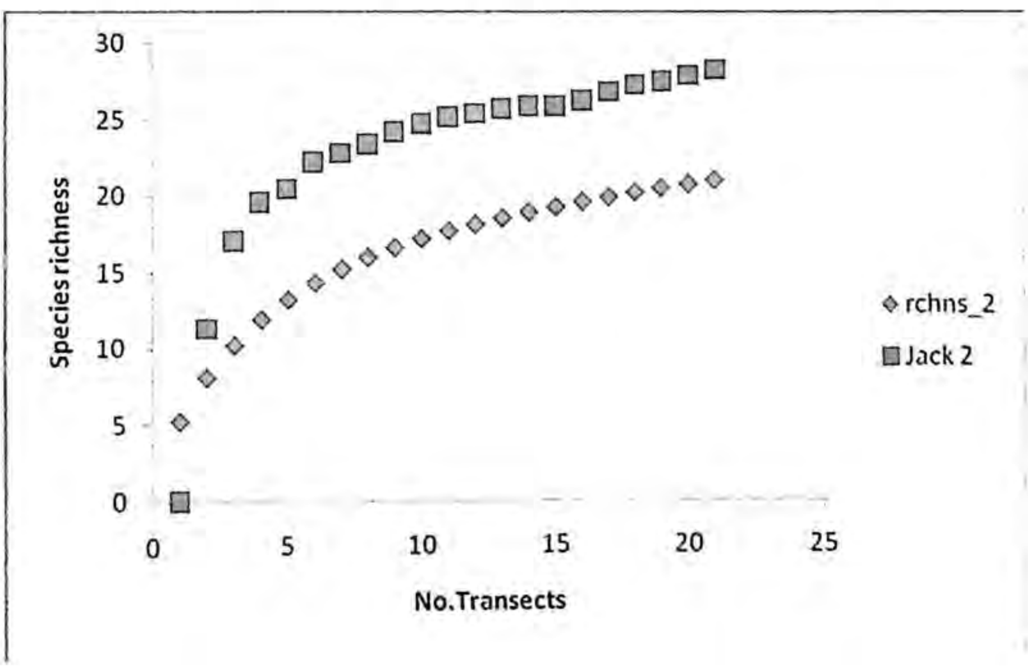


Figure.7. Graph with Jack 2 estimator species richness and observed species richness for altitude range 900-1350 meters

