



Collaboration for Environmental Evidence

Systematic Review No. 73

DO TREE PLANTATIONS SUPPORT HIGHER SPECIES RICHNESS AND ABUNDANCE THAN PASTURE LANDS

Draft Review Report

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Cover Sheet

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Summary

1. Background

Increased worldwide demand for wood products, coupled with public concern over the loss or degradation of natural forests, has led to a steady increase in plantation establishment throughout most regions of the world. Most of the world's new plantations are generally established on former agricultural lands that are often of declining economic value for grazing or cropping. There is an expectation that when established within intensively used landscapes, plantations can contribute positively to biodiversity conservation.

2. Objectives

We conducted a systematic global review of differences between timber plantations and pasture lands in terms of animal and plant species richness and abundance, and assessed the results using meta-analysis techniques. Our principle aim was to test the hypothesis that plantations contain higher species richness or abundance than pasture.

3. Methods

We searched multiple electronic databases and the internet using different combinations of Boolean search-terms. Search terms were run in separate or limited combinations depending on the requirements or limitations of the database used. We also obtained papers from colleagues and through reference lists from published studies including major review articles and books on plantations. Furthermore, we obtained information from some government studies and reports. Data were available for meta-analyses comparing the species richness and abundance of plantations and pasture lands for five taxonomic groups: plants, invertebrates, reptiles/amphibians, mammals, and birds. Studies that provided estimates of mean species richness and/or abundance, and the corresponding estimates of standard deviations and sample sizes, were included in the meta-analysis.

4. Main results

Our systematic literature search identified 1,967 articles of potential relevance to our study. Of these articles, 70 provided biological monitoring information for plantations and agricultural lands. A further 29 articles were excluded from the meta-analysis due to their lack of provision of information necessary for the analysis, or in one case, inadequate experimental design. In total, 41 primary articles met our criteria for inclusion within the meta-analysis. Of these articles, 36 compared species richness or abundance in pastures and plantations (Table 4). Studies varied widely in the information provided about factors affecting the species richness or abundance of different taxa within pastures

and plantations. We were limited to assessing those factors that were consistently reported in the literature. The majority of studies provided multiple contrasts of species richness and/or abundance between pasture lands (control) and plantations (treatment). Some studies contrasted multiple treatments to a common control, and others contrasted multiple controls to a common treatment, hence creating divisions within studies.

For birds, plantations possessed higher species richness than pastures. For the small subset of studies where it was reported whether or not pastures included remnant vegetation, the difference between plantation and pasture was greater when the pasture did not include remnants. For mammals, the difference in species richness between plantations and pastures appeared to be affected by whether or not the plantations consisted of native or exotic timber species. Mammal species richness was lower in plantations consisting of exotic timber species than it was in pastures, and it was higher in plantations consisting of native timber species than it was in pastures. No significant effects were found for other taxa. No significant effects on abundance were found for any taxa.

5. Conclusions

We found that for most taxa, plantations and pasture lands were not sufficiently consistent in their impact on species richness or species abundance to allow for general conclusions regarding their relative biodiversity value. Some taxa did have higher species richness (birds, and possibly reptiles/amphibians) in plantations than in pasture lands. However, our findings indicated that it was the variability of biodiversity responses to plantations and agricultural lands that was more informative than any single estimate of a response. There is insufficient evidence to support assumptions that plantations contain higher species richness or abundance than pasture, unless caveats are taken into account regarding the taxa considered, landscape context, and the specifics of how the land-use is managed. In other words, caution is warranted when making general statements about the inherent biodiversity value of any diverse and broadly-defined land-uses. The biodiversity value of both pasture lands and plantations is a product of past and present management decisions and landscape context.

Main Text

1. Background

Increased worldwide demand for wood products, coupled with public concern over the loss or degradation of natural forests (Lamb et al. 2001; Lindenmayer and Hobbs 2004), has led to a steady increase in plantation establishment throughout most regions of the world (FAO 2007). Plantations are being established globally at a rate of 3 million ha per year (2000-2005, FAO 2006) and currently provide almost 50% of the world's wood

production (FAO 2007). In some nations, plantations comprise a substantial proportion of national forest area (FAO 2006). The principle benefit of plantations is that they enable large volumes of wood products to be produced per unit of land area (Sedjo 1999), although their capacity to sequester carbon has made this land-use a potential contributor to climate change mitigation efforts (Laclau 2003; Miehle et al. 2006; Paul et al. 2008; Redondo-Brenes 2007).

