E-2 Studies on the impacts of forest fires on natural resources and on the evaluation of ecosystems (Abstract of the Final Report)

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1. Introduction

The natural forest cover continues to decrease year after year in the world. Deforestation rates are quite high in tropics and one of the major causes of deforestation is forest fire derived from slash and burn. Indonesia has been suffering large forest fires after long droughts that occur several-year intervals. Because of the severe drought caused by the 1997-98 El Niño-Southern Oscillation (ENSO) phenomena, uncontrolled fires spread widely through Kalimantan and Sumatra, Indonesia. East Kalimantan province, especially, has widely and severely burned from January to April in 1998. About one million ha of Indonesia's forests have been destroyed by the forest fires that have burned almost continuously for several months. Monitoring of recovery process of post fire at landscape or regional scale is very important not only for conservation of forest ecosystem but also wildlife protection that live in forest. Many study concerned with forest fire observation using satellite data have been done[1)-11)]. However forest recovery process modeling on regional scale has not done so far. Both environmental and economic influences were serious but the damage did not be estimated accurately due to a lack of credible data about forest resources. The recovery process of tropical rainforests after large-scale fire at landscape or regional level also has not been clear for the same reason.

Forest fires cause great damage to nature and economies, especially in losses of forest resources, decrease of biological diversity and deterioration of forest environment. The forest fires appear to have exerted a great influence on species diversity, populations and genetic diversity of plants, animals and microorganisms in forests. However, there was much difficulty in studying the impact of fire on forest ecosystem/biodiversity, because the baseline data are not enough for evaluation of species diversity, population structure, genetic diversity and forest environment. It is needed to analyze the change of these basal data after the fire and to find biological indicators for evaluating the effect of fire on forest ecosystem and biodiversity. It is also requested to show guidelines for recovering fire-affected forests to healthy forests.

2. Research Objectives

The objectives of this study are as follows:

(1) to clarify which themes are already studied and which themes are yet uncertain, through the review of existing research results on the forest fire events in the world, as well as which themes are important to understand the effect of forest fires on the ecosystem and biodiversity and for acceleration of the recovery from damage.

(2) to develop a methodology for monitoring and evaluating the recovery process of damaged forests by fires at landscape level using high-resolution satellite data.

(3) to inspect the ability of satellite synthetic aperture radar (SAR) to understand condition of damage by forest fire and to clarify observation parameters for fire damages using airborne SAR with high performance.

(4) to develop a monitoring method of burnt forest using time series of SPOT VEGETATION (SPOT-VGT) data that can be widely and frequently observed.

(5) to evaluate the impact of forest fire on tree community and studying recovery process of main tree species

(6) to elucidate the effect of forest fire on species diversity and population in small mammals, insects and saprophytic fungi

(7) to clarify the flora of bryophyte, lichen, ectomycorrhizae and community structure of soil bacteria of lowland tropical rain forest and to evaluate the effect of forest fire on these groups.

(8) to study the recovery of bryophyte, lichen, ectomycorrhizae and soil bacteria during the vegetational succession and to find good bio-indicators for restoration of the forest ecosystems.

3. Methods

(1) First, we recompiled the results of the existing studies gathered from 1998, according to the three aspects, i.e., 1) the cause and spreading process of forest fires, 2) the effect of forest fire on ecosystem and biodiversity, and 3) the recovery process of forest from the damages.

Next, we evaluated damages by large-scale forest fire at landscape level using satellite high-resolution data. A natural forest area and the surroundings of Bukit Bangkirai, East Kalimantan, Indonesia, was selected for the study area. This area is characterized by natural rainforest, secondary forest, selective logging area, grassland failed rubber planting, and agricultural land. Landsat TM data of pre-fire and Landsat

ETM+ data of post-fire were prepared for the study. IKONOS data and QuickBird data with 1-meter ground-resolution were also obtained to estimate the stand structure. Ground data were collected at permanent plots and 63 temporary points according to the degree of damages by fires. At first, Landsat TM data of pre-fire were classified with the k-means method to understand the condition of the area before fires. In a tropical rainforest region, it is usually difficult to acquire satellite data with cloud-free because of its weather condition. A practical method using a mask procedure for cloud and integrating results from multi-temporal satellite data was developed. Next, normalized difference vegetation index (NDVI) derived from Landsat ETM+ data and LAI derived from hemispherical photographs form field survey were compared to evaluate the effect of fire on a damaged forest at landscape level.

