Abundance and diversity of anuran species in Danum Valley, Sabah, Borneo

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Abstract

1. Anurans are important components of tropical ecosystems; however, the biodiversity of these species is under threat due to the rapid deforestation of Southeast Asian forests.
2. Abundances and numbers of individuals of anuran species from three different sites were surveyed. One site being that of a relatively undisturbed primary Dipterocarp forest, the other two being disturbed habitats, a secondary forest recovering from logging and a drainage ditch which has formed a pool site.
3. Species abundance and numbers of individuals was significantly different $P<0.05$ between the three sites. The primary forest site showed higher mean abundances of species and individuals of anuran species, with the secondary forest having the lowest abundances and the pool site having an intermediate value.
4. Variables of temperature and light levels were shown to have an impact upon frog species, with the highest temperatures and light readings found in the sites with less species and individuals. pH was neutral for all three sites so was not seen as a consequence effecting anurans.
5. The differences in anuran abundances and species in the three sites may indicate that environmental factors may be having detrimental impacts on anurans.
6. The need to census amphibians has never been more urgent than it is now. Among herpetologists, there is a growing awareness that amphibians are declining and becoming extinct in many parts of the world.

Key- words: Anurans, deforestation, detrimental impacts, Southeast Asia.

Introduction

Southeast Asia has the highest relative rate of deforestation of any major tropical region, and could lose three quarters of its original forests by 2100 and up to 42% of its biodiversity (Sodhi *et al.* 2004). The looming Southeast Asian biodiversity disaster demands immediate and definitive actions, yet such measures continue to be constrained by socioeconomic factors, including poverty and lack of infrastructure (Sodhi *et al.* 2004). Tropical ecosystems are exceptionally rich and exclusive reservoirs of much of the biodiversity on Earth (Laurance, 1999). Deforestation is particularly severe in Southeast Asia, where natural habitats, such as lowland rain forests, are being destroyed at relative rates that are higher than those of other tropical regions (Achard *et al.* 2002). This biodiversity crisis is likely to develop into a full- fledged disaster, as the region is home to one of the highest concentrations of endemic species (Myers *et al.* 2000).

Large scale deforestation in the region began during the 1800s as a result of agricultural expansion, which was needed to meet the increasing local and global demand for rice *Oryza sativa* (Flint, 1994). The planting of perennial export crops, including rubber *Hervea brasiliensis,* oil palm *Elaeis guineensis* and coconut *Cocos nucifera,* also accounted for 20-30% of the total cultivated area of the region (Flint, 1994). After 1950, increasing demand for Asian timber led to proliferation of commercial logging activities (Flint, 1994). The diverse Dipterocarp species can be grouped into just a few end-use classes, so is extremely valuable to the logging industry for domestic consumption and export (Whitmore, 1998). Most of the timber goes to Japan, which consumes 40 percent of the world's hardwood supplies (Park, 1992). Peninsula Malaysia has seen the greatest losses (Park, 1992). In 1900 it was almost 100 percent covered by primary tropical forest, which is a valuable capital asset for a country seeking a fast track to development. Timber is a major source of foreign income in southern Malaysia, bringing in M$1013.92 million in 1982 and accounting for about a fifth of the state's total earnings. If the rate of deforestation continues it will mean the end of an irreplaceable ecological resource, also the end of a mainstay of the country's export economy (Park, 1992). Today Malaysia accounts for two thirds of world production and established 60,000 ha of new plantations in 1989 alone (Hoon, 1989).

Within Danum valley, Sabah, Borneo, two main types of forest exist, those of primary and those affected by logging termed secondary forests. The environmental conditions of each habitat may have different effects on anurans. Primary forests are made up of many climax species; these are slower growing, leading to trees having denser timber and denser crowns (Whitmore, 1998). These properties make the environment below the canopy much more suitable for anuran species, as it has a cooler habitat with a much higher humidity level. In comparison to these conditions, logged forests experience greater fluctuations and extremes in temperature, light and humidity compared to those of a closed canopy primary forest. In Malaysian rainforests following logging, areas are dominated by pioneer tress such as (*Macaranga, Octomeles, Neolamarkia*, and *Duabanga*), open areas of grasses, ferns, vines, and climbing bamboo (*Dinochloa* spp.), and exposed and compacted mineral soil with little or no vegetation cover (Willot *et al.* 2000). Secondary tropical rainforests have only a few tree species per hectare, and sometimes only one or two, by contrast to primary forests which are usually very rich (Whitmore, 1998). There are also small pools around the edges of the forests formed from runoff from roads or drainage ditches which form another habitat for some anuran species.

