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Insect diversity in post-mining areas: Investigating their potential role as bioindicator of reclamation success

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Abstract. *Buchori D, Rizali A, Rahayu GA, Mansur I. 2018. Insect diversity in post-mining areas: Investigating their potential role as bioindicator of reclamation success. Biodiversitas 19: 1696-1702.* Reclamation can be a pivotal process to return an ecosystem to its condition prior to human disturbance, by recreating a landscape so that its structure and function closely resemble a natural community. Unfortunately, there is a lack of empirical data as to whether reclamation efforts successfully establish sustainable of the ecosystem or not. The objective of this research was to study insect diversity in post-mining areas and investigate their potential role as bioindicators of reclamation success. An ecological research was conducted in post-mining reclamation areas managed by PT. Berau Coal in Binungan, East Kalimantan. We selected sub-areas that had been subject to reclamation efforts for varying periods, ranging from 2 to 10 years, for observation. We also used an area of undisturbed natural forest as a comparison. Inside each of these subareas of different reclamation age, insects were sampled using pitfall traps and malaise traps along a 100-meter transect. Our results showed that insect diversity differed in areas of different reclamation age. Based on CCA revealed that environmental factors i.e. pioneer tree age, vegetation diversity and soil chemistry (N total) affected the diversity of insects in the reclamation area. In particular, NMDS analysis showed different species composition in ant communities found in subareas of varying reclamation age. We conclude that ants are the most useful potential bioindicator to assess reclamation success in post-mining areas.

Keywords: Ant, Berau, reclamation area, revegetation, species composition

INTRODUCTION

As a country with significant mineral resources and extensive mining, Indonesia's government has enacted regulations related to reclamation of landscapes previously subject to mining (PP No.78, Year 2010), with a goal to protect ecosystems from collapse after mine closures. Mining companies' restoration activities in closure areas generally consist of planting pioneer trees, with the presumption that in time the ecosystem will fully recover functionality and structure (Ge et al. 2010). Unfortunately, there is little data as to whether this reclamation strategy will succeed in producing a sustainable ecosystem. Therefore, ecosystem assessments are needed to provide crucial evidence of reclamation outcomes.

One indicator of reclamation success is new soil formation. In mining areas, such as for coal, the soil layer is removed as a result of exploration activity. Assessing the success of soil regeneration post-mining is challenging because soil development is extremely complex and the details are poorly understood. Soil development itself is a product of both physical and biological processes which link abiotic and biotic variables (Walker and del Moral 2003). However, we do know that the reclamation age of an area (chronosequence) is an important factor for soil development. Different aged reclamation areas will presumably manifest different stages of ecological succession which encompasses not only environmental conditions but also biotic factors (Stevens and Walker 1970).

Biotic factors, particularly the composition of plant and animal communities present, are the most important element in the development of new soil in depleted areas. Plants selectively concentrate soil nutrients, transport water from the soil to the atmosphere, and add organic matter when they decay. In addition, animals use plants for food, nest sites, and protection, and plants and animals mutually influence each other as animals seek out and use these resources. Through these mechanisms, animals alter soils by burrowing, feeding, defecating and dying. Hence, interactions between plants and animals play an important role in soil formation as well as influencing ecological succession in reclamation areas (Walker and del Moral 2003). In this study, we measured soil chemistry and composition in order to determine the health and ecological status of soil in our study sites. In general higher levels of organic carbon and nitrogen correlate to increased soil formation.

The changes in species composition of plant communities during succession are accompanied by changes in animal communities as well. All of these groups mutually interact in feedback loops, so that changes in one group of organisms influence other groups. Consequently, attempting to distinguish between cause and effect may be difficult or impossible. In studies of these relationships, animals are often treated as passive responders to changes in plant succession (Bradshaw 1983). Plants provide the primary food source and habitat structure without which most animals cannot survive. The course of plant succession is intimately linked to animals that disperse seeds, pollinate flowers and eat various plant parts, as well as redistribute nutrients and improve soil structure. Animal succession may respond to changing plant resources, abiotic conditions or interactions among animals themselves. However, animal succession may be more dependent on vegetation cover and structure than on plant species composition, resulting in a partial uncoupling of plant and animal community compositions related to succession (Gallé 1991).

