

Research Article

Abundance and diversity of anurans in a regenerating former oil palm plantation in Selangor, Peninsular Malaysia

JAMES B. BARNETT^{1, 3}, ROSMUND L. BENBOW¹, AHMAD ISMAIL²
and MARK D. E. FELLOWES¹

¹*School of Biological Sciences, University of Reading, Whiteknights Park, Reading, Berkshire, RG6 6BX, U.K.*

²*Department of Biology, Universiti Putra Malaysia 43400 UPM Serdang, Selangor Malaysia.*

³Corresponding author: 4D27, School of Experimental Psychology, University of Bristol, 12a Priory Road, Bristol, BS8 1TU, U.K. (j.barnett@bristol.ac.uk)

ABSTRACT - The spread of oil palm plantations across Southeast Asia has resulted in significant species loss and community change due to the simplification of what were once complex ecosystems. In this study we examined how the return of a former area of oil palm plantation in Selangor, Malaysia, to other uses may have affected the anuran assemblages present. In our study site, a tract of oil palm plantation had been retained, while other areas of former oil palm plantation had been converted to coconut plantation, grassland, or allowed to naturally regenerate to secondary woodland. We found no evidence of recolonisation by habitat specialists in regenerating areas, instead finding species commonly associated with disturbed habitats. While the number of anuran species found was similar between habitats, the assemblage composition varied. Furthermore, there was a considerable difference in anuran counts, with the greatest numbers in secondary woodland, followed in rank order by grassland, oil palm plantation and coconut plantation, and a near 10-fold difference in anuran counts between secondary woodland and coconut plantation. Oil palm plantation was below optimum even for disturbed habitat specialist species which increased in diversity and abundance once oil palm had been removed.

INTRODUCTION

Peninsular Malaysia has experienced rapid change and development of its economy and landscape in recent years (Birdsall et al., 2001). These changes have led to conflicts between the native fauna, including amphibians, and the needs of the local people (Pautasso, 2007). As a result of development, a large proportion of native forest has been removed and replaced with agricultural and urban landscapes. Southeast Asia contained 11% of the world's tropical rainforest in 2007 (Koh & Wilcove, 2007) but the region has the highest rate of deforestation in the world (Soh et al., 2006), double the world average (Liow et al.,

2001). The greatly increased production of palm oil from oil palm (*Elaeis* spp.) is one of the biggest factors in Malaysia's rainforest degradation (Wilcove & Koh, 2010).

Together Indonesia and Malaysia produce >80% of the world's palm oil (Koh & Wilcove, 2007), which in 2007 equated to 3.6 million hectares of plantation in Malaysia alone with a 55-59% rise in production rate between 1990 and 2005 (Koh & Wilcove, 2008). The conversion of primary forest to oil palm has the highest biodiversity loss of any land use change in Malaysia, and has been considered the most important threat to Southeast Asian biodiversity (Wilcove & Koh, 2010).



Figure 1. Location of the study sites, near the Universiti Putra Malaysia campus in Selangor, Malaysia; Kuala Lumpur (star) UPM campus and field sites (circle).

A reversal of the conversion to oil palm is needed to protect biodiversity and ecosystem services (Kettle, 2010). This is particularly important where fragmentation threatens the sustainability of the remaining natural ecosystems (Haddad et al., 2003). Agricultural landscapes may provide connectivity for common species but many specialised species require continuous natural habitat in order to connect breeding populations and preserve gene flow (Gamage et al., 2011). In order to preserve biodiversity in remaining habitat and to increase species' range, regeneration of natural areas and corridor habitat will likely be required (Yaap et al., 2010).

Currently, 107 species of amphibian have been recorded in Peninsular Malaysia (Onn et al., 2010), the majority of which are adapted to primary forest. A range of species do take advantage of human-influenced ecosystems, appearing to tolerate or even thrive in disturbed habitats (Inger et al., 1974). The amphibian richness of Peninsular Malaysia may have been underestimated, as many new species have been described in recent years from areas currently being deforested (Grimser, 2007). A key approach to maintaining anuran biodiversity will rely on the conversion of oil palm plantations to other habitats, including secondary woodland (Dunn, 2004). It is not

clear if this alone will allow natural anuran assemblages to re-establish, or if these assemblages will be dominated by habitat generalists in place of the former, more specialised anurans. To address this key concern, we studied the abundance and diversity of anurans inhabiting a current oil palm plantation, and three habitats which previously had been part of that plantation, but since 1931 had been converted to coconut plantation, open grassland or allowed to regenerate to secondary woodland (Samad, 2011).