For several reasons, anurans were chosen to study the effects of forest disturbance in Danum Valley. The need to census amphibians has never been more urgent than it is now. Among herpetologists, there is a growing awareness that amphibians are declining and becoming extinct in many parts of the world, in many instances in areas of apparently pristine and protected habitat, led to the formation in 1991 of the Declining Amphibian Populations Task Force (DAPTF) set up under the auspices of the International Union for the Conservation of Nature (IUCN). Since 1991, it has become apparent that the situation is even worse than expected (Sutherland, 2006). The IUCN Global Amphibian Assessment (GAA) has revealed that 32% of the world's 5743 amphibian species are threatened with extinction (Stuart *et al.* 2004).

Frogs have been found to occupy a wide variety of habitats. The majority of anurans in Borneo live in the warm humid forests. Species are found living on the ground amongst the leaf litter, a few burrow in the soil, or are found perching on branches of trees or shrubs at varying heights above the forest floor, while other species can be found living in and around bodies of freshwater (Inger & Stuebing, 2005). Virtually all leaf litter anurans depend upon the constant diversity of the leaf litter microhabitat for predator escape, nesting, protection from desiccation and invertebrate prey (Scott, 1976; Vitt & Caldwell, 1994, 2001). There are six families which exist within Borneo, Bombinatoridae, Megaphyridae, Bufonidae, Microhylidae, Ranidae and Rhacophoridae (Inger & Stuebing, 2005). Adult anurans are generally opportunistic in their feeding with little specialization. Most feed on a variety of non aquatic invertebrates and overlap between diets is extensive (Meijaard *et al*. 2005). Some species may specialise on ants (e.g. Microphilidae, Das, 1996; Bufonidae, Inger, 1969). There may be a correlation between size of frog and size of prey consumed (Inger, 1969). This could allow a greater number of species to live amongst each other (Meijaard *et al.* 2005).

There are very few studies on the effects logging has on anuran species. The aim is to add to the few studies that have been carried out. Firstly, asking whether there are differences in abundances of species and individuals found between, undisturbed (primary forest) and disturbed sites (secondary forest and pool sites). Testing the hypothesis that primary forests are richer than disturbed sites in both abundance of species and numbers of individuals.

Methods and materials

Three sites were surveyed within Danum valley, Sabah, Borneo; primary forest, secondary forest and a pool site, (Fig. 1, 2 and 3).

100m transects were run along watercourses in the three different sites. The 100m transect was laid out using a measuring tape, 5 metres was measured either side of the transect (Sutherland, 2006). Nocturnal searches were carried out at 8pm every night. Anurans were pinpointed using head torches, and recorded when found along the 100 m transect and within the 5m cross belt. Photographic records were kept of every anuran, which were then later identified to species level using taxonomic guides (Indraneil, 2007) and (Inger & Stuebing, 2005). This process of recording and identifying was repeated 4 times for each site. Habitat variables were recorded at 10m intervals along the 100m transect along the watercourses, at 2pm for each site. pH readings were taken using a Oakton pH tester (Eutech instruments, Nijkerk, Netherlands). Light readings were taken using a Digital lux meter (model

Fig1. Photograph of primary forest site sampled (Author, 2008).

Fig.2. Photograph of secondary forest site sampled (Author, 2008).

Fig.3. Photograph of pool site sampled (Author, 2008).

LX101, Lutron Electronics, Taiwan).Temperature readings were taken for soil and air using a Copper constant Thermocouple (Duplex, TC limited, Uxbridge, England).

Using the programme Minitab™, Kolmogorov Smirnoff tests were carried out on the results for number of species, number of individuals, temperature for air and soil, pH and light readings to find out whether they were normally distributed. One way anova tests were carried out for the normally distributed data, to test for significant differences between the sites, as it was hypothesised that there would, indeed, be a significant difference. A Kruskal- Wallis test was carried out for non parametric data. For the non parametric data means were plotted with interquartile ranges of 1^{st} and 3^{rd} quartile ranges shown. Primer software (Clarke & Warwick, 2001) was used to carry out an Anosim test on the data, which is an analysis of similarity.

Results

Abundance Of Species And Individuals

The greatest abundance of species of anurans were found in the primary forest site with the mean value of 7.75 ± 1.258 S.D., the secondary forest had the lowest abundance of anuran species, with the mean value of 3.50 ± 1.915 S.D., the pool site had the intermediate mean value of 3.75 ± 0.500 S.D (Fig. 4). The mean number of species differed significantly between sites ($P < 0.05$) (Appendix 1.0).

