AMPHIBIAN DISTRIBUTION AND ABUNDANCE IN THE POLILLO ISLANDS

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ABSTRACT

From June to December 2001 transect surveys were used to assess amphibian populations across the Polillo Islands, and to determine the effects of forest fragmentation on species abundance and distribution. Aural transects were used as an effective tool to estimate density and abundance of rare, sensitive and cryptic species for which visual transects were inadequate. Two new records brought the total number of species on Polillo to 19, including two undescribed species and the endemic Polillo forest frog *Platymantis polillensis. Bufo marinus, Rana vittigerra, Polypedates leucomystax, Kaloula picta* and *K. conjuncta* were demonstrated to be agriculture specialists; *Rana woodworthi, R.. similis, Platymantis dorsalis, Occidozyga laevis,* and *P. luzonensis* were found at their highest densities in forest; and *P. polillensis*, *P*. sp., and *Rhacophorus appendiculatus* were rare species recorded exclusively in forest. Several habitat characteristics correlated strongly with distance from forest edge forming a gradient of increasing habitat quality. The density of five forest dependant species increased significantly with respect to these factors. Consequently forest was concluded to be the most important habitat for amphibian conservation, supporting several rare and restricted range species and key sites across Polillo were identified that harbour the rarest species. Habitat fragmentation and forest edge effects are significant factors determining amphibian distribution and abundance.

1.1 Introduction

Amphibians are considered to be particularly vulnerable to habitat change and good indicators of habitat quality due to their permeable skins, dual life mode and limited dispersal capabilities. Understanding factors that determine amphibian species distributions can allow informed decisions to be made in conservation, increases our understanding of how land management impacts on amphibian species and therefore contributes towards understanding amphibian declines and rarity on a wider scale.

Over 70% of the 100 plus amphibian species found in the Philippines are endemic. If the present rate of deforestation in the Philippines continues most endemics face a high probability of extinction in the near future (Alcala & Brown 1998). The 2001 Philippine Amphibian assessment added several species to the 32 already recommended for inclusion in the IUCN Red list of threatened animals. A disproportionate majority of these species are found in South Luzon including the Polillo Islands.

As a result of his collecting trips to Polillo in the early 1900s, a time when the island was entirely covered in lush tropical forest, E. H. Taylor described several new amphibians including the endemic Polillo Forest Frog *Platymantis polillensis* (Taylor 1922). Since that time intensive logging activities have cleared Polillo of almost all its forest and *P. polillensis* was presumed extinct. Surveys conducted in 1999 found 16 amphibian species including *P. polillensis*. Over half these species are endemic to the Philippines, many are restricted to the South Luzon faunal region (Hampson 2000) and several are forest dependant specialists (Hampson, 2001). This study aims to examine how forest fragmentation affects amphibian abundance across the Polillo islands.

1.2 AIMS:

1) Determine the density and abundance of amphibian populations in the Polillo islands, focusing on rare and sensitive species and the factors that influence their distribution
2) Collect taxonomic and ecological information for amphibians found on Polillo particularly those groups that are currently little known to facilitate identification based on live specimens and/or calls.

1.3 Survey Sites

Study sites were selected after thorough discussions with local inhabitants knowledgeable of the islands' geography. The largest forested areas representing the greatest possible geographical coverage of the islands were chosen. Time limitations, inaccessibility, and the need to combine varied aims of the conservation project constrained the choice of potential sites and prevented random allocation. Formal surveys were conducted at 13 sites that included interior forest, forest-edge and forest agriculture boundaries. Other sites considered unfeasible for standard surveys were visited where possible (for single days or overnight) to make a rapid visual assessment, take GPS locations and ground truth inhabitants' descriptions.

1.4 Methods

1.4.1 Density estimates

Due to the diverse ecology of amphibians found in the Polillo Islands, no single methodology was thought adequate to measure the abundance of each species. Therefore a combination of techniques was used to determine the density of amphibian species at study sites. Short (5m x 2m) transects perpendicular to waterbodies were searched to estimate relative abundance and densities for most species. A minimum of three transects were completed at each site, although usually more than six transects were searched. Aural transects were used to determine the density of species for which visual surveys were inadequate. Transects (100 to 400m) were laid with a tape measure, the perpendicular distance from the transect line to calling males measured, and densities calculated using the programme DISTANCE (Buckland *et al*, 1993). Opportunistic call recording and visual encounter surveys provided additional qualitative information on the ecology of species for which the above techniques were unproductive.

1.4.2 Habitat characterisation

Several habitat characteristics thought to be important to certain species, or represent a measure of disturbance were quantified: Landuse was described, abundance of screw pines (*Pandanus* spp.), dead logs, bamboo, ground flora, extent of canopy closure, and stream features (width, speed, substrate) were recorded together with time since last rain. Location from forest edge was recorded to provide suitable comparison criteria.

1.4.3 Analysis techniques

For each site total frog density and density of each species, calculated from the transect data, was regressed against distance from forest edge. Model criticism was conducted for each analysis and if any model assumptions were contravened, appropriate transformations of the data were made. The same methods were used to test for correlations between habitat characteristics and distance from forest edge and between habitat characteristics and density of each species.

1.4.4 Rare species abundance estimates

During formal surveys and opportunistic searches including those at sites visited for single nights rare species were sometimes encountered. Where possible density estimates were made using aural transects as were used to estimate densities of *P.luzonensis.* A measure of area searched (distance walked) was always recorded if aural transects were not possible.