There is a large literature assessing the relative biodiversity value of plantations versus natural forests (see Barlow et al. 2007; Hartley 2002; Lindenmayer and Hobbs 2004). In almost all cases, plantations contain fewer native fauna and flora relative to that found within natural forests, with a corresponding increased abundance and species richness of exotic species (Barlow et al. 2007; Hartley 2002; Lindenmayer et al. 2002). However, most of the world's new plantations are generally established on former agricultural lands (Sedjo 1999), that are often of declining economic value for grazing or cropping (Lamb et al. 2001). Under these circumstances, plantation establishment may provide both economic and environmental benefits. For instance, plantations can be used to sequester carbon and thereby reduce net greenhouse gas emissions (Jackson and Schlesinger 2004); lower water tables to help reduce dry land salinisation (Walker et al. 2002); and under some circumstances, relieve some of the pressure of timber demands from natural forests (Hartley 2002).

There is an emerging expectation that when established within intensively used landscapes (eg. agriculture), plantations can contribute positively to biodiversity conservation (Hartley 2002; Lugo 1997; Moore and Allen 1999). For instance, the flora and fauna of industrial scale plantations can compare favorably to that found within intensive land uses such as annual crop and pasture lands (Carnus et al. 2006; Hartley 2002; Moore and Allen 1999). For this reason, there has been promotion of the view that plantations provide higher environmental benefits, associated with increased biodiversity value, than agricultural landscapes (Moore and Allen 1999). We suggest that part of this expectation arises from plantations providing increased structural complexity relative to agricultural landscapes, which increases the variety of available resources upon which greater species diversity can rely (August 1983; Brokaw and Lent 1999; McElhinny et al. 2005). There is empirical and theoretical support for the positive relationship between increasing structural complexity and increases in biodiversity (but see Erdelen 1984; MacArthur et al. 1966; MacArthur and MacArthur 1961; McElhinny et al. 2005). However, if increased structural complexity is to enable plantations to support higher species richness than agricultural areas, then this one factor must dominate other contributing factors to species richness, such as habitat heterogeneity and the presence of native versus exotic vegetation. If generalizations are warranted, and these are to be incorporated into environmental policy and planning, it is important that the form and direction of changes in species richness, abundance and composition associated with these land-uses are identified, as plantations are increasingly replacing a significant percentage of many nations' agricultural lands (Kanowski et al. 2005).

2. Objectives

In this paper our objective was to review existing evidence of how plantations and pasture lands influence species richness and abundance by summarizing the data from the literature using meta-analysis techniques. We formally synthesized the available evidence to test the following hypotheses for different taxonomic groups of flora and fauna,

1. That plantations support higher species richness than pasture lands.
2. That plantations support a high abundance of organisms than pasture lands.

After taking into account available explanatory variables to explain some of the between study variation.

3. Methods

3.1 Question formulation

The review topic was originally proposed by Charlie Zammit of the Department of Environment, Water, Heritage & the Arts, Australia in response to plans to treble the area of plantations in Australia. As the majority of this increase in plantation are would occur on pasture lands the question was refined to specifically address this land-use conversion. An argument for the proposed benefit of this scheme was biodiversity would increase, hence the basis for the question formulation.

3.2 Search strategy

We defined plantations as stands of trees with native or exotic species, created by the regular placement of cuttings, seedlings or seed, selected for their wood-producing potential and managed for the purposes of timber or pulp harvesting (modified from AFS 2003). We defined pasture as an area with natural or improved vegetation used for the grazing of livestock. We searched multiple electronic databases and the internet using different combinations of Boolean search-terms. The databases used were Dogpile (<http://www.dogpile.com/>), Google (<http://www.google.com.au/>), Google Scholar (<http://scholar.google.com.au/>), Web of Science (<http://www.isiwebofknowledge.com/>), and Scirus (<http://www.scirus.com/>). We used the following search terms in various combinations: (plantation* OR “planted forest*” OR afforestation OR “production forest*”) AND (agricult* OR meadow* OR crop* OR farm* OR grass* OR pastur* OR paddock* OR graz* OR field* OR range*) AND (biodiversity OR diversity OR richness OR abundance OR species OR bird* OR mammal* OR reptile* OR amphibian* OR frog* OR invertebrate* OR insect* OR arthropod* OR plant* OR flora OR fauna). Search terms were run in separate or limited combinations depending on the requirements or limitations of the database used. We also obtained papers from colleagues and through reference lists from published studies including major review articles and books on plantations (eg. Hartley 2002; Lindenmayer and Hobbs 2004; Moore and Allen 1999; Salt

et al. 2004). Furthermore, we obtained information from some government studies and reports.

