Republic of Indonesia
JICA(Japan International Cooperation Agency) – BRG (Peatland Restoration Agency in Indonesia)
Project Final Report

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1. Introduction

1.1 Background

The Republic of Indonesia (hereafter "Indonesia") is home to the third largest remaining area of tropical forest in the world. Tropical forests are highly significant areas for conservation of global biological diversity and wildlife habitats. However, the late 20 century saw the spread of large scale logging and the establishment of canals in tropical peatland forests. This has contributed to carbon emissions through the increased frequency of wildfires and microbial decomposition. Such fires in peatland areas are difficult to extinguish.

Japan's International Cooperation Agency (JICA) has undertaken a five year cycle of technical cooperation, completed in July 2015. This was known as the "Program of Community Development for Fire Control in Peatland Areas (FCP)". In specific targeted provinces, village facilitation teams were established and village-based fire prevention activities were conducted. These Tim Pendamping Desa (TPD) teams comprised fire brigades (Manggala Agni: MA) and community groups in Riau and West Kalimantan Provinces. They succeeded in decreasing the frequency of burning by community members and reducing the creation of hotspots. 2015 was an El Nino year, and large scale forest and peatland fires broke out. The adverse impacts included the release of large volumes of Green House Gases (GHGs), a spike in the incidence of respiratory diseases, and flight cancellations. The resulting haze spread to neighboring countries. In 2015, an application for further technical cooperation was submitted to Bappnenas: "Community Movement Program on Forest and Land Fire Prevention", based on the outputs from the earlier collaboration.

In January 2016, JICA dispatched experts on forest and peatland fires to Indonesia. Since May 2016, JICA has been conducting the Data Collection Survey on Forest and Peatland Fire Control and Peatland Restoration. The project has undertaken data collection and analysis, with a focus on the control of fires in priority provinces. In September 2016, at the request of the host country, JICA HQ dispatched a Detailed Planning Survey Team. The Head of BRG called for supplemental surveys to be conducted urgently in four districts of three provinces (hereafter the "Preliminary Feasibility Study" or "Urgent Survey"). In response, the JICA Survey Mission conducted additional surveys to establish the priorities, and collected additional information on the roles of the authorities involved in peatland monitoring and on cost sharing.

Based on the results, BRG submitted a written proposal for the additional surveys in October 2016. In November 2016, BRG and JICA accepted the Minutes of the Meeting on Basic Information Surveys for Peatland Restoration. The first phase of a study was conducted, supporting pilot trials of peatland monitoring.

To extend the collaboration and to follow up on previous work, on 19 May 2017, BRG and JICA held a series of discussions on a satellite-based approach to ground water level monitoring, peatland restoration, and capacity building for universities. Knowledge inputs were proposed, including international conferences and round-table meetings under the “BRG-JICA Project: Consignment work relating to emergency support for peatland restoration in Indonesia” umbrella.

As a prerequisite, groundwater levels must be monitored to establish the hydrological function of the peatland. It is also necessary to build social institutions and organizations that encourage local people to pay attention to and take part in peatland restoration. There is a still more pressing need to recognize the growing threat from peatland fires and from greenhouse gas emissions as the water level is reduced by developments such as canal construction. The groundwater level can act as a proxy indicator of the risk of peat fires and the emission of greenhouse gases. In the program of peatland restoration, zoning methods will be developed and, more importantly, the active participation of local people will be encouraged, to allow the methods to be replicated in other provinces after external support ends. Table 1-1 lists the main items in the project proposal.

Table 1- 1 Project plan

No.	Framework	Summary of Contents
1.	Title	Consignment work relating to emergency support for peatland restoration in Indonesia
2.	Period	May 2017 – March 2018
3.	Objectives	- To establish a satellite-based model for monitoring groundwater levels - To support the planned peatland restoration pilot activities - To strengthen the human resource capacity of universities - To make inputs to the advancement of monitoring and restoration work in Indonesia in national and international fora
4.	Major components	1) Satellite based model for monitoring groundwater levels a. Establishment of a realtime groundwater level monitoring model using data from the National Center for Atmospheric Research (NCAR) and the Weather Research and Forecasting Model (WRF) program b. Capacity building of reseachers in Indonesia and Japan to encourage collaboration and support future extension of the model c. Development of a forecasting model that incorporates rainfall and climate data d. Workshop to introduce the model and explore future perspectives 2) Peatland restoration a. Collection of scientific and technical information on peatland management and restoration in general b. Review and scientific and technical assessment to support planning of pilot actions 3) Capacity building within universities a. Sharing of scientific and technical information obtained with Indonesian universities and other stakeholders b. Development of training modules on monitoring and restoration of peatland 4) Knowledge sharing, nationally and internationally a. Share information about the latest developments of Tier 3 method for CO_2 emission monitoring with concerned experts related to IPCC and SABSTA b. Initiation and facilitation of the Tropical Peatland Roundtable under the International Peatland Society and the International Advisory

		Committee for Peatland Restoration in Indonesia
5.	Target sites for action number 2	1) Tebing Tinggi Island (Riau) 2) Kahayan-Sebangau Rivers (Central Kalimantan)

1.2 Objectives and Scope of Project

(1) Objectives of Project

The project aims to establish collaboration on current issues and challenges facing peatland restoration in Indonesia and, by March 2018, to generate a short-term action plan to address them. Table 1-2 lists the objectives of the project.

Table 1- 2 Objectives of project

No.	Objectives
1.	Development of a satellite-based model for monitoring groundwater levels: To develop a satellite-based model for monitoring groundwater levels, based on the results of an earlier research project conducted by Hokkaido University and the Government of Indonesia under JICA, Japan's Science and Technology Agency (JST), and the Science and Technology Research Partnership for Sustainable Development (SATREPS) program
2.	Design and proposal of pilot peatland restoration activities within the targeted areas: To conduct a survey to support the design of pilot activities within the targeted areas
3.	Strengthening human resource capacities of universities: To strengthen the human resource capacities of universities by involving them in the survey
4.	Holding a Tropical Peatland Roundtable: To provide inputs that support the advancement of monitoring and restoration work in Indonesia both nationally and internationally, by convening a Tropical Peatland Roundtable under the International Peatland Society.
5	Cooperation Activity on Peatland Restoration and Transmission of Information To participate in other conferences such as IPCC (COP23) and share the information of activity on tropical peatland roundtable. To discuss the responsible management of tropical peatland in IPS Executive Board Meeting

(2) Scope of Project

The survey will focus on Tebing Tinggi Island (Riau) and Kahayan-Sebangau River (Central Kalimantan). The organizations to be surveyed will include BRG and the relevant authorities within ministries and agencies. This will include the Directorate of Peatland Damage Control (PKG) in the

Ministry of Environment and Forestry (MoEF), provincial and district government agencies with responsibility for peatland restoration within the prioritized provinces, the private sector, international donors, the Agency for the Assessment and Application of Technology (BPPT), and local universities. Table 1-3 outlines the scope of the project.