The results for the mean amount of individuals found in each site mirrored those results for the mean abundance of species found. The greatest amount of individuals was also found in the primary forest site with the mean value of 16.75 ± 2.217 S.D., the secondary forest had the lowest mean amount of individuals with the value of 6.50 ± 3.000 S.D., and the pool having the intermediate mean value of 9.25 ±, 2.217 S.D (Fig 5). The mean number of individuals also had a significant difference between sites ($P<0.05$) (Appendix 1.1).

Environmental Variables Within Each Site

The secondary forest site had the highest mean pH value of 7.51 ± 0.2844 S.D., followed by the pool site with the mean value of 7.38 ± 0.2401 S.D., and the primary site with a mean value of 7.23 ± 0.4839 S.D (Fig 6). The mean pH readings were not significantly different between sites ($P>0.05$) (Appendix 1.2).

The pool site had the highest mean air temperature (˚C) readings with the value of 30.5 ± 3.503 S.D., with the primary forest having the lowest mean reading with the mean value of 23.54, S.D 0.555 the secondary forest had an intermediate mean value of 26.99 ± 1.82 S.D(Fig 8). There was a significant difference between the mean air temperatures between the 3 sites ($P <0.001$) (Appendix 1.3). These results mirrored those of the results for the mean soil temperature (˚C) readings. The pool site had the highest mean reading of 30.83 ± 2.538 S.D., with the primary forest having the lowest mean value of 22.67 ± 0.352 S.D., the secondary forest had an intermediate mean value of 27.67 ± 2.975 S.D (Fig. 7). The soil temperature readings were significantly different between the 3 sites ($P <0.001$) (Appendix 1.4).

Light readings (Fc) for the 3 sites were significantly different (P<0.05) (Appendix 1.5). The pool site had the highest mean value of 619, lower quartile 322.50, upper quartile 683.50 with the primary forest having the lowest mean value of 0.80, lower quartile 0.65, upper quartile 2.90 the secondary forest site had an intermediate mean value 598, lower quartile 53.70, upper quartile 832.50 (Fig 9).

Anosim

The Anosim test showed that all three sites are significantly different to each other (P<0.001) (Appendix 1.6). All sites have enough biological similarity to remain within their habitat classification. 3 distinct clusters can be identified one for each site, showing that species within the sites were generally found only in one habitat type whether it be primary, secondary or pool. Species within each site are more similar to each other than species from different sites.

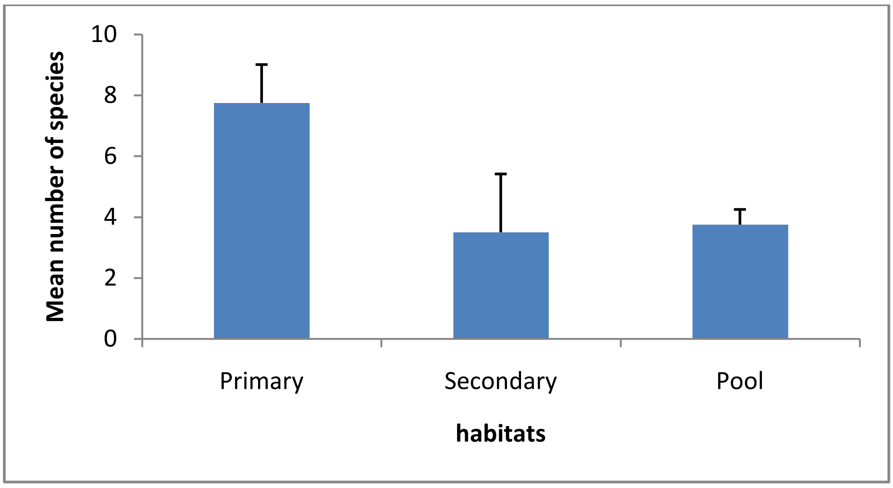

Fig.4. The mean number of anuran species found at 3 different sites, primary forest, secondary forest and pool. Bars represent S.D.

