4. Resource Partitioning by Frogs around Water Bodies at Luckunda.

Kate Sanders

4.1. Introduction

Evidence generated by community ecologists suggests that interspecific competition is a primary factor in shaping the structure and maintaining the diversity of biological communities (Pianka 1994). Interspecific competition is reduced by niche differentiation, which occurs by partitioning of shared resources. This ensures maximum utilisation of the physical environment and facilitates coexistence by preventing competitive exclusion of species. (Schoener 1983, Roughgarden 1982).

Resource partitioning can occur in a number of ways; most often species segregate spatially, this is expressed as microhabitat or geographical dispersion (Pianka 1994). Alternatively resource partitioning may be temporal, with species using the same resources but at different times of day or in different seasons (Huey *et al.* 1983). Variation in diet and feeding strategy can also segregate species (Huey *et al.* 1983). Communities may be organised in clusters or 'guilds' of functionally similar species that are separated from other such guilds by an ecological distance greater than the greatest distance between the two most disparate members of the guild concerned. Interspecific competition is more intense within the guilds than with the remainder of the community (Pianka 1994).

Holt's (1984) theory of 'apparent competition' describes an alternative situation in which resource partitioning might occur. In this case a single predator harms two prey species; the predator benefits from feeding on both species, so the presence one prey species increases predator abundance, which has an indirect, adverse effect on the other prey species. The persistence of each prey species is favoured by occupying a different habitat or by adopting a different behaviour pattern from the other species. The result of pressure from a shared predator is indistinguishable to the observer from that which would occur if the species were competing for resources. Amphibians are common prey to a variety of predators in the tropics (Duelman and Trueb 1986), in light of this 'apparent competition' is relevant to studies of amphibian resource partitioning.

Due to conflicting theories and a shortage of experimental evidence discussion of the mechanisms that drive resource partitioning should be cautious. Amphibians have gained relatively less attention than birds and mammals in community-level research and to my knowledge there have been no attempts to study competition in amphibian communities experimentally. However, comparative studies of amphibian communities have been conducted in Costa Rica (Duelman 1967), Thailand (Inger 1986) and south India (Das 1996). This research included habitat use, microhabitat use and diet; species-specific differences in the utilisation of these resources and groupings of aquatic, terrestrial and arboreal species were recognised in these communities.

Resource partitioning studies concentrate on biotic factors of the environment, spatial distribution and temporal segregation. The importance of abiotic environmental variables in species' niche is relatively unexplored. As amphibians are exothermic and have a permeable body covering for gas exchange, they are more susceptible to fluctuation in their environment than any other tetrapod, this restricts the majority of species to warm

tropical regions where there is high ambient moisture. (Duelman and Trueb 1986). The influence of the abiotic environment on amphibian species is therefore worthy of study.

It is known that Western Ghats amphibians are most abundant during the monsoon season (June to September) with some species being active only in the monsoon season (Daniels, 1991). The majority of Indian species avoid desiccation and ultra-violet light by being exclusively nocturnal; however some are opportunistic, switching between nocturnal and diurnal habits depending on the environmental conditions. For example, *Microhyla ornata* is nocturnal in open habitats, but can be both nocturnal and diurnal in closed-canopy forests where temperature, light and ground moisture are regulated (Daniels, 1991). From this it seems that the abiotic environment has a large influence on Western Ghats amphibians. However, research on the importance of daily fluctuations in the environment on an amphibian assemblage has not been published.

4.2. Research objectives

This study looks at microhabitat use and response to environmental conditions in six breeding pond communities. The aims are to determine the microhabitat preferences of species within each community, also to investigate the effect of daily fluctuations in weather on species density and breeding behaviour.

4.3. Methodology

All fieldwork was carried out in August/September 1998. Pilot surveys identified six study sites with a varying sizes of amphibian assemblage and heterogeneity of microhabitats; each site was mapped to scale using squared paper and a 30m measuring tape. Microhabitat patches were described by randomly placing $0.5m^2$ quadrats, the number of which was proportional to the patch size. This determined the % vegetation cover; vegetation type (shrub, grass, dead wood, leaf litter) and average vegetation height (cm) of microhabitats. (Appendix 1).

The attributes of each pond were calculated using a number of methods. Approximate pond dimensions were recorded using a 30m tape measure. The average depths of the larger ponds were obtained from estate records. The depths of smaller ponds were measured using a marked 2m rod at several points in the water body. The volume of each pond was calculated by multiplying the area by the average depth. Pond pH was measured using a hand held pH meter. Readings were taken at different locations in the water and an average was taken. Whether or not a pond was temporary or permanent and whether it was natural or man-made was deduced from estate records. The ratio of arboreal to terrestrial microhabitat was calculated by dividing the total area of arboreal habitat by the total area of terrestrial habitat in the same study area. Vegetation above 1m was regarded as arboreal for this calculation.

Quadrat sampling

The amphibian community was sampled with $1m^2$ quadrats. For terrestrial microhabitats quadrats were made from rigid plastic sheeting. This had 0.6m high walls, which prevented the frogs from escaping before they were counted, and was supported by a vertical wooden strut at each corner. The 'walled' quadrat could not be effectively placed in marsh, brash and hedge microhabitats; alternatively a straight stick, 1 metre in length, was used to determine the sample area within these microhabitats. Marsh, brash and hedge were open areas in which frogs were easily visible and could be counted and

identified without handling, this reduced the probability of frogs escaping before they were counted.

Fieldwork took place between 8.30pm and 11pm when amphibian species are most active. Sampling protocol required 3 field personnel. Two people haphazardly placed the quadrat or metre stick; they captured the frogs within the quadrat by hand and identified species using recently published keys, Daniels 1997. Identified frogs were placed outside of that quadrat, on the side opposite the direction of observer movement to avoid recapture. This was the only way in which frogs were handled; individuals were not removed from the study site. A third person carried a clipboard and recorded the biological and environmental data: number of individuals of each species; number calling; number of pairs in amplexus (copulatory position); substrate moisture (dry/damp/wet/water-logged); rain (nil/light/moderate/heavy); cloud cover (clear/scant/moderate/complete); temperature (°C, read 3 times, at intervals in the sampling period) and moon (% visible). These data were recorded separately for each quadrat.

To minimise disturbance to unsampled patches, sampling started at one end of the site and continued towards the opposite end, a distance of 70m. Fieldwork began at alternate ends each night to avoid bias caused by surveying at different times of night. A standard number of quadrats were placed in each patch every sampling night, in proportion to the patch area. Forty-three $1m^2$ quadrats were placed each night for a total of 17 nights at Pond 1, and 5 nights each at Ponds 2-6.

Transect Sampling.
In order to determine the spatial distribution of aquatic species at Pond 1, a 70m long, 1m wide transect line with distance markers every 2.5m was placed along the water edge. The transect was walked once before and once after quadrat sampling. The position and species of each individual was recorded.

Statistical Techniques

Multivariate statistics:
Detrended correspondance analysis (DECORANA) on the ordination package PC-ORD was used to determine microhabitat use and partitioning within the communities which had sufficiently high amphibian density and species number. Ordination graphs were plotted for species and microhabitats separately, equal distances on the plot correspond to equal differences in samples so that similar entities are situated close by and dissimilar entities are far apart. The aim was to arrange species and microhabitats into recognisable classes. (Gauch 1982).

Principal component analysis (PCA) was used to investigate patterns of species density in response to a variety of weather conditions. PCA identifies and combines the variables that explain the largest amount of variation in the data. New variables, Principal Components, are created from existing ones. Principal component one (PC1) corresponds to the largest amount of information in the data set. Principal component two (PC2) is intended to be as different as possible from PC1 and corresponds to the second largest amount of information in the data. (Fowler *et al.* 1998).

Univariate statistics:
Univariate techniques were used to analyse correlations and associations between environmental variables and frog abundance for most species. ANOVA analysis of variance determined differences between means of species abundance under a variety of environmental conditions.

4.4. Results.

Species-Microhabitat Association.

Pond 1: Ordination of 10 microhabitats by their species (Table 4i) revealed three groupings which I have outlined on the ordination plot (Figure 4a). Species were mainly terrestrial, mainly arboreal and aquatic. Two species were generalists.

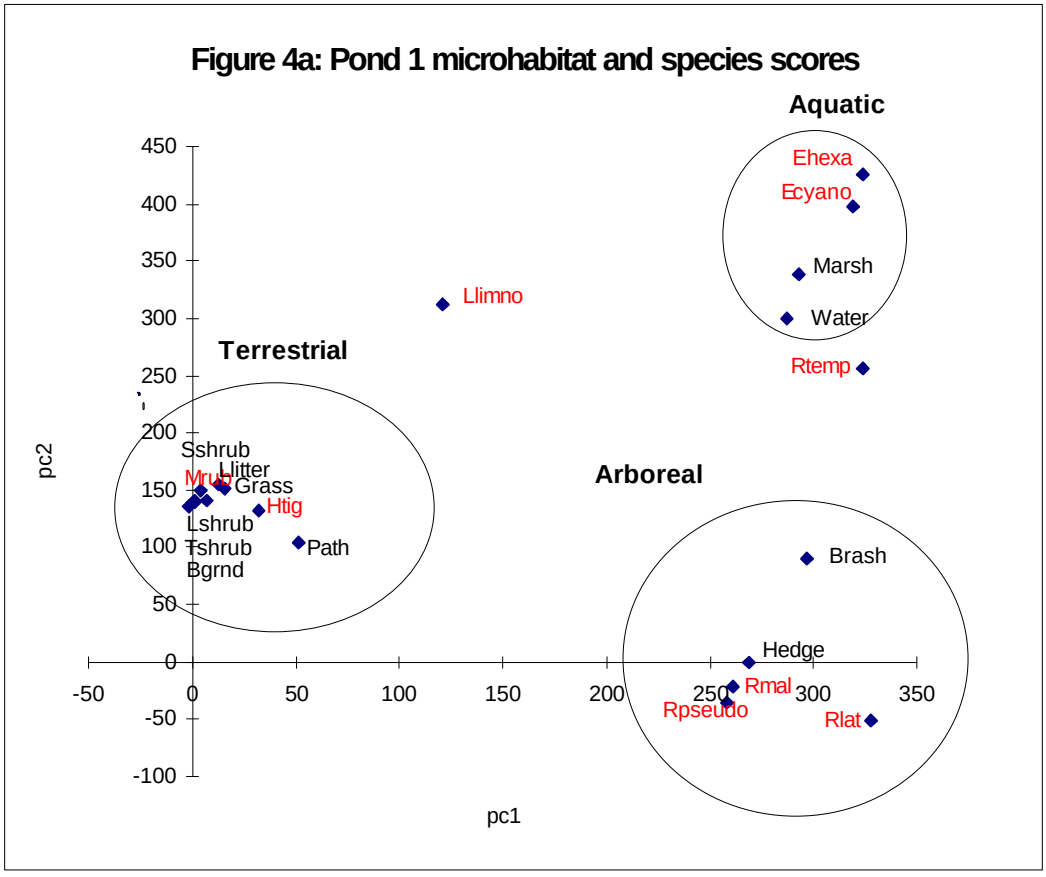


Table 4i: Pond 1 Microhabitat Species Composition. (n/m^2)