Table 1- 3 Scope of project

Step	Assignment	Main Assignments in Indonesia	Remarks
Preparation	Preparatory works in Japan		
1st Step	Work in Japan	Capacity development: - Two researchers from BPPT to undertake joint research and training at Nara University for 10 days in May 2017. Development of water table model - Two researchers from Riau University to conduct research at Rakuno Gakuen University for 1 month in October 2017. Development of remote sensing system for water level monitoring and detection of canal construction	May 2017 & October 2017
2nd Step	August 2017 – March 2018	Forecasting: Elaboration of model for realtime monitoring of groundwater levels based on NCAR and WRF program	August 2017 – March 2018
3rd Step	August 2017 – October 2017	Collection of scientific information: Field surveys in Riau and Central Kalimantan	August 2017 – October 2017
4th Step	November 2017	1st Tropical Peatland Roundtable	November 2017
5th Step	Novebmer 2017	Presentation in COP23	
6th Step	January 2018	Review and assessment: Field survey in Central Kalimantan involving universities	January 2018
7th Step	February 2018	Preparation of Draft Final Report: Joint Symposium on Tropical Peatland Restoration	February 2018
Closing	February 2018	Preparation of Final Report	February

	- March 2018		2018 - March 2018

1.3 Project Framework

(1) Counterpart Agencies

Recognizing that peatland restoration must involve multiple stakeholders, the implementing agencies, JICA and BRG, have established close collaboration with the relevant agencies to facilitate inter-organizational coordination.

On the Japanese side, Hokkaido University, Kyoto University, and RIHN are taking a lead role in establishing overall coordination. Other agencies/universities including Nara University and Rakuno Gakuen University are providing technical and scientific inputs to support the development of the model.

On the Indonesian side, BRG is the counterpart agency at the central level. BRG is taking the lead role in facilitating and coordinating the work, in close collaboration with other agencies and organizations. Within the target area, activities have been conducted by BRG in collaboration with the Provincial Peatland Restoration Team (TRGD) and with local universities including Palangka Raya University and Riau University. BPPT is the counterpart agency for the satellite-based model of groundwater level monitoring.

(2) Composition of Project

Table 1-4 lists the project members.

Table 1- 4 Project Team

Responsibility	Name	Affiliation
Team Leader	Mitsuru Osaki	Hokkaido University
JICA Representative (Jakarta site)	Hideyuki Kubo	IJ-REDD JICA
Assistant for satellite data analysis	Ayako Oide	Hokkaido University
Assistant for soil data analysis	Kayo Matsui	Hokkaido University

(3) Structure of Report

Table 1-5 describes the structure of the final report of the BRG-JICA Project: Consignment work relating to emergency support for peatland restoration in Indonesia. It is organized into five chapters plus an annex.

Table 1- 5 Structure of Report

Chapter	Main Contents
Chapter 1	**Introduction and background**
Chapter 2	**Establishment of MRV method** - Support for development of GWL estimation model (-) Model site (-) Parameter correction by GWL observation (-) Guideline preparation - GHG evaluation (-) Estimation of greenhouse gas emissions (-) Guideline preparation - Fire hazard prediction map based on GWL estimation model (-) Development and assessment of rainfall prediction model over approximately three months (creation of vegetation detail map & proposal for fire frequency / intensity prediction map) (-) Guideline preparation - Proposal for operational system (-) Scientific validity and accuracy (-) Data reliability - Implementation (-) Collaboration with relevant organizations (-) Building collaborative relationships among stakeholders
Chapter 3	**Proposal for model pilot project** - Field survey (-) Riau Province (-) Central Kalimantan Province - Guidelines for model pilot projects - Proposal for operational system (-) Clarification of components

	(-) Structure of project implementation by BRG (budget agreement & securing of human resources) - Implementation: (-) Collaboration with relevant organizations (-) Building collaborative relationships among stakeholders
Chapter 4	**Proposal of capacity building method for peatland restoration project** - Establishment of capacity building center (-) Proposal to field research institutes (-) Support by research institutes for consultation and installation procedures - Support for university network consortium (-) Manuals and guidelines for education and practical training (university, private sector, government, local residents) - Implementation structure (-) Collaboration with relevant organizations (-) Building collaborative relationships amongst stakeholders
Chapter 5	**Support for launching of International Committee for Peatland Restoration in Indonesia** - Coordination of participating organizations - 1st Tropical Peatland Roundtable - Presentation at roundtable - Implementation structure (-) Collaboration with relevant organizations (-) Building collaborative relationships amongst stakeholders
Chapter 6	**Cooperation Activity on Peatland Restoration and Transmission of Information** -Presentation at COP23 -Discussion for responsible management of tropical peatland in IPS Executive Board Meeting
Chapter 7	**Summary of Proposal**
Annex	- GUIDEBOOK FOR ESTIMATING TROPICAL PEATLAND ECOSYSTEM - Activity list - Documentation of materials

2. Establishment of the MRV method

With the scientific model developed historically under Cooperation in Science and Technology (SATREPS) as the foundation for the method of calculating GHG emissions from peatlands, we have proposed a method for conducting peat underground estimates, GHG release evaluations, and creating fire risk prediction maps in real time. When carrying out this work, we paid attention to securing the appropriateness and accuracy of the scientific approach, as well as the ease of obtaining reliable data, and ease of understanding the operational method and manual. As concrete support items, we provided support for creating an underground water level estimation model (2.1), supported the construction of a relational model with GHG emissions based on underground water level estimation model and peat decomposition（2.2）, and constructed a peat fire frequency prediction model based on the water level estimation model.

2.1. Creation of ground water level estimation map

Here, in cooperation with the BPPT, we created a model for estimating the underground water level in peatlands, based on meteorological and precipitation data from satellites. In particular, we used the central Kalimantan area as a model region and corrected the applicable parameters based on underground water level observation, and provided technical support for its identification.

(1) Parameter correction based on ground water level observation

We corrected the parameters for this water level estimation model based on the underground water level observed values, and provided technical support for creating an underground water level map in quasi-real-time.

Table 2-1 Appendix

Establishing the ground water level estimation map

A. Sulaiman (Geostech laboratory- BPPT) reported the strong relationship between ground water level (GWL) and soil moisture in tropical peatland which will be used as a basic for GWL mapping. The soil moisture data 0.25o grid from NCEP scale down into 1.7km x 1.7km grid by using WRF model. Regression analysis between GWL and soil moisture is used to estimate the GWL map of Central Kalimantan and Riau.

The soil moisture data 0.25o grid from NCEP scale down into 1.7km x 1.7km grid by using WRF model. Regression analysis between GWL and soil moisture is used to estimate the GWL map of Central Kalimantan and Riau. Carbon flux estimation will be calculated based on Hirano model.

The main data is a soil moisture data taken from 0.25 degree global tropospheric analyses and forecast grids (https://rda.ucar.edu/datasets/ds083.3/). The data is update everyday and usually it can be obtained 12 hours ago at 00 UTC. The four layer of soil moisture will be downloaded every six-hour. This input data is processed by using the weather research and forecasting model (WRF) which is one of the leading open source mesoscale meteorological in the fields. By using physical law module, we get the downscaling of 0.25 degree in to 1km x 1km mesh grid. The downscaling procedure by using WRF is depicted in Fig.1. This result should be overlaid with drained and burned peat map. The groundwater level (GWL) map will be obtained by applying empirical model of the relation between soil moisture and GWL.