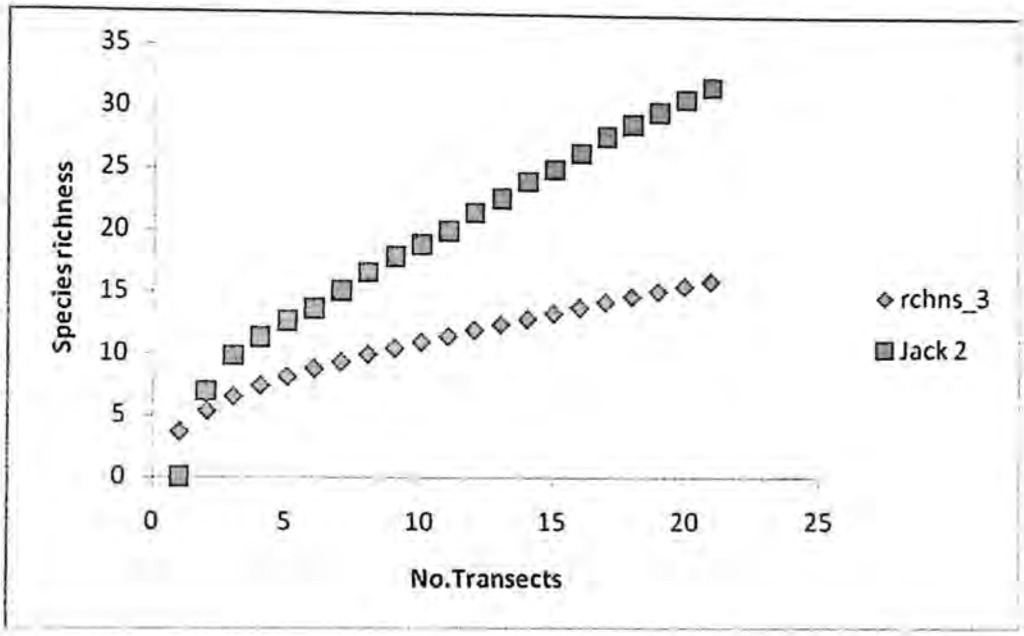
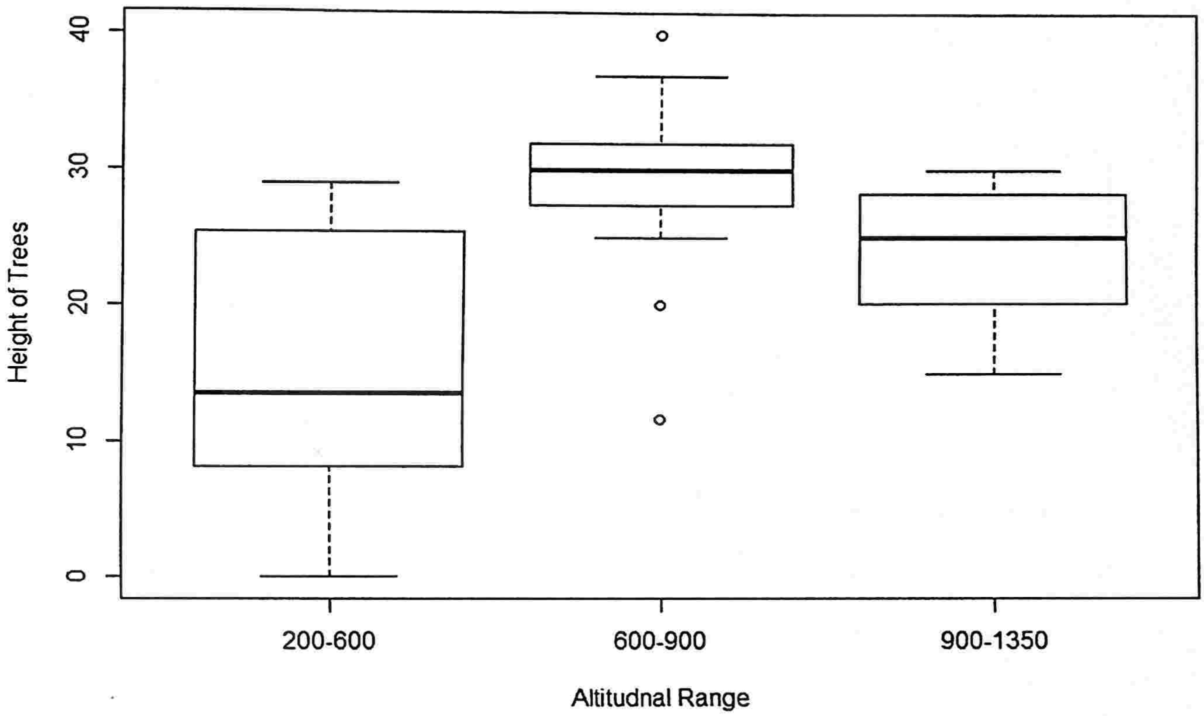