Microhabitat	*M.rub*	*R.mal*	*R.lateralis*	*P.pseudo*	*R.temp*	*L.limno*	*E. hexa*	*E.cyano*	*H.tiger*
Hedge	0	0.06	0.02	0.31	0.04	0	0	0	0
Brash	0	0.2	0.16	0.29	0.49	0	0	0	0
Grass	1.94	0.02	0	0.04	0	0.7	0	0	0
Bare ground	0.29	0	0	0.03	0	0.04	0	0	0.07
Sparse shrub	1.16	0	0	0	0	0.03	0	0	0
Low shrub	0.67	0.006	0	0	0	0.14	0	0	0
Tall shrub	1.61	0.05	0	0.03	0	0.08	0	0	0
Leaf litter	0	0	0	0.06	0	0.3	0	0	0.12
Marsh	0	0	0.02	0	0.41	0.14	0	0.23	0
Track	0	0.01	0	0	0	0	0	0	0
Water	0	0.0002	0.0001	0.0001	0.15	0.06	0.018	0.22	0.0004

Terrestrial species: *H.tigerinus* was mainly found on bare ground and leaf litter. Its strongest association was with leaf litter. This species was also recorded in water although very rarely. The *Microhyla* species were found on all terrestrial microhabitats. *M.rubra* was most abundant on grass and tall shrub. *M.ornata* was most abundant in tall shrub and sparse shrub and rare in water. (Table 4i)

Arboreal species: *R.malabaricus* and *P.pseudocruciger* had the greatest habitat overlap. Both were strongly associated with brash and hedge, but were found in aquatic and ground microhabitats, although rarely. *P.pseudocruciger* was most closely associated with hedge but also brash, leaf litter, grass, bare ground, tall shrub and water. *R.malabaricus* was most closely associated with brash, then hedge, tall shrub, grass, low shrub, track and was rare in water. Similarly, *R.lateralis* species was found mainly on arboreal microhabitats, mostly on brash then hedge. *R.lateralis* was not found on ground microhabitats; but was observed in marsh and at low densities in water. (Table 4i)

Aquatic species: *E.cyanophlyctus* was found only in the marsh and on the water transect. *E.hexadactylus* was found only on the water transect. (Table 4i)

Exceptions to the 3 main ecological types are *R.temporalis* and *L.limnocharis. R.temporalis* can be described as arboreal/aquatic. It was found in arboreal microhabitats, brash and hedge, also in marsh and water. *L.limnocharis* demonstrated the most generalist use of microhabitats, it was associated with all terrestrial (except track) and aquatic niches. This species was most abundant in grass, then leaf litter, marsh and low shrub, tall shrub, water, bare ground and sparse shrub. (Table 4i)

Pond 2: Ordination showed no grouping of 9 microhabitats or their 9 species.

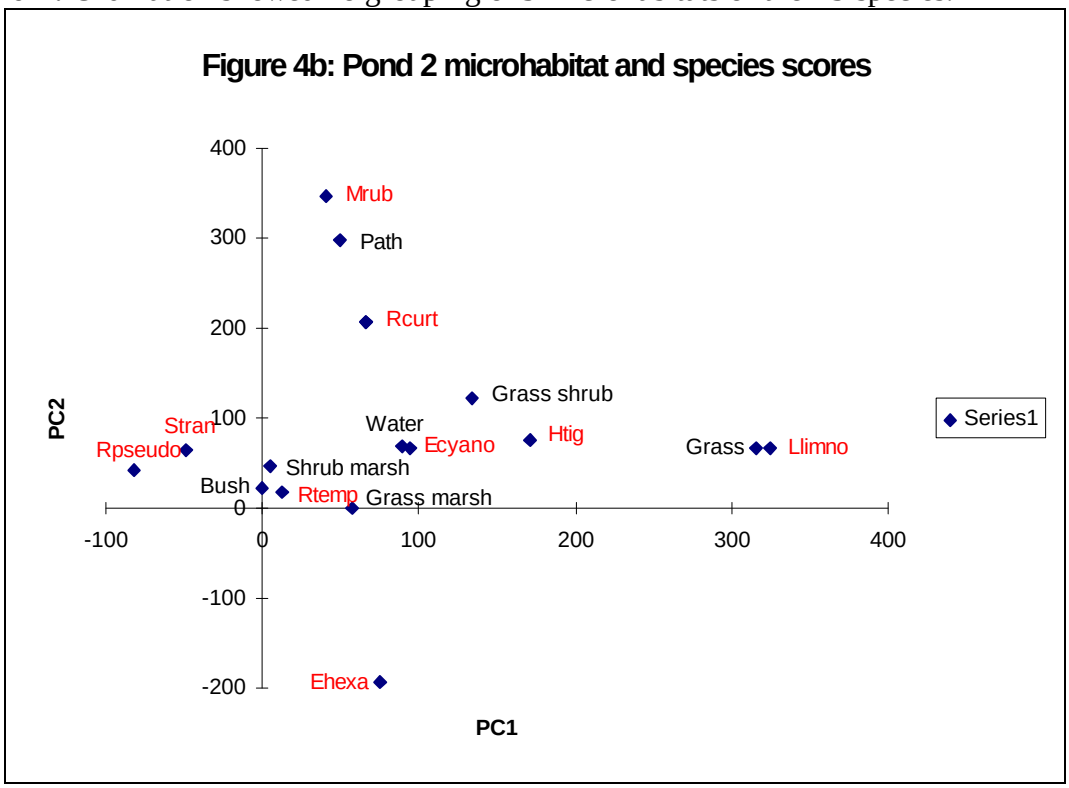


Table 4ii: Pond 2 Microhabitat Species Composition. (n/m^2)

Microhabitat	*M.rub*	*P.pseudo*	*R.temp*	*Stran*	*L.limno*	*R.curt*	*H.tig*	*E.cyano*	*E.hexa*
Bush	0	0.03	0.2	0	0	0	0	0	0
Grass	0	0	0	0	0.66	0	0.04	0	0
Grass marsh	0	0	0.27	0.02	0.05	0	0	0	0.05
Grass shrub	0	0	0	0	0	0.07	0.13	0	0
Track	0.13	0	0	0	0	0.07	0	0	0
Tall shrub	0	0	0	0	0	0.07	0	0	0
Sand bank	0	0	0	0	0	0	0	0	0
Shrub marsh	0	0	0.47	0.13	0.14	0.23	0	0	0
Water	0.043	0	0.2	0	0.07	0.014	0.014	0.043	0.014

Mainly terrestrial species: *M.rubra* was found only on the track and in water. *H.tigerinus* was most common in grass shrub, then grass and was rare in water. *Indirana sp.* ("strped ranid") were found only in the waterlogged terrestrial habitats, they were most abundant in shrub marsh and grass marsh. *L.limnocharis* was most common in grass, then shrub marsh, water and grass marsh. *R.curtipes* was most common in the shrub marsh, was also found in grass shrub, track and tall shrub, and was rare in water. (Table 4ii).

Mainly aquatic species: *E.cyanophlyctis* was recorded only in water. *E.hexadactylus* was most abundant in grass marsh then water. (Table 4ii).

Arboreal species: *P.pseudocruciger* was found only on bush. (Table 4ii).

Exceptions: *R.temporalis* was most abundant in shrub marsh, then grass marsh and was also found on bush and in water. (Table 4ii).

Pond 3: Ordination of 8 microhabitats by their 11 species (Table 4iii) revealed a weakly structured community (Figure 4c). Arboreal species comprised a distinct guild, other species were terrestrial, semi-aquatic and arboreal-aquatic.

Figure 4c: Pond 3 species and microhabitat scores

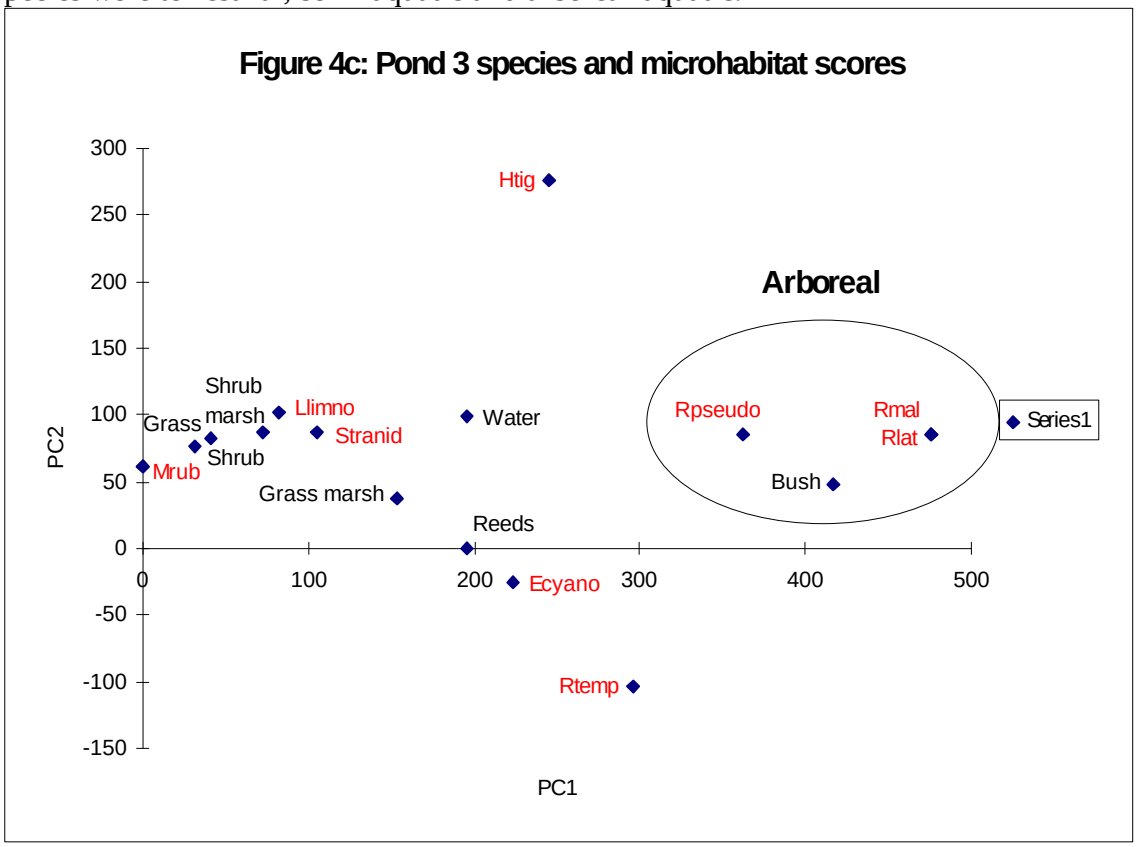


Table 4iii: Pond 3 Microhabitat Species Composition. (n/m^2)