Thirdly, we test the capability of SAR to investigate the effect of forest fire. A SAR yields different information from a optical sensor and a infrared sensor. The microwave of long wavelength is presented under canopy so information of internal forest is obtained by a SAR. Furthermore, polarimetry is related with the scattering mechanism and the structure of the target. Moreover radar interferometry provides the elevation of ground surface including trees. The coherence between two SAR data is expected to classify the status of surface. Japanese Earth Resources Satellite-1 (JERS-1) had observed earth by an L-band SAR since 1992 till 1998. JERS-1 had an advantage to observe forest because JERS-1 used longer wavelength than other spaceborne SARs. We generated the coherence of JERS-1 SAR data on East Kalimantan before and after forest fire in 1998 to extract the damage of forest fire. An airborne SAR has conducted higher signal-noise ratio, higher resolution than a spaceborne SAR. CRL and NASDA have developed an airborne SAR named a Polarimetoric and Interferometric SAR (Pi-SAR) and carried out a series of flight experiments in Japan since 1996. The resolution of Pi-SAR is 3.0 m. Pi-SAR yields full polarimetoric data and has a function of cross-track single-pass interferometory to measure the surface height. We investigated the capability of Pi-SAR for the detection of forest fire damage.

Finally, SPOT-VGT data acquired between April 1998 and June 2002 were used. Landsat TM data acquired were used as a reference data. The southern part of East Kalimantan province was selected as a study area. This area was dominated with lowland forest, mangrove forest, secondary forest, agricultural field and forest fire scar covers. Original SPOT-VGT data contains many noises such as cloud and haze. Noise reduced NDVI data were obtained through the following procedures. 1) Local Maximum filter and 2) PCA and Inverse PCA transform. Time series analysis was performed on these data. Landsat-5 TM images were used for validation of these results.

(2) For ground survey, research plots were established at Bukit Bangkirai, East Kalimantan, Indonesia in Feb. 2001. One-hectare plot was made in the non-affected area (K-plot), in the lightly-damaged area (LD-plot) and in the heavily-damaged area

(HD-plot), respectively.

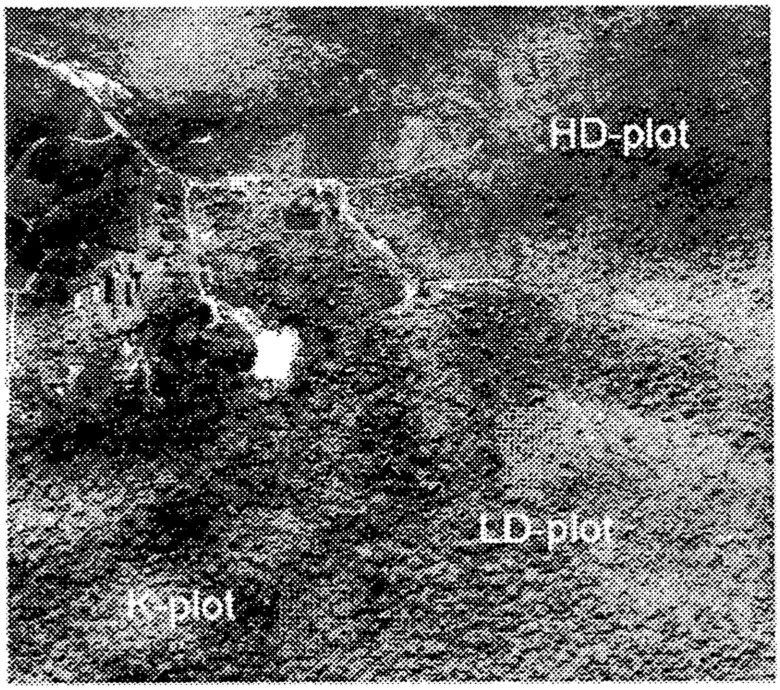

Fig. 1. K, LD and HD-plot at Bukit Bangkirai

The atmospheric data were recorded in each plot for air temperature, soil temperature, relative humidity, and photosynthetic photon flax density (PPFD). Additionally, air temperature, soil temperature, relative humidity, PPFD, precipitation, and wind velocity were measured at open site, out of the forest at Bukit Bangkirai.