1.5 RESULTS

1.5.1 Presence/ absence

18 different species were recorded throughout the survey period. The only species found in 1999 but not in 2001 was *Rhacophorus appendiculatus.* Table 1 lists the species recorded at each site (during formal surveys and informal observations), and is colour coded according to the habitat in which each species was found.

Table 1.

SPECIES	Sibulan watershed	Abaca	Aluyon watershed	Baleta	Lipata	Anibawan	Jerry Hilario	Mount Malulod	Patnanungan	Kalubakis	Aluyon	Sibulan agriculture	Jomalig	Polillo town
Rhacophorus appendiculatus	F													
Platymantis sp.**						F								
*Platymantis polillensis****	F	F	F	F	F									
*Platymantis luzonensis**	F	F	F	F	F	F	FB	FB	F	FB	FB			
*Rana woodworthi**	F	F	F	FB	FB	FB	FB	FB	FB	FB	FB	FB	FB	
*Rana similis**	F	F	F	FB	FB	FB	FB	FB	FB	FB	FB	FB	FB	
Occidozyga laevis	F	F	FB	FB	FB	FB	FB	FB	FB	FB	FB	FB		
Platymantis dorsalis	F	F	FB	FB	FB	FB	FB	FB	FB	FB	FB	FB		
Platymantis corrugatus	F	F	FB	FB	FB	FB	FB	FB	FB	FB	FB	A		
*Rana luzonensis**	F	F	FB	F	FB	FB	FB	FB			FB	FB		
Rhacophorus pardalis	F	F				FB	FB	FB				A	A	
Rhacophorus bimaculatus	F	F	F	F		F		FB						
Limnonectes macrocephalus	F	F	F	F	F			FB				FB		A
Kaloula sp**	F											FB		
Polypedates leucomystax					A	A	A	A	A	A	A	A	A	A
Rana vittigerra						A	A				A	A	A	A
Kaloula picta											A	A		A
Bufo marinus									A			A	A	A
Kaloula conjuncta									A				A	A

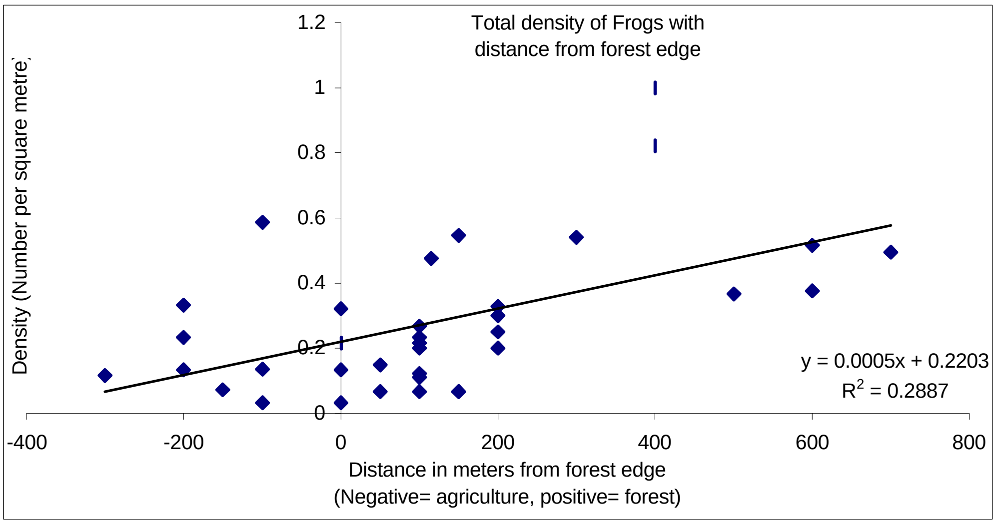
Found in forest
Found in forest and forest-agriculture boundary
Found in agriculture

* Range restricted to the South Luzon Faunal Region
****** Undescribed and known from only a few locations in Quezon Province (R. Brown. *Pers comm*.)
***Critically endangered and endemic to Polillo Island

1.5.2 Total frog density

Total frog density was found to increase with distance from forest edge (Figure 1). Highest densities were found in interior forest sites and lowest densities in agriculture and forest boundary sites. The best fitting model that normalised the residuals and stabilised the variance was a square-root transformation (appendix I). Total frog density also correlated strongly with abundance of *Pandanus* spp. (p=0.002, R^2 adj=23.9%), abundance of logs (p=0.002, R^2 adj=24.4%), and extent of canopy closure (p=0.008, R^2 adj=17.8%, using log total density); density of ground flora was insignifict (p=0.087).

Figure 1. Untransformed data is used for clarity.