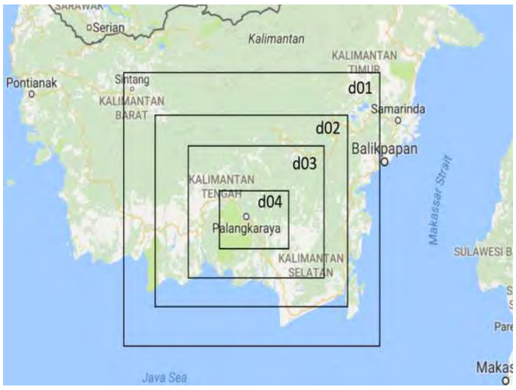

Fig-1. The domain of WRF simulation.

The result of WRF simulation is depicted in Fig.2. The figure shows the soil moisture map with 1km x 1km grid on January 3rd, 2017. The soil moisture tends to high close to the shore line and river. The high soil moisture is also observed at undrained forest and low value at drained and burned forest.

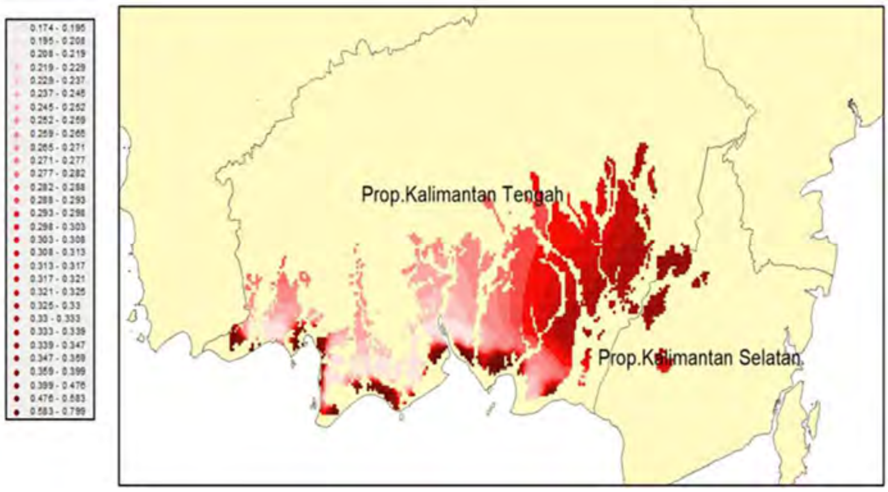

Fig.2. Soil moisture with 1kmx1km grid in Central Kalimantan.

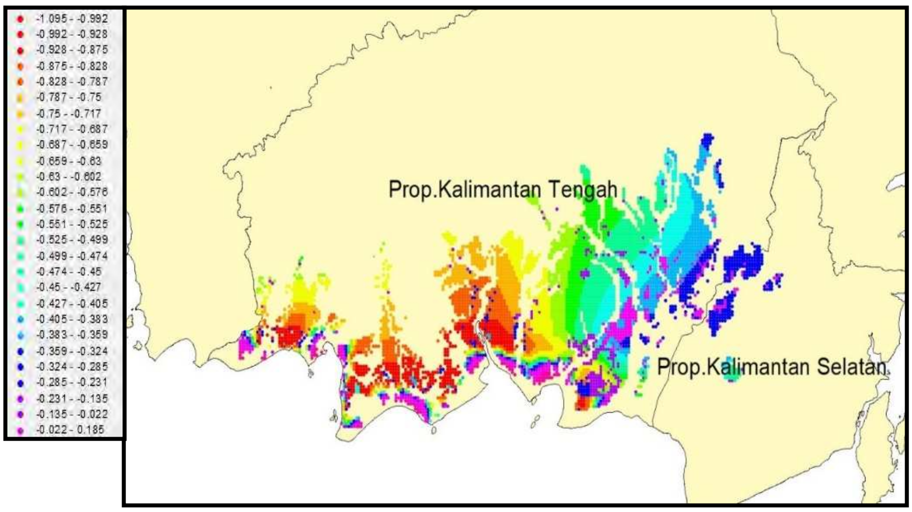

Fig.3. Groundwater level map with 1 km x 1 km grid in Central Kalimantan

The GWL map of central Kalimantan is depicted in Fig.3. The GWL down on the western part and height at the eastern part of Central Kalimantan. The result match with soil moisture map where it has high value in the eastern part and low at the western part. The increasing of soil moisture associated with the increasing of GWL.

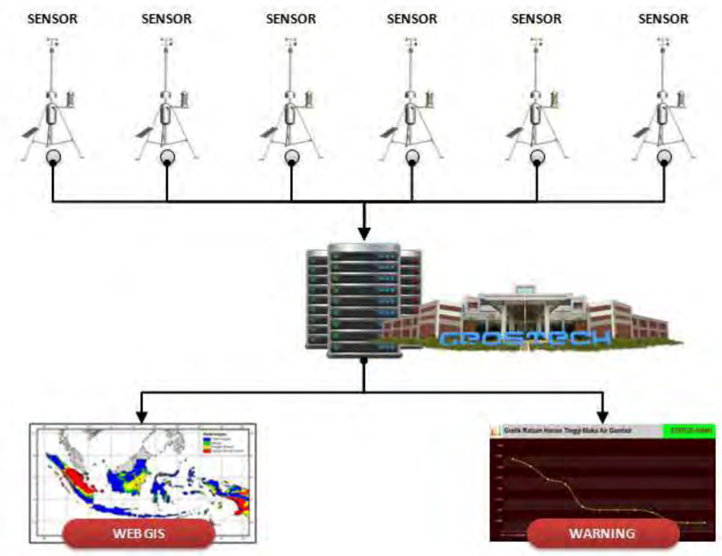

Fig.4 Data communication scheme

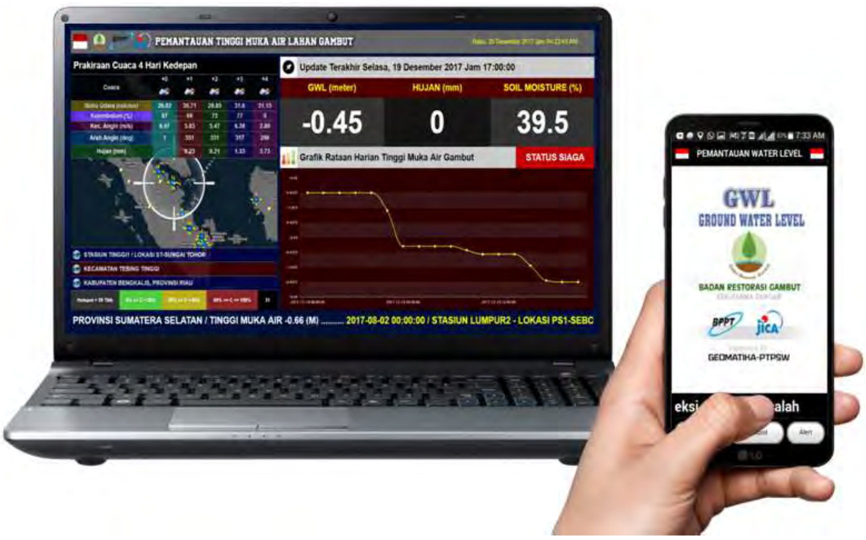

Fig.5. Groundwater level monitoring system.