Animal succession can be influenced by diversity in local flora or in abiotic conditions, which affect the structure and availability of habitat and the functional ability of animals to act as seed dispersers and pollinators. In the succession process, herbivores cannot colonize an area until plant resources are present and available, providing a form of obligatory facilitation. Similarly, predators and parasites must colonize either simultaneous to, or after, the arrival of their prey and hosts (Edwards 1988). This dependency on habitat variables (e.g., the presence of food or predators) has been described by a model of habitat accommodation and applied to situations such as colonization of ants on mined lands in Brazil (Majer 1992). In this case, animals become important as bioindicators of succession in restoration habitat.

Certain groups of animals may be used as surrogates for species diversity or assemblage composition of other taxa, to understand the effect of habitat disturbance (McGeogh 1998). Observation of arthropods can potentially reveal restoration status, as shown in studies with beetles (McGeoch et al. 2002; Pearce and Venier 2006), spiders (Pearce and Venier 2006), grasshoppers (Bazelet and Samways 2011) and ants (Gollan et al. 2011). Nevertheless, the use of insects as indicators of restoration success has largely been overlooked, with most studies focused only on vegetation (Colloff et al. 2010; Déri et al. 2011). Insects can be particularly useful as indicator species because they are extremely sensitive to environmental change (Rosenberg et al. 1986; Peck et al. 1998).

The objective of this research was to study insect diversity in post-mining areas and investigate their potential role as bioindicators of reclamation success.

MATERIALS AND METHODS

Research site

Our study was conducted in a reclamation area managed by PT Berau Coal, Berau, East Kalimantan, Indonesia (Figure 1). Sites had previously been mined for coal, and had subsequently been planted, after mine closure, with pioneer tree species such as acacia (*Acacia sieberiana*), johar (*Cassia siamea*) and sengon (*Paraserianthes falcataria*). To study the succession process, we selected several reclamation sub-areas of different reclamation age, ranging from two to ten years since the inception of reclamation efforts (planting of pioneer trees). Two plots were defined in each subarea as replication. Two plots in adjacent natural undisturbed forest were also selected to compare insect diversity there to that of study reclamation sites (Table 1).

Insect sampling

The sampling methods were adapted from Majer et al. (2007). A 100 m transect was laid out in a representative part of each subarea of different reclamation age (Figure 2). Along each transect, we placed ten plastic glasses (6.5 cm diameter × 9.5 cm depth) in the ground as pitfall traps. The traps were located at 10 m intervals and left open for six consecutive days and nights. Two malaise traps were also placed on each transect and left for 3 days. Pitfall traps capture insects on the soil surface in order to estimate abundance and richness. Malaise traps capture flying insects primarily and allow measurement of airborne insect diversity within each reclamation subarea. Insect sampling was conducted between July and August 2012.

Insects collected from pitfall traps and malaise traps were placed in plastic vials filled with 70% alcohol. Then, in the laboratory, collected specimens were sorted and identified to broad taxonomic levels (order or family level) using a reference key such as Borror *et al.* (1996). Some specimens were further identified to genera or morphospecies level (e.g., identification key of Bolton (1994)).

Vegetation and soil analysis

Plant and vegetation diversity were surveyed within 100 meters on either side of the transects laid for insects sampling. Vegetation was surveyed once during the study period, with visual identification of the species *in situ* and measurement of species abundance along each transect. Plants that could not be identified in the field were collected for later identification in the lab. Vegetation analysis showed that the pioneer trees most commonly planted in the transect areas were acacia (*A. sieberiana*), johar (*C. siamea*) and sengon (*P. falcataria*). Plant diversity tends to increase with subarea reclamation age (Figure 3, Table 1). Therefore, in studying the relationship between insect diversity and reclamation age, we were able to use reclamation age as a proxy for plant diversity and successful succession.

To obtain data about soil chemistry and composition, soils samples from each transect were analyzed in the laboratory. The results showed no relationship between reclamation age and soil chemistry (Figure 4a, Table 1) or soil composition (Figure 4b, Table 1). Therefore, we cannot assume that reclamation age can proxy for soil characteristics and ecosystem function of soils.