MATERIALS AND METHODS

Study site

Four different disturbed habitats around the Universiti Putra Malaysia (UPM) campus in Selangor, Peninsular Malaysia, were studied in June and July 2010 (Fig. 1). Historically the sites would have been covered in lowland dipterocarp forest (Heaney, 1991). However, they had been cleared for oil palm production, until the university took over the land in 1931, and now have reverted to other uses (Samad, 2011). One area of remaining working oil palm plantation ($2^{\circ}59'06.23''\text{N}$, $101^{\circ}43'11.44''\text{E}$) was studied along with three different habitats which have arisen since 1931. These were a coconut plantation ($2^{\circ}59'04.35''\text{N}$, $101^{\circ}43'19.88''\text{E}$), semi-natural grassland

Abundance and diversity of anurans in Malaysia

(2°59'13.29"N, 101°43'23.57"E) and secondary forest (3°00'29.81"N, 101°42'29.13"E) which have all developed on the sites of former oil palm plantations. It is not clear when the transformation from oil palm plantation to coconut, open grassland and areas allowed to regenerate to secondary woodland occurred. However, this is likely to have occurred at least 30 years ago, and more likely >50 years ago.

Habitat description

For each habitat, twenty 1 m² quadrats were set up at random intervals within the surveyed habitat. This work was undertaken diurnally to maximize visibility and to reduce any impacts on the amphibian surveys. Percentage ground cover was estimated in 10 quadrats by the same observer to within 10% discrete categories following Babbitt et al. (2010). Plant diversity was estimated in 10 separate quadrats by counting the number of different plant families found in each 1 m². All species, independent of abundance or size, were counted equally. All habitats were situated close together (< 3 km apart) and were likely to be within the dispersal potential of the species studied. It seems likely that migration and colonisation would have occurred between sites if species were able to exploit the habitat.

Anuran surveys

Fifteen nocturnal 50 m transects were used to survey for amphibians within each site: regenerating forest, grassland, coconut plantations and oil palm plantations. Transects were unconnected but due to safety concerns and restricted access transects had to follow small pre-cut paths. Each habitat was surveyed once a week, on separate days, for three weeks with five transects being completed each night, with each habitat therefore receiving a total of fifteen transects. Anurans were searched for, between 1 and 3 hours after sunset, with the use of handheld and head torches along 50 m long transects within each habitat. Transects were walked slowly by the same three observers, with each surveying 2 m (Marsh & Haywood, 2010) either side of the transect line thoroughly and quickly scanning for additional specimens outside of the area. Transects were walked slowly at a steady pace to ensure replication between sites. The search was also suspended

while a specimen was being examined, to prevent certain areas being searched more comprehensively than others. The species, lifestage and sex of frogs were recorded; using morphological features following Inger & Stuebing (2005) and Inger (1966), as well as a web resource (amphibia.my, 2009).

Statistical analysis

Simpsons Diversity Index; (D = diversity score, N = total abundance, n = species abundance), was used to estimate species diversity. Each replicate transect provided the raw data for the analyses (count data for total anurans and individual species counts). For species richness and relative abundance, data was analysed using a non-parametric approach, with overall comparisons between habitats made using Kruskal-Wallis tests in SPSS version 18 (SPSS Inc, Chicago, IL, USA). To correct for unintended Type I errors following repeated post-hoc pairwise comparisons, Holm's sequential Bonferroni approach was applied (Holm, 1979).

RESULTS

Habitat

Habitats visually differed in their botanical structure and substrate (Table 1) (Fig. 2, results below). Secondary forest contained the greatest diversity of plants as well as a thicker leaf litter. Diversity was present in height and age of plants with synergy between different forest components from canopy to leaf litter. Conversely, grassland was dominated by short grass with scattered groups of trees and scrub. Small open water sources (small ponds) were present in the grassland. The two plantations were dominated by crop trees, which formed a canopy far above all understorey vegetation. Scrub plants were common but a bare sandy soil was visible (Fig. 2).