The field study was conducted in Jan.-Feb. 2001, Aug.-Sept. 2001, Jan.-Feb. 2002, July-Sept. 2002 and Jan.-Feb. 2003. In these plots, we conducted census for each tree bigger than 4.8 cm in DBH. For study of recovery process of main tree species, we surveyed saplings and seedlings in a part of the each plot. We resurveyed these trees, saplings and seedlings for monitoring. We studied regeneration of trees in burned and unburned area. At September 2001, we selected 8 species that dominated in K-plot and 5 species that dominated in LD- and HD-plot as objects of study. We measured DBH or height of saplings of those species smaller than 4.8 cm in DBH. Until February 2003, we measured DBH of trees every half year.

For survey of fungal flora, fruit-bodies of wood-inhabiting fungi were collected from three middle-size plots (20 x 20 m) in each plot and cultures were isolated from some of them.

Community structure of small mammals was investigated quantitatively with capture and recapture methods. Trapping carried out in permanent plots and tentative plots. We set up 121 traps and 52 traps respectively.

In Bukit Bangkirai Forest, to recognize profiles of longicorn in various forests, which were natural one, and light damaged and heavy damaged ones by forest fire, investigations were carried out in Bukit Bangkirai Research Site by using Malaise traps, Hanging traps and *Artocarpus* traps for a year, February 2001 to January 2002 and one month. But first two traps were sometimes broke out by monkey. Accordingly, for lack of something better, I studied the result of *Artocarpus* traps.

(3) From the survey at Bukit Bangkirai area, 90 species of bryophyte was found in this area and the species richness of bryophytes increased in order of HD-, LD- and K-plots. Some bryophyte species of Calymperaceae dominated in LD- and HD-plots and the bryophytes found in burnt area were seemed to emmigrate from unburnt natural forest after the forest fires by dispersal of diaspores. The survey of species comparison among HD-, LD- and K-plots showed that *Arachniopsis majo, Mizutania riccardioides, Trichosteleum boschii* and *Zoopsis liukiuensis,* which usually grew on rotten logs in damp site, could be indicator plants for the natural forest environment. Furthermore, 60 species were first recorded in East Kalimantan of Indonesia from this survey from Febrruary 2001 to Janualy 2003. This results showed that lowland tropical rain forest should be studied as soon as possible, before the richness of bryophyte diversity would decrease not only forest fire but also other humannactivities.

The evergreen tropical lowland rainforest at Bukit Bangkirai area supports an abundant corticolous lichen flora. There, in contrast to montane rainforests, macro lichens are obviously rare. No lichens were collected on the ground and 46 species of lichens are collected on trunks and alive leaf. The species richness of lichen increased in order of HD-, LD- and K-plots. These results seem to reflect the increase in the species diversity with the ecological restoration. Most macro lichens were collected in K-plot and all lichens with apothecia were collected at the base of trunks and alive leaf. From these results it can be concluded, that the crustose thallus organization in combination with sexual reproduction is the most successful life form in tropical lowland rainforests in East Kalimantan. The foliose growth form is largely restricted to the base of tree trunk, where it occurs most often as minute and closely oppressed thallus. *Squamella* sp. (=*Cladonia* sp. 1?), *Coenogonium* spp.、*Coccocarpia* sp., *Pannnaria* sp. may be the indicatyor lichen candidayes. Further, *Squamella* sp. (=*Cladonia* sp. 1?), *Graphis* sp. 1, *Graphi* sp.2, *Sarcographa leprieurii* var. *leptastra*, *Cyclographina macgregorii, Pyrenula gigas* were new to East Kalimantan.

Dipterocarp trees are well known to be dependent on ectomycorrhizae, but they distribute mainly in the top soil especially in the organic layer, which is vulnerable to forest fire. Soil organic layer had recovered in damaged plots after 3 or 4 years after forest fire. Mycorrhizae were found around surviving trees in lightly damaged LD-plot three years after forest fire although the amount was uneven. However, total amount of ectomycorrhizae did not recover during this study because the numbers of surviving host trees in HD- and LD-plot were 2% and 20% of K- plot. No relationship was observed between the distribution of host trees and that of mycorrhizae or mycorrhizal sporocarps. Soil water content in HD-plot where the canopy had been broken was relatively unstable, but always enough for plants' growth. Mycorrhizal sporocarps, which reflect the mycorrhizal flora to a certain extent, were different between HD and other plots. *Russula* sp. and *Amanita* sp., which are known to be typical to mature forest, were collected in LD-plot three years after forest fire and it suggest that the mycorrhizal fungi had survived the forest fire in LD-plot. On the other hand, no mycorrhizal fungi was collected in HD-plot until four years after forest fire and the only fungi collected there was *Laccaria vinaceoavellanea* which is typical to disturbed or young forest and indicates that the mycorrhizal flora in HD-plot was once destructed and re-colonization started. *Laccaria vinaceoavellanea* could be a bio-indicator species for heavily damaged forest, and *Russula rosacea* (Pers.) S.F. Gray and *R. castanopsidis* Hongo could be indicators of natural or slightly damaged forest.