Fig.6. Dissemination awareness raising activities on GWL monitoring system

Reported by Sulaiman and Awaldin in International Workshop on “Forest Ecological Resources Security for Next Generation: Development and Routine Utilization of Forest Ecological Resources and their Domestication” 15th January 2017

(2) Creation of Guidebook

The target region for this study was the tropical peatlands in the Palangkaraya outskirts of the Central Kalimantan area of Indonesia. Based on a large amount of research in the past, we established a method of estimation using a relational expression based on the lowest annual value among the monthly underground water levels for both 1） annual CO2 emissions through microbe-based peat decomposition（Hirano et al., 2016）, and 2） annual carbon emissions due to peat fires（Takahashi et al, 2013） This method can be used for technology transfer to administrative officials involved in the local management of tropical peatlands, through hands-on training that includes the establishment of monitoring materials and the creation of a carbon emissions estimation manual （Hamada et al., 2017 a,b）。

With the aim of improving the accuracy of estimation using this method and applying this to tropical peatlands in other regions, we focused on the development and deployment of a low-cost remote observation system for (1) grasping the details of relationships between moisture conditions, (2) understanding the time changes in the chemical properties of peat pore water in the region, (3) grasping changes in the actual carbon storage quantity, and (4) multi-point monitoring. This enabled us to grasp the status and organize issues related to current MRV systems, investigate the newly developed system and select the sensors to be used. The result of this is that we have summarized a procedural document outlining the detailed procedure as a protocol (attached document 1).

Table 2-2 Appendix

Study for collecting and improving information on the current situation of MRV system

1. Current situation and issues

Based on previous studies, two linear relationships exist between carbon emissions and the groundwater level (GWL) at the study site, comprising tropical peatland near Palangaka Raya, Central Kalimantan, Indonesia. These are relationships between: 1) annual CO2 emission by peat decomposition and lowest annual monthly-mean GWL (Hirano et al., 2016) and 2) carbon loss by peat fires and lowest annual monthly-mean GWL (Takahashi et al., 2013). Local administrative staff with responsibility for tropical peatland management were given on-site training in evaluation methods, including the installation of telemetry systems and the creation of teams. A manual was compiled to support estimation of carbon emissions (Hamada et al., 2017 a,b).

To increase accuracy and extend the application of these evaluation methods to other areas of tropical peatland, the following improvements are recommended:

（1） Detailed measurement of moisture levels

The GWL can be used to approximate annual carbon emissions from peat decomposition and burning. Surface peat may ignite under extremely dry conditions. The surface dryness is affected by recent rainfall, vegetation density, and the physical properties of the peat. Direct measurement of soil moisture is therefore informative.

The microbial activity responsible for peat decomposition is also known to have a preferred moisture level, and drops when conditions are both wetter and drier. Under extremely dry conditions, peat decomposition may be inhibited. The CO2 emission model of Hamada et al. (2017b) combined soil moisture data from satellite imagery with GWL measurement at each site to create a map of the distribution. Direct measurement of soil moisture levels would contribute significantly to the accuracy of the model.

The effect of microbial activity becomes much more complex if methane release (CH4) is also taken into account. The global warming potential of methane is 25 times that of CO2 for the same mass, although the carbon content is much lower. CH4 is produced from anaerobic decomposition of peat under reduced conditions, whereas it is oxidized to CO2 in the presence of oxygen. The CH4 produced below the GWL can therefore be separated into two types: that emitted directly to the atmosphere and that oxidized to CO2 in the surface peat layer. The ratio between them depends strongly on the dryness of the surface peat. It was assumed that CH4 emissions from tropical peatland were much lower than those from northern peatland (Couwenberg et al., 2010). A recent report from the study area, however, found that burnt areas of tropical peatland could produce significant CH_4 emissions (Adji et al., 2014). Since a large proportion of Indonesia's peatland has been affected by fire, the contribution of its CH_4 emissions to climate change cannot be discounted.

(2) Cyclical changes in peat water chemistry at each site

The linear relationship between annual CO_2 release from peat decomposition and lowest annual monthly-mean GWL were confirmed at three sites (two in areas of pristine forest, one in a burnt area; Hirano et al., 2016). Although the three sites were only separated by a maximum distance of 15-16 km, drainage and fire have a significant influence on peatland ecosystems, for example through alteration of the physical and chemical properties of surface peat and vegetation. Despite the potential effect of these influences, the annual CO_2 emissions from the three sites showed a similarly linear relationship with the lowest annual monthly-mean GWL. This suggests that a similar trend may be found in the tropical peatland in other areas of Indonesia, including. Sumatra and Papua.

However, a difference in the slope and intercept of these linear equations was noted between areas of pristine forest and areas of burning, reflecting the influence of drainage and fire. When extending the evaluation methods to carbon emissions from other areas, therefore, environmental factors should be expected to influence the slope and intercept of the linear relationships with GWL, which are assumed to occur across all peatlands.

Environmental factors such as vegetation type, plant biomass, and the physical and chemical properties of the peat are normally determined by field surveys and laboratory analysis of samples. However, the chemistry of the groundwater and water in peat soil pores varies as the GWL and soil moisture level changes.

Key parameters include pH, electric conductivity (EC), and oxidation-reduction potential (ORP). A low pH can inhibit the microbial activity that drives decomposition of tropical peat, even when the temperature is high. The pH can be increased by minerals in the peat, increasing emission of both CO_2 and CH_4 (Ye et al., 2012). An increase in these minerals can be detected from an increase in EC, allowing their effect to be monitored. The ORP is a proxy for oxidation-reduction, which plays an important role in the production and oxidation of CH_4 (Hirano et al., 2016).

(3) Practical measurement of ecosystem carbon storage

In deriving the two relationships noted above, Hirano et al. (2016) calculated the peat carbon loss due to fire from actual measurements of the depth of the burnt peat. In contrast, estimates of CO_2 emission by peat decomposition are derived from the difference in influxes and effluxes of CO_2 between aboveground vegetation and the atmosphere, including photosynthesis and respiration by vegetation. Long-term estimation of the dynamics of a peatland ecosystem is based on these individual factors.

Peat loss by decomposition can be detected directly from subsidence of the soil. However, the peatland surface also rises and falls in response to changes in water supply and drainage, which produce swelling and shrinking of the peat layer. Precise estimation of peatland subsidence therefore requires these fluctuations to be removed, by parallel measurement of the GWL and soil moisture.