Species richness

Overall, 229 individual anurans were recorded, belonging to 10 species. There was great overlap in species between habitats with most species being found in multiple habitat types: except for *Microhyla heymonsi* that was only found in regenerating secondary forest, *Hylarana erythraea* only in grassland, *Ingerophrynus parvus* only in coconut and *Leptobrachium*



Figure 2. Examples of ground vegetation variation between sites: A – Grassland, B – Secondary Forest, C – Oil Palm Plantation, D – Coconut Plantation. (Photographs by J.B. Barnett).

nigrops only in the oil palm plantation (Table 2).

There was a significant difference in amphibian species richness between habitats ($H = 26.891$, $df = 3$, $P < 0.001$). Pairwise tests showed no difference in the number of species recorded between grassland and forest, or between oil palm and coconut plantation. However, forest held significantly higher species richness than oil palm ($H = 14.423$, $df = 1$, $P < 0.001$) and coconut ($H = 15.370$, $df = 1$, $P < 0.001$), as did grassland when compared to oil palm ($H = 9.792$, $df = 1$, $P = 0.002$) and coconut ($H = 10.827$, $df = 1$, $P = 0.001$). All were significant at $P < 0.05$, following Holm's sequential Bonferroni correction.

Species diversity

Simpson's diversity index showed all habitats to have very similar scores ($S =$ number of species, $n =$ total abundance, $D =$ diversity indices): coconut ($S = 5$, $n = 13$, $D = 0.722$), forest ($S = 6$, $n = 126$, $D = 0.667$), grassland ($S = 7$, $n = 73$, $D = 0.665$) and oil palm ($S = 5$, $n = 17$, $D = 0.644$).

Species counts

Although anuran diversity was similar in each habitat, there were differences in the number of individuals recorded in each. A Kruskal-Wallis test comparing total anuran counts across all

four habitats found significant differences in abundance ($H = 39.351$, $df = 3$, $P < 0.001$). Pairwise post-hoc tests showed no significant difference in anuran counts between forest and grassland, or oil palm and coconut habitats. There were significant differences in total anuran counts between secondary forest and oil palm ($H = 18.747$, $df = 1$, $P < 0.001$), secondary forest and coconut ($H = 19.939$, $df = 1$, $P < 0.001$), grassland and oil palm ($H = 18.132$, $df = 1$, $P < 0.001$) and grassland and coconut ($H = 19.638$, $df = 1$, $P < 0.001$). All were significant at $P < 0.05$ following Holm's sequential Bonferroni correction.

Species also showed significant difference in counts between habitat types (*Duttaphrynus melanostictus*: $H = 26.420$, $df = 3$, $P < 0.001$; *Kaloula pulchra*: $H = 29.197$, $df = 3$, $P < 0.001$; *Polypedates leucomystax*: $H = 12.991$, $df = 3$, $P = 0.005$; *Microhyla fissipes*: $H = 43.567$, $df = 3$, $P < 0.001$; *Hylarana erythraea*: $H = 9.310$, $df = 3$, $P = 0.025$; *Microhyla heymonsi*: $H = 9.382$, $df = 3$, $P = 0.025$; *Leptobrachium nigrops*: $H = 23.304$, $df = 3$, $P < 0.001$). *Fejervarya limnocharis* and *Fejervarya cancrivora* showed no significant difference between sites, and as only a single *Ingerophrynus parvus* was recorded, statistical analysis for this species was not possible.

Grassland had significantly higher counts of *D. melanostictus* than secondary forest ($H =$

Abundance and diversity of anurans in Malaysia

Habitat	Mean % ground cover	Mean no. of plant species per 1 m ²	Major plant families
Grassland	90≥100	1	Poaceae
Oil Palm	80≥90	2.3	Arecoideae (<i>Elaeis guineensis</i>), Poaceae
Coconut	80≥90	3.1	Arecoideae (<i>Cocos nucifera</i>), Poaceae
Forest	50≥60	3.2	Poaceae, Eudicotyledonae, Pteridophyta

Table 1. Vegetation structure per habitat, mean % ground cover and mean number of plant.