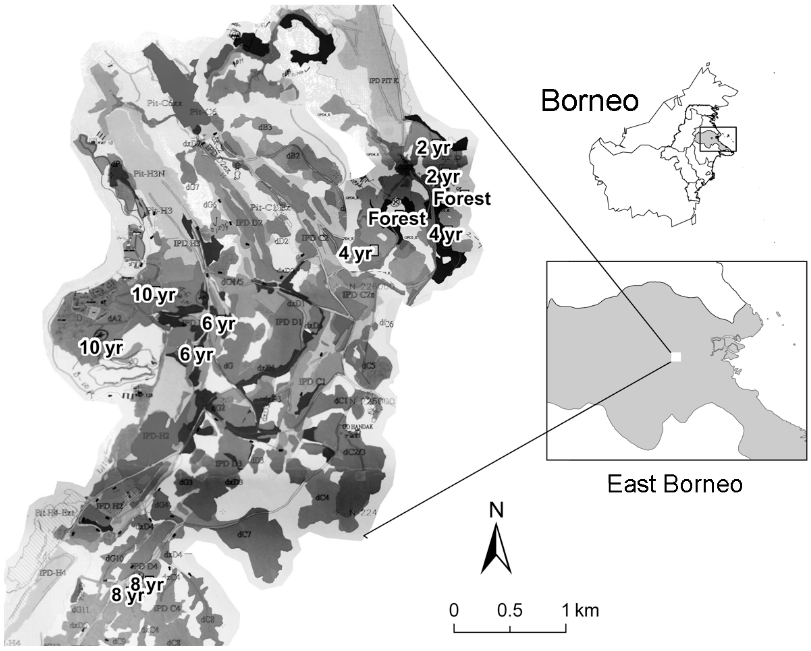

Figure 1. Map of the reclamation area managed by PT. Berau Coal in Binungan, Berau District, East Kalimantan, Indonesia. The reclamation age of study sites ranges from 2 to 10 years of active restoration activity

Table 1. Geographic coordinates, vegetation diversity and soil chemistry and composition in each subarea of the Berau, East Kalimantan, Indonesia reclamation area

Code (year)	Plot	Ordinate		Vegetation (# individuals)		Soil chemistry				Soil composition (%)		
		Latitude	Longitude	Tree	Scrub	pH H_2O	pH $CaCl_2$	Organic C	N total	Sand	Dust	Clay
PIT (2yr)	P1	2.053807	117.458412	4	18	4.5	3.8	1.01	0.04	34.6	17.7	47.7
	P2	2.056141	117.457633	2	15	5.3	5.0	2.74	0.06	42.3	25.5	32.2
D1 (4yr)	P1	2.049139	117.458613	2	22	4.8	4.1	0.66	0.08	30.9	19.8	49.3
	P2	2.047614	117.452660	2	15	4.4	3.8	1.41	0.15	13.0	29.0	58.0
H1 (6yr)	P1	2.041938	117.440290	5	17	4.6	4.1	2.74	0.24	15.8	34.3	49.9
	P2	2.039421	117.438549	3	14	4.8	4.3	1.34	0.16	13.5	55.1	31.4
D4 (8yr)	P1	2.020904	117.434565	4	16	4.2	3.9	1.46	0.17	32.8	22.5	44.7
	P2	2.020052	117.433025	2	12	4.5	3.9	1.68	0.15	19.5	24.6	55.9
A2 (10yr)	P1	2.039995	117.432074	11	8	4.6	3.8	1.46	0.16	19.7	23.2	57.1
	P2	2.044273	117.435080	10	17	5.1	4.4	1.11	0.13	59.2	13.5	27.3
Forest	P1	2.050399	117.454673	40	8	3.9	3.4	2.83	0.20	35.5	27	37.5
	P2	2.052015	117.459928	68	6	4.4	3.7	1.22	0.13	29.3	34.1	36.6