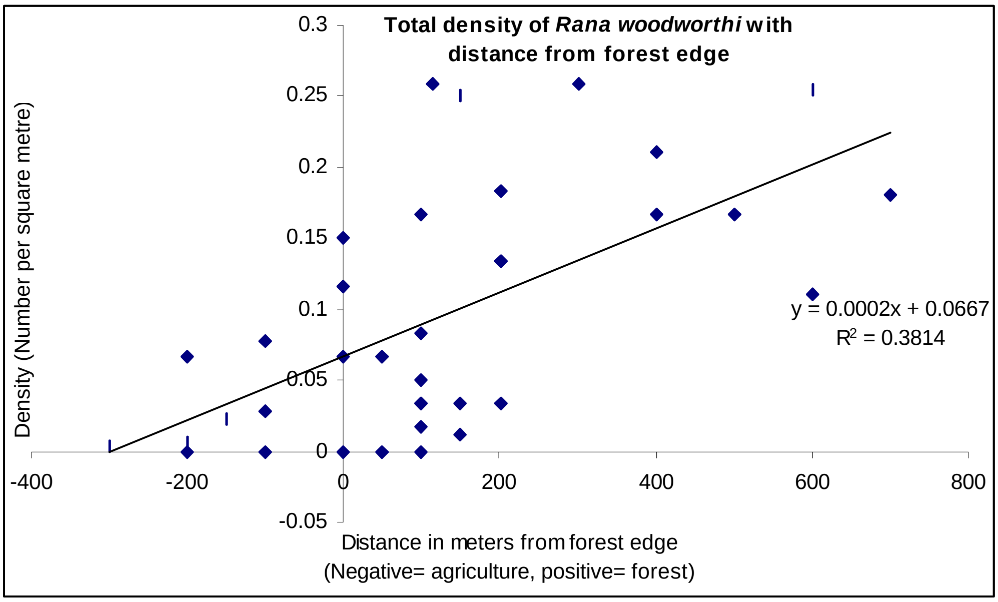
1.5.3 Individual species density

Four of the species recorded in transects, were at high enough densities to permit further analyses; *Rana woodworthi, Rana similis, Occidozyga laevis,* and *Platymantis dorsalis.* Only *Rana similis* did not increase in density with distance from forest edge, (although did show such a correlation when the data from Jomalig was excluded). The other three species were all found to increase in density with distance from forest edge (Table 2), with highest densities in forest interior and lowest densities in agriculture sites eg *Rana woodworthi* (Figure 2). Square root was found to be the most appropriate transformation for each species. Correlations between density of each species and habitat characteristics including distance from agriculture are given in table 2. In summary, when each habitat variable is used independently the following significant relationships were found: *R.woodworthi* density increased with decreasing density of ground flora, with increasing abundance of dead logs and increased canopy cover; *R. similis* density increased with abundance of *Pandanus* plants, *O.laevis* density increased with abundance of *Pandanus*, with abundance of dead logs, and with increased canopy cover and *P.dorsalis* density increased with abundance of dead logs and increased canopy cover.

Table 2. P values, adjusted R^2 values and the best transformation (if necessary), are listed.

	HABITAT CHARACTERISTIC					
Species	**Distance from forest edge**	**Abundance of Bamboo**	**Abundance of pandanus**	**Density of ground flora**	**Abundance of dead logs**	**Canopy closure**
R.woodworthi	p<0.0005, Rsq(adj)=35.6%, Square rooted	p>0.05, NS	p>0.05, NS	p=0.046, Rsq(adj)=9.1%	p<0.0005, Rsq(adj)=35.3%	p<0.0005, Rsq(adj)=38.0%
R.similis	p>0.05, NS	p>0.05, NS	p=0.003, Rsq(adj)=22.2%	P=0.091, NS	p>0.05, NS	p>0.05, NS
O.laevis	p=0.002, Rsq(adj)=21.7%, Square rooted	p>0.05, NS	p=0.001, Rsq(adj) 29.1%	p>0.05, NS	p=0.003, Rsq(adj)=22.1% Square rooted	p=0.005, Rsq(adj)=19.5%, Square rooted
P.dorsalis	p=<0.0005, Rsq(adj)=33.9%, Square rooted	p>0.05, NS	p>0.05, NS	p>0.05, NS	p=0.009, Rsq(adj)=16.7%, Square rooted	p=0.077, NS

Figure 2. Untransformed data used for clarity



1.5.4 Habitat versus distance from forest edge

The habitat variables listed in table 2 all co-vary with distance from forest edge (correlations are given in Table 3). The transformations excluded negative values therefore the relationship between distance from agriculture and abundance of *Pandanus* spp. and density of ground flora is only applicable to forest sites up to and including the forest boundary agriculture but not for coconut plantations or rice fields.

Table 3.

Best fit Equation	F ratio	P value	Rsq (adj)	
Ground Flora = 150 - 44.5 logDist	64.33	<0.0005	75.10%	Excluding agriculture sites
Pandanus abundance = - 31.5 + 19.5 logDist	24.87	<0.0005	53.20%	Excluding agriculture sites
Abundance of dead logs= 7.57 + 0.0355 Dist	25.58	<0.0005	42.70%	All sites
Canopy Closure = 18.7 - 0.0240 Dist	55.31	<0.0005	62.20%	All sites

1.5.5 *Platymantis luzonensis* Density

P. luzonensis density was found to increase significantly with distance from forest edge (Figure 3), with abundance of *Pandanus* (Figure 4) and with increasing canopy cover (figure 5) and to decrease significantly with density of ground flora (Figure 6). Best fitting equations are listed in Table 4. Rain had a significant effect on activity of *P.luzonensis*. Following a period of at least three days (and nights) with no rain, no *P. luzonensis* were heard calling, even at normally high-density sites. All analyses are based upon data with recent (within 2 days) rainfall.

Table 4.