Microhabitat	*M.rub*	*R.mal*	*P.pseudo*	*R.lat*	*R.temp*	*Stran*	*L.limno*	*H.tig*	*E.cyano*
Bush	0	0.025	0.075	0.2	0.075	0	0	0	0
Grass marsh	0.8	0	0	0	0	0	0.8	0	0
Grass	0.733	0	0	0	0	0	0.466	0	0
Reeds	0.044	0	0	0	0.133	0	0.067	0.022	0.067
Low shrub	0.36	0	0.025	0	0.012	0.05	0.52	0	0
Shrub marsh	0	0	0	0	0	0	0.1	0	0.1
Tall shrub	0.533	0	0	0	0	0	0	0	0
Water	0.01	0	0	0	0.03	0	0.035	0.05	0.02

Mostly terrestrial species: *M.rubra* was most dense in waterlogged terrestrial grass marsh habitat and grass, but was also recorded in tall and low shrub, and was less common in the reeds and water. Striped ranids (*Indirana sp.*)were rare at this pond and found only in low shrub. *L.limnocharis* was common and found in all habitats with the exception of bush and tall shrub. It was most strongly associated with low shrub and grass, and also recorded in semi-aquatic and aquatic habitats: shrub marsh, reeds and water. (Table 4iii)

Mainly aquatic species: *E.cyanophlyctis* was mainly aquatic and found in reeds and water. *H.tigerinus* was found at low density at this pond, and was recorded in water and reeds. (Table 4iii)

Arboreal species: *R.malabaricus* and *R.lateralis* were associated only with bush habitat, *R.lateralis* was more common than it's sympatric *R.malabaricus. P.pseudocruciger* was also rare and found at it's highest density in bush, but was also recorded in low shrub. (Table 4iii)

Arboreal-aquatic: *R. temporalis* was found frequently in both aquatic and arboreal habitats; it was most common on reeds, then bush, water and low shrub. (Table 4iii)

Pond 4: Most species were found too rarely for ordination analysis of this community.

Table 4iv: Pond 4 Microhabitat Species Composition. (n/m^2)

Microhabitat	*St ranid*	*L.limno*	*M.rub*	*P.pseudo*	*R.mal*	*E.cyano*	*H.tig*	*E.hexa*	*R.temp*
Bush	0	0	0	0	0	0	0	0	0
grass	0.014	0.086	0.14	0.028	0.014	0.014	0.014	0	0.043
grass marsh	0.286	0	0	0	0	0	0	0	0
mud marsh	0.1	0.05	0	0	0	0.05	0	0.025	0
Sparse shrub	0	0.12	0	0	0	0	0	0	0
Shrub	0.12	0.16	0.04	0	0	0	0	0	0
water	0.003	0	0	0	0	0.006	0.003	0.09	0.037

Terrestrial species: *M.rubra* was strictly terrestrial and most common in grass, then shrub. *P.pseudocruciger* and *R.malabaricus* were found only in grass, at very low densities. (Table 4iv)

Terrestrial-aquatic species: The striped ranid (*Indirana* sp.) and *L.limnocharis* were found in most microhabitats. Striped ranids were most common in grass marsh, then shrub and mud marsh, and was rare in grass and water. *L.limnocharis* was most common in shrub, and sparse shrub, and was also found in grass and mud marsh. Similarly

H.tigerinus was found in grass and water. *E.cyanophlyctis* was most abundant in grass and then water. *R.temporalis* was found in grass and water. (Table 4iv)

Mostly aquatic species: *E.hexadactylus* was most common in water, then mud marsh. (Table 4iv)

Pond 5: Ordination was not possible for this data set as the community comprised only 3 species.

Table 4v: Pond 5 Microhabitat Species Composition. (n/m^2)

Microhabitat	*L.limno*	*Indirana*	*Yellow thigh*
bush	0	0	0.07
grass	0.03	0.05	0
grass path	0	0.1	0
grass marsh	0.35	0.15	0
grass/shrub marsh	0.15	0.15	0
reeds	0.05	0	0.05
uncultivated paddy	0.15	0.25	0
cultivated paddy	0.05	0.15	0
bare ground	0.05	0	0
water	0.19	0.08	0

Terrestrial-aquatic species: Both *L.limnocharis* and *Indirana* were found in terrestrial and aquatic habitats. *L.limnocharis* was most common in grass marsh, then water, grass/shrub marsh and uncultivated paddy, was less common in cultivated paddy, bare ground and reeds and was least common in grass. *Indirana* were most abundant in the uncultivated paddy, then grass marsh, grass shrub marsh and cultivated paddy, grass track, and was least abundant in water. (Table 4v)

Arboreal species: The yellow thighed *Philautus* was rare at the site, highest density was on bush, then reeds. (Table 4v)

Pond 6: Ordination analysis was not possible as there was too little variation in the microhabitat use of this community**.**

Table 4vi: Pond 6 Microhabitat Species Composition. (n/m^2).

Microhabitat	L.limno	Wh sp	R.temp	R.lat	E.cyano	M.rub
Grass shrub	0.2	0	0	0	0	0
Grass	0.15	0.05	0	0	0	0
Cardamom plants	0	0	0.025	0.025	0	0
Cardamom leaf litter	0	0	0	0	0	0
Bare ground	0	0	0	0	0	0
Shrub	0	0	0	0	0	0
Pool	0	0	0	0	0.09	0
Stream	0.035	0.15	0	0	0	0.003

Mostly terrestrial species: *L.limnocharis* was mainly found in grass shrub and grass, and was found at low density in the stream. No frogs were recorded in the leaf litter below the cardamon plants, on bare ground or in shrub. (Table 4vi)

Mostly aquatic species: *Nyctobatrachus* sp. was most abundant in the stream, but also found in grass. *M.rubra* was found at low abundance only in the stream. *E.cyanophlyctis* was found in the pool, and was absent from the stream. (Table 4vi)

Arboreal species: *R.temporalis* and *R.lateralis* were rare and found only on the cardamom plants. (Table 4vi)

Pond attributes and species composition.

Ordination of ponds by their species and separately by their physical characteristics allows us to investigate whether species choose breeding sites according to the attributes of those sites. Ordination of ponds by 14 physical characteristics (including vegetation structure, water attributes and surrounding habitat) shows ponds 1 and 2 close together on the plot, indicating that they are similar in terms of the characters measured. Ponds 3 and 5 are placed at the opposite end of axis 1 indicating dissimilarity with ponds 1 and 2; ponds 4 and 6 are intermediates. (Figure 4d). Ordination of ponds by their species shows a different arrangement. Ponds 1 & 3 and 5 & 6 are placed at opposite ends of axis 1, ponds 2 and 4 are higher on axis 2 and intermediate on axis 1. (Figure 4e). Comparison of the plots shows a lack of correspondence between pond character and the species which are found there. For example, whereas ponds 1 and 2 are similar in their physical attributes they are very different in species composition. Likewise, ponds 5 and 6 are different in physical attributes, but more similar in species composition.

Figure 4d: Pond character scores

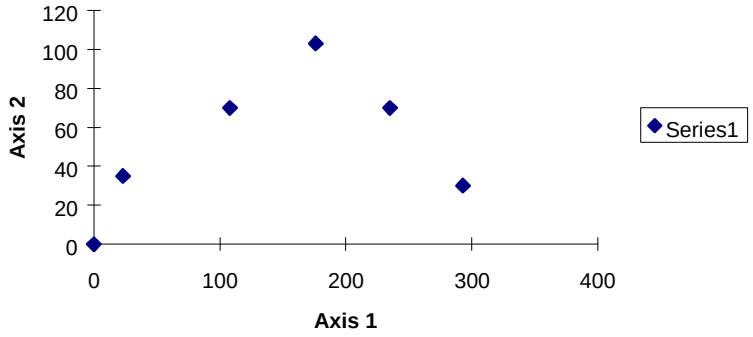


Figure 4e: Pond species scores

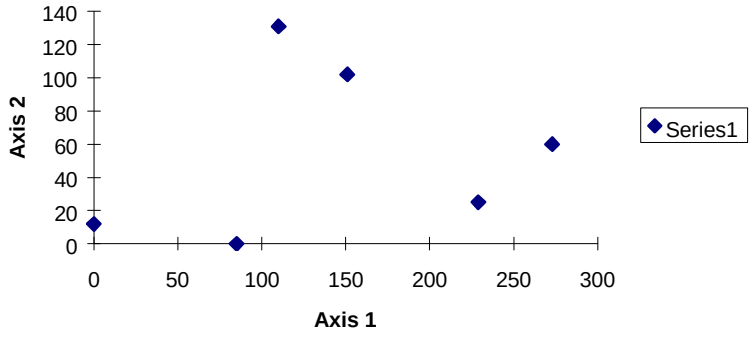


Table 4vii: Pond species composition (n/m^2).

Pond	Ecyano	Ehexa	Htig	Llimno	Micro	P.pseudo	Rtemp	Rmal	St ranid	Ythigh	Rlat	White spot	Rcurt
1	0.12	0.01	0.0005	0.085	1.23	0.04	0.135	0.025	0	0	0.015	0	0
2	0.022	0.012	0.018	0.114	0.022	0.0001	0.165	0	0.0001	0	0	0	0.012
3	0.019	0	0.027	0.159	0.139	0.012	0.038	0.001	0.001	0	0.02	0	0
4	0.01	0.047	0.001	0.035	0.019	0.001	0.025	0.001	0.043	0	0	0	0

5	0	0	0	0.158	0	0	0	0	0.082	0.001	0	0	0
6	0.007	0	0	0.029	0	0	0.001	0	0	0	0.0001	0.055	0

Table 4viii: Pond attributes.