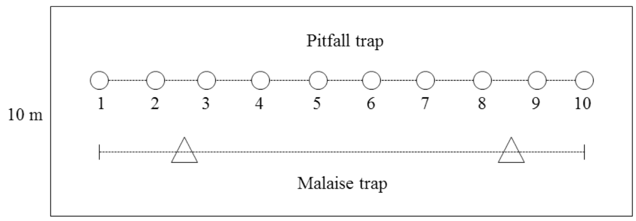

Figure 2. 100 m transect laid within each subarea of different reclamation age

Statistical analysis

Species richness and abundance of sampled insects within the measured taxonomic level were summarized for each transect or reclamation subarea. Shannon (H') and Simpson (1/D) diversity indices (Magurran 2004) were measured to compare the diversity of insects between reclamation age. Pearson's correlation analysis was used to measure the relationship between insect species diversity, reclamation age, and environmental variables. In addition, the assemblage composition across various taxa was compared between each of the reclamation subareas and the natural forest sample sites, using the Bray-Curtis index, followed by non-metric multidimensional scaling (NMDS), which is recommended as a statistical tool for bio-indicator assessment (Smith and Mather 2012). Analysis of similarity (ANOSIM) was used to compare species composition between subareas of different reclamation age. The relationship between insect species composition and environmental variables were analyzed using ordistep method within canonical correspondence analysis (CCA) (Borcard et al. 2011). All analyses were performed using R statistics (R Core Team 2017) and vegan package (Oksanen et al. 2015).

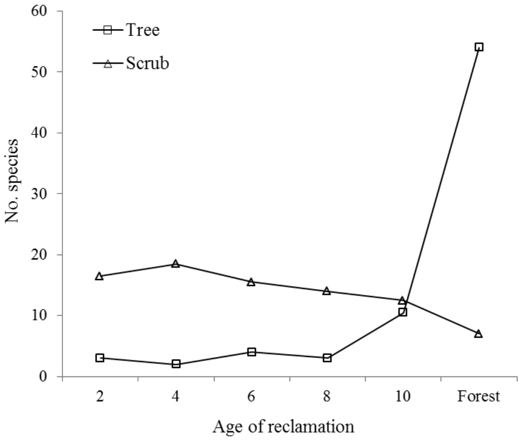

Figure 3. Relationship between subarea reclamation age and vegetation diversity (tree and scrub)

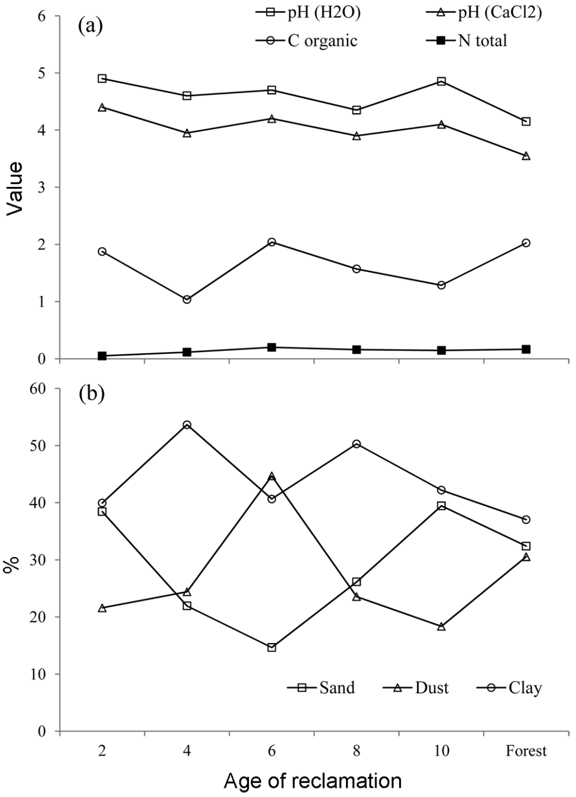

Figure 4. Relationship between subarea reclamation age and (a) soil chemistry (pH $H_2$0, pH $CaCl_2$, Organic C and N total) and (b) soil composition (sand, dust, and clay)

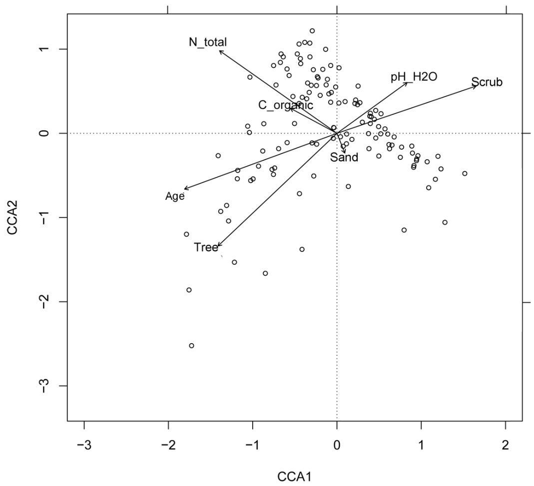

Figure 5. Ordination of canonical correspondence analysis (CCA) for data on insects and other arthropods in the reclamation area. Arrows represent environmental variables and arrow length indicates the relative importance and direction of correlation, of the variable to the axes. The orthogonal projection of a species point on an environmental arrow represents the approximate center of the species distribution along that particular environmental gradient. Species are indicated with circle points and labeled. Some species are not labeled in order to avoid congested graph