Net carbon uptake by vegetation can be derived from the growth of plant biomass. This is usually calculated by measuring the diameter of a tree trunk at breast height (DBH).

(4) Telemetry system for low-cost multi-site monitoring

The base structure of most peatland is a peat dome. The depth of the peat layer, the GWL, and the vegetation type changes gradually along a transect from the center of the dome to the periphery. However, Indonesian peatland has been affected by human activity, including drainage and surface burning. When additional factors such as crop types and water management policies are taken into account, the factors affecting carbon emissions from peatland become overwhelming. To track these factors from site to site via ground-level observation, an inexpensive multi-site monitoring system is needed. A decline in the GWL can also be used to predict peat fires.

While many areas of Indonesia's peatland have become developed, most remain difficult to access. A data logger equipped with a data transfer module is therefore needed. Data transfer can also minimize the loss of data due to failure of a sensor or theft of solar cells.

A field data transfer system named "SESAME" has been installed at many locations in the tropical peatlands of Indonesia. The system has been integrated into the peatland monitoring system of BRG. In the current version of SESAME, every data logger is fitted with a data transfer module connected to the mobile phone network. This introduces certain limitations: 1) data transfer requires access to the mobile phone network, 2) every data logger incurs a communication fee. Many areas within Indonesia's peatlands have no mobile phone coverage, or unreliable access. It is expensive and inefficient to install sufficient monitoring sites to determine the influence of geographical factors across small areas. A new monitoring system should be developed to address these problems.

2. Development of new MRV system and selection of new sensors

A plan has therefore been made for the development of a new MRV system using novel sensors.

The new system uses three types of sensor node, and is connected by a new data transfer method. Schematics of the new sensor nodes and data transfer network are shown as Figs. 1 and 2, respectively.

（1） Sensors for water balance measurement (Fig. 1a)

The first sensor node is equipped with a water level sensor for GWL monitoring, a rainfall gauge, and a soil moisture (and soil temperature; see below) sensor. The pressure-type water level sensor and tipping-bucket-type rainfall sensor are standard in the SESAME system. The SESAME data logger is equipped with ports that can accept a voltage output from a soil moisture sensor and a thermistor-type soil temperature sensor. This sensor node is therefore compatible with the data loggers and sensors that have already been widely and successfully deployed across the Indonesian peatland, and also with BRG's peatland monitoring system.

A waterproof, immersion-type pressure sensor (STS, Switzerland) that has also been used with SESAME was selected for GWL measurement. A previous field survey tested an alternative monitoring system that uses a supersonic sensor within a plastic pipe for water level measurement. This was found to be unsuited to GWL measurement, as the signal was reflected many times from the wall of the pipe, and the speed of the signal depended on the air temperature.

A typical tipping-bucket-type rain gauge sensor was selected (0.5 mm resolution; Ohta Keiki, Japan). A customized mounting frame, fabricated from angled steel, was developed for installation in peatland and compatibility with BRG's monitoring system. This frame allows the rain gauge to be attached to the back of the logger case. The Davis Model 6463M was considered as an inexpensive alternative (0.2 mm resolution; Davis, USA). In a short-term laboratory test, its precision was found to match the manufacturer's specification. However, it uses a different mounting arrangement, and confirmation of its long-term stability and weather-resistance will require longer testing.

After balancing cost and durability, soil moisture sensor model SM150 (Delta, UK) was selected. This has now been upgraded to SM150T, after addition of a thermistor. The sensor outputs a voltage, which is then converted to volumetric water content using two algorithms provided by the manufacturer. These take account of the mineral or organic nature of the soil, with the latter being applicable to peatland. To improve measurement accuracy, on-site calibration should be conducted after soil collection.

（2） Sensors for chemical measurement (Fig. 1b)

A sensor node equipped with an ORP sensor is buried in the surface peat layer and

EC/pH sensors are immersed in groundwater within a plastic pipe. These sensors have not previously been used with SESAME, so the existing logger will need to be updated, or a new logger developed. The current version of the data logger may be used if no pH measurements are taken. We return to this below.

Since the ORP in the surface peat layer is an important factor, the sensor must be capable of measuring ORP in the pores of the peat, and not in the groundwater. The National Agriculture and Food Research Organization (NARO) has reported the development of a novel ORP sensor in cooperation with Fujiwara Seisakusho, Japan (NARO website, 2018) that can be used in paddy soil. This should also be applicable to peat soil, and on-site trials will be conducted.

The EC and pH are measured from groundwater seeping into a perforated plastic pipe driven into the peat layer. Many inexpensive, maintenance-free EC sensors are available, but most pH sensors require periodic manual calibration and a supply of KCl solution. The search for an appropriate pH sensor is continuing.

(3) Sensors for ecosystem biomass measurement (Fig. 1c)

Peatland subsidence and vegetation growth, which are directly related to the carbon balance in the peatland ecosystem, are already measured by SESAME.

A ground surface-level meter developed by Midori Engineering Laboratory Co., Ltd. (MEL) has been selected for measurement of subsidence. A reference height is established by fixing an iron rod to the bottom of the peat layer. The vertical distance between the reference point and a measuring point, which moves up and down with the ground surface, is precisely measured using a laser rangefinder (Keyence, Japan).

The sensor used to measure the circumference of a tree trunk is called a dendrometer. A wire is passed around the trunk at breast height, and its length is recorded using a rotary or a linear potentiometer. As the tree grows, the circumference of the trunk reaches the upper limit of the measurement range, and the potentiometer must be manually repositioned in situ. The model MIJ-02 dendrometer (Environmental Measurement Japan, Japan) has been used with SESAME, mainly in Hokkaido. Although it offers high precision, its measurement range is limited. In the Indonesian peatland, tree growth continues throughout the year, and it is often difficult to make frequent visits to the observation sites to reset the potentiometer. The search is continuing for a replacement dendrometer with a wider measurement range.

(4) Data transfer using a low power wide area (LPWA) wireless network connected to a satellite mobile network (Fig. 2)

To allow data transfer from areas without mobile phone coverage, a system has been developed that combines an LPWA network with a satellite mobile network. Each sensor node periodically sends the collected data to a gateway, which passes it via a modem to the satellite mobile network, and onwards to the SESAME cloud server.

The LoRa LPWA communication standard is used for data transfer between the sensor node and the gateway. This standard has attracted growing attention over recent years. It uses the 920 MHz band and a specific spectrum spread technology called LoRa modulation to allow communication over distances exceeding 10 km. Communication standards such as ZigBee and WiSUN were also considered, but were unable to achieve their theoretically-predicted communication range. When the major mobile phone carriers in Japan threw their weight behind LoRa, MEL conducted tests of the system under real field conditions. The communication range was shown to exceed 10 km when used in an open area, but this fell to less than 1 km in areas of poor visibility, such as dense forest.
A decision was therefore made to separate the sensor node into a data logger and a communication module, connected via wires. In areas of poor visibility, the data logger can be located with the sensors at ground level, while the communication module is located high in the canopy.