Pond	water area (m^2)	water vol (m^3)	water depth (m)	pH	arb ht (m) *	terr ht (m)**	undev(m) ***	wat(m) ****	ar:terr ?	sn/dev ??	t/p ???	ave. veg. cover (m^2)	% shrub	% grass
1	1188	2495	2.1	7.1	1	0.08	0	0	0.07	s/nat	temp	65	50	8
2	4400	33000	7.5	7.3	1.4	0.1	20	0	0.13	s/nat	perm	90	31	43
3	72	18	0.25	6.5	2	0.12	200	120	0.05	s/nat	temp	100	49	13
4	392	196	0.5	7.7	1.25	0.05	120	0	0.02	dev	perm	74	11	63
5	27.5	1.4	0.05	6.4	3.8	0.05	50	320	0.2	dev	temp	96	1	38
6	72.5	7.25	0.1	6.6	2.5	0.23	30	0	0.4	dev	perm	89	7	7

*height of arboreal habitat (m); **height of terrestrial habitat (m); ***distance to nearest undeveloped habitat (m);
****distance to nearest permanent water source (m); ?ratio of arboreal to terrestrial microhabitat;
??surrounding habitat semi-natural or developed; ???water source temporary or permanent.

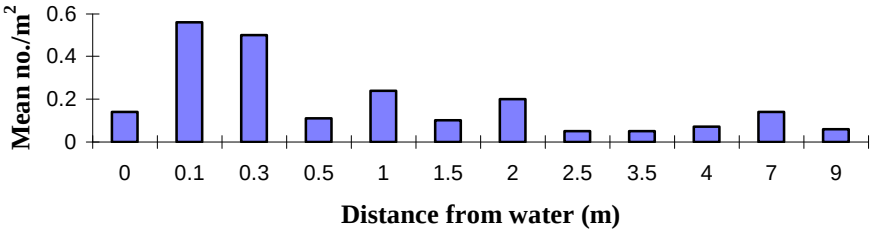
3.3. Within microhabitat partitioning.

3.3.1. Effect of distance from water on species density.

Pond 1:

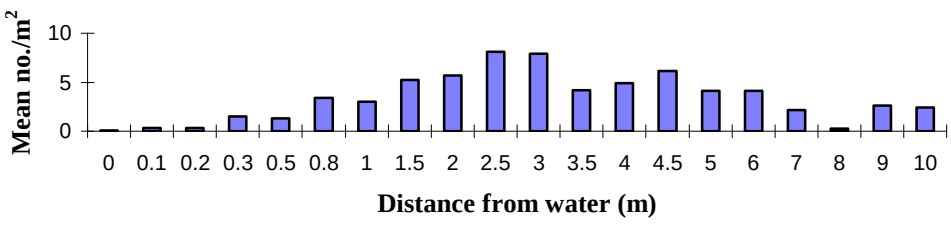
L.limnocharis varied in species density at different distances from the water edge. (ANOVA P=0.033, DF=11, F=1.93,n=713). Density was highest between 0.1m and 0.3m from water, and low between 0.5m and 9m from the water edge. (Figure 4f).

Figure 4f: Pond 1 *L.limnocharis:* Variance in mean density with distance from water



M.rubra density varied with distance from the water edge. (ANOVA P = 0.001, F=8.86, D.F. = 19,n=713). *M.rubra* density was low up to 1.5m from the water, peaked between 1.5m and 3m, and was low between 3.5m and 10m. (Figure 4g).

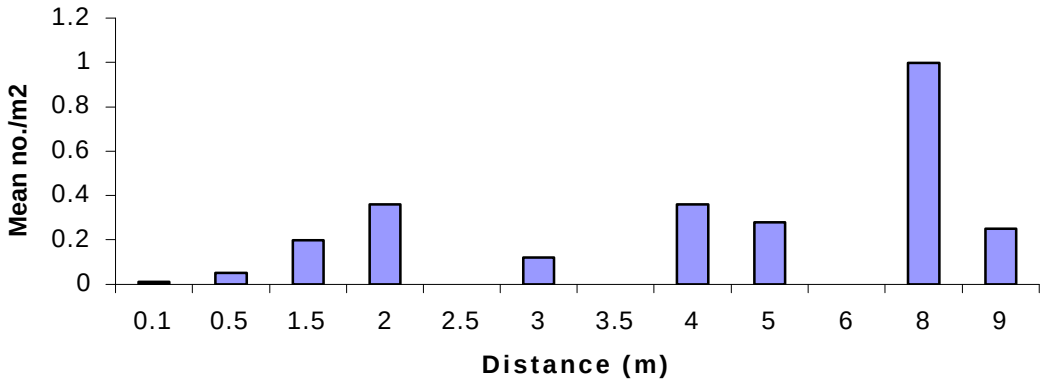
Figure 4g: Pond 1 *M.rubra* : Variance in mean density with distance from water



Pond 2:

L.limnocharis. There was a significant variance in species density at different distances from the water edge. (ANOVA P=0.025, DF=11, F=2.05,n=254). Density fluctuated between 0.5m and 9m from the water edge, and peaked at 8m from the water edge. (Figure 4h)

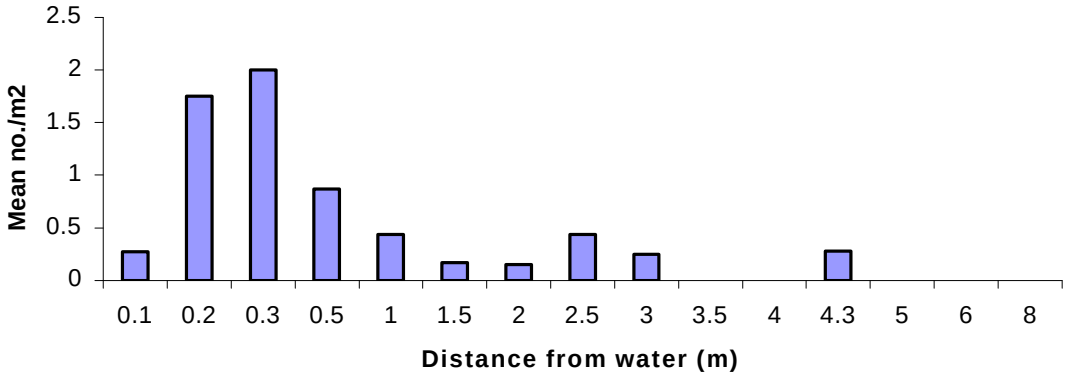
Figure 4h: Pond 2 *L.limnocharis*: Variance in mean density with distance from water



Pond 3:

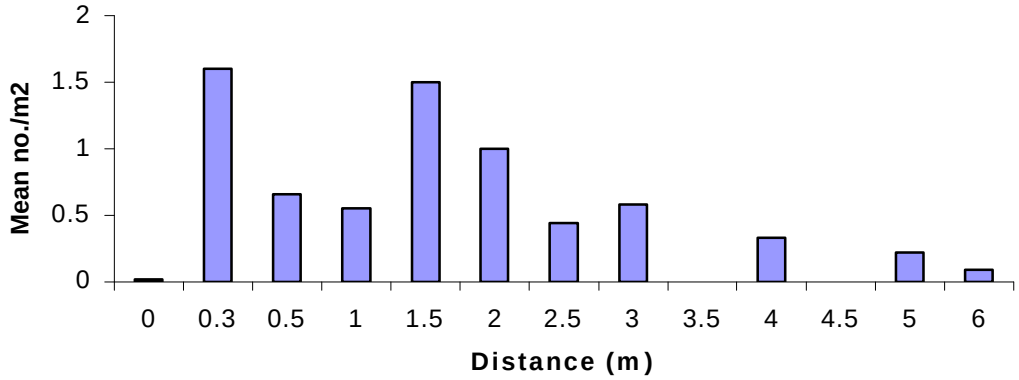
L.limnocharis. Density varied significantly at different distances from the water, peaking between 0.2m and 0.3m from the water edge. (ANOVA P=0.001, DF=14, F=5.89,n=177). (Figure 4i)

Figure 4i: Pond 3 *L.limnocharis*: Variance in mean density with distance from water



M.rubra. There was a significant variance in species density at different distances from the water edge. (ANOVA P=0.001, DF=12, F=5.92,n=152). Density fluctuated between 0.3m and 6m, and was generally highest closest to the water edge. (Figure 4j)

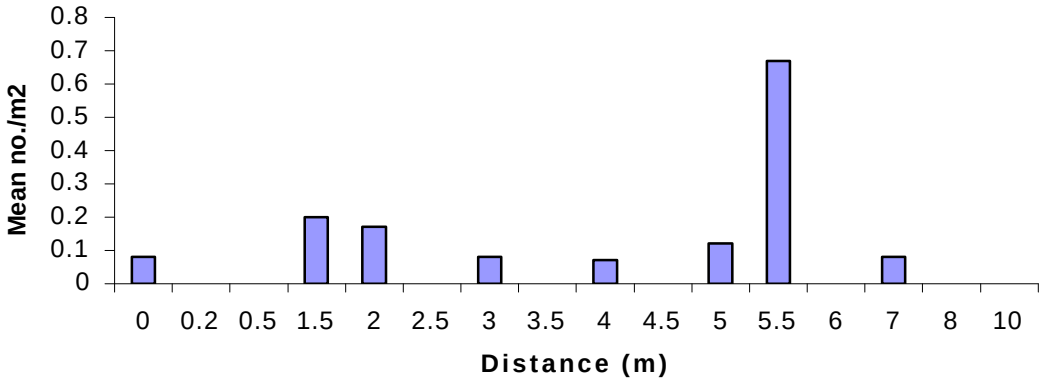
Figure 4j: Pond 3 *M.rubra* : Variance in mean density with distance from water



Pond 4:

L.limnocharis. Density varied significantly at different distances from the water, fluctuating between 0m and 7m, and peaking at 5.5m from the water edge. (ANOVA P=0.017, DF=16, F=1.98,n=185). (Figure 4k)

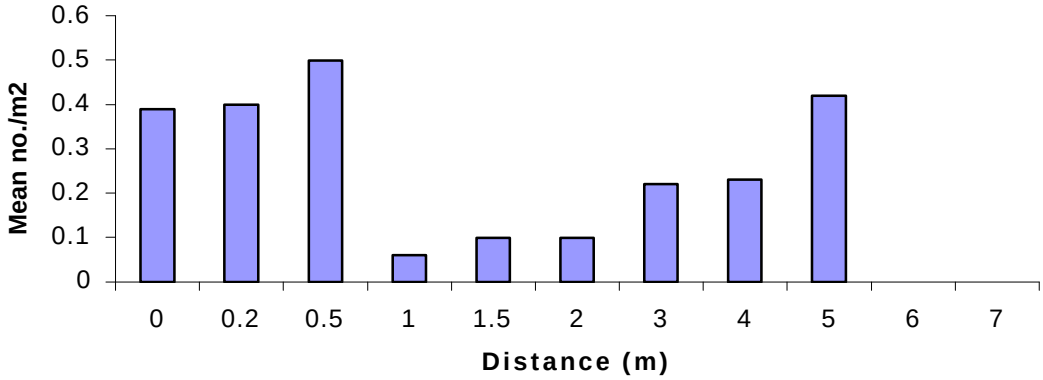
Figure 4k: Pond 4 *L.limnocharis* : Variance in mean density with distance from water



Pond 5:

L.limnocharis. There was not a significant variance in species density at different distances from the water edge. (ANOVA P=0.322, DF=10, F=1.16,n=127). Density fluctuated between 0.2m and 7m from the water edge, and was generally highest closest to the water edge. (Figure 4l).