Best fit equation	F ratio	P value	Rsq (adj)
P. luzonensis Density = 3.49 + 0.0216 Dist	58.44	<0.0005	72.30%
P. luzonensis Density = 1.69 + 0.670 Pandanus	73.8	<0.0005	78.40%
P. luzonensis Density = 18.5 - 0.168 ground flora	11.7	0.003	34.90%
P. luzonensis Density = 21.6 - 0.931 canopy	28.03	<0.0005	58.70%
P. luzonensis Density = 5.78 + 0.138 logs	3.55	0.075	11.30%

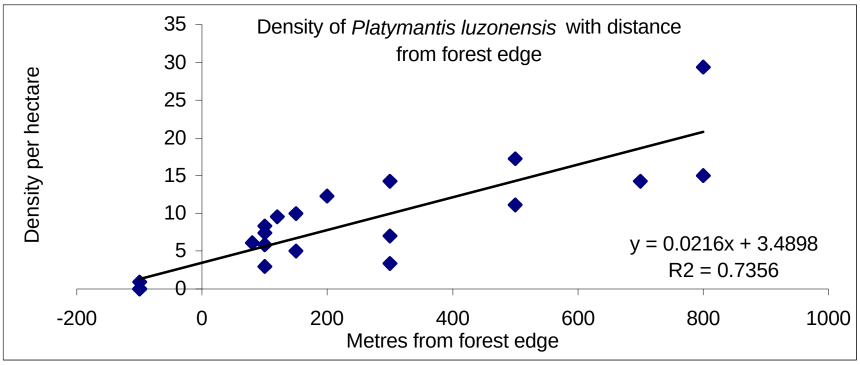


Figure 3.
Effects of Distance from Forest edge of *P.luzonensis* density

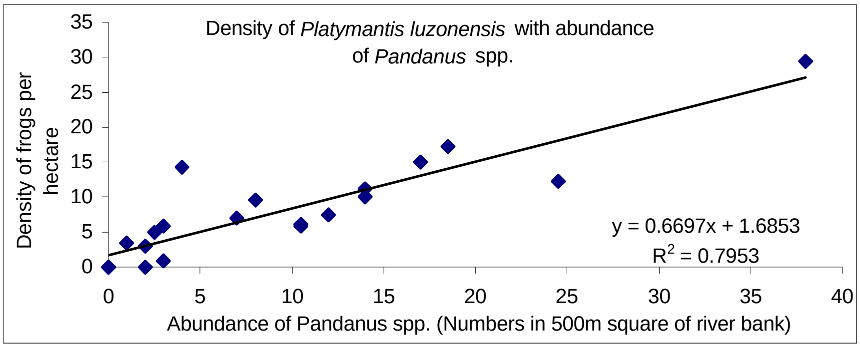


Figure 4.
Effects of abundance of *Pandanus* spp. on *P.luzonensis* density.

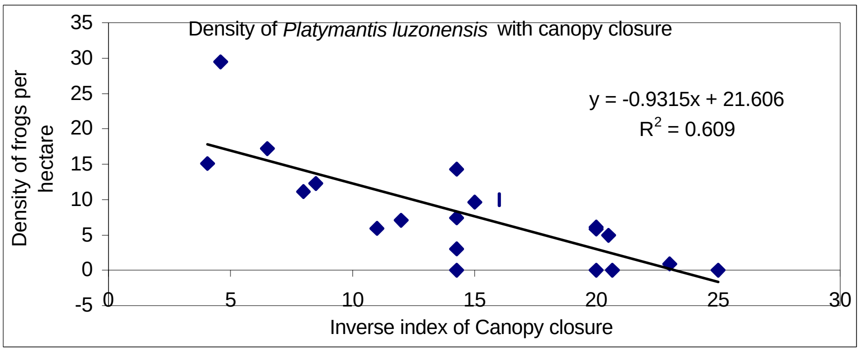


Figure 5.
Effect of canopy cover on *P.luzonensis density*

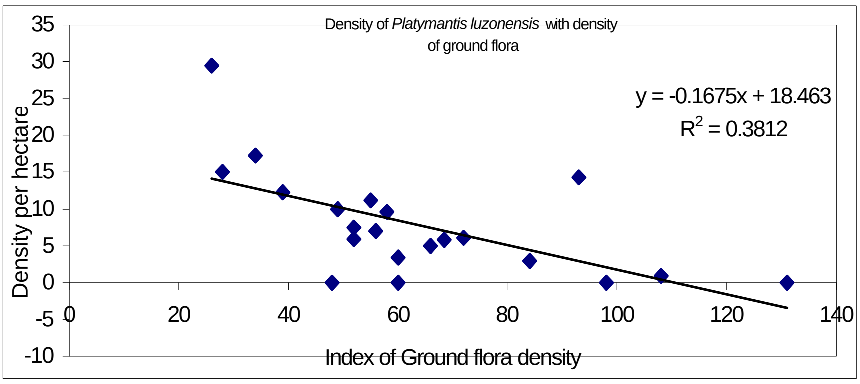


Figure 6.
Effect of ground flora density on *P.luzonensis* density

1.5.6 Rare species abundance estimates

Density estimates for *P. polillensis* and *P.*sp are listed in table 5 together with approximate vicinity to water bodies. Numbers of *Kaloula* sp. and *R.appendiculatus* (from 1999) are also given.

Table 5.