Japan's Wireless Radio Act requires the use of a LoRa module an output greater than 20 mW to be registered with the Ministry of Internal Affairs and Communications. Most LoRa modules sold in Japan therefore have an output below this threshold. Indonesia's regulatory system allows an output of 500 mW. A LoRa module with a maximum output of 250 mW (RF Link, Japan) was selected for use as the communication module.

For the satellite mobile network, Inmarsat's BGAN M2M, which has a maximum rate of 448 kbps, was selected. The cost of using a satellite network is usually higher than that of a mobile phone network. By combining the two networks, however, the cost may be lower than the cost of equipping all loggers with a mobile phone modem. The contract with the Inmarsat provider must be made through a local distributor, and in this case with an Indonesian agent of the SESAME system. If a SESAME user has an existing contract with Inmarsat, MEL can act as the contracting party.

The gateway can handle up to three cameras. Still images taken at the time of data transfer from the gateway to the server are sent immediately to the server. These image files are much larger than the sensor data files, but tests conducted in Japan suggest that this will not cause transmission problems. However, further analysis of the frequency, resolution, and quality of the images should be conducted to minimize the communication cost.

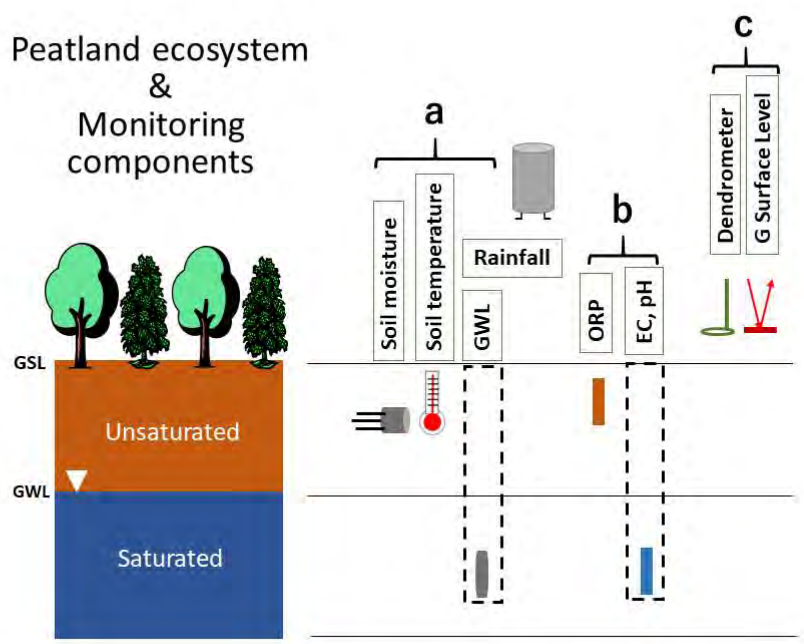

Fig. 1 Schematic diagram of the new MRV system. a. sensor node for water balance, b. sensor node for chemistry, and c. sensor node for ecosystem biomass.

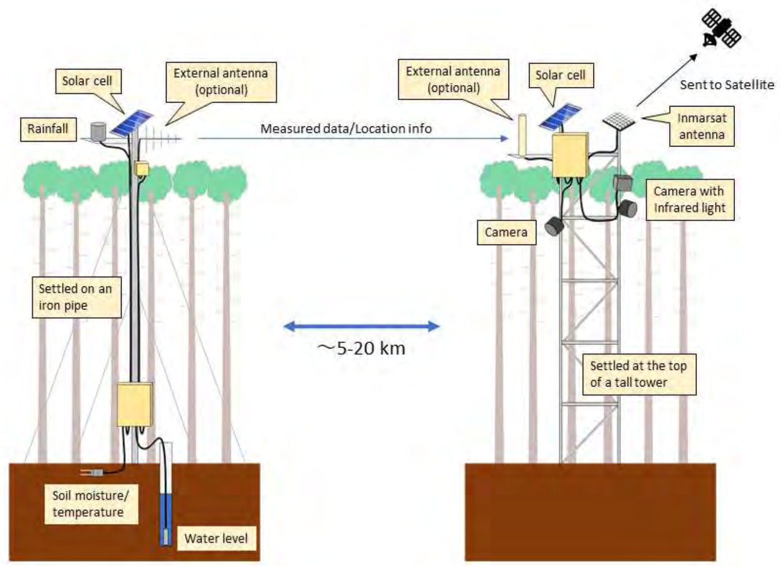

Fig. 2 New data transfer system using low power wide area (LPWA) wireless network connected with a satellite mobile network.

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濱田洋平・辻　宣行・高橋英紀・繁永幸久・内藤瑠美・小林　浩・高原　繁・大崎　満（2017a）: インドネシア・中部カリマンタン州における熱帯泥炭地からの炭素排出量評価のためのガイドブック作成と技術移転の取組み（その１）. 水利科学, No. 355, 92-122.

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農研機構ウェブサイト（2018）: 安価な小型データロガーを用いた土壌酸化還元電位の自動経時計測方法.
http://www.naro.affrc.go.jp/project/results/laboratory/karc/2013/13_005.html（2018 年 2 月 27 日確認）

1.4 Support for the construction of an undergound water level estimation model and association model for underground water level and GHG emission quantity due to peat decomposition

Based on the association model (Hirano model) for the underground water level and GHG emission quantity due to peat decomposition, which is one of the important achievements of the Cooperation in Science and Technology (SATREPS), we have developed a method of estimating GHG emission quantity, by combining the underground water level estimation model described above and a method of classifying peatland vegetation distribution based on satellite images etc.

Utilizing the results of an association model for the underground water level and GHG emission quantity due to peat decomposition, which is one of the important achievements of the Cooperation in Science and Technology (SATREPS), we integrated the results of 1) – 6) below as an integrated system, and aimed for and investigated its application to conservation of the South-East Asian tropical peat ecosystem, which is a giant carbon pool.

(i) Quantification of CO2 emission quantities from the tropical peat ecosystem due to disturbances caused by drainage and droughts, through long-term cultivated land monitoring

(ii) Elucidating the impact on underground water levels (GWL) of CO2 emission quantities resulting from oxidative peat decomposition

(iii) Quantification of methane (CH4) emission quantities on an ecosystem scale due to vortex covariation from the tropical peat forests

(iv) Development of a phased evaluation system for GIS-based land cover changes and woody biomass using L－Band PALSAR data

(v) General carbon balance simulation for Borneo based on field data and customization of a multi-purpose process-based terrestrial biosphere model (VISIT) for tropical rainforests.

(vi) Evaluate the carbon dynamics of the Borneo tropical ecosystem based on the individual tropical carbon distribution map information results

Details of this estimation protocol are organized as a manual in the attached guidebook(See Annex 01).

Table 2-3 Appendix

Developing an integrated system to evaluate the carbon dynamics of tropical peat ecosystems in Borneo

Integrated MRV System WS on 15 Jan. 2018 @ Kyoto Univ.