Anuran species	Grassland	Oil palm	Coconut	Forest
<i>Duttaphrynus melanostictus</i> (Schneider)	38	1	2	0
<i>Fejervarya limnocharis</i> (Boie)	12	2	4	4
<i>Fejervarya cancrivora</i> (Gravenhorst)	15	4	5	20
<i>Polypedates leucomystax</i> (Gravenhorst)	1	0	1	11
<i>Kaloula pulchra</i> (Gray)	1	1	0	19
<i>Microhyla fissipes</i> (Boulenger)	1	0	0	66
<i>Microhyla heymonsi</i> (Vogt)	0	0	0	6
<i>Hylarana erythraea</i> (Schlegel)	5	0	0	0
<i>Ingerophrynus parvus</i> (Boulenger)	0	0	1	0
<i>Leptobrachium nigrops</i> (Berry and Hendrickson)	0	9	0	0
Total recorded per habitat	73	17	13	126

Table 2 Number of individuals of each species captured during the study per habitat type.

13.770, $df = 1$, $P < 0.001$), coconut ($H = 10.185$, $df = 1$, $P = 0.001$) and oil palm ($H = 11.816$, $df = 1$, $P = 0.001$). Although *H. erythraea* was only recorded in grassland it was data deficient in terms of pairwise comparisons. All were significant at $P < 0.05$ following Holm's sequential Bonferroni correction.

Pairwise tests showed that secondary forest had higher counts of *K. pulchra* than grassland, coconut and oil palm plantation (all $H = 13.555$, $df = 1$, $P < 0.001$), and *M. fissipes* was more abundant in secondary forest than grassland, coconut and oil palm plantation (all $H = 17.841$, $df = 1$, $P < 0.001$). *Polypedates leucomystax* showed a significantly higher count in secondary forest than in oil palm ($H = 7.151$, $df = 1$, $P = 0.007$), but pairwise tests were unable to conclusively show difference between the other habitats. *Microhyla heymonsi* was only recorded in secondary forest habitat, but the count was too low to statistically conclude on habitat preference.

Leptobrachium nigrops was only found in oil palm, and so was significantly more abundant there than in forest, grassland or coconut habitats (all $H = 8.7$, $df = 1$, $P = 0.003$). The

single *I. parvus* was recorded in the coconut plantation, and there was no significant pairwise difference in the counts of *F. limnocharis* or *F. cancrivora*.

DISCUSSION

In this study we found that areas of former oil palm plantation (presently coconut plantation, open grassland, regenerating secondary woodland) had similar numbers of anuran species to current oil palm plantations. However, the anuran faunas of these habitats were surprisingly different, with different species dominating each habitat area. Furthermore, significantly more individuals were found in grassland and regenerating secondary woodland than in areas of coconut and oil palm plantation. In all cases, the anuran fauna remained highly depauperate, and we found that plantations and regenerating habitats do not support pre-plantation fauna, only those species commonly associated with disturbed habitats (Inger, 1966).

Diversity in each habitat was low. In forest and grassland, one species dominated (*Microhyla fissipes* and *Duttaphrynus melanostictus* respectively), whereas in

Anuran species	Generalist/specialists	Major habitat
<i>Duttaphrynus melanostictus</i>	S	Grassland
<i>Hylarana erythraea</i>	S	Grassland
<i>Polypedates leucomystax</i>	S	Forest
<i>Kaloula pulchra</i>	S	Forest
<i>Microhyla fissipes</i>	S	Forest
<i>Microhyla heymonsi</i>	S	Forest
<i>Ingerophrynus parvus</i>	S	Coconut
<i>Leptobrachium nigrops</i>	S	Oil palm
<i>Fejervarya limnocharis</i>	G	Grassland/coconut
<i>Fejervarya cancrivora</i>	G	Grassland/forest

Table 3. Habitat preference of amphibian species. Specialist species are found predominantly in a single habitat type, whereas generalists are found in multiple.

plantations all species counts were very low. The distribution of species between these habitats showed that they may be split into ‘specialists’, with the majority of their population in one habitat type, and ‘generalists’ which are found in equal counts in multiple habitats (Table 3). Grassland and forest have equal species richness and total counts, which is significantly higher than either plantation. However, secondary forest has a greater number of specialist species (*Kaloula pulchra*, *Polypedates leucomystax*, *Microhyla fissipes*, and *Microhyla heymonsi*) which may be more valuable for conservation (Pardini et al., 2009).