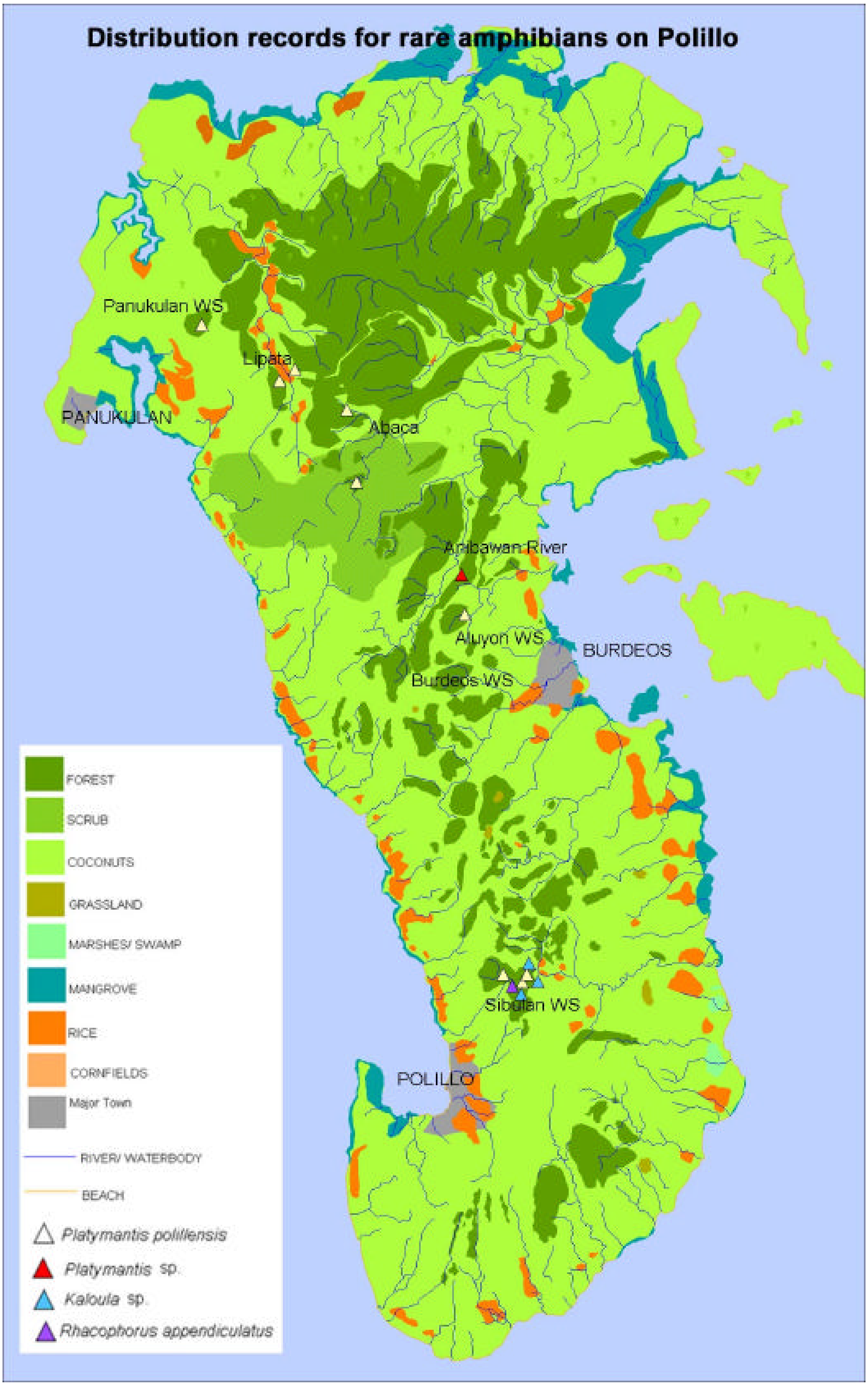
Species	Site	Numbers found/ heard	Distance searched	Maximum density estimate per hectare	Location with respect to water
P. polillensis	Abaca	12	300m	18.182	within 20m
P. polillensis	Aluyon WS	8	200m	26.667	within 20m
P. polillensis	SibulanWest	2	500m	-	within 20m
P. polillensis	Sibulan East	1	500m	-	within 20m
P. polillensis	SibulanEdge	1	600m	-	within 20m
P. polillensis	Baleti	5	400m	-	within 20m
P. polillensis	Lipata	5+	800m	-	within 20m
P. polillensis	Panukulan	1	600m	-	within 20m
P. sp	Anibawan	10	500m	6.9444	Distant (>1km)
R. appendiculatus	Sibulan	1	opportunistic	-	No prediction
Kaloula sp	Sibulan WS	1	opportunistic	-	within 20m
Kaloula sp	Sibulan edge	1	opportunistic	-	within 20m
Kaloula sp	Sibulan edge2	10+	opportunistic	-	within 20m
Kaloula sp	Path nr Sibulan	5+	opportunistic	-	within 20m

Kaloula sp**.**

Platymantis polillensis

Platymantis sp.

Rhacophorus appendiculatus


Distribution records for rare amphibians on Polillo
Panukulan WS
Lipata
PANUKULAN
Abaca
Anibawan River
Aluyon WS
BURDEOS
Burdeos WS
Sibulan WS
POLILLO
FOREST
SCRUB
COCONUTS
GRASSLAND
MARSHES/ SWAMP
MANGROVE
RICE
CORNFIELDS
Major Town
RIVER/ WATERBODY
BEACH
Platymantis polillensis
Platymantis sp.
Kaloula sp.
Rhacophorus appendiculatus

Map 1.

1.6 DISCUSSION

1.6.1 Species presence/ absence

Nineteen amphibian species have been recorded from Polillo since 1999, 3 new records for the island; *Rhacophorus bimaculatus, Platymantis* sp., and *Kaloula* sp. (the latter two, known from only a couple of locations in Quezon Province, are currently being described), and 2 species not seen since E. H. Taylor's visit in 1919; *Rhacophorus bimaculatus* and *Platymantis polillensis*. Only *Philautus surdus* has not been found since Taylor's work and is presumed to be extinct locally.