Figure 4l: Pond 5 *L.limnocharis*: Variance in mean density with distance from water



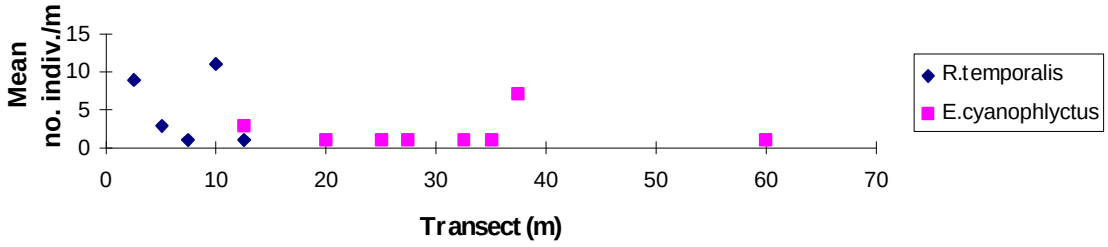
Within microhabitat partitioning.

Spatial distribution of transect species at Pond 1.

For most transects *R.temporalis* and *E.cyanophlyctis* showed significant variance in their distribution along the water edge, with *R.temporalis* found mainly between 0m and 15m and at higher densities than *E.cyanophlyctis* which was found mainly between 12m and 60m of the 70m transect. (Figures 4m,n,o,p).

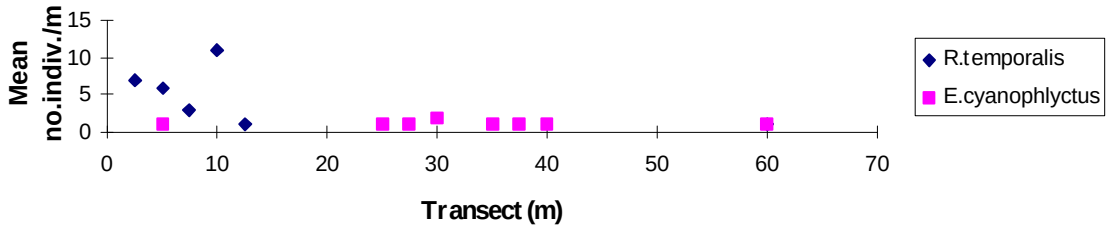
11/08 Transect 1:
R.temporalis: (ANOVA P=0.002, DF=27, F=2.25, N=140)
E.cyanophlyctis: (ANOVA P=0.001, DF=27, F=4.90, N=140)

Figure 4m: Transect species distribution



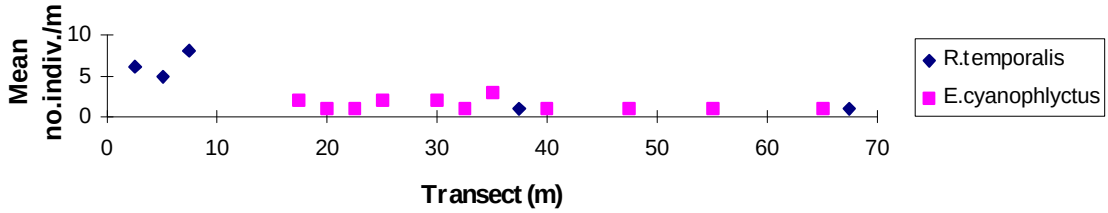
11/08 Transect 2:
R.temporalis: (ANOVA P=0.001, DF=27, F=3.53, N=140)
E.cyanophlyctis: (ANOVA P=0.069, DF=27, F=1.52, N=140)

Figure 4n: Transect species distribution



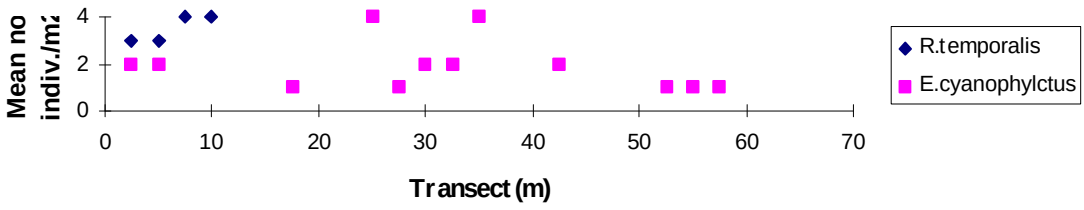
13/08 Transect 1:
R.temporalis: (ANOVA P=0.001, DF=27, F=3.80, N=140)
E.cyanophlyctis: (ANOVA P=0.025, DF=27, F=1.73, N=140)

Figure 4o: Transect species distribution



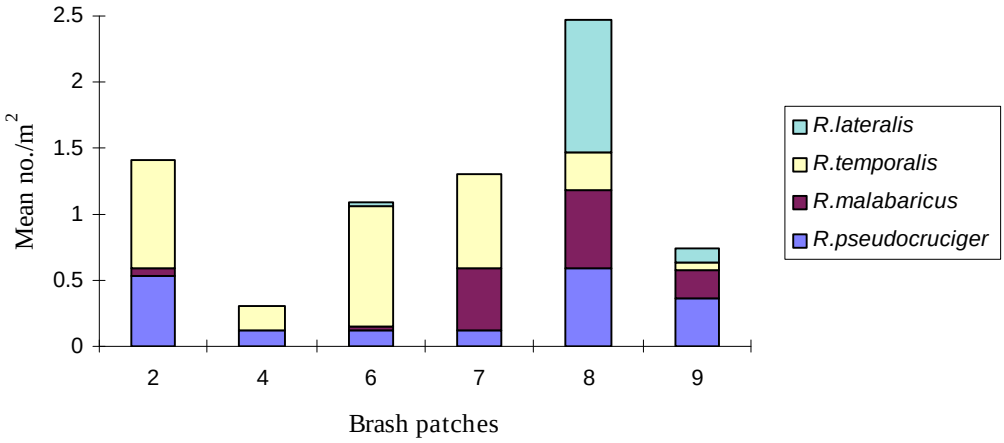
13/08 Transect 2:
R.temporalis: (ANOVA P=0.001, DF=27, F=3.80, N=140)
E.cyanophlyctis: (ANOVA P=0.001, DF=27, F=2.31, N=140)

Figure 4p: Transect species distribution



Partitioning of microhabitat patches by arboreal species at Pond 1.
The density of each species differs significantly between six patches of brash. (Figure 4q).
R.malabaricus: (ANOVA P=0.001, DF=5, F=4.45, n=135).
P.pseudocruciger: (ANOVA P=0.004, DF=5, F=3.66, n=135).
R.temporalis: (ANOVA P=0.001, DF=5, F=5.22, n=135).
***R.lateralis*:** (ANOVA P=0.001, DF=5, F=24.62, n=135).

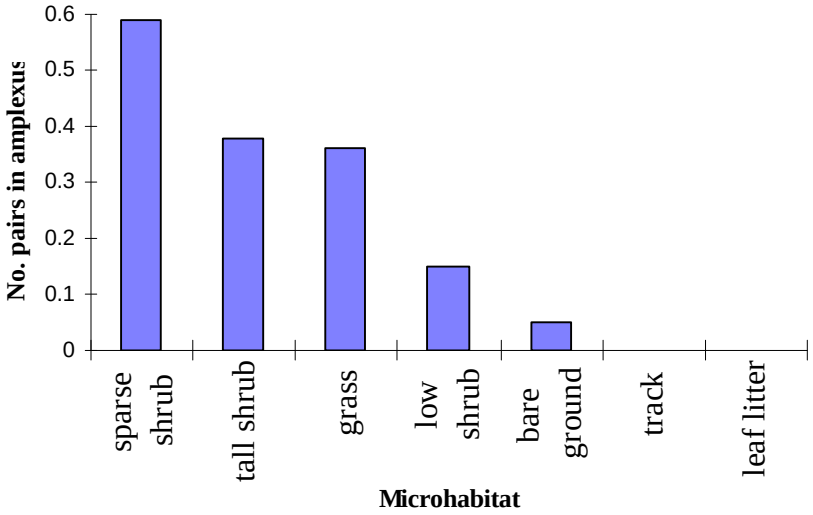
Figure 4q: Partitioning of brash patches by arboreal species



Amplexus microhabitat of *Microhyla* species at Pond 1.

M.rubra showed a significant variance in the frequency of amplexus in different microhabitats. (ANOVA P=0.046, F=2.18, DF=6, n=239). (Figure 4r). Amplexus is most frequent in sparse shrub, tall shrub and grass,
respective

Figure 4r: *M.rubra* : Microhabitat preference for amplexus



The effects of weather on species density.

Principal Component Analysis

Principal Component Analysis (PCA) was used to investigate patterns of species density in relation to environmental variables. Each species record (density) was treated as an independent variable, with associated environmental attributes (air temperature, cloud cover, rainfall, rainfall in last 24 hours, moon and substrate moisture).

PCA of *R.malabaricus*

Only PC1 and PC2 are considered in this analysis, since together they explain 65% of information in the data set. PC1 has an eigenvalue of 2.40. The highest component loading is rainfall in the last 24 hours. PC2 has an eigenvalue of 1.52 and the highest component loading is temperature. The PCA plot shows strong clustering, with only 3 outlying data points. Samples are distributed most closely at the high positive end of the PC2 axis, indicating a preference of animals for higher air temperature. The data are also centred between -1 and +1 on the PC1 axis. This indicates a preference for medium rainfall in the previous day. Intermediate and high density samples are grouped within the main cluster and there is one outlying high density point. (Figure 4s).

PCA of *L.limnocharis*.