RESULTS AND DISCUSSION

Insect diversity in the PT. Berau Coal reclamation area

Results showed that insect assemblage diversity measured within the Berau Coal reclamation area differed between subareas of different reclamation age. Sixteen arthropod orders were identified from the total combined insects collected from pitfall traps and malaise traps, in all subareas including the natural forest control site (Table 2). Some arthropod orders, including Coleoptera, Hymenoptera (especially Formicidae), Orthoptera, Acarina, and Collembola, were found in every research plot but exhibited different species richness and abundance in plots of different reclamation age. Based on Shannon and Simpson diversity indices showed that insect diversity tended to increase with increasing reclamation age. The highest diversity was found in 8 years-old reclamation area and then decrease or prone to be stable in 10 years-old reclamation area, approximately similar to forest (Table 2).

Implication of environmental change on insects

As a reflection of the different duration of reclamation efforts (reclamation age) in reclamation subareas, subarea environmental conditions were expected to vary in terms of tree age, vegetation diversity (tree and scrub), soil chemistry (pH, organic C, and N total) and soil composition (Table 1). However, although we did find such differences between subareas, our analysis revealed no significant relationship between reclamation age and characteristics of soil chemistry and soil composition. Nevertheless, there was an indication that the age of reclamation area was marginally correlated with changes in C/N ratio ($r= 0.512$, $P= 0.089$).

Table 2. Species richness (S) and abundance (N) at the order level, of insects, collected from sites (P1 and P2) within subareas of different reclamation age in the PT. Berau Coal reclamation area.

Order		PIT (2yr)		D1 (4yr)		H1 (6yr)		D4 (8yr)		A2 (10yr)		Forest	
		P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
Insects													
Blattodea	N	2	7		5	1	4	2	1	1		2	2
Coleoptera	S	8	11	15	11	15	7	10	9	12	12	8	13
	N	14	13	15	13	15	7	10	9	15	16	8	18
Dermaptera	N									1	1		
Diptera	N	6	7	5	8	10	10	10	7	16	12	10	9
Hemiptera	N	6	6	7	8	10	9	9	7	5	5	5	9
Hymenoptera													
a. Formicidae	S	27	24	25	28	30	24	15	15	22	31	21	18
	N	118	106	79	94	58	59	25	18	53	101	61	29
b. Non Formicidae	N	9	7	2	5	2	5	7	1	8	8	10	6
Isoptera	N			1		1		1		3	2	5	1
Lepidoptera	N	6	1	2	1	3	7	5	4	2	3	3	1
Odonata	N										1		
Orthoptera	S	16	10	13	17	11	7	13	4	6	1	3	11
	N	30	19	23	27	13	13	26	4	6	1	4	12
Phthiraptera	N				1								
Psocoptera	N		1		2			4	1			1	
Thysanoptera	N	2	1				4		2	3	1	2	
Other Arthropods													
Acarina	S	1	2	4	3	9	2	1	5	5	10	1	1
	N	1	6	8	3	25	3	1	16	17	36	1	1
Arachnida	N	8	10	9	8	9	13	9	10	10	12	9	6
Collembola	S	7	6	7	5	7	6	7	8	11	10	6	11
	N	39	37	36	34	51	25	41	40	47	48	23	47
Shannon index (H')		1.612		1.733		1.975		2.104		1.825		1.867	
Simpson index (1/D)		3.170		3.785		5.206		6.211		4.362		4.531	

Table 3. The effect of environmental variables on community composition of insects and other arthropods in the PT Berau Coal reclamation area. Table shows the results of a forward selection procedure within a canonical correspondence analysis (CCA) using ordistep method with 1000 permutations. Significant codes: 0 = ***, 0.001 = **