3.3 Study inclusion criteria

Data were available for meta-analyses comparing the species richness and abundance of plantations and pasture lands for five taxonomic groups: plants, invertebrates, reptiles/amphibians, mammals, and birds. Studies that provided estimates of mean species richness and/or abundance, and the corresponding estimates of standard deviations and sample sizes, were included in the meta-analysis.

3.4 Study quality assessment

Variation in the scale of replication and the general quality of experimental design used in the primary studies has the potential to contribute to statistical differences in between-study results. This may result in misleading outcomes from the meta-analysis (Gates 2002), so we assigned each paper a data quality category as outlined in Table 1. Papers were excluded from analyses if they fell into category IV.

Table 1. Hierarchy of quality of evidence based on the information provided in research papers. Modified from Pullin & Knight (2003).

Category	Quality of evidence presented
I	Randomized controlled trial with matched pairs of treatments and controls, Study conducted at an adequate scale for subject taxa
II	Controlled trial of adequate scale for study organism. Unpaired treatments and controls.
III	Unpaired treatments and controls. Scale of study raises potential of confounding effects for the subject taxa considered.
IV	Evidence deemed inadequate due to inherent problems with experimental design.

3.5 Data extraction

Qualitative data was not used. The primary reviewer extracted all quantitative data, with subsequent checking of a subset of this data by a second reviewer, ensuring consistency and validity of extraction technique. All useful data was stored in a database. See table one for exclusion criteria.

3.6 Data synthesis

For all treatments and controls, we tabulated the estimates of mean species richness and/or abundance, estimates of the standard deviations about the means, and the sample sizes. If an estimate of a standard deviation were not provided, it was calculated from the estimate of the standard error and sample size. In some cases, the estimate of the standard error was measured from error bars in the figures provided. This information is presented in forest plots which provide the means and 95% confidence intervals for primary studies in a format which enables ready comparison with a common axis (Whitehead 2002).

For species richness and abundance, a standardized difference between treatment and control means is typically used to summarize the findings of each study (Cooper and Hedges 1994, Whitehead 2002). This is done so that the quantitative findings from the different primary studies are in a standardized form that permits meaningful numerical comparison and analysis across studies. We used the statistic known as Hedges' g (Hedges and Olkin 1985)

$$g = \frac{\bar{x}_T - \bar{x}_C}{s_p} \times J$$

where \bar{x}_T is the treatment species richness or abundance mean, \bar{x}_C is the control mean, s_p is the pooled standard deviation and J is a correction factor for small sample bias.

$$s_p = \sqrt{\frac{(n_T - 1)s_T^2 + (n_C - 1)s_C^2}{n_T + n_C - 2}}$$

$$J = 1 - \frac{3}{4(n_T + n_C - 2) - 1}$$

Where n_T is the treatment sample size, n_C is the control sample size, s_T is the treatment standard deviation and s_C is the treatment standard deviation.

The standardized differences in means (contrasts) were analyzed using linear mixed models, which provide a flexible framework for meta-analysis, incorporating both fixed and random effect terms (Gurevitch & Hedges 1993, Stram 1996). These models allow for heterogeneity between studies in the effect of the treatment of interest. The heterogeneity is partly explained by fixed effects of study-level covariates, and partly by study-level random effects.

4. Results

4.1 Review statistics

Fixed and random effects were estimated using residual maximum likelihood (REML) estimation (McCulloch and Searle 2001, Demidenko 2004). The significance of fixed effects was assessed by computing scaled Wald statistics which were treated as having an approximate F distribution (Kenward and Roger 1997). The significance of variance components (random effects) was assessed using likelihood ratio test statistics. These were treated as being distributed approximately as chi-squared random variables (McCulloch and Searle 2001, Demidenko 2004). Non-significant effects were not included in the models.