The biomass, the respirations rates, and the activity of phosphomonoesterase of soil microorganisms such as bacteria were generally large in K-plot, and small in HD-plot. However, these results easily change according to the sampling time, and have great difference among subplots, which indicates that these properties cannot be the indicators of the impact of forest fire. As the results of diversity analyses of soil bacteria, little impact of forest fire on taxonomic structure of dominant soil bacteria was recognized. On the other hand, the difference between K- and HD-plot was clearly shown in single carbon source metabolism diversity, indicating that the difference in vegetation after forest fire has affected organic carbons supplied to soil. Isolation and identification of culturable soil bacteria revealed that all the plots have common dominant bacteria. Although it seems hard to select the indicator species of forest fire, *Bacillus sphaericus* was the only candidate of the indicator species because this taxon was major in K-plot but few in the other plots. In addition, at least four taxa of novel species/genera candidates were obtained. It is possible to mention that unknown bacteria are still abundant in tropical forest.

4. Results and discussion

(1)We concluded the results of reviewing of previous studies as follows:

①Forest fires, which are regular natural phenomena through the long time, have tended to expand in their frequency and magnitude recently, due to the human disturbances such as land use changes.

②There are some study results on forest dynamics, behavior change of particular species of mammals and birds, species components of some taxa of insects and mycorrhizae, in the field of the effects of forest fires on the ecosystem and biodiversity. But, yet there are few studies on herbaceous plants, bryophytes, lichens or fungi.

③The topography and spatial position (distance from village etc.) of the stand causes the deference of the patterns of effect and recovery process of forests.

④We held the symposium for dissemination of research results to promote the public awareness and for sharing the information with scientists and stakeholders who are related to forest fires in order to develop the measure to use the result for the implementation.

We thought that setting indicator species is effective to grasp the damage from forest fires and the stage of recoveries. These indicator species are also surveyed in relation with forest dynamics. The study on the relationships between the effect of the forest fire and the position and status of the stand through the remote sensing measures are essential to understand the situation of the ecosystem and biodiversity. The development of the measure to social sharing the results of the survey is an important target along with study on the recovery process from damages. Many stakeholders address their needs during the symposium. The accumulation of information about the biodiversity in the areas is essentially important to measure the effect of forest fires.

Forest patch structure in the damaged forest was extracted from commercial high-resolution satellite data with 1-meter ground resolution such as IKONOS and QuickBird data. We could deduce from the analysis that there was a negative correlation between NDVI and LAI. This result was related to the recovery process of vegetation in the damaged forest. It was obvious that forest patch structure in the study area depended on the topography and the distance from the source of fire. Practical use of satellite data in a tropical rainforest region is very important and necessary, because satellite data with cloud also contain significant information that could not be obtained from ground survey.

Because the coherence of the data before and after forest fore was low in the analysis of JERS-1 SAR data, we have not identified a forest fore area. From the analysis of airborne Pi-SAR, the damaged area by forest fire was identified by using polarimetric data.

From the analysis of SPOT-VGT data, the following results was found, 1) forest scar could be detected by SPOT-VGT acquired on April 1998, 2) recovery of forest damaged by forest fire was monitored, 3) difference of forest recovery processes was fitted by non-linear function using SPOT-VGT. This result seems to be extension work from local scale to regional scale of Viedma's study[11)]. Results of present study indicate that the frequently observation satellites such as NOAA, SPOT-VGT and MODIS are useful for recovery monitoring of forest damaged by forest fire.