Variable	df	AIC	F	N.Perm	P
Age	1	72.608	1.6493	999	0.001***
Tree	1	72.759	1.5038	999	0.001***
Scrub	1	72.800	1.4647	999	0.005**
N total	1	72.838	1.4288	999	0.005**
pH H_2O	1	73.284	1.0117	999	0.394
Sand	1	73.479	0.8337	999	0.821
Organic C	1	73.518	0.7992	999	0.851

Results of ordistep analysis within CCA showed that certain environmental factors significantly affect the characteristics of insect communities in our sample areas (Table 3, Figure 5). Tree age, vegetation diversity (tree and scrub) and N total significantly influence insect diversity in the reclamation area. In this case, increased age of pioneer trees was closely correlated with the increase in vegetation diversity, indicating that the older reclamation areas provide suitable habitat for insects.

Relationship between insect diversity and age of reclamation area

Ants (Hymenoptera: Formicidae) were the predominant insect group found throughout the reclamation area, in terms of both in species richness and abundance (Table 2, Figure 6a). This is expected given that ants are the most dominant insect in terrestrial ecosystems earth wide (Wilson 1990) and are often caught in pitfall traps. Ants were found in all subareas regardless of reclamation age. However, ant species richness was fluctuated and not correlated with age of reclamation area ($P>0.05$, Figure 6a). Specifically, ant species richness increases with reclamation age until 6 years, whereupon it declines steeply before rising again in sites of 8 years and declining less steeply in areas where 10 years.

Different patterns were observed for sampled insects of beetle (Order Coleoptera) and grasshopper (Order Orthoptera). Although not significantly correlated ($P>0.05$), species richness for both of these insect orders tended to decrease with increasing age of reclamation area (Figure 6a). In contrast, species richness for sampled insects of termite (Order Isoptera) tended to increase with increased reclamation age ($r=0.704$, $P=0.011$, Figure 6a). The presence of termites is very important in reclamation areas because they have a pivotal role in decomposing organic materials (decomposer). Their presence and community characteristics are therefore closely correlated with vegetation conditions (r=0.706, P=0.010). Increased vegetation diversity facilitated the presence of termites in reclamation areas.

Species diversity for other arthropods, i.e. mites (Acarina) and springtails (Collembola) showed a similar pattern to that of termites, and their species diversity tended to increase with increased reclamation age (Figure 6b). A longer reclamation duration may allow for increased leaf litter on the soil surface, which serves as the primary habitat for Collembola. In addition, the presence of Collembola may affect other insect populations due to their role as saprophage in the ecosystem and also as primary prey for insect predators.

Effect of reclamation age on insect species composition: the role of insect as bioindicator

Results from NMDS analysis showed no significant difference in community composition in relation to reclamation age, for all insects (Figure 7a, ANOSIM statistic R=0.031, P=0.430) and other arthropods (such as Collembola) (Figure 7d, ANOSIM statistic R=0.342, P=0.080). This suggests that using composite of these organisms is not effective as bioindicators, nor will they serve as an effective tool to assess reclamation success. As also suggested by McGeogh (1998), to utilize the insects as bioindicator require to select certain taxa or groups based on a priori suitability criteria.

Unlike composite of all insects as well as other arthropods mentioned above, two taxa did show significant differences in community composition depending on reclamation age i.e. coleopteran (Figure 7b, ANOSIM statistic R=0.372, P=0.020) and ants (Figure 7c, ANOSIM statistic R=0.408, P=0.010). Community composition for coleopteran and ant groups clearly varied in sites of different reclamation age. However, the species composition of coleopteran found in the natural forest control site vs. that composition in the 2-year-old reclamation subarea, was found to be quite similar, more so than that of the ant groups in the same comparison (Figure 7b). This suggests that coleopteran is not an effective indicator of reclamation success, despite findings in earlier research that some groups of coleopteran have such potential (McGeoch et al. 2002). Our findings indicate that, of the arthropod groups we studied, ants are the most effective potential bioindicator to evaluate reclamation success in the PT Berau Coal reclamation area. Previous research by Majer *et al.* (2007) also supports the use of ants as the best bioindicator of reclamation success in post-mining areas.

Ant communities in the Berau reclamation area were dominated by tramp species, which always co-exist with humans (McGlynn 1999). Human activities in mining areas may be conducive to maintaining ant populations, by providing additional food resources for ants (Kaspari and Majer 2000). In addition, the proximity of intact natural forest surrounding the mining area in Berau may be especially helpful for recovery of ant diversity as well as other species. Such natural habitat plays an important role as a reservoir and source of indigenous insect taxa that can repopulate nearby disturbed habitat (Rizali et al. 2002).