It is common in meta-analysis to assume that the within study variation is estimated accurately for each study and can be treated as if it was known. In the majority of the studies we have considered here, the amount of replication was low, so the estimates of standard deviations were imprecise. In view of this, we decided not to assume that the standard error of each contrast was known. It is also common to use the amount of replication for each contrast to weight the contrasts in the analysis. Because of the differences in the types of experimental units in different studies, this could have given inappropriately high weight to a few studies. We decided to give equal weight to each study.

It is also common in meta-analysis to test for heterogeneity of treatment effects across studies. Due to the nature of ecological studies, we did not expect there to be a consistent difference in biodiversity between plantations and pastures and hence we expected heterogeneity. We accounted for this heterogeneity by fitting study-level covariates as fixed effects and study and division within study random effects.

We initially began our analysis using the software package MetaWin (Rosenburgh et al, 2000), a specialized package designed to conduct meta-analyses. However MetaWin did not allow us to account for the correlation of contrasts within a study, or within a division within study, nor did it allow us to fit more than one covariate in the model. Meta-analysis using linear mixed models does not require specialist software and can be done using standard statistical software (Sheu & Suzuki 2001). We used functions available in GenStat (Payne et al, 2007) to fit our models.

4.2 *Description of studies (sub-headings as applicable)*

The majority of studies provided multiple contrasts of species richness and/or abundance between pasture lands (control) and plantations (treatment). Some studies contrasted multiple treatments to a common control, and others contrasted multiple controls to a common treatment, hence creating divisions within studies. This structure in the data

meant that contrasts within a study or within a division within a study could not be assumed to be independent. Study and division within study were fitted as random effects to account for potential correlation between contrasts within a study or observations that used common treatments or controls within a study. See Table 2 for details of individual studies and their sources.

Table 2. Summary table of primary studies, sample sizes, and explanatory variables for comparison of bird species richness and abundance in plantation and pasture lands used in the meta-analysis.

Author	Taxa	Region	Control sample size	Treatment sample size	Climate	Remnant-veg pasture	Remnant-veg plantation	# trees planted	Native exotic	Plantation age	Plantation size
(Borsboom et al. 2002)	Birds, mammals, reptiles/ amphibians, plants	Asia-pacific	3	2, 3	subtropical	no remnant	no remnant	1	native	1,3,16,40	6, 7, 17
(Catterall et al. 2004)	Birds, invertebrates	Asia-pacific	5	5,10	Tropical, subtropical	unknown	no remnant, unknown	1 to 13	native	7, 10, 60	6
(Cremene et al. 2005)	Invertebrates, plants	Europe	5	3	Temperate	unknown	unknown	1	native	20	12
(Cunningham et al. 2005)	Invertebrates	Asia-pacific	4	4	Temperate	unknown	remnant	1	native	5	78, 325
(Downie et al. 1996)	Invertebrates	Europe	3	3	temperate	unknown	unknown	1	exotic	37.5	unknown
(Eggleton et al. 2005)	Invertebrates	Europe	16	16	temperate	unknown	unknown	1	native	unknown	100
(Freemark et al. 2002)	Plants	Americas	10	9	temperate	unknown, remnant	unknown	1	native	unknown	unknown
(Garcia et al. 1998)	Birds	Americas	15	2,5,6	temperate	unknown	unknown	1,3	Exotic native	unknown	unknown
(Hanowski et al. 1997)	Birds	Americas	8	12	temperate	unknown	unknown	1	exotic	5,6	10
(Hicks and McCaughan 1997)	Invertebrates	Asia-pacific	4	4	temperate	unknown	unknown	1	exotic	unknown	unknown
(Hobbs et al. 2003)	plants	Asia-pacific	4	4	temperate	unknown	remnant	1	native	5	325
(Igboanugo et al. 1990)	plants	Africa	3	3	tropical	remnant	unknown	2	exotic	15	13.37
(Kanowski et al. 2006)	Reptiles/ amphibians	Asia-pacific	5	5, 10	Tropical, subtropical	unknown	no remnant, unknown	1, 13	native	7, 10, 60	6
(Klomp and Grabham 2002)	Birds	Asia-pacific	3	3	temperate	unknown	unknown	1	native	4	11
Lindenmayer, D.B. unpublished data	Birds, mammals, reptiles/ amphibians	Asia-pacific	10	10	temperate	remnant	remnant	1	exotic	5	10000
(Loyn et al. 2007)	Birds	Asia-pacific	25	58	temperate	remnant	remnant	1	native	6	2
(Maccherini and De Dominicis 2003)	Plants	Europe	30	30	temperate	unknown	unknown	2	exotic	26	13
(Moss et al. 1979)	Birds	Europe	3	3,4,5	temperate	unknown	unknown	1	exotic	6	6,300 to 8,900
(Munro et al. 2009)	Birds, mammals, reptiles/ amphibians,	Asia-pacific	3, 6	2	temperate	no remnant, remnant	no remnant	1	native	3	8