Only PC1 and PC2 are considered in this analysis, since together they explain 54% of the information in the data set. PC1 has an eigenvalue of 1.97. The highest component loadings are rainfall in the last 24 hours and moon, respectively. PC2 has an eigenvalue of 1.27 and the highest component loadings are rainfall at time of data collection and substrate moisture in that order. Data in the PCA plot are distributed at the negative end of the PC1 axis, with the exception of 4 points. Data are not clustered on the PC2 axis. This suggests a preference for low levels of rainfall in the past 24 hours and low visibility of moon. Intermediate and high density samples are not clustered. (Figure 4t).

PCA of *P.pseudocruciger*

Only PC1 and PC2 are considered in this analysis, as together they explain 62% of the information in the data. PC1 has an eigenvalue of 2.39. The highest component loading is rainfall in the last 24 hours. PC2 has an eigenvalue of 1.34 and the highest component loadings are rainfall in the last 24 hours, substrate moisture and rainfall at time of data collection, in that order. The PCA plot shows no meaningful pattern. Data points are widely distributed on both axes and intermediate and high density samples are haphazardly distributed. (Figure 4u).

Figure 4u: PCA plot of *R.pseudocruciger*

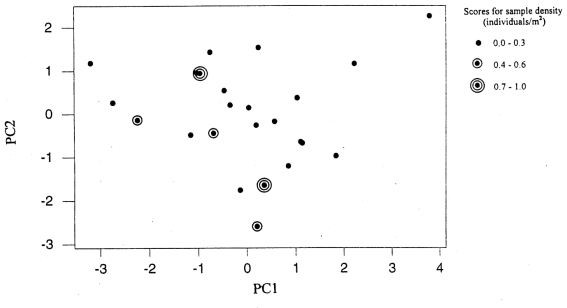


Figure 4v: PCA plot of *R.lateralis*

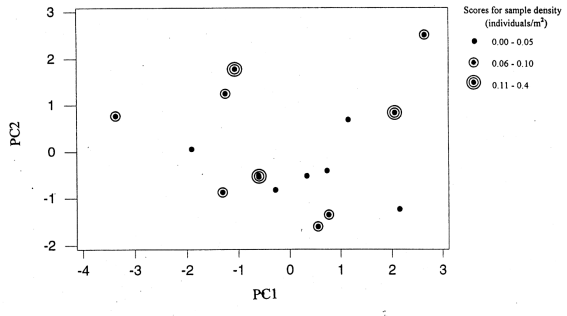


Figure 4w: PCA plot of *R.temporalis*

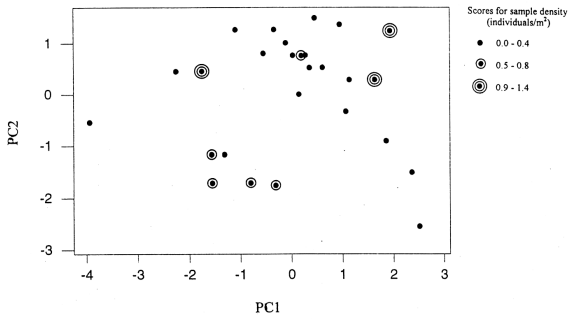


Figure 4x: PCA plot of *M.rubra*

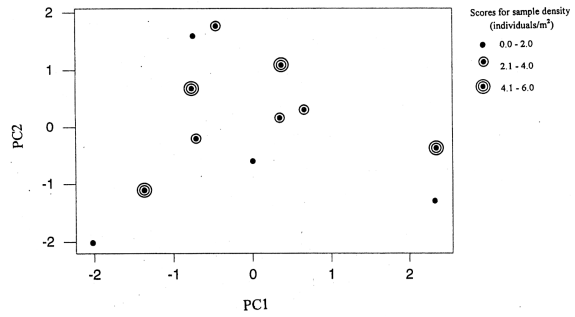


Figure 4s: PCA plot of *R.malabaricus*

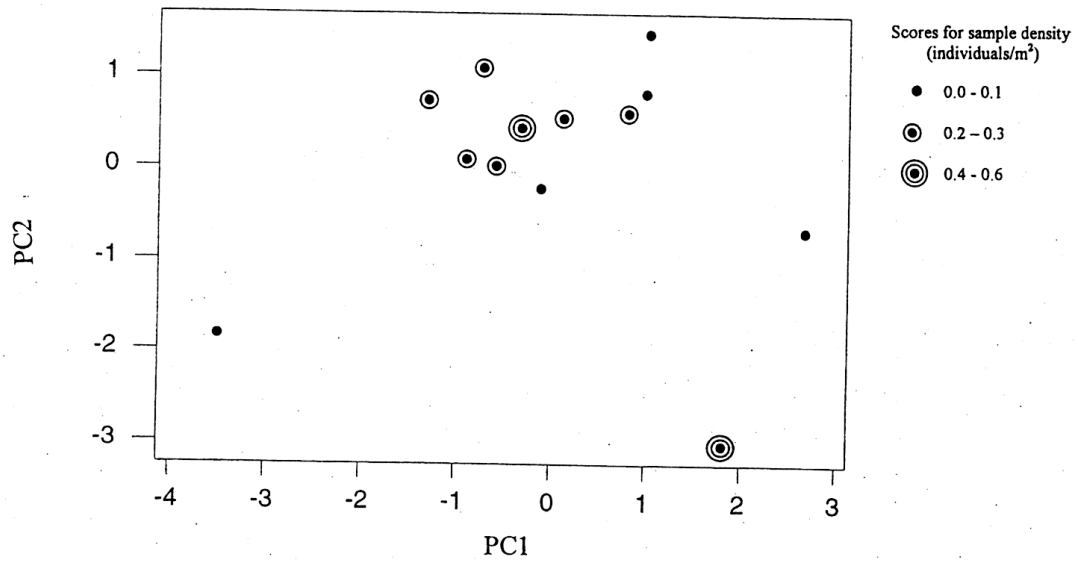
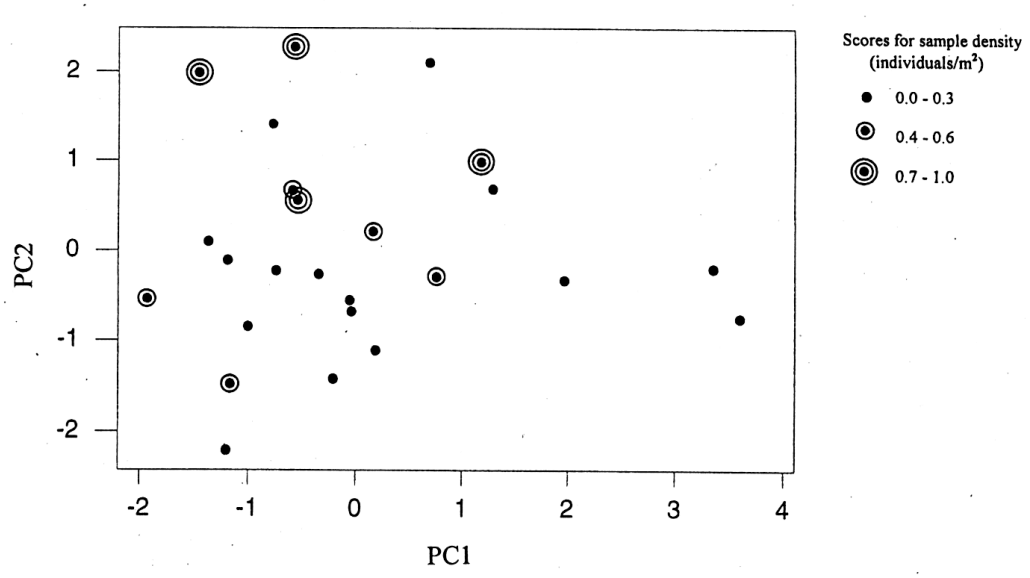


Figure 4t: PCA plot of *L.limnocharis*



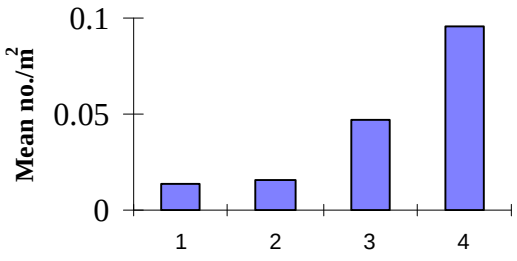
PCA of *R.lateralis*:
PC1 and PC2 are considered in this analysis, since together they explain 67% of the information in the data. PC1 has an eigenvalue of 2.59. The highest component loadings are cloud cover, substrate moisture and temperature, in that order. PC2 has an eigenvalue of 1.41 and the highest component loadings are moon and rainfall at time of data collection, in that order. There is no meaningful pattern in PCA plot. Samples are widely distributed on both axes and there is no clustering of points of intermediate and high density. (Figure 4v).

PCA of *R.temporalis.*
Only PC1 and PC2 are considered in this analysis, as together they explain 60% of the information in the data. PC1 has an eigenvalue of 2.24 and the highest component loadings are cloud cover, temperature and rainfall at time of data collection, in that order. PC2 has an eigenvalue of 1.34, the highest component loading is temperature. Data are weakly clustered at the positive ends of both axes. If the clustering were meaningful it would suggest a preference for overcast conditions, high air temperature and rainfall on the PC1 axis. Samples with intermediate and high density are not grouped. (Figure 4w).

PCA of *M.rubra*
Only PC1 and PC2 are considered in this analysis, as together they explain 62% of the information in the data. PC1 has an eigenvalue of 1.76 and the highest component loadings are rainfall in the last 24 hours and cloud cover in that order. PC2 has an eigenvalue of 1.35. The highest component loading is air temperature. The PCA plot reveals no meaningful pattern. Data are widely distributed on both axes and intermediate and high density samples are haphazardly distributed. (Figure x).

Effect of cloud cover on species abundance.
There was a weak significant variance in the abundance of *R.malabaricus* at different levels of cloud cover, 1 (clear) to 4 (complete). (ANOVA P=0.057, DF=3, F=2.52, n=752). Abundance was lowest at cloud levels 1 and 2 respectively, and highest at levels 3 and 4 respectively. The above test was also run for *R.malabaricus* abundance at cloud level 1 and 2 combined and 3 and 4 combined. The result was significant. (ANOVA P=0.045, DF=1,F=4.05, n=752). (Figure 4y). All other species showed no significant response to cloud cover.

Figure 4y: *Rhacophorus malabaricus* :
Variance in mean density with cloud cover



Cloud cover (1=clear; 2=scant; 3=moderate; 4=complete).

Affect of moon on species abundance
There was no significant variance in the abundance of species in relation to the proportion of visible moon.