A number of predominantly forest or agriculture inhabitants are evident from the presence/ absence data alone. *Bufo marinus, Rana vittigerra,* and *Polypedates leucomystax* are agriculture specialists, frequently found in high densities close to human habitation. Occasionally *P. leucomystax,* can be found along forested ridges clustered nearby temporary pools. Presence/ absence data also suggests that both *Kaloula picta* and *Kaloula conjuncta* do not depend on forest.

1.6.2 Densities

Following surveys around Sibulan watershed in 1999 several species were identified as forest specialists. Surveys from 2001 show that throughout the Polillo Islands the common species *Rana woodworthi, Occidozyga laevis* and *Platymantis dorsalis* increase in density with distance from forest edge, are found at highest densities in forest, and are virtually always absent from agricultural land. *Rana similis* also lives at highest densities in forest sites, but on Jomalig, where no primary forest remains, and the few secondary growth fragments are all less than 5 hectares, *R. similis* was found at extremely high densities. This atypical site was prolific in *Pandanus* plants, a habitat characteristic that correlates with *R. similis* abundance and normally increases in abundance with distance into forest. In addition the rare and more sensitive forest species *Platymantis luzonensis* was absent in agriculture, found at low densities in forest edge, and highest densities in core forest, exhibiting a clear edge effect.

For several species found at very low densities (*Limnonectes macrocephalus*) or with clustered distributions (*Rhacophorus pardalis*), patterns of abundance could not be determined. Both *L.macrocephalus,* and *R.luzonensis* were found in primary forest and beside tree lined streams in coconut plantations. *R.pardalis* found in both forest and agriculture, calls from above temporary still water pools, whereas *R.bimaculatus* also found in forest and agriculture though always nearby forest edge apparently requires fast flowing water. Surveys in 1999 indicated *P.corrugatus* is present at highest densities in central forest sites, but is also found in coconut plantations. Insufficient transects were completed per site to confirm whether this pattern is true across the Polillo Islands.

Total frog density increased with distance from forest edge, and covaried with several habitat characteristics. At forest-agriculture boundaries both forest and agriculture species coexist at low densities, and with increasing distance into forest, agriculture species are absent and forest species are more abundant.

1.6.3 Habitat Correlations

All the habitat characteristics correlated to some degree with distance from forest edge, although it is not clear whether any are the underlying causes responsible for frog abundance. Together they may increase microhabitat complexity and local humidity levels, and reduce surface temperatures with distance from forest edge, creating an edge effect likely to influence amphibian distribution and densities. Certain factors were more influential on some species than others; for example *Pandanus* spp. abundance affects *R. similis* density, this semi-arboreal species mostly inhabits understory vegetation, perching on plants, logs and rocks, though rarely above 1 metre high. The entirely ground dwelling *R.woodworthi* was unaffected by *Pandanus* abundance, yet increased with canopy cover, abundance of dead logs and decreased with ground flora density. Total frog density, largely composed of *R. woodworthi* (the most abundant species), consequently had very similar correlations. Although specific characteristics are more likely to influence some species than others, due to the large covariance of these factors it is unlikely that each acts in isolation. More likely together they represent increasing 'habitat quality' causing frog abundance to increase, e.g. density of *P.luzonensis* was correlated to several the habitat characteristics.

1.6.4 Rare and cryptic species

- *Kaloula* sp. has been found within the primary forest of Sibulan watershed reserve, at forest edge and in agriculture close to forest. Finding this rare species is exacerbated by its cryptic fossorial ecology. It has previously only been found after very heavy rain when occasionally groups of at least ten have been heard calling together.
- *Platymantis* sp. was first recorded from Polillo in the 2001 along a forested ridge near the Anibawan River where densities of calling males reached 6.9 frogs per hectare. It has not been heard elsewhere in the Polillo Islands outside the 2km range in Anibawan.
- The endemic Polillo forest frog *Platymantis polillensis*, considered extinct until rediscovered in 1999, was recorded at several forested sites across Polillo. The highest density recorded was 26.6 per hectare in Aluyon Watershed, although its distribution appeared very localized and always within 20m of a stream/ river. Activity was highly dependent on recent rainfall. Single individuals were found at two sites in 1999, therefore these surveys greatly increase the frog's former known range.
- *R. appendiculatus* was found only once in 1999 (the first time since 1919) and not at all in 2001. It is unclear why this frog is so rare on Polillo whereas relatively common in Mount Makiling on Luzon.

Map 1 shows the distribution records of the above four species on Polillo, all of which were found within or very close to forest. All shown sites should therefore be considered important for amphibian conservation.

1.6.5 Methodologies

Short transects were successful in depicting large scale patterns in frog abundance, although greater effort per site is required to make accurate density estimates for several of the rarer species. Similarly in order to determine trends acting at a scale of less than 200m from forest boundaries more transects per site (preferably over several nights) are necessary to reduce the variance of density estimates. Since most forest patches are less than 400m in diameter such surveys of greater resolution would be valuable to investigate more localized patterns of frog abundance.

Visual transects are inadequate to survey *P.luzonensis.* This sensitive forest specialist calls from two metres or more above the ground and occurs at much lower densities than the common species detected using visual transects. Surveys of calling males were very effective in determining densities of *P. luzonensis*, and demonstrate its sensitivity to habitat changes. This methodology was also suitable for other rare or cryptic platymantids such as *P.polillensis* and *P.*sp that would remain undetected by visual searches and demonstrated the dependence of these species on rainfall to initiate breeding activity; unless rain has fallen within the previous 3 days, *P. luzonensis* does not call. Aural surveys conducted in dry periods are therefore ineffective.