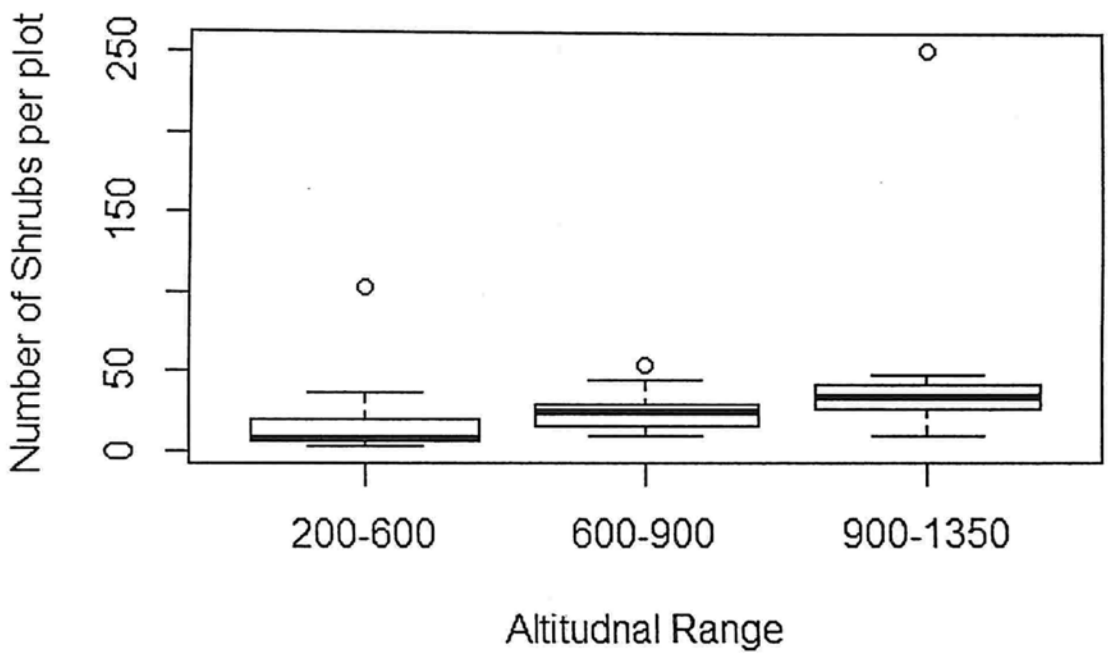
Figure.8. box plot for height of trees for different altitudinal ranges