plants											
(O'Connor 2005)	plants	Africa	3	3	temperate	unknown	unknown	1	exotic	12	unknown
(Oxbrough et al. 2006)	Invertebrates	Europe	8	8	temperate	unknown	unknown	1	exotic	5	unknown
(Paquet et al. 2006)	Birds	Europe	41	34	temperate	unknown	unknown	1	native	16	unknown
(Petit et al. 1999)	Birds	Americas	4	4	tropical	remnant	unknown	1	native	23	unknown
(Pik et al. 1999)	Invertebrates	Asia-pacific	5	5	temperate	unknown	unknown	1	native	4	3.5
(Powers et al. 1997)	Plants	Americas	4	4	tropical	unknown	unknown	1	Native, exotic	7	0.25
(Proctor et al. 2003)	Invertebrates, plants	Asia-pacific	5	5, 10	tropical subtropical	unknown	no remnant unknown	1,13	native	10, 60, 7	6
(Rossi 2003)	Birds, Mammals	Asia-pacific	6	13, 17	temperate	unknown	unknown	1	Exotic, native	18	unknown
(Rossi and Blanchart 2005)	Invertebrates	Asia-pacific	5	5	tropical	unknown	unknown	1	exotic	8	unknown
(Rotenberg 2007)	Birds	Americas	16	40	tropical	remnant	remnant	1	exotic	10	unknown
(Schnell et al. 2003)	Invertebrates	Asia-pacific	5	5	temperate	unknown	unknown	1	native	10	3.5
(Shakir and Dindal 1997)	Invertebrates	Americas	5	5	temperate	unknown	unknown	1,3	exotic	65,75	unknown
(Thompson and Townsend 2004)	Invertebrates	Asia-pacific	3	6	temperate	unknown	unknown	1	exotic	30	unknown
(Townsend et al. 1997)	Invertebrates	Asia-pacific	2	2	temperate	unknown	unknown	1	exotic	30	2510
(Vallan 2002)	Reptiles/ amphibians	Africa	2	3	tropical	unknown	unknown	1	exotic	unknown	unknown
(Wilson and Sykes 1988)	Invertebrates	Asia-pacific	5	5	temperate	unknown	unknown	1	exotic	75	unknown
(Yeates and Saggar 1998)	Invertebrates	Asia-pacific	3, 10, 40	3,10,40	temperate	unknown	unknown	1	exotic	2, 13, 14, 25	2

4.3 *Study quality assessment*

Studies varied widely in the information provided about factors affecting the species richness or abundance of different taxa within pastures and plantations. We were limited to assessing those factors that were consistently reported in the literature. Table 3 shows the covariates which we were able to extract. The study-level random effects were included to account for the effect of other unreported factors that may have contributed to differences in species responses to the control and treatment. The variables shown in Table 3 were fitted as fixed effects to allow us to assess the relationship between the treatment effects and the study characteristics.

Table 3. Explanatory variables provided by primary studies and included in meta-analyses of species richness and abundance for plantations and pasture lands. Potential explanatory variables such as proximity of remnant vegetation, pasture grazing frequency, plantation tree densities, etc., were not provided consistently enough to allow analysis for any single taxa.

Explanatory variable	Description	Percentage of papers containing relevant information for explanatory variable				
		Birds	Mammals	Reptiles/ amphibians	Invertebrates	Plants
Climate	Dominant climate where study conducted (tropical, temperate, sub-tropical)	100%	100%	100%	100%	100%
Region	Geographic region where study conducted (Americas, Asia-pacific, Europe, Africa)	100%	100%	100%	100%	100%
Quality	Quality of evidence (see Table 1)	100%	100%	100%	100%	100%
Area	Area in hectares, used for plantation only	83%	73%	95%	87%	81%
Plantation age	Time since last tree planting	94%	100%	95%	97%	94%
Number of trees	Number of tree species planted in the plantation	100%	100%	100%	100%	100%
Native/ exotic	Planting of predominantly native or exotic tree species in the plantation.	100%	100%	100%	100%	100%
Remnant-veg pasture	Retention or absence of remnant vegetation in the pasture	27%	73%	55%	10%	23%
Remnant-veg plantation	Retention or absence of remnant vegetation in the plantation	31%	73%	85%	41%	35%