1.6.6 Platymantids

Frogs of the *Platymantis* genus are generally small to medium sized, terrestrial breeders that inhabit closed canopy forests. 15 of the 22 described species of *Platymantis* spp. are recommended for inclusion in the 1999 IUCN Red list of threatened animals, 10 as critically endangered or endangered (C. Banks 1999). Polillo harbours 5 *Platymantis* species, which all are either at their highest densities in forest or have been found only in forest. These include the critically endangered Polillo forest frog and one undescribed species. *P. luzonensis* is not known from lowland forest on Luzon, and there are notable differences between the call and appearance of individuals on Luzon to those on Polillo (Hampson 2000). Taxonomic review is required to determine whether this forest sensitive species is distinct from higher elevation populations on the mainland.

It is likely that in addition to typical anuran sensitivity to moisture, platymantids could be particularly influenced by ambient humidity. As terrestrial breeders, platymantids are dependant on soil water retention for their egg development. Correspondingly both *P.luzonensis, P.polillensis* were found to be inactive during dry spells, yet began calling after rain, and *P.dorsalis* appeared to call less frequently and in lower numbers during dry spells.

1.7 CONCLUSION

Negative effects of forest fragmentation have been documented for many animal groups (Laurance 1991, Bierregaard *et al*. 1992), however, little is known about the effects of fragmentation on frog communities (Tocher *et al*. 1997). Despite this some have suggested that amphibians may be particularly sensitive to habitat fragmentation (Blaustein 1994), because amphibians often show strong site fidelity (Sinsch 1990) and many have limited dispersal capabilities (Marsh & Pearman 1997). Both statements are supported by conclusions from this study. Several species are found only in agriculture and others only in forest. At least 5 species are at their highest densities in core forest compared to forest edge and agriculture. These patterns of forest dependence shown by amphibian species in and around Sibulan watershed (Hampson 2000) are widespread across the Polillo islands.

Fragmentation may affect amphibian populations in several ways: by causing changes in habitat quality, increasing influence of edge related microclimatic changes such as elevated temperature and reduced humidity (terrestrial amphibians may be particularly sensitive due to their dependence on moisture regimes), increased tree fall, alteration of vegetational composition and isolation from suitable breeding habitats. Trends in densities of forest-dependant amphibians correlated to changes in habitat characteristics such as canopy cover, abundance of dead logs and of *Pandanus* plants, and were somewhat species specific. As a result of reduced habitat quality edge effects therefore greatly influence amphibian populations.

Several species of amphibians are endangered on Polillo due to fragmentation of forest habitat. Most rare amphibian species on Polillo (including the endemic and critically endangered Polillo forest frog) were exclusively found in forest, which therefore appears to be the most important habitat for conservation of amphibians on Polillo.

Aural surveys were effective for studying the effects of forest fragmentation on *Platymantis* populations and to investigate the ecology of this poorly known group. Calls are particularly useful to determine the presence of otherwise cryptic groups and those of specific conservation concern, and aural surveys can dramatically improve our knowledge of frog distributions over a large area in a relatively short period of time.

Field studies of amphibians in the Philippines are hampered by taxonomic difficulties and the absence of suitable keys, however every species on Polillo can be individually recognized by its call. Photographs and calls of each species are given in the amphibian species guide to Polillo. Notable call differences between individuals found on Polillo and those on the mainland suggest further taxonomic reviews are required for certain species.

1.8 Recommendations:

- Retain habitat characteristics that reduce isolation of forest fragments such as streams bordered by trees that serve as corridors.
- Conserve forest habitats that support particularly rare species such as Sibulan, Aluyon and Panukulan watershed, undisturbed forest in the northwest near Abaca and Lipata, and forest bordering the southern reaches of Anibawan River (Map 1).
- Use aural surveys to determine whether other forested regions particularly in Panukulan and Burdeos municipalities (essential in Burdeos watershed) are important for rare amphibians.

1.9 APPENDIX

Model criticism was completed for every analysis, and two examples are listed below:

Total density of frogs was regressed against distance from forest edge. Analysis of residual plots (figure 7) found the data to have a right skew; therefore various transformations were tried (table 6). Under a square root transformation, the residuals approached normality and variance was standardized (Figure 8). Under all the transformations significance remained high.