Affect of rainfall on species abundance

M.rubra was significantly more abundant during light and nil rain (4.09/m^2), than during moderate and heavy rain (1.99/m^2). (ANOVA P=0.001, DF=1, F=6.78,n=731). All other species were unaffected by rain falling at the time of data collection.

Affect of rainfall in the last 24 hours on species abundance.

R.malabaricus was significantly more abundant when there were medium levels of rainfall in the last 24 hours. (ANOVA P=0.001, DF=11, F=3.03,n=731) (Figure 4z(i)). *M.rubra* also showed a significant increase in abundance with increasing rainfall in the previous day, but declined in abundance at the highest rainfall (1.13 inches). (ANOVA P=0.001, DF=11, F=5.03,n=731) (Figure 4z(ii)). Other species were unaffected by rainfall in the previous day.

Figure 4z(i): *Rhacophorus malabaricus:* Variance in mean density with rainfall in the previous day

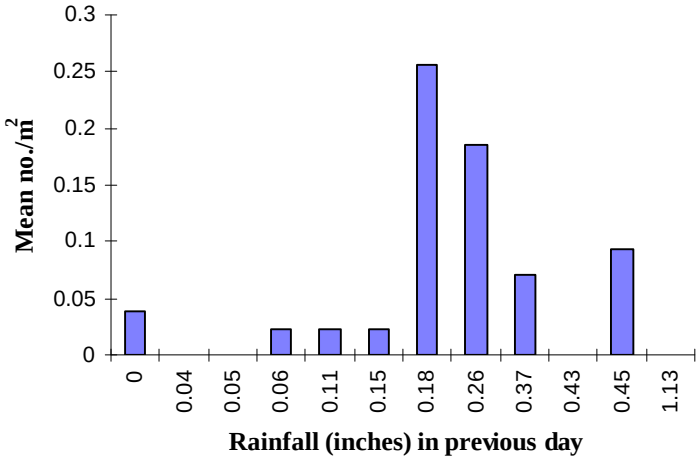
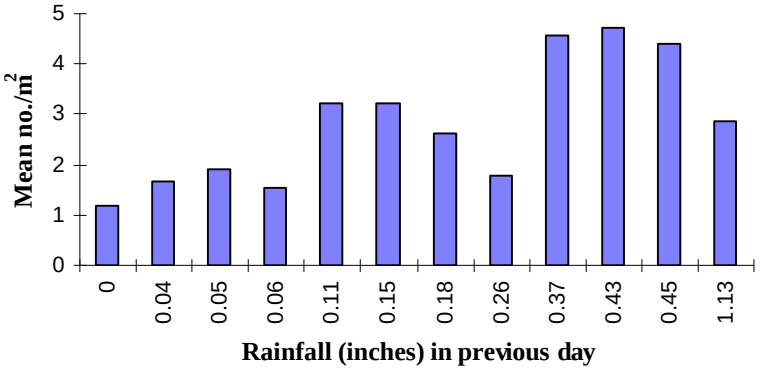


Figure 4z(ii): *M.rubra* :
Variance in mean density with rainfall in the previous day



Affect of substrate moisture on species abundance.

Three species were affected by substrate moisture. *R.temporalis* was significantly more abundant on damp substrates than on wet or dry substrate. (ANOVA P=0.003, DF=2, F=1.72,n=731).

R.lateralis showed a significant increase in abundance on dry substrate than on damp or wet substrate. (ANOVA P=0.033, DF=2, F=3.43,n=731). *M.rubra* showed a significant preference for damp substrates, compared to wet and dry substrates. (ANOVA P=0.001, DF=2, F=9.39,n=731). (Table 4ix). All other species showed no significant response to substrate moisture.

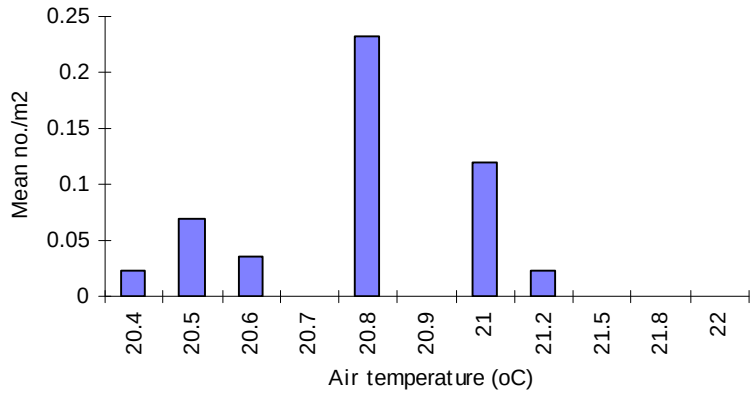
Table 4ix: Variation in species density with substrate moisture

Substrate moisture	**Species (n/m^2)**		
	R.temporalis	***M.rubra***	***R.lateralis***:
Dry	0.149	2.289	0.065
Damp	0.031	4.408	0.011
Wet	0.148	3.091	0.033

Affect of temperature on species abundance

R.malabaricus was most abundant at medium air temperature. (ANOVA P=0.030, DF=10, F=2.00,n=731). (Figure 4z). All other species show no significant difference in the abundance in relation to air temperature.

Figure 4z(iii): *R.malabaricus*:
Variance in mean density with air temperature



Affect of rainfall on frequency of amplexus.

ANOVA reveals a significant difference in number of *M.rubra* pairs in amplexus in light-nil rain compared to number of pairs in moderate-heavy rain. (ANOVA P=0.043, F=4.09, DF=1, n=573). Amplexus was most frequent during light and nil rainfall, with 0.178 pairs in amplexus/m^2. There were no observations of *M.rubra* in amplexus during moderate and heavy rain.

4.5 Discussion

Each breeding pond community was clearly partitioned by species' microhabitat use. In addition, daily environmental fluctuations caused species density to vary under different conditions, creating the potential for temporal resource partitioning. The present study cannot relate the observed species-specific differences in resource use to the underlying mechanisms that drive this

phenomenon. Interspecific competition is a likely explanation and is supported by Pianka (1994), Schoener (1973) and Das (1996). The 'apparent competition' theory of species segregation as a means of reducing the pressure of a shared predator is also a viable explanation for partitioning of resources within communities (Holt 1984).

Microhabitat use segregates species to a greater degree than response to environmental conditions, and segregation in this dimension alone may create sufficient ecological distance between species to allow coexistence. Species-specific responses to environmental fluctuations could be explained by a number of alternative factors, including physiological restraints, optimum conditions for mate location/amplexus, prey availability and evasion of predators. Segregation within microhabitats (e.g. brash and water transect) may allow females to locate conspecific males more easily than if they were aggregated with calling members of other species.

Regardless of ecological explanation, each amphibian species is uniquely and intimately affected by the biotic and abiotic components of its environment. This has clear implications for conservation. Biological communities are shaped by the structure of their environments on an evolutionary time scale; natural rainforest habitats provide a wide variety of niches that support a corresponding level of amphibian diversity (Pianka 1994). Cultivated land is markedly less heterogeneous than native habitat, and it seems reasonable to expect that the ability of species to exist/co-exist in these areas depends on the variety of microhabitats they offer, as well as their proximity to native habitats. The observed sensitivity of species to abiotic fluctuations in their environment is another area of concern in light of anticipated climate change. Such species may suffer niche restriction and a subsequent reduction of activity, in response to either climate change or the loss of their native rainforest microclimate. If this is the case, amphibian species may require particularly close attention in wildlife monitoring programmes.

Highly altered environments are extremely important sites for ecological study, as these comprise an increasing majority of the available wildlife habitat. In the present study we were fortunate to find a frog-friendly estate. Lukunda sports several large water bodies, has substantial areas of uncultivated land, adjoins a reserve of native forest and is managed without the use of pesticides, qualities reflected by the richness of amphibian species found there. The potential of commercially managed land to support amphibian diversity is especially relevant when considering that only isolated fragments of rainforest remain in the Western Ghats (Thapar 1996). Valuable future research would involve a wide scale investigation of the amphibian communities supported by coffee, tea and rice plantations, with a focus on the impacts of varying management practices, including the use of pesticides and inclusion of undisturbed habitat. Information generated by such research would allow the development of guidelines for managing commercial land with the aim of supporting a maximum diversity of amphibian fauna.

4.6 Appendix -- Microhabitat classification

Pond 1:

Microhabitat	Patch	Quadrat	Gradient	Components	%cover	Ave. Ht/Depth
Marsh	1	1	0	aquatic grass	50	0.3m
				water	50	0.09m
		2	0	aquatic grass	30	0.32m
				water	70	0.09m
		3	0	aquatic grass	30	0.41m
				water	70	0.17m
Brash	2		1	standing brash	25	1.5m
	4		1	standing brash	30	1.5m
	6		1	standing brash	30	1.5m
	7		1	standing brash	25	1.5m
	8		1	standing brash	30	1.5m
	9		1	standing brash	20	1.5m
Leaf Litter	3	1	1	leaf litter	100	0.015m
Low Shrub	5	1	2	mixed shrub	100	0.03m
		2	2	mixed shrub	90	0.04m
				bare soil	10	
		3	2	mixed shrub	90	0.05m
				bare soil	10	
		4	2	mixed shrub	100	0.09m
		5	2	mixed shrub	85	0.07m
				bare soil	15	
Low Shrub	17	1	0	mixed shrub	95	0.05m
				bare soil	5	
		2	1	mixed shrub	90	0.07m
				bare soil	10	
		3	0	mixed shrub	65	0.04m
				bare soil	35	
		4	0	mixed shrub	90	0.05m
				bare soil	10	
Bare Ground	10	1	0	bare soil	100	
	18	1	2	bare soil	100	
	19	1	1	bare soil	100	
Patchy Low Shrub	11	1	1	mixed shrub	40	0.07m
				bare soil	60	
		2	1	mixed shrub	25	0.08m
				bare soil	75	
		3	1	mixed shrub	10	0.05m
				bare soil	90	
Tall Shrub	12	1	2	mixed shrub	85	0.15m
				bare soil	15	
		2	0	mixed shrub	70	0.2m
				bare soil	30	
		3	2	mixed shrub	70	0.2m
				bare soil	30	
Grass	13	1	1	grass	50	0.03.m
				bare soil	50	
		2	0	grass	60	0.03m
				bare soil	40	
		3	1	grass	50	0.02m
				bare soil	50	
Tall Shrub	14	1	0	mixed shrub	80	0.15m
				bare soil	20	
		2	0	mixed shrub	70	0.2m
				bare soil	30	
		3	0	mixed shrub	75	0.2m
				bare soil	25	
		4	0	mixed shrub	60	0.1m
				bare soil	40	
Path	15	1	0	bare stone	100	
Hedge	16	1	0	leaf cover	30	1.05m
		2	0	leaf cover	50	1m
		3	0	leaf cover	70	0.72m
		4	0	leaf cover	100	1.25m