4.4 Quantitative synthesis/Meta-analysis

Species richness

For birds, mammals and plants there was a range of responses from positive to negative, with the most extreme responses possessing wide confidence intervals. For reptiles and amphibians there were no extreme negative responses. For invertebrates a few comparisons show large negative effects, albeit with wide confidence intervals. The remaining comparisons showed small effects ranging from negative to positive.

Table 4. Tests of effects on differences in species richness and abundance between pastures and plantations. Significant results as asterisks.

Taxa	# of studies	# of comparisons	Fixed effects	Random effects	F statistic	df	p
Species richness							
birds	13	32	overall	division	4.87	1,14	*
birds (subset)	6	12	rem-veg pasture		24.2	1,10	**
reptiles/amphibians	5	20	overall	division	4.09	1,5	NS
mammals	4	15	overall	division	0.08	1,4	NS
invertebrates	11	20	overall	study	0.52	1,10	NS
plants	10	51	overall	division	0.0	1,17	NS
abundance							
birds	7	14	overall		1.01	0,58	NS
reptiles/amphibians	3	4	overall	study	0.10	1,2	NS
mammals	3	7	overall	division	0.07	1,2	NS
invertebrates	3	65	overall	division	0.08	1,22	NS
plants	3	10	overall		0.65	1,9	NS

4.6 Outcome of the review

For birds, plantations possessed higher species richness than pastures (Table 4). For the small subset of studies where it was reported whether or not pastures included remnant vegetation, the difference between plantation and pasture was greater when the pasture did not include remnants (Table 4). For mammals, the difference in species richness between plantations and pastures appeared to be affected by whether or not the plantations consisted of native or exotic timber species ($F = 4.2$, $df = 1,13$, $p = 0.06$). Mammal species richness was lower in plantations consisting of exotic timber species than it was in pastures, and it was higher in plantations consisting of native timber species than it was in pastures. No significant effects were found for other taxa.

Abundance

Table 4 contains the results of fitting mixed models to the standardized differences in abundance between plantations and pastures for all taxa. No significant effects on abundance were found for any taxa.

5. Discussion

5.1 Evidence of effectiveness

We found that for most taxa, plantations and pasture lands were not sufficiently consistent in their impact on species richness or species abundance to allow for general conclusions regarding their relative biodiversity value. Some taxa did have higher species richness (birds, and possibly reptiles/amphibians) in plantations than in pasture lands. However, our findings indicated that it was the variability of biodiversity responses to plantations and agricultural lands that was more informative than any single estimate of a response. There is insufficient evidence to support assumptions that plantations contain higher species richness or abundance than pasture, unless caveats are taken into account regarding the taxa considered, landscape context, and the specifics of how the land-use is managed.

5.2 Reasons for variation in effectiveness

Previous studies lend support to the influence that stand-level features have on plantation biodiversity. These features include: 1) the cultivation of native or exotic timber species (Hartley 2002), 2) the use of mixed species stands or a monocultures (Catterall et al. 2004; Hartley 2002), 3) the retention or removal of understorey plant species (Bonham et al. 2002), and 4) the preservation or removal of biological legacies (*sensu* Franklin et al. 2000) such as remnant trees, windrows, and logging slash (Hartley 2002; Lindenmayer and Hobbs 2004). In this study, there were insufficient published papers to make definitive statements about the effect of stand-level features of plantations on the taxonomic responses of the taxa. However,

examination of the data suggested the possible presence of effects which could be investigated further if data from more studies become available.