Developing an integrated system to evaluate the carbon dynamics of tropical peat ecosystems in Borneo

The Environment Research and Technology Development of the Ministry of the Environment, Japan (2015-2017)

- Hokkaido University
- National Institute for Environmental Studies (NIES)
- Japan Aerospace Exploration Agency (JAXA)
- Japan Space Systems

Final goals through three years (2015-17)

To scientifically contribute to the implementation of REDD+ and the evaluation of countermeasure techniques…

Goal #1: Development of an integrated system

An integrated system to evaluate the carbon dynamics and the GHGs balance of tropical peat ecosystems in Borneo will be developed.

Borneo

Study area

Goal #2: Evaluation of countermeasure techniques

Using the outcome of #1, countermeasure techniques to reduce GHGs emissions, such as damming up of degraded peat lands and forest conservation, will be evaluated.

Damming

Final goals through three years (2015-17)

To scientifically contribute to the implementation of REDD+ and the evaluation of countermeasure techniques…

Goal #1: Development of an integrated system

An integrated system to evaluate the carbon dynamics and the GHGs balance of tropical peat ecosystems in Borneo will be developed.

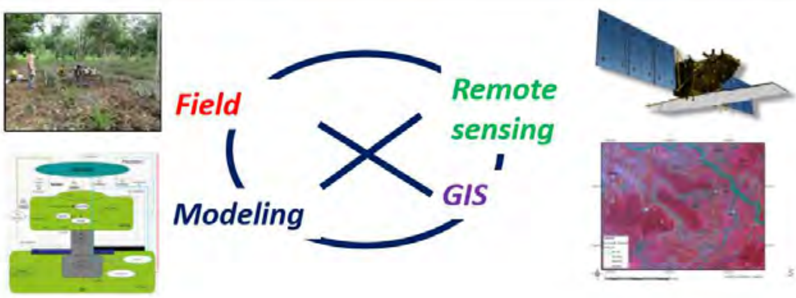
Goal #2: Evaluation of countermeasure techniques

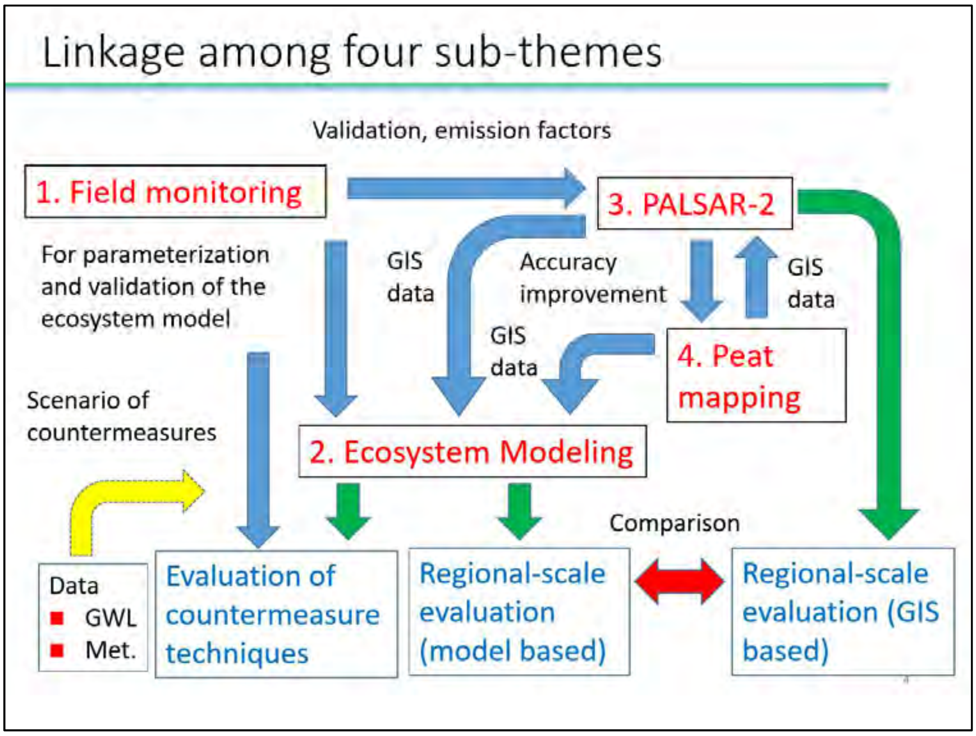
Using the outcome of #1, countermeasure techniques to reduce GHGs emissions, such as damming up of degraded peat lands and forest conservation, will be evaluated.

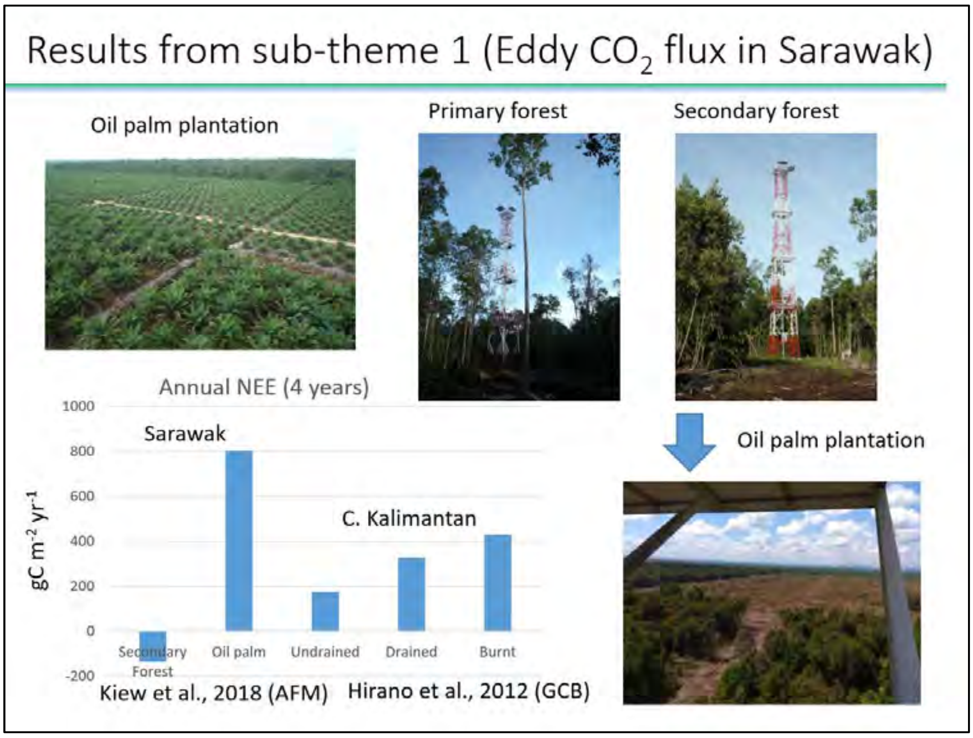
Damming

Four sub-themes by each institutes

1. Field monitoring of GHGs fluxes: Hokkaido University
2. Development of an ecosystem model for carbon dynamics assessment: NIES
3. Development of an regional-scale evaluation system of carbon dynamics using satellite data (PALSAR-2): JAXA
4. High-precision mapping of peatlands: Japan Space System