Published work on the native anuran biodiversity of this region may provide an insight into the expected amphibian fauna of the study site. The original habitat for this region would have been lowland dipterocarp forest, some of which remains in parts of Peninsular Malaysia. A recent study in the Gunung Inas Forest Reserve in Kedah an area of intact primary forest in northern Peninsular Malaysia, recorded 28 species of anuran (Ibrahim et al., 2012). Also, the Ayer Hitam Forest Reserve is situated close to the field site of this study and its ecology has been extensively studied. This area represents a highly disturbed, logged and fragmented patch of remaining dipterocarp forest but one which has never been clear felled for oil palm (Awang Noor et al., 2007). There have been 18 species of anuran recorded in this patch (Haji et al., 1999; Nuruddin et al., 2007). Therefore, it is likely that at least 18 species of anurans could potentially be found in the

regenerating forest surveyed.

Of the species recorded in Ayer Hitam only four were detected in this study; *Duttaphrynus melanostictus*, *Fejervarya limnocharis*, *Polypedates leucomystax* and *Hylarana erythraea*. Of these, all but *H. erythraea* were found in working plantations as well as regenerating patches (although in low numbers), indicating possible persistence through the land use transition. The other species recorded within plantations and regenerating habitats do not represent the fauna seen in the original forest habitat, and all species are commonly associated with disturbed and human environments in the IUCN red list assessments (IUCN, 2011).

We believe that once the primary forest is removed, the amphibian assemblage is reduced to a minimal indigenous fauna, lacking the vast majority of forest species, as well as the adaptable species commonly found in disturbed habitat. Once the plantation is removed, disturbed habitat species colonise and increase in abundance. However, there is no evidence of recolonisation by the majority of the original amphibian fauna. A similar situation is seen with rainforest ants in Sabah, Malaysia, and is seen in all parts of the forest structure (Fayle et al., 2010). Oil palm plantations only support 5% of the ant species found in the original forest, and the assemblage is dominated by non-forest and introduced species (Bruehl & Eltz, 2010). This pattern is also seen in birds (Aratrakorn et al., 2006; Koh & Wilcove, 2008; Azhar et al., 2011), and in small mammals (Stuebing & Gasis, 1989). A recent meta-analysis has shown

Abundance and diversity of anurans in Malaysia

that across all taxa, 85% of forest species are lost in conversion to oil palm; and of the vertebrates, only 22% are found in both habitats, with plantations supporting 38% of the number of vertebrates found in forest (Danielsen et al., 2009).

The simplification of the landscape due to plantation monocultures has also been implicated in the loss of amphibian diversity. Heinen (1992) found a positive correlation in herpetofauna diversity and species richness with leaf litter depth and moisture content in forest regenerating from plantations in Costa-Rica, indicating that the lack of leaf litter seen in plantation habitats reduces their suitability for anurans. Amphibian diversity is linked to habitat heterogeneity through microhabitat and keystone features, both biotic and abiotic (Tews et al., 2004), and is especially linked to aquatic breeding sites (da Silva et al., 2011). These features are significantly diminished in oil palm plantations when compared to primary forest (Luskin & Potts, 2011).

Oil palm plantations are a poor substitute for degraded forest (Fitzherbert et al., 2008). Plantations are below optimum for all species, even those able to successfully exploit other semi-natural habitats. This has conservation implications because simply allowing land to regenerate is not sufficient in itself to restore amphibian biodiversity due to the effects of fragmentation (Lehtinen & Galatowitsch, 2001; Cushman, 2006). Natural recolonisation by amphibians seems limited and so management may be needed to restore the natural amphibian assemblage.