In this synthesis, we found that the use of native or exotic timber tree species appeared to influence whether the species richness of mammals within plantations was higher relative to pasture lands. In general, the planting of native trees can enable the persistence of those organisms (especially microorganisms and invertebrates) which over evolutionary timescales will have co-evolved with the native flora (Hartley 2002). This result is also influenced by the fact that the dominant exotic tree species grown (i.e. *Pinus* species Richardson et al. 1994), lack nectar and other resources provided by their native counterparts. As such, in regions where they are exotic, *Pinus* plantations are found to support fewer species of nectarivorous, frugivorous, and foliage-gleaning birds and mammals (but see Bonham et al. 2002), than their native timber species counterparts (Friend 1982; Gepp 1976; Hartley 2002; Lindenmayer and Hobbs 2004; Norton 1998). Furthermore, the diversity of fauna is often found to be higher within plantations when native vegetation is proximate to their edges (Curry 1991; Gepp 1976; Hobbs et al. 2003; Lindenmayer et al. 2002). In these cases, the adjacency of native vegetation provides a source from which populations can migrate to the plantation, and also enables species to occur within the plantation even if the entire complement of necessary resources is not provided (Hobbs et al. 2003; Lindenmayer and Hobbs 2004). The influence of adjacent vegetation on species richness highlights the fact that the composition or richness of communities found within plantations is not determined solely by within-plantation processes, but by larger-scale landscape processes (Ricklefs 1987; Whittaker et al. 2001). For example, retention of different sizes, shapes and types of remnant native vegetation within and adjacent to a plantation, are all features that are likely to increase the species richness of the plantation (Hartley 2002; Lindenmayer and Hobbs 2004). The incorporation of these factors contributes to the creation of a landscape mosaic, with associated increases in landscape heterogeneity directly contributing to the range of species that the plantation environment can support (Lindenmayer and Hobbs 2004).

In this study, the presence of remnant vegetation within pastures was associated with higher bird species richness than in plantations. Notably, this was not the case if remnant vegetation was absent from pasture lands. The retention of scattered individual trees or small tree patches (< 1 ha) within pastures can provide shelter and substrate for native flora (Reid and Landsberg 2000), habitat and resources for invertebrates (Oliver et al. 2006), food for animals reliant on pollen, nectar, seeds, and invertebrates (Carruthers et al. 2004), and habitat for hollow-dependent fauna (Nilsson et al. 2005). Notably, agricultural lands may contain higher densities of biological legacies (sensu Franklin et al. 2000), such as large hollow bearing trees than forests managed for timber production (Nilsson et al. 2005). Our finding that the retention or absence of scattered trees within pastures altered the species richness for bird communities within pasture lands was consistent with the evidence that scattered trees are keystone structures (Manning et al. 2006) utilized by both open country and woodland birds (Fischer and Lindenmayer 2002a, b). Furthermore, this outcome is consistent with studies demonstrating the ecological benefits of retaining scattered trees within agricultural landscapes (Carruthers et al. 2004; Manning et al. 2006). The outcome of any comparative study of the biodiversity value of different land-uses largely depends on a suite of variables operating at the scale of the stand, and at the scale of the landscape for each of the land-uses compared (Benton et al. 2003; Fischer

et al. 2008a; Lindenmayer and Hobbs 2004; Tews et al. 2004). There are a suite of local stand level and landscape level issues which can alter the relative biodiversity value of both plantations (Carnus et al. 2006; Hartley 2002; Lindenmayer and Hobbs 2004) and agricultural lands (Bengtsson et al. 2005; Benton 2007; Benton et al. 2003; Fischer et al. 2008a). The use of a common scale, such as that used in this meta-analysis, with which to compare the relative biodiversity value of these two land-uses is likely to vary between a positive, neutral or negative effect size simply depending on the type of plantation and agricultural land compared. For instance, the outcome of a comparison of species richness between intensively used cropland and a complex native plantation is likely to be very different than a comparison between organic agriculture and an industrial scale homogenous exotic timber plantation. Therefore, there are likely to be legitimate ecological reasons for differences in response outcomes, as repeatedly demonstrated in this assessment.

5.3 *Review limitations*

Although meta-analysis allows factors contributing to an effect to be explored (Gurevitch and Hedges 1999), relationships are often confounded by methodological differences between studies included in the analysis (Pullin and Stewart 2006; Stewart et al. 2005). Furthermore, meta-analyses are often restricted by the lack of relevant information reported in the primary studies. In this study we were often unable to include the results of published studies for some analyses due to insufficient provision of necessary information regarding their treatments and controls (see Table 2). One way to alleviate this problem is to develop consistency among journals regarding minimum standards for the information included in published studies. Careful consideration needs to be given to the interpretation of meta-analysis results when assessing questions which involve human modified systems. In these cases, the inherent variability of biological systems is compounded by variation in the way humans can modify a system and its surrounding landscape. Inevitably the distillation of a single estimate from a meta-analysis in these cases relies on the assumption that these differences can be downplayed (see Bailar 1997), or that there is sufficient consistency between primary studies to assess the influence of these differences on the outcome (Gurevitch and Hedges 1999).