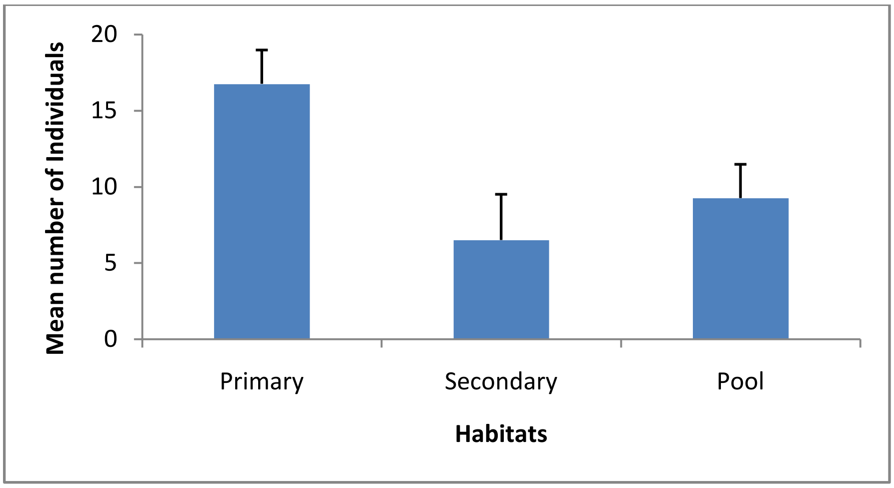

Fig.5. The mean number of anuran individuals found at 3 different sites, primary forest, secondary forest and pool. Bars represent S.D.

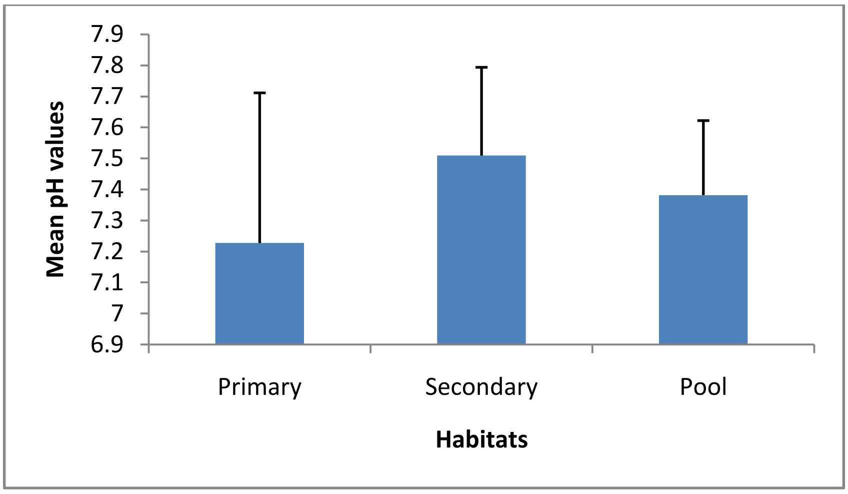

Fig.6. The mean pH values for 3 different sites, primary forest, secondary forest and pool, at 10m intervals along a 100m transect. Bars represent S.D.

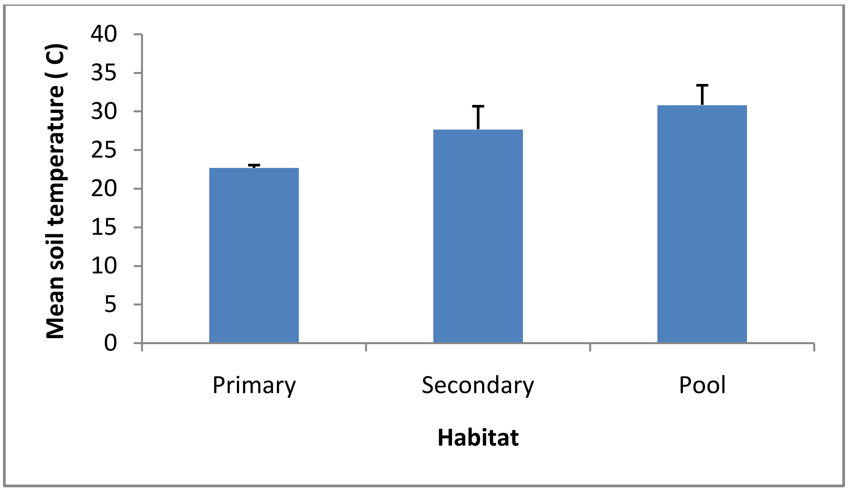

Fig. 7. The mean soil temperatures (˚C) for 3 different sites, primary forest, secondary forest and pool, at 10m intervals along a 100m transect. Bars represent S.D.