Figure 7

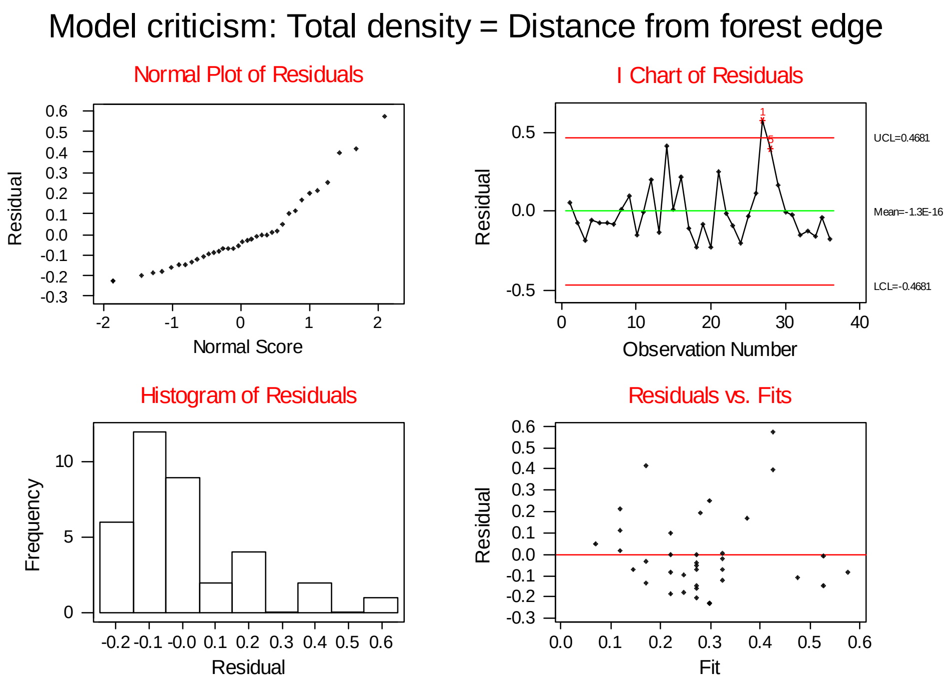
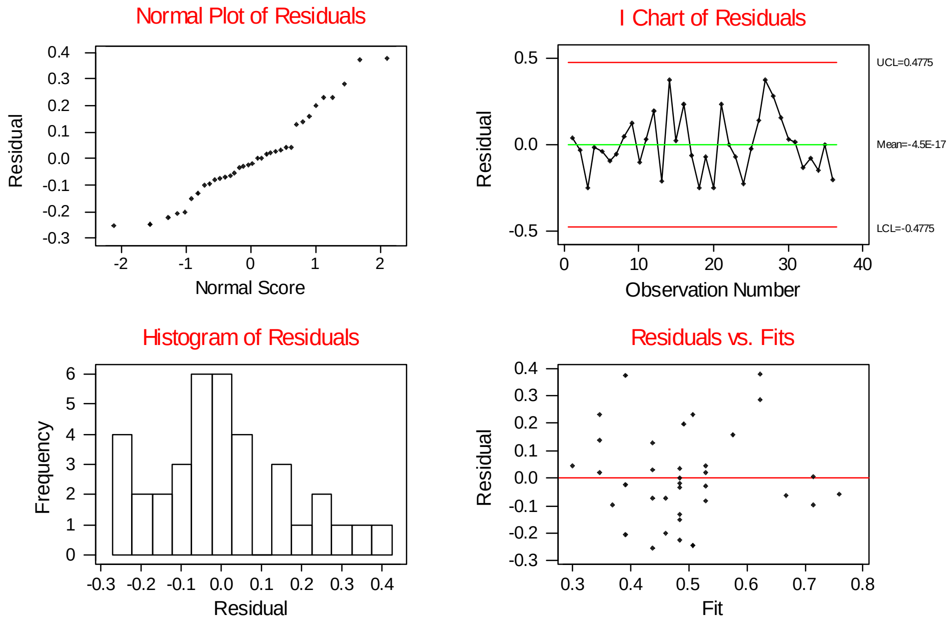


Table 6.

Equation	F ratio	P value	Rsq (adj)
Total density = 0.220 +0.000510 dist	13.80	0.001	26.80%
log total density = - 0.785 +0.000805 dist	11.78	0.002	23.50%
squareroot total density = 0.437 +0.000462 dist	14.15	0.001	27.30%

Figure 8.

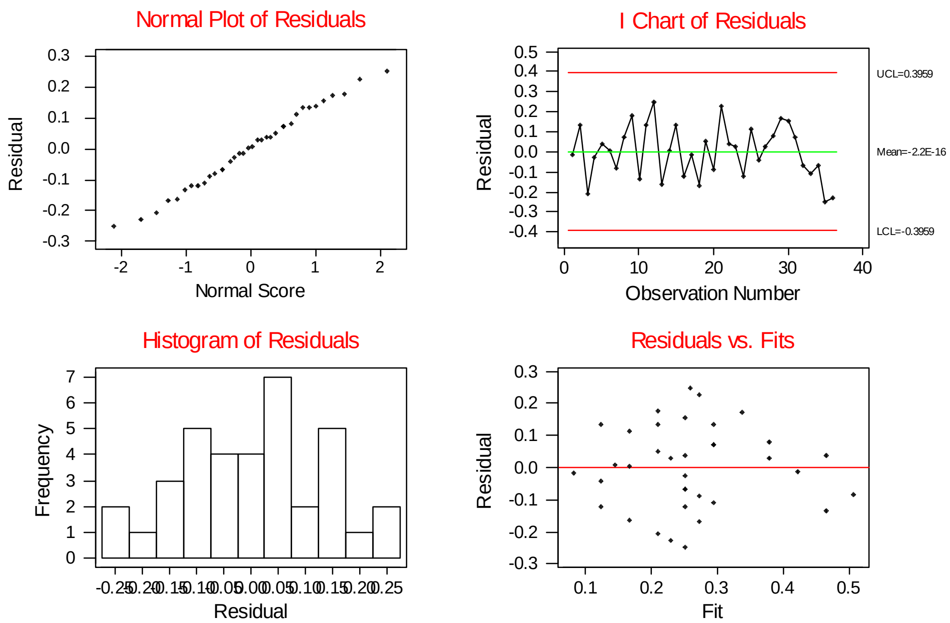
Model criticism: Sqrt Total density = Distance from forest edge



Similarly *Rana woodworthi* density when regressed against distance from forest edge, a square root transformation was found to normalize the residuals and stabilize the variance, Figure 9.

Figure 9.

Model criticism: Sqrt Woodworthi density = Distance from forest edge



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