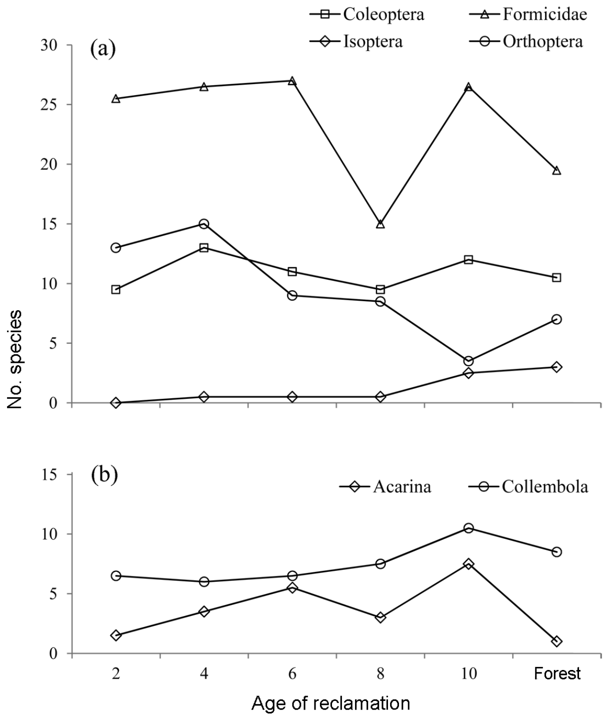

Figure 6. Pattern of species richness of (A) insects (Order Coleoptera, Isoptera, Orthoptera and Hymenoptera (Formicidae)) and (B) other arthropods (Acarina and Collembola) in areas of different reclamation age

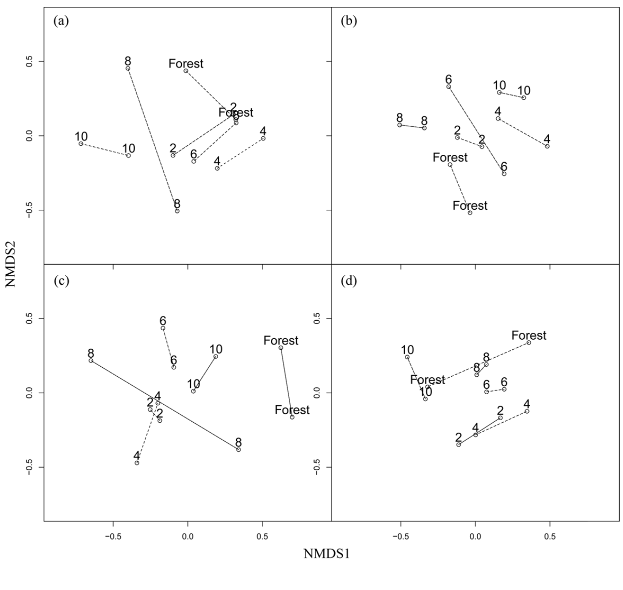

Figure 7. Non-metric multidimensional scaling analysis (NMDS) based on similarity of insect species composition across sites of different reclamation age, using Bray-Curtis index. (A) Insect and other Arthropod, stress=0.145, (B) Coleoptera, stress=0.048, (C) Ant, stress=0.138, and (D) Collembola, stress=0.086

Trends for changes in ant diversity and composition in mine reclamation areas may differ from that found in another habitat types. In agricultural ecosystems, for example, rice fields, only ant abundance, but not richness and composition of ant species, were influenced by the age of the crop (Settle et al. 1996; Setiani et al. 2010). For annual crops such as cacao raised in agroforestry plots, the age of cacao trees affected ant species composition despite the fact that habitat conditions were not otherwise altered (Rizali et al. 2013).

In conclusion, the key factors to assess reclamation success with respect to biodiversity recovery include of time elapsed since reclamation began (reclamation age), vegetation diversity and soil chemistry (N total). Although insects have potential to serve as bioindicators of environmental disturbance, not all insects are effective bioindicators of reclamation success and biodiversity recovery. Ants show the greatest potential as a bioindicator of reclamation success in post-mining areas.

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