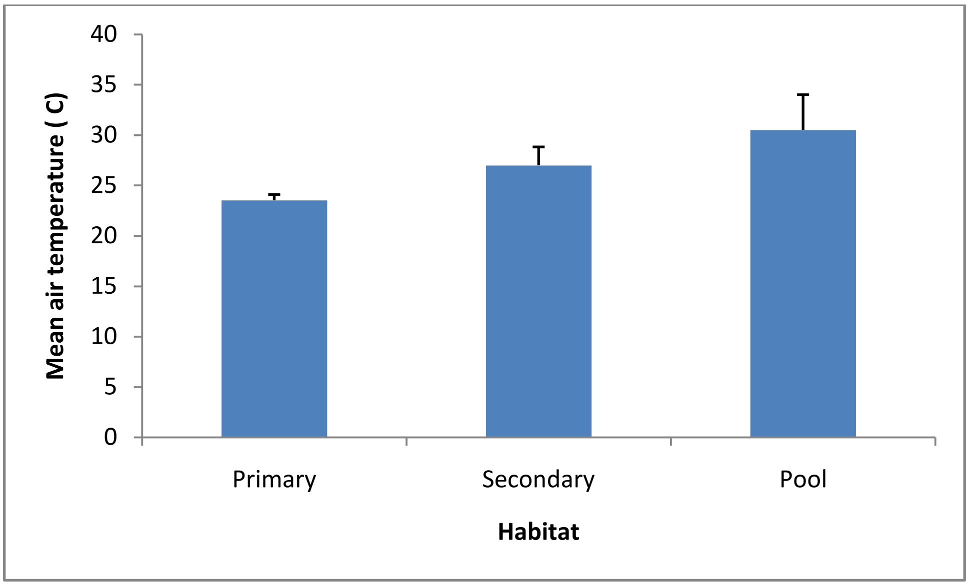

Fig.8. The mean air temperatures (˚C) for 3 different sites primary forest, secondary forest and pool, at 10m intervals along a 100m transect. Bars represent S.D.

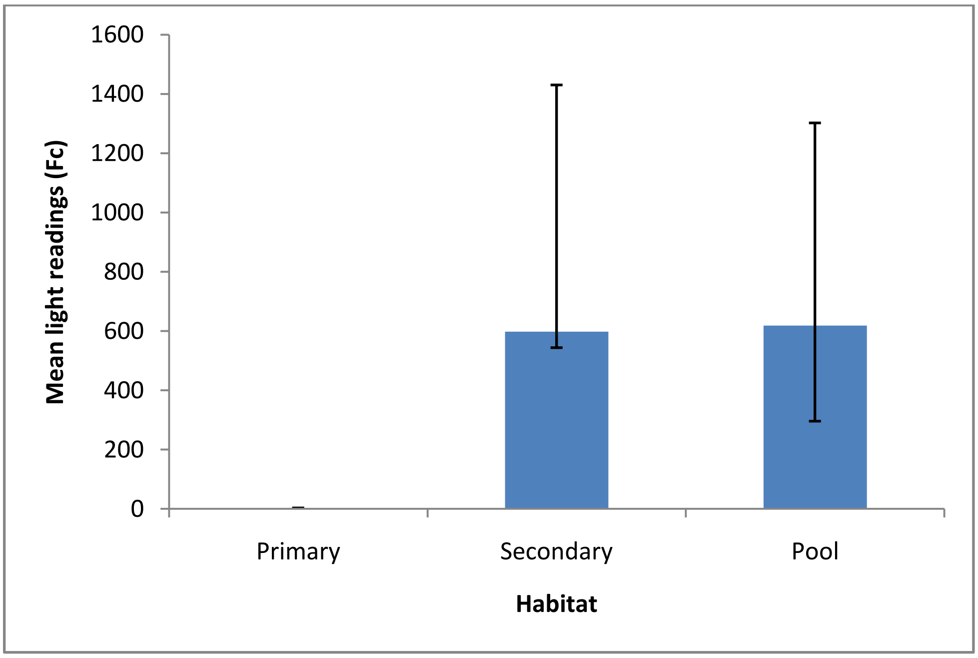

Fig. 9. The mean light readings (Fc) for 3 different sites, primary forest, secondary forest and pool, at 10m intervals along a 100m transect. Bars represent quartiles.