(2)Monthly rainfall was more than 300 mm at most during 10 months from March to December 2002 and less than 55 mm from July to Sept. At open site, the monthly average of air temperature (Tavg) was about 26–27 °C, the monthly average of daily maximum value (Tmax) was between 32–35 °C, and the monthly average of daily minimum value (Tmin) was between 22–23 °C. For soil temperatures, Tmax was between 29–32 °C, Tmin was between 26–27 °C and the variation of soil temperature was small. Wind velocities were mostly between 4-8 m/s, but exceeded 10m/s three times from the end of July to the middle of December, 2002. Regarding air temperatures in HD-, LD- and K-plot, there was not much difference in Tavg between each plot. However, Tmax was higher in order of open site, HD- , LD-, K-plot and Tmin was lower in order of HD-, LD-, K-plot, and Tmin of open site was nearly equal to that of LD-plot. For relative humidity, the monthly average of daily maximum values (RHmax) was 100% in all plot, the monthly average of daily minimum values (RHmin) was lower in order to open site, HD-, LD-, K-plot. When the soil temperature was compared between each plot, Tmax was the highest at HD-plot and Tmin tended to be lower in order of LD-, HD-, K-plot. PPFD at open site changed at about 25–35 mol/m^2/day, and one of points in HD-plot was 95% of light intensity at open site. But, at one of other points, it was less than 10% of relative light intensity. At all four points in K-plot it was about 15% or less.

Eight species dominated in unburned forest: There was a little sapling of those species in burned area, and there were no establishments of seedling in HD-plot. Abundant seedlings of *Madhuca kingana* were established in K and LD-plot. Distance between those seedlings and trees of same species was shorter in LD-plot than in K-plot. DBH increment of a species was almost constant between K and LD-plot, while that of other two species incresed significantly in LD-plot. Five species dominated in burned area: Saplings of these were also observed in unburned forest, except a species. Density of pioneer tree was increasing and density of those saplings was decreasing in burned area, due to small number of seedling establishment. No sapling of *Macaranga gigantea* that most dominating species in burned area reached 1.3 m in height on nearly open place in HD-plot.

One hundred and fourty four species of fungi were collected from each of K-, LD- and HD-plot during the survey in total. There was not much difference in numbers of collected fungi between K-, LD- and HD-plot, but was distinct difference in species composition between them. Many fungi occurred on the fallen stems of fast-growing trees, *Macaranga gigantea*, on the valley side, but small numbers of fungi were found on the hillside where big dead and fallen trees were present. Some fungi were commonly found in K-, LD- and HD-plot, while other fungi occurred only in K-, LD- or HD-plot. Fungal flora appeared to depend on supply of dead wood and to be strongly affected by the microclimate in each small plot. Several fungi, e.g. *Camarops ustulinoides*, *Perenniporia corticola* and *Xylaria curta*, were only observed in K-plot and other fungi, e.g. *Gloeophyllum* sp., *Pycnoporus sanguineus* and *Schizophyllum commune*, were only found in HD-plot. *Perenniporia corticola* occurred on the living tree of *Shorea laevis* and showed low tolerance to desiccation in cultural experiment. *Pycnoporus sanguineus* and *S. commune,* occurred on fallen trees in the exposed area in HD-plot, showed high tolerance to high temperatures and the latter also showed high tolerance to desiccation. *Gloeophyllum* sp., however, showed low tolerance to high temperatures and desiccation, though the fungus often occurred on exposed dead trees in

HD-plot. *Perenniporia corticola* is considered to be suitable for an indicator of undisturbed forest and *Py. sanguineus* and *S. commune* could be indicators for heavily affected forest.

Forest fire is a catastrophic event and it breaks down home range of animals. It caused to the isolation and fragmentation in ecosystems. Oka et al[12] showed that gibbons might be one of the species most sensitive to forest fragmentation by fire. However, little is known about the relationship between habitat fragmentation by forest fire and small mammals in tropical region. *Maxomys whiteheadi* was dominant in non-damaged forest. *Leopordamys sabanus*, *Tupaia glis* and *Tupaia splendidula* were disposed to occur in forest where is rather light than closed, likely isolated forest patches after forest fire. *Rattus tiomanicus* has the tendency of occurrences to prefer open area such as grassland or heavily damaged forest. We caught less than arboreal mammals for other species. Forest fire is a catastrophic event and it breaks down home range of animals. It particularly affects small mammals because of the limitation of their movements. It was found that habitat of each species after fire was related to landscape structure. A part of captured animals were provided for specimen in the Museum of Indonesian Institute of Sciences. We collected 1000 individuals in 25 species totally. We suggested 6 species as indicator candidate species.