Pond 2:

Microhabitat	Patch	Quadrat	Gradient	Components	%cover	Ave. Ht/Depth
Tall Shrub	1	1	1	mixed shrub	100	1.10m
		2	2	mixed shrub	100	1.75m
		3	1	mixed shrub	100	1.25m
Bush	2	1	2	bush	100	1.75m
Shrub Marsh	3	1	0	mixed shrub	90	0.3m
				water	10	0.2m
		2	0	mixed shrub	70	0.65m
				water	30	0.2m
		3	0	mixed shrub	50	0.3m
				water	50	0.2m
Sand Bank	4	1	2	sand	100	0m
Grass Marsh	5	1	0	grass	30	0.6m
				water	70	0.4m
		2	0	grass	5	0.6m
				water	95	0.75m
Path	6	1	0	grass	10	0.03m
				bare soil	90	-
		2	0	grass	30	0.02m
				bare soil	70	-
		3	0	bare soil	100	-
		4	0	grass	75	0.03m
				bare soil	25	-
Grass Shrub	7	1	0	grass	45	0.07m
				shrub	50	0.1m
				bare soil	5	-
		2	0	grass	20	0.05m
				shrub	20	0.3m
				bare soil	40	-
		3	0	grass	40	0.03m
				shrub	50	0.3m
				bare soil	10	-
		4	0	grass	20	0.05m
				shrub	50	0.25m
				bare soil	30	
Grass Marsh	8	1	0	grass	5	0.7m
				water	95	0.5m
		2	0	grass	30	0.7m
				water	70	0.55m
Bush	9	1	0	bush	75	1.75m
		2	0	bush	80	1.6m
		3	0	bush	60	1.4m
Grass	10	1	0	grass	80	0.02m
				bare soil	20	-
		2	0	grass	80	0.02m
				bare soil	20	-
		3	0	grass	75	0.09m
				bare soil	25	-
Pond	11	1	0	water	100	0.5m
		2	0	water	100	0.6m
Grass Marsh	12	1	0	grass	10	0.7m
				water	90	0.6m
			0	grass	40	0.8m
				water	60	0.5m
Grass	13	1	1	grass	95	0.03m
				shrub	5	0.4m
		2	1	grass	85	0.04m
				bare soil	15	-
		3	1	grass	80	0.05m
				bare soil	20	-

Pond 3:

Microhabitat	Patch	Quadrat	Gradient	Components	%cover	Ave. Ht/Depth
Low Shrub	1	1	0	mixed shrub	100	0.15m
		2	0	mixed shrub	100	0.18m
		3	0	mixed shrub	100	0.2m
Bush	2	1	0	bush	100	3.5m
Low Shrub	3	1	1	mixed shrub	100	0.1m
		2	1	mixed shrub	100	0.15m
Grass	4	1	0	grass	100	0.2m
		2	0	grass	100	0.25m
Reeds	5	1	0	reeds	80	0.45m
				water	20	0.2m
Shrub marsh	6	1	0	shrub	55	0.1m
				water	45	0.15m
		2	0	shrub	70	0.3m
				water	30	0.1m
Reeds	7	1	0	reeds	90	0.4m
				water	10	0.25m
Reeds	8	1	0	reeds	75	0.3m
				water	25	0.1m
Reeds	9	1	0	reeds	95	0.45m
				water	5	0.1m
		2	0	reeds	90	0.45m
				water	10	0.8m
		3	0	reeds	95	0.4m
				water	5	0.7m
Bush	10	1	1	bush	80	1.5m
Bog Shrub	11	1	1	shrub	70	1.6m
				mud	30	-
Low Shrub	12	1	0	mixed shrub	100	0.2m
Low Shrub	13	1	0	mixed shrub	100	0.15m
Low Shrub	14	1	0	mixed shrub	100	0.25m
Tall Shrub	15	1	0	shrub	95	0.16m
				bare soil	5	0m
		2	0	shrub	100	0.1m
		3	0	shrub	85	0.2m
				bare soil	15	0m
Low Shrub	16	1	1	mixed shrub	100	0.15m
Low Shrub	17	1	1	mixed shrub	100	0.15m
Low Shrub	18	1	1	mixed shrub	100	0.25m
Low Shrub	19	1	1	mixed shrub	100	0.2m
Grass Marsh	20	1	0	grass	90	0.2m
				mud	10	-
		2	0	grass	75	0.2m
				mud	25	-
		3	0	grass	90	0.25m
				mud	10	-
Bush	21	1	1	bush	80	1.75m

Pond 4:

Microhabitat	Patch	Quadrat	Gradient	Components	%cover	Ave. Ht/Depth
Patchy Shrub Bank	1	1	1	shrub	70	0.03m
				bare soil	30	0m
		2	1	shrub	65	0.15m

				bare soil	35	0m
		3	1	shrub	70	0.10m
				bare soil	30	0m
Grass Marsh	2	1	0	grass	90	0.12m
				mud	10	-
		2	0	grass	95	0.1m
				mud	5	-
		3	0	grass	90	0.15m
				mud	10	-
Grass	3	1	0	grass	60	0.02m
				bare soil	40	0m
				grass	50	0.05m
				bare soil	50	0m
				grass	95	0.07m
				bare soil	5	0m
Grass Mound	4	1	0	grass	90	0.02m
				bare soil	10	0m
				grass	90	0.03m
				bare soil	10	0m
				grass	95	0.02m
				bare soil	5	0m
Mud Marsh	5	1	1	grass	50	0.08m
				mud	50	-
		2	1	grass	40	0.07m
				mud	60	-
		3	1	grass	40	0.1m
				mud	60	-
Grass Mound	6	1	0	grass	30	0.08m
				bare soil	70	0m
				grass	40	0.06m
				bare soil	60	0m
Low Shrub Bank	7	1	1	mixed shrub	100	0.044m
		2	1	mixed shrub	100	0.02m
		3	1	mixed shrub	100	0.06m
Bare Mound	8	1	1	bare soil	100	0m
Bush	9	1	0	bush	90	1m
Bush	10	1	0	bush	80	1.5m

Pond 5:

Microhabitat	Patch	Quadrat	Gradient	Components	%cover	Ave. Ht/Depth
Bush	1	1	1	bush	80	1m
Grass Path	2	1	0	grass	85	0.2m
				shrub	5	0.05m
				bare soil	10	0m
		2	0	grass	85	0.25m
				shrub	15	0.05m
		3	0	grass	93	0.05m
				shrub	7	0.03m
Dry Path	3	1	0	grass	40	0.03m
				bare soil	60	0m
		2	0	grass	45	0.03m
				bare soil	55	0m
		3	0	grass	30	0.04m
				bare soil	70	0m
Bush	4	1	0	bush	80	1.5m
Bare Ground	5	1	0	shrub	10	0.02m
				bare soil	90	0m
		2	0	shrub	8	0.02m
				bare soil	92	0m
Grass Bank	6	1	0	grass	100	0.08m
		2	0	grass	100	0.08m
		3	0	grass	100	0.08m
Grass Marsh	7	1	0	grass	90	0.1m
				water	10	0.05m
		2	0	grass	80	0.1m
				water	20	0.04m
Bush	8	1	0	bush	100	2m
Grass Marsh	9	1	0	grass	50	0.15m
				shrub	40	0.15m
				water	10	0.05m
		2	0	grass	99	0.2m
				water	1	0.03m
		3	0	grass	98	0.1m
				water	2	0.02m
Reeds	10	1	0	reeds	100	1.5m
Uncultivated Paddy	11	1	0	rice plants	97	0.05m
				mud	3	-
		2	0	rice plants	90	0.05m
				mud	10	-
Reeds	12	1	0	reeds	100	1m
Cultivated Paddy	13	1	0	rice plants	25	0.3m
				mud	75	-
		2	0	rice plants	25	0.4m
				mud	75	-
Grass Bank	14	1	0	grass	100	0.06m
		2	0	grass	98	0.2m
				bare soil	2	0m
		3	0	grass	100	0.07m
Stream	15	1	0	stagnant water	100	0.06m
		2	0	stagnant water	100	0.06m

Pond 6:

Microhabitat	Patch	Quadrat	Gradient	Components	%cover	Ave. Ht/Depth
Cardamom	1	1	0	cardamon plants	-	2.5m
Leaf Litter	1	1	0	leaf litter	50	0.02m
				bare soil	50	0m
Cardamon	2	1	0	cardamon plants	-	2.7m
Leaf Litter	2	1	0	leaf litter	85	0.03m
				bare soil	15	0m
Cardamon	3	1	0	cardamon plants	-	2.7m
Leaf Litter	3	1	0	leaf litter	85	0.03m
				bare soil	15	0m
Cardamom	4	1	0	cardamom plants	-	2.8m
Leaf Litter	4	1	0	leaf litter	40	0.03m
				bare soil	60	0m
Cardamom	5	1	0	cardamom plants	-	3m
Leaf Litter	5	1	0	leaf litter	40	0.02m
				bare soil	60	0m
Grass	6	1	0	grass	100	0.6m
		2	0	grass	50	0.3m
				shrub	50	0.3m
		3	0	grass	60	0.3m
				shrub	40	0.2m
Bare Ground	7	1	0	leaf litter	5	0.01m
				bare soil	95	0m
		2	0	leaf litter	5	0.01m
				bare soil	95	0m
Termite Mound	8	1	2	packed soil	100	0.95m
Bare Ground	9	1	0	bare soil	100	0m
Grass Shrub	10	1	0	shrub	50	0.2m
				leaf litter	25	0.01m
				bare soil	25	0m
		2	0	shrub	40	0.3m
				grass	60	0.25m
		3	0	shrub	40	0.4m
				grass	60	0.2m
Grass Shrub	11	1	1	shrub	75	0.12m
				grass	25	0.2m
		2	1	shrub	80	0.15m
				grass	20	0.15m
		3	1	shrub	90	0.2m
				grass	10	0.2m
Stream	12	1	0	slow flowing water	70	0.03m
				leaf litter	30	0.03m
Stream	13	1	0	slow flowing water	80	0.04m
				leaf litter	20	0.04m
Stream	14	1	0	slow flowing water	95	0.01m
				grass	5	0.13m
Stream	15	1	0	slow flowing water	70	0.02m
				grass	30	0.08m

NB: Gradient: 0=level; 1=slopping; 2=vertical