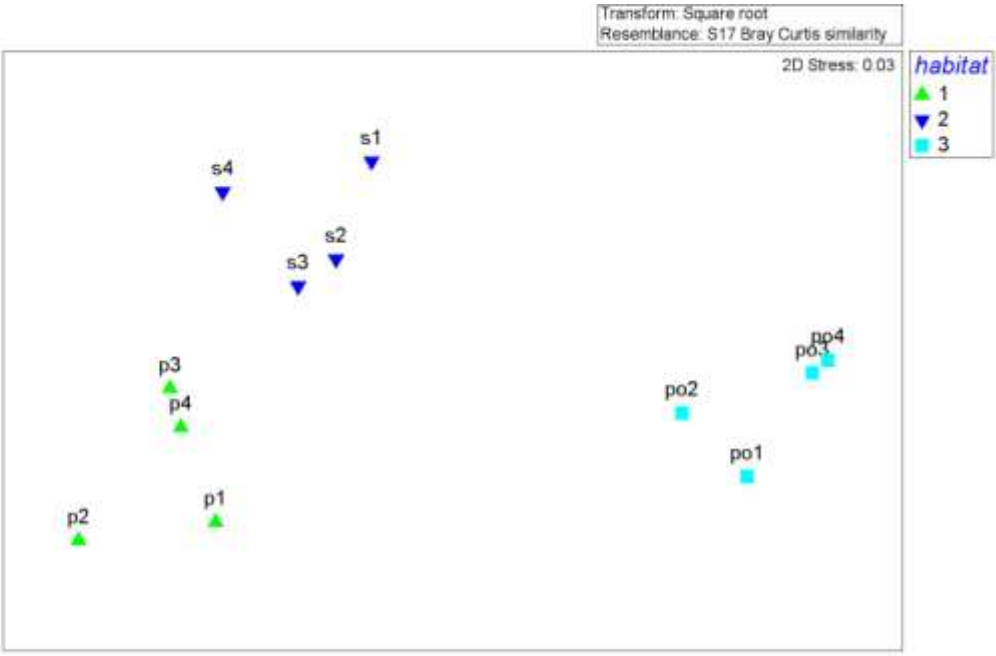

Fig. 10. ANOSIM similarity plot, transformed using square roots. Comparing primary forest (green triangle), secondary forest (blue inverted triangle) and Pool site (turquoise square).

Discussion

The most disturbed sites, those of the secondary forest and pool site tended to have the lowest species richness and amount of individuals. These results could be due to a number of factors, as anurans rely on different conditions to survive.

Logging may directly and indirectly affect anurans through its impact upon ponds and streams in the immediate vicinity of logging operations, on watersheds throughout the area, and on microhabitat conditions in the forest leaf litter in non riparian habitats (Meijaard *et al.* 2005).

Forests re-growing after a cyclone or human destruction i.e. logging, are dominated by pioneer or near pioneer species (Whitmore, 1998). Secondary tropical rainforests have only a few tree species per hectare, and sometimes only one or two, by contrast to primary forests which are usually very rich. Most pioneer species produce a large volume of low density wood by fast growth, with open- branched crowns (Whitmore, 1998). These open branch crowns mean that the forest floor has a very different environment to those of primary forests. The results from the study reflect this, as higher light levels for secondary forests indicate a greater amount of light reaching the forest floor.

Previous studies have indicated that within secondary forests wind speeds during the day are higher, as is air temperature; while relative humidity is lower (Whitmore, 1998). This observation is consistent with the findings of the current study where results for air and soil temperature were both considerably higher, in the secondary forest and pool site, compared to the primary forest. This could make it a challenging place to live for anurans.

Logging forests, leads to many other consequences for the habitat in which anurans rely upon, this could have lead to the decrease in the abundance of species and individuals in the disturbed pool and secondary forest sites. Destruction of floor litter and lower vegetation has been shown to lead to extreme levels of erosion during rains this lead to an enormous increase in sedimentation levels in streams (Meijaard *et al.* 2005). Douglas *et al.* (1992, 1993) showed that selective logging in Sabah, increased sediment loads in nearby streams 18 fold within five months after logging, while a year after logging monthly sediment yields were still four times those of undisturbed catchments. Sedimentation has clear detrimental effects on reproduction in several species of stream breeding frogs, effectively preventing survival of tadpoles (Meijaard *et al.* 2005). Hartwell *et al.* (1998) found that densities of amphibians were significantly lower in streams impacted by sediment. Douglas *et al.* (1992, 1993) also concluded that the water chemistry also changed after these logging processes in Sabah.

Canopy opening drastically affects the ground level forest environment (e.g., incident light, temperature, humidity and rates of litter accumulation) (Meijaard *et al.* 2005). The removal or change in quality of the leaf litter directly and indirectly affects anurans (Zou *et al.* 1995). Iskandar (1999a, b) showed the negative effects of logging and changes in leaf litter in North Sumatra. He found that frog species abundances were less for logged forests; there were 20% less species of individuals found in an unlogged forest of the same area. Their abundances were correlated with the amount of forest litter (Meijaard *et al.* 2005). This could be another factor affecting the anurans in the secondary and pool site.