Management maybe required, especially in the short term, to increase habitat heterogeneity, and to aid recolonisation (Kettle, 2010; Hector et al., 2011). When comparing rehabilitated forest to naturally regenerated forest, the act of planting native plant species, such as Dipterocarpaceae, in the regenerated plots has been shown to increase avian diversity within 15 years (Kobayashi, 2007; Edwards et al., 2009). Amphibians are less able to colonise habitat due to a lack of mobility and often strict microhabitat requirements (Williams et al., 2009) and cannot recolonise at all unless direct connectivity with a source population in undisturbed habitat exists. Therefore, a management strategy of regeneration coupled

with corridor and buffer habitat linking to primary forest may be required (Laurance & Laurance, 1999; Gamage et al., 2011).

Given how widespread oil palm plantations have become in Southeast Asia, there is little doubt that further investigation of their influence on abundance and diversity, as well as how these effects can be reduced is needed. Global demand for the products of oil palm will continue to grow, and there is an urgent need to devise strategies to mitigate this great threat to tropical biodiversity. We recommend further study of oil palm plantations and the impacts on amphibians, especially as they seem to offer even less than other disturbed habitats. Specifically, more work is needed to understand which species make use of plantations on a wider scale. Continued monitoring of the success of amphibian recolonisation and establishment in regenerated habitats is desirable. Assessment of the viability of natural recolonisation is also crucial, as it will determine whether human assistance is needed to repair connectivity. Additionally, identification of key habitat features may allow for improved management of oil palm to allow greater amphibian success within plantations.

ACKNOWLEDGMENTS

Thanks go to Ms Shahrizad Yusuf and Mr Faid Abdul Rahman of Universiti Putra Malaysia for all their advice, expertise and help with field work. Thanks also go to Dr Barry Clarke (Natural History Museum, London) and Dr Sam Shonleben for their advice in the planning stages of the project.

REFERENCES

- Aratrakorn, S., Thunhikorn, S. & Donald, P.F. (2006). Changes in bird communities following conversion of lowland forest to oil palm and rubber plantations in southern Thailand. *Bird Conservation International* 16: 71–82.
- Awang Noor, A.G., Norini, H., Khamurudin, M.N., Ainduddin, N.A. & Thorsen, B.J. (2007). Economic valuation of timber resources in Ayer Hitam Forest Reserve, Puchong, Selangor. *Pertanika Journal of Tropical Agricultural Science* 30 (2): 83–96.
- Azhar, B., Lindenmayer, D.B., Wood, J., Fischer, J., Manning, A., McElhinny, C. &