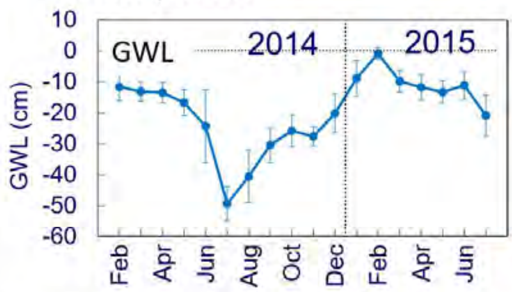


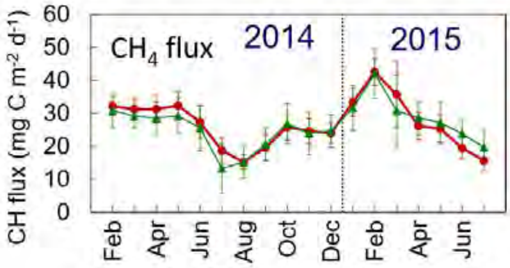

Linkage among four sub-themes
Validation, emission factors
1. Field monitoring
3. PALSAR-2
For parameterization and validation of the ecosystem model
GIS data
Accuracy improvement
GIS data
GIS data
4. Peat mapping
Scenario of countermeasures
2. Ecosystem Modeling
Comparison
Data
GWL
Met.
Evaluation of countermeasure techniques
Regional-scale evaluation (model based)
Regional-scale evaluation (GIS based)


Results from sub-theme 1 (Eddy CO_2 flux in Sarawak)
Oil palm plantation
Primary forest
Secondary forest
Annual NEE (4 years)
Sarawak
C. Kalimantan
gC m-2 yr-1
1000
800
600
400
200
0
-200
Secondary Forest
Oil palm
Undrained
Drained
Burnt
Kiew et al., 2018 (AFM)
Hirano et al., 2012 (GCB)
Oil palm plantation

Results from sub-theme 1 (Eddy CH_4 flux in Sarawak)

Monthly mean





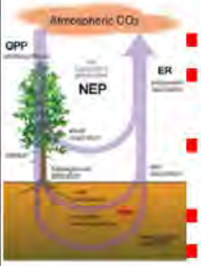
@ an primary forest in Sarawak

- CH_4 source throughout a year
- Positive relationship of CH_4 emissions with GWL
- Large discrepancy in annual emissions between the EC (9.2 g C m^{-2}) and chamber (<1.0 g C m^{-2}) method.

Xhuan et al., under revision (AFM)

Sub-theme 2 (Ecosystem modeling)

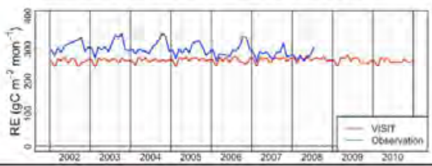
Ecosystem model: VISIT



- Simulation of GHGs
- Carbon dynamics of ecosystems
- Multiple scales: from site to globe
- Daily time steps
- Many applications

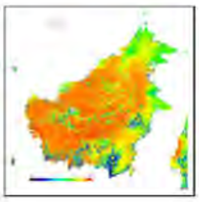
1. Development of a sub-model for tropical peat

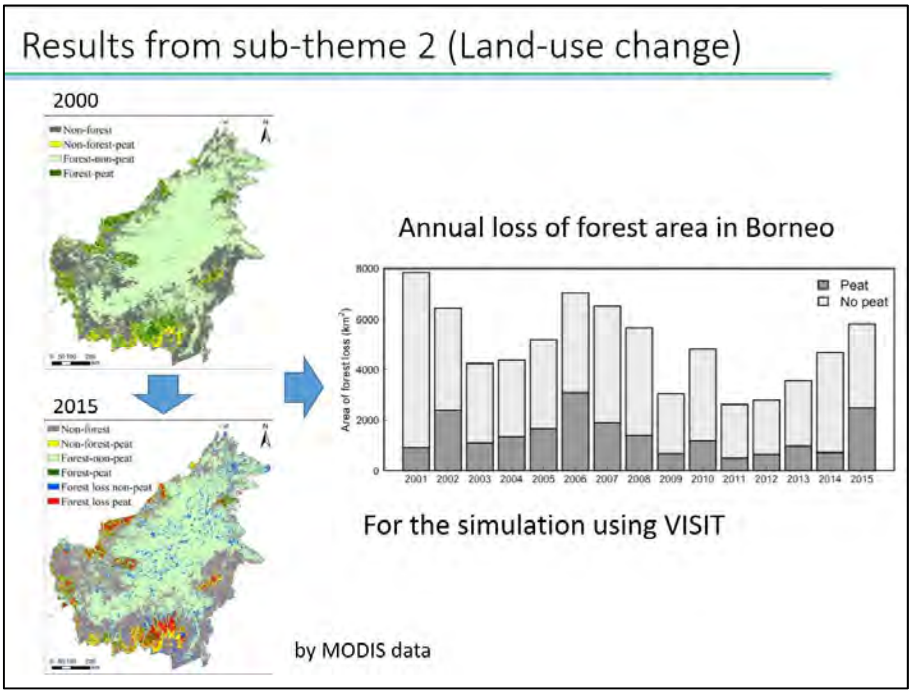
- Using field data from the sub-theme 1, the sub-model will be parameterized and validated.



2. Development of a regional-scale model

- Assessment of the carbon dynamics and GHG fluxes in Borneo.
- Evaluation of countermeasure techniques.





Presented by Takashi Hirano in International Workshop on "Forest Ecological Resources Security for Next Generation: Development and Routine Utilization of Forest Ecological Resources and their Domestication" 15th January 2017

1.5 Creating fire risk prediction maps based on an underground water level estimation model

An association model for water level and occurrence of fire has not yet been constructed. However, from the results of projects until now, it is clear that precipitation is a major factor working on the increase and decrease of peat underground water levels. Additionally, based on the knowledge accumulated by SATREPS "optimization of land and sea network observation and high-precision precipitation forecasting in short-term weather change K excitation limited regions" mainly in Indonesia（Representative Yamanaka University）, we investigated with the related institutions the possibility of developing a precipitation 3-month forecast model in Sumatra and Kalimantan in Indonesia（1）.

(1) Development study of rainfall prediction model of about 3 months

Keiji Kimura (Nara University)'s research team estimated the soil moisture at the SESAME point in Palangkaraya by using the numerical weather simulation WRF and the FNL data of NCEP as the initial data. They estimated the ground water level with the result of the WRF. The estimation of continuous about one month is very good, but the parameter is different of the other period.

Tropical peatland fire often occurs when the ground water level (GWL) is under 40cm. In order to predict the GWL, the numerical weather simulation is useful. Now they analyze the WRF (Weather Research and Forecast model), which is often used for the local weather stimulation, soil moisture content and compare with the GWL at one SESAME (Sensory Data Transmission Service Assisted by Midori Engineering) point in Palangkaraya.
They used the NCEP FNL data as initial weather data and simulated the soil moisture content of the four soil layers with WRF. The validate data is