The results from this study showed that for secondary and pool sites there were higher light reading than that taken for the primary site. Previous studies have shown that logging can lead to increased UVA and UVB radiation these can lead to amphibian population declines (Lannoo, 2005). Macias *et al.* (2007) showed that the frog species which they examined displayed detrimental effects of UVB radiation. Many field studies, by numerous investigators, have shown that ambient levels of UVB radiation decreases the hatching success of some amphibian species at their natural oviposition sites (Blaustein *et al.* 2001). There are also an increasing number of studies showing that UVB radiation harms amphibians at later stages of development, including larvae and juvenile stages (e.g. discussion in (Blaustein & Bancroft, 2007). Due to the destruction of the forest canopy more UVB rays are reaching the forest floor, the UVB rays could damage the primary producers of the ecosystem such as phytoplankton, which is a nitrogen consumer. The UVB rays affect these processes such as the uptake of ammonium and nitrate (Hader *et al.* 1998). This damage to the key producers may increase the availability of reactive nitrogen to amphibians. There could also be a significant reduction in food availability for anuran tadpoles if UVB kills or damages the plankton (Macias *et al*. 2007).

UVB radiation is a well known stressor on many amphibian species and has been proposed as a contributor to global amphibian declines alone or combined with other environmental stressors such as acidification, some polycyclic aromated hydrocarbons (PAHs) or nitrate (Blaustein *et al.* 2001). Acidification can be ruled out for the reason for declines in anuran numbers as the pH for all 3 sites ranged around neutral.

In contrast to the low numbers of species and individuals found in the pool site and the secondary forest site, there was a much greater abundance of individuals and species found in the primary site. This could be due to the forest having optimum conditions for the survival of anurans, with low light intensity, and the lowest soil and air temperatures, keeping the habitat for anurans moist and humid.

These optimum conditions could be related to the amount of understorey vegetation found at each site, in (Fig. 2 and 3) it is clear to see that little understorey vegetation is present in both the secondary forest and pool site, compared to (Fig. 1) of the primary site. Parris & McCarthy's (1999) study has shown that species composition of understorey vegetation in the riparian zone is significantly correlated with the composition of frog assemblages. Understorey vegetation has been found to be important to frogs, providing them with moisture, shelter and calling sites (Parris & McCarthy, 1999). Although it is easy to observe that the primary forest had more understorey vegetation present than the other two sites, and this could be a reason as to why more species and individuals were found in this site. It would have been beneficial to do a vegetation assemblage map, to see the exact correlation of vegetation to amount of anurans found.

The pool and secondary forest sites had the lowest abundance of species and individuals of anurans. However, the pool site had slightly more species in particular individuals. This could be due to certain species being adapted to human activity; this is clear in the Anosim results (Fig. 10), that shows species existing in each site are more similar to each other. Species which were found in the pool site which was previously a drainage ditch at the side of a road, which the anurans have colonised. The frogs which were found in only in this site such as the Cricket Frog (*Rana nicobariensis*), Grass Frog (*Fejervarya limnocharis*) and the Four- lined Tree Frog (*Polypedates leucomystax*) (Appendix 1.7) all live close to humans; they even depend on humans to create favourable environmental conditions such as puddles, ponds and ditches with large open, disturbed areas (Inger & Stuebing, 2005).

Many of these species are quite resilient and tough. They can withstand fairly high temperatures and some dryness (Inger & Stuebing, 2005). This could be an explanation as to why a higher abundance of individuals and species were found in the pool site compared to that of the secondary forest, although the pool site had the highest air and soil temperature readings from the three sites tested.

Stream width and length has been shown to be a major factor in the amount of frog species found in studies. Stream breeding frogs require a stream that is large enough to hold water for a sufficient length of time for their tadpoles to develop metamorphosis (Parris & McCarthy, 1999). Larger streams provide a suitable breeding habitat for a greater range of frog species than small streams because they contain water for longer (Parris & McCarthy, 1999). Kats *et al.* (1988) found that many amphibian species are excluded from temporary water bodies because their larval life span is longer than the duration of water in these habitats. This could be a major factor in our results of fewer species and individuals being found in the secondary forest and pool site as the habitats are more open as seen in (Fig. 2, 3) leading them to be a lot dryer and exposed to higher temperatures, so are at constant threat of drying up and becoming temporary habitats, compared to the primary forest which is covered as seen in (Fig. 1) leading to much cooler temperatures, so the stream is at less threat of drying up so is a more stable habitat, more species may be drawn to this habitat to breed, resulting in higher numbers of species and individuals.