- Zakaria, M. (2011). The conservation value of oil palm plantation estates, smallholdings and logged peat swamp forest for birds. *Forest Ecology and Management* 262: 2306–2315.
- Babbitt, K.J., Versey, J.S. & Tanner, G.W. (2010). *Measuring habitat*. In: Amphibian Ecology and Conservation, Dodd Jr., C.K. (ed). New York, USA: Oxford University Press.
- Birdsall, N., Pinchney, T. & Sabot, R. (2001). *Natural resources, human capital, and growth*. In: Resource abundance and economic development, Auty, R.M. (ed). Oxford, U.K: Oxford University Press.
- Bruehl, C.A. & Eltz, T. (2010). Fuelling the biodiversity crisis: Species loss of ground-dwelling forest ants in oil palm plantations in Sabah, Malaysia (Borneo). *Biodiversity and Conservation* 19: 519–529.
- Cushman, S.A. (2006). Effects of habitat loss and fragmentation on amphibians: a review and prospectus. *Biological Conservation* 128: 231–240.
- Danielsen, F., Beukema, H., Burgess, N.D., Parish, F., Bruehl, C.A., Donald, P.F., Murdiyarto, D., Phalan, B., Reijnders, L., Struebig, M. & Fitzherbert, E.B. (2009). Biofuel plantations on forested lands: Double jeopardy for biodiversity and climate. *Conservation Biology* 23: 348–358.
- Dunn, R.R. (2004). Recovery of faunal communities during tropical forest regeneration. *Conserv. Biol.* 18 (2): 302–309.
- Edwards, D.P., Ansell, F.A., Ahmad, A.H., Nilus R. & Hamer, K.C. (2009). The value of rehabilitating logged rainforest for birds. *Conservation Biology* 23: 1628–1633.
- Fayle, T.M., Turner, E.C., Snaddon, J.L., Chey, V.K, Chung, A.Y.C., Eggleton P. & Foster W.A. (2010). Oil palm expansion into rain forest greatly reduces ant biodiversity in canopy, epiphytes and leaf-litter. *Basic and Applied Ecology* 11: 337–345.
- Fitzherbert, E.B., Struebig, M.J., Morel, A., Danielsen, F., Bruehl, C.A., Donald, P.F. & Phalan, B. (2008). How will oil palm expansion affect biodiversity? *Trends in Ecology and Evolution* 23: 538–545.
- Gamage, S.N., Weerakoon, D.K. & Gunawardena, A. (2011). Current status of vertebrate diversity in anthropogenic and natural ecosystems in south-western Sri Lanka. *Journal of the Natural Science Foundation of Sri Lanka* 39: 383–389.
- Grismer, L.L. (2007). A new species of *Ingerophrynus* (Anura: Bufonidae) from a lowland rain forest in southern peninsular Malaysia. *Journal of Herpetology* 41: 225–230.
- Haddad, N.M., Bowne, D.R., Cunningham, A., Danielson, B.J., Levey, D.J., Sargent, S. & Spira, T. (2003). Corridor use by diverse taxa. *Ecology* 84: 609–615.
- Haji, J., Rajagopal, A.S. & Yaacob, A. (1999). Short notes of the vertebrate fauna of Ayer Hitam Forest Reserve, Puchong, Selangor. *Pertanika Journal of Tropical Agricultural Science* 22 (2): 179–183.
- Heaney, L.R. (1991). A synopsis of climatic and vegetational change in Southeast-Asia. *Climatic Change* 19: 53–61.
- Hector, A., Philipson, C., Saner, P., Chamagne, J., Dzulkifli, D., O'Brien, M., Snaddon, J.L., Ulok, P., Weilenmann, M., Reynolds, G. & Godfray, H.C.J. (2011). The Sabah Biodiversity Experiment: A long-term test of the role of tree diversity in restoring tropical forest structure and functioning. *Philosophical Transactions of the Royal Society B: Biol. Sciences* 366: 3303–3315.
- Heinen, J.T. (1992). Comparisons of the leaf litter herpetofauna in abandoned cacao plantations and primary rain-forest in Costa Rica – some implications for faunal restoration. *Biotropica* 24: 431–439.
- Holm, S. (1979). A simple sequentially rejective multiple test procedure. *Scandinavian Journal of Statistics* 6: 65–70.
- Ibrahim, J., Nur Hafizah, I., Nurul Dalila, A.R., Choimber, T. & Muin, M.A. (2012). Amphibian diversity of Gunung Inas Forest Reserve, Kedah, Malaysia. *Pertanika Journal of Tropical Agricultural Science* 35(2): 249–256.
- Inger, R.F. (1966). *The Systematics and Zoogeography of the Amphibian of Borneo*. Sabah, Malaysia: Natural History Publications (Borneo) Sdn. Bhd.
- Inger, R.F. & Stuebing, R.B. (2005). *A Field Guide to the Frogs of Borneo*. Sabah, Malaysia: Natural History Publications (Borneo) Sdn. Bhd.
- Inger, R.F., Voris, H.K. & Voris, H.H. (1974).

Abundance and diversity of anurans in Malaysia

- Genetic-variation and population ecology of some Southeast-Asian frogs of genera *Bufo* and *Rana*. *Biochemical Genetics* 12, 121–145.
- IUCN. (2011). *The IUCN red list of threatened species* (Version 2011.2.) <http://www.iucnredlist.org> [Accessed: 15 May 2012].
- Kettle, C.J. (2010). Ecological considerations for using dipterocarps for restoration of lowland rainforest in Southeast Asia. *Biodiversity and Conservation* 19: 1137–1151.
- Kobayashi, S. (2007). An overview of techniques for the rehabilitation of degraded tropical forests and biodiversity conservation. *Current Science* 93: 1596–1603.
- Koh, L.P. & Wilcove, D.S. (2007). Cashing in palm oil for conservation. *Nature* 448: 993–994.
- Koh, L.P. & Wilcove, D.S. (2008). Is oil palm agriculture really destroying tropical biodiversity? *Conservation Letters* 1: 60–64.
- Laurance, S.G. & Laurance, W.F. (1999). Tropical wildlife corridors: Use of linear rainforest remnant by arboreal mammals. *Biological Conservation* 91, 231–239.
- Lehtinen, R.M. & Galatowitsch, S.M. (2001). Colonization of restored wetlands by amphibians in Minnesota. *American Midland Naturalist* 145: 388–396.
- Liow, L.H., Sodhi, N.S. & Elmqvist, T. (2001). Bee diversity along a disturbance gradient in tropical lowland forests of South-east Asia. *Journal of Applied Ecology* 38: 180–192.
- Luskin, M.S. & Potts, M.D. (2011). Microclimate and habitat heterogeneity through the oil palm lifecycle. *Basic and Applied Ecology* 12 (6): 540–551.
- Marsh, D.M. & Haywood, L.M.B. (2010). *Area-based surveys*. In: Amphibian ecology and conservation. Dodd, C.K. (ed). New York, USA: Oxford University Press. Ch. 14.
- Nuruddin, A.A., Hjortso, C.N., Haron, N., Nor, K.M., Ghani, A.N.A. & Ahmad, I. (2007). Introducing stakeholder analysis in Malaysian forestry – The case of Ayer Hitam Forest Reserve. *Pertanika J. of Tropical Agricultural Science* 30 (2): 131–139.
- Onn, C.K., Belabut, D. & Ahmad, N. (2010). A revised checklist of the amphibians of Peninsular Malaysia. *Russian Journal of Herpetology* 17: 202–206.
- Pardini, R., Faria, D., Accacio, G.M., Laps, R.R., Mariano-Neto, E., Paciencia, M.L.B., Dixo, M. & Baumgarten, J. (2009). The challenge of maintaining Atlantic forest biodiversity: A multi-taxa conservation assessment of specialist and generalist species in an agro-forestry mosaic in southern Bahia. *Biological Conservation* 142: 1178–1190.
- Pautasso, M. (2007). Scale dependence of the correlation between human population presence and vertebrate and plant species richness. *Ecology Letters* 10: 16–24.
- Samad, F.A. (2011). *UPM*. In: History. <http://www.upm.edu.my/?l=e&aktvt=content&kat=D&kod=20060424114103210172165493>. [Accessed: December 2011].
- da Silva, F.R., Gibbs, J.P. & Rossa-Feres, D.D. (2011). Breeding habitat and landscape correlates of frog diversity and abundance in a tropical agricultural landscape. *Wetlands* 31 (6): 1079–1087.
- Soh, M.C.K., Sodhi, N.S. & Lim, S.L.H. (2006). High sensitivity of montane bird communities to habitat disturbance in peninsular Malaysia. *Biological Conservation* 129: 149–166.
- Stuebing R.B. & Gasis, J. (1989). A survey of small mammals within a Sabah tree plantation in Malaysia. *Journal of Tropical Ecology* 5: 203–214.
- Tews, J., Brose, U., Grimm, V., Tielbörger, K., Wichmann, M.C., Schwager, M. & Jeltsch, F. (2004). Animal species diversity driven by habitat heterogeneity/ diversity: The importance of keystone structures. *Journal of Biogeography* 31: 79–92.
- Wilcove, D.S. & Koh, L.P. (2010). Addressing the threats to biodiversity from oil-palm agriculture. *Biodiversity and Conservation* 19: 999–1007.
- Williams, S.E., Williams, Y.M., Vanderwal, J., Isaac, J.L., Shoo, L.P. & Johnson, C.N. (2009). Ecology specialization and population size in biodiversity hotspot: How rare species avoid extinction. *Proceedings of the National Academy of Sciences* 106: 19737–19741.
- Yaap, B., Struebig, M.J., Paoli, G. & Koh, L.P. (2010). Mitigating the biodiversity impacts of oil palm development. *CAB Reviews* 5: 1–11.