The quantified biodiversity value of any land-use will be determined by 1) the taxa studied, 2) the measure of species diversity used, and, 3) the spatial and temporal scale of the study (Tews et al. 2004). Keeping these caveats in mind, our results indicate that plantations do provide for higher species richness than pastures for some taxa. However, even in these cases, the value of this metric may not be sufficiently informative on which to base conservation or policy decisions.

The results of this meta-analysis relied on species counts (species richness), or counts of individuals belonging to a particular taxa (abundance). However, such metrics can be misleading as they can indicate equivalency between two different land-use types in terms of biodiversity value, regardless of the existence of substantial underlying differences in the composition of the fauna or flora considered (see Sax et al. 2005). For instance, higher species richness may be the cumulative outcome of improving conditions for invasive exotic or otherwise unwanted species (Lindenmayer and

Hobbs 2004). Higher species richness cannot be used to infer an increase in conservation value (Lindenmayer and Hobbs 2004).

Determining the biodiversity value of a land-use therefore requires consideration of its impact on the landscape within which it is nested. In landscapes in which large amounts of clearing of native forest has occurred, there may be conservation benefits for remnant forest-dependent fauna and flora through the establishment of plantations in conjunction with the retention of remnant trees (Lindenmayer and Hobbs 2004). In contrast, in landscapes where native grasslands have been lost to alternative land-uses, agricultural landscapes that support a mosaic that includes native pastures and remnant grasslands may provide higher biodiversity benefits than plantations. Further consideration also may need to be given to issues involving landscape permeability and connectivity (August 1983; Pryke and Samways 2001; Suckling 1982; Taylor et al. 1993; Tews et al. 2004), invasive timber species (Richardson 1998; Williams and Wardle 2005), and hydrology (Carnus et al. 2006; Jackson et al. 2005).

6. Reviewers' Conclusions

6.1 Implications for *management / policy / conservation*

We conclude from our meta-analysis that whether or not plantation establishment in pasture lands will produce biodiversity benefits is a question best answered by a combination of empirical and normative considerations specific to the region and taxa in question. Just as site-specific management is needed to sustain soil quality and long-term site productivity (Fox 2000), so are site-specific approaches needed for plantations when addressing biodiversity benefits and disbenefits. Both pasture lands and plantations can support various combinations of exotic and native taxa (Fischer et al. 2008b; Lindenmayer and Hobbs 2004), and both land-uses can be altered to make them more or less favourable for specific taxa (Bengtsson et al. 2005; Benton et al. 2003; Hartley 2002; Lindenmayer and Hobbs 2004). As such, deciding which land-use is “best” cannot be separated from (1) landscape context, 2) the conservation value of the taxa being considered, and (3) the components and metrics of biodiversity that are evaluated.

Our results emphasize that caution is required in making general statements about the relative biodiversity benefits of one broadly-defined land-use over another. Our results also emphasize the numerous options available to managers of both plantations and agricultural lands in attempting to improve biodiversity values. Neither of the two land-uses has an inherent biodiversity advantage in terms of the species richness or abundance of species they are capable of supporting. Rather, both exist along a controllable and variable continuum of biodiversity value that is primarily dependent on management decisions and landscape context.

6.2 Implications for research

Although meta-analysis does in fact allow contributing factors to be explored (Gurevitch and Hedges 1999), the relationships are often confounded by methodological differences between studies included in the analysis (Stewart et al., 2005; Pullin and Stewart 2006). Furthermore, meta-analyses are often restricted by

the lack of relevant information reported in the primary studies. We suggest that this is a variant of the “file drawer” problem (studies reporting non-significant results are less often published Rosenthal 1979) that has not been adequately dealt with in the ecological literature: The inability to include the results of many published studies solely due to their insufficient provision of necessary descriptive information regarding aspects of their treatments and controls. We suggest that one way to alleviate this problem is to develop and call for more consistent standards among journals regarding the minimum site descriptive and statistical information required to accompany published studies of this nature.

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7. Potential Conflicts of Interest and Sources of Support

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