Although anurans are at the forefront of studies of declining species, their habits and life histories pose a number of major problems for seeking their abundances accurately. Many species spend the greater part of their lives underground making them inaccessible to biologists (Sutherland, 2006). The study was carried out at night to try and overcome this problem as most species are nocturnal and venture out around this time. Anurans have very low food requirements, so can afford to emerge only when conditions are optimal, typically when the weather is warm and wet (Sutherland, 2006). This behaviour could have affected the results, as over the sampling period there was variation in weather conditions, varying from a hot dry climate, to wet humid climate with rapid rises in water level, this could have had an effect on the abundances and species found on particular sampling nights. However, to try to limit this inaccuracy sampling was avoided during excessively raised water levels. Water levels of each site could have been measured to try and limit this possible inaccuracy in sampling. An annual seasonal survey of water levels for each site would be useful as although rainfall in Borneo is generally heavy and usually without pronounced dry periods, patterns of precipitation vary from year to year, between areas, and even locally over very short time periods (Inger & Voris, 1993, Voris & Inger, 1994). This could affect the results that were taken at the precise time, season and area that they were taken, therefore, our results of abundance of species and individuals of anurans could vary.

In tropical species of anurans, breeding may occur over an extended period of the year, sometimes sporadically (Sutherland, 2006), so the limited time period of two weeks could have affected the results as abundances of species could have been vastly different. To get the most accurate results possible sampling of all three sites should have been maintained over many weeks or months. It would have been also beneficial to the study, if samples were taken annually of all forest sites, or we were able to attain access to previous studies done on anuran species in this region on the forest assemblages. This would allow us to tell whether our results for anuran species show declines or rises in species numbers and individuals, and whether secondary forests are beginning to recover or primary forests conditions for anurans are beginning to decline.

There were clear differences in numbers of species and numbers of individuals found in each site sampled, it needs to be noted that anurans are generally secretive creatures that are only occasionally active, they are much more difficult to detect at some times, and in some habitats, than others (Sutherland, 2006). This could have been a reason as to why more species and individuals were found in the pool sample than the secondary forest sample, as the pool site was more open and accessible to sampling. However, this doesn't account for the highest species number and amount of individuals being found in the primary forest site, as from this statement we would expect to find the lowest number of species and individuals as it was the most covered and inaccessible site sampled, making it harder to detect the anuran species. The fact that many species and individuals were found in this site, which was the most difficult to sample implies that the sampling method being used was accurate. However, Schmidt, (2003, 2004) suggests that most data used to show changes in amphibian abundances, are unreliable as they do not allow for variation in detection probability and consequently underestimate the true population size. This could be a factor in our study as the sites sampled varied in density of vegetation, making it harder to identify and count individuals.

The method of sampling using a 100m transect, is a cheap and simple method to use, however has been found to be labour intensive (Rodel & Ernst, 2004). This method has been shown to be best combined with other methods of sampling (Sutherland, 2006). Therefore, to get more accurate results, methods such as drift fencing, scan searching, netting, trapping and removal methods could have been included. However, the conclusion was made, that the method of transect sampling was the least invasive process to the anurans, so for ethical reasons other methods were eliminated from the study. If the method of trapping and removing anuran individuals was used this could have yielded more data, which could have been very beneficial to assess the long term viability of amphibian populations in the face of decline (Sutherland, 2006). Assessments could have been made on female reproductive status (Reyer & Battig, 2004); recording deformities of the limbs (Ouellet, 2000); and screens can be made for the infectious diseases particularly the disease of chytridiomycosis (Briggs & Burgin, 2003). All of these could have lead to conclusions of why fewer species and individuals were found in the pool and secondary forest site. Infectious diseases have been found to be a major cause of amphibian declines in populations throughout the world (Sutherland, 2006).

In conclusion, the wide range of ecological specializations in Bornean frogs makes it hard to generalise about the effects of logging on species richness and abundance (Meijaard *et al.* 2005). The results of the study appear that at least some species of anurans are less affected by logging such as the species *Limnonectes leporinus* and *Rana chalconata,* which were still found in fairly high abundances within the secondary forest, while others are more affected showing low abundances or are completely absent (Appendix 1.7).

However, it is clear to see from the results of the study, that logging of forests can have severe detrimental effects upon anuran species, showing the lowest number of individuals found in the secondary forest site. These results need to be taken heed of and certain conservation measures need to be put in place as amphibians represent a significant portion of vertebrate fauna of tropical forests. They have been found to be important components of tropical food webs, where they are probably the principal terrestrial insectivores (Reagon & Waide, 1996). Yet the ecology of anurans in Southeast Asian rainforests has been dealt with in only a few papers, and fewer still have dealt with the response of herpetofauna to logging (Meijaard *et al.* 2005). If anuran species are to be conserved more studies need to be done to show the effects logging and human impacts can have on these complex diverse communities.

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