The author could order the data for nine month, from February to October in 2001, and one month, August in 2002. And the results of this study, I could get two effects. One is that I could find indicated and semindicated species for natural and all burning forests. These species were the followings. Indicated species for natural forest: *Sybra vitticollis* Breuning et de Jong, *Ropica angusticollis* Pascoe, *R. sparsepunctata* Breuning, *R. quadricristata* Breuning, *Pterolophia scopulifera* (Pascoe), *Amechana nobilis* Thomson, *Metopides occipitalis* Pascoe, *Parepicedia fimbriata* (Chevrolat), *Acalolepta dispar* (Pascoe), *A. unicolor* Fisher, *Gnoma vittaticollis* Aurivillius and *G. longicollis* (Fabricius). Semindicated species: *Epepeotes luscus* (Fabricius), *E. spinosus* (Thomson), *Acalolepta fluvoscutellata* Breuning. Another one is that profiles of cerambycid fauna in heavy damaged forest cannot be recoverable, but in light damaged one can be recoverable a little the former state for only four years after big fires. And the results of this study, we could get two effects. One is that we can find indicated and semindicated species for natural and all burning forests. These species are the followings. Indicated species for natural forest: *Sybra vitticollis* Breuning et de Jong, *Ropica angusticollis* Pascoe, *R. sparsepunctata* Breuning, *R. quadricristata* Breuning, *Pterolophia scopulifera* (Pascoe), *Amechana nobilis* Thomson, *Metopides occipitalis* Pascoe, *Parepicedia fimbriata* (Chevrolat), *Acalolepta dispar* (Pascoe), *A. unicolor* Fisher, *Gnoma vittaticollis* Aurivillius and *G. longicollis* (Fabricius). Semindicated species: *Epepeotes luscus* (Fabricius), *E. spinosus* (Thomson), *Acalolepta fluvoscutellata* Breuning. Another one is that profiles of cerambycid fauna in heavy damaged forest cannot be recoverable, but in light damaged one can be recoverable a little the former state for only four years after big fires.

(3)Some species of Calymperaceae dominated in LD- and HD-plots. The species richness increased in order of HD-, LD- and K-plots. The bryophytes found in burnt area were seemed to emmigrate from unburnt natural forest after the forest fires by dispersal of diaspores. It was considered that *Arachniopsis majo*, *Mizutania riccardioides*, *Trichosteleum boschii* and *Zoopsis liukiuensis*, which usually grew on rotten logs in damp site, could be indicator plants for the natural forest environment.

The evergreen tropical lowland rainforest at Bukit Bangkirai area supports an abundant corticolous lichen flora. There, in contrast to montane rainforests, macro lichens are obviously rare. No lichens were collected on the ground, 46 species of lichens are collected on trunks and alive leaf. Among the three plots, 46 species of lichens were collected in K-plot, 17 species in LD-plot and 16 species in HD-plot. These results seem to reflect the increase in the species diversity with the ecological restoration. Most macro lichens were collected in K-plot and all lichens with apothecia were collected at the base of trunks and alive leaf.

From these results it can be concluded, that the crustose thallus organization in combination with sexual reproduction is the most successful life form in tropical lowland rainforests in East Kalimantan. The foliose growth form is largely restricted to the base of tree trunk, where it occurs most often as minute and closely oppressed thallus. During the study about the forest fire and lichen in Bukit Bangkirai, East Kalimantan of Indonesia, we found some interesting lichens.

Cladonia sp. 1 and *Graphis* sp. 1 seams to be new species. *Squamella* S. Hammer was established by only one species of *S. spumosa* S. Hammer. *Cladonia* sp. 1 is very similar to *S. spumosa*, but differs from *S. spumosa* by having simple spores and the chemical substance of psoromic acid. During the examination of Holotype specimen of *S. spumosa*, we found apothcia and colorless, 4-selled spores, 8-per ascus. *Graphis* sp. 1. is similar to *Graphis proserpnens* Vainio but differs from the greenish thallus and smaller spores., *Sarcographa Leprieurii* L. (Mont.) Muell. Arg. var. *leptastra* (Mass.) Zahlbr., *Cyclographina macgregorii* (Vain.) Awas. & M. Joshi and *Pyrenula gigas* Zahlbr. were new to East Kalimantan.

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