one way Anova- F value – 11.41 , P <0.001

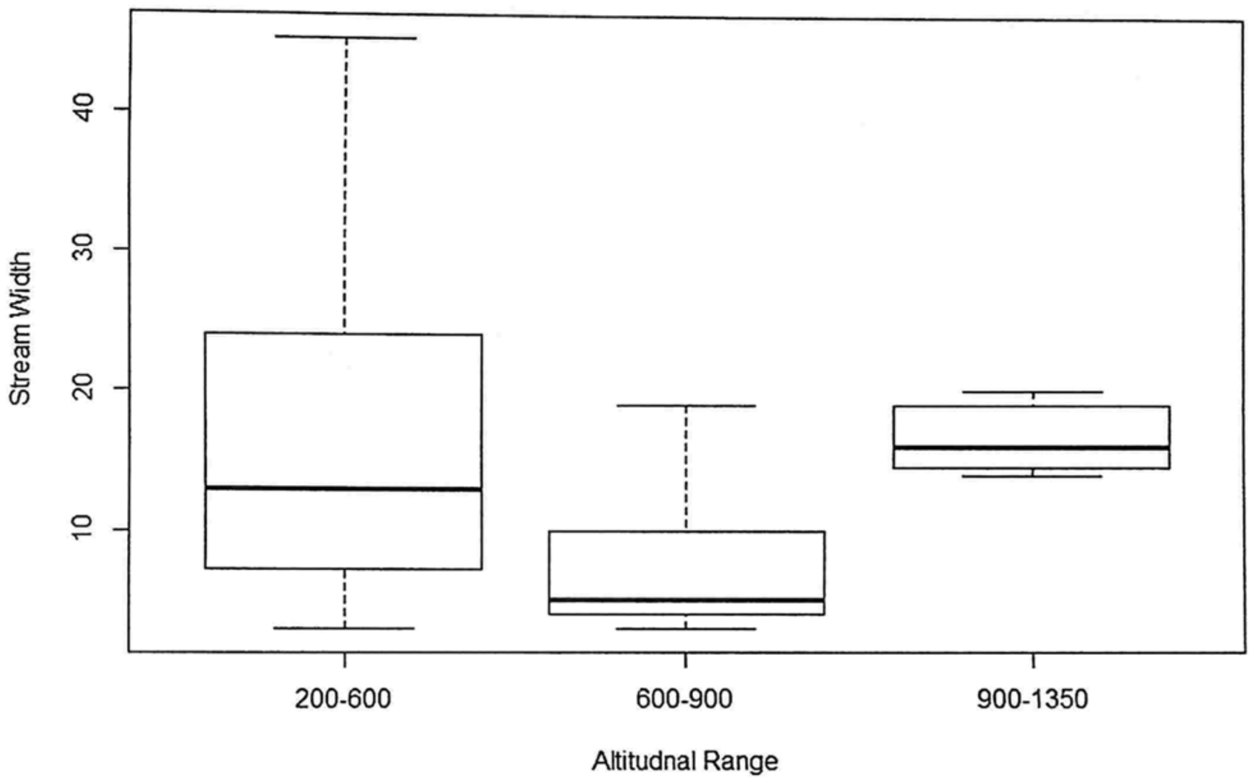
Tukey's HSD - 600-900-200-600, p- 0.001

Figure.9. box plot for shrub density for different altitudinal ranges



one way Anova- F value – 2.876 , P <0.1

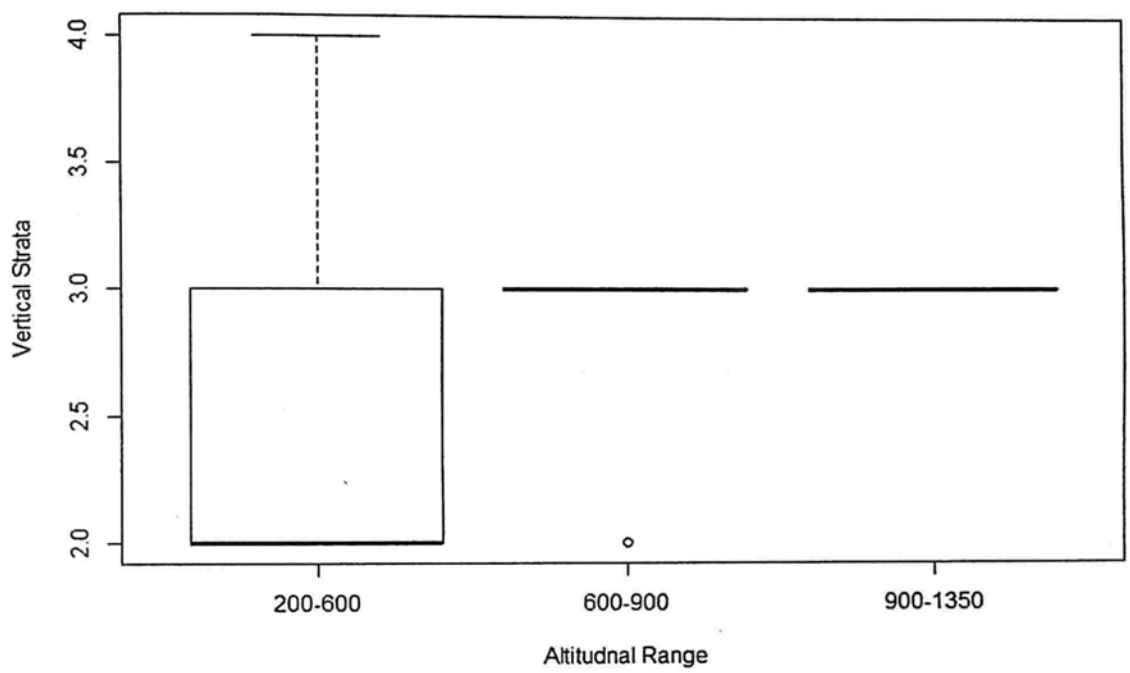
Figure.10. box plot for stream width for different altitudinal ranges



one way Anova- F value –6.09 , P <0.01

Tukey's HSD -200-600-600-900 , P-0.0094

Figure.11. box plot for number of vertical strata for different altitudinal ranges



one way Anova- F value – 2.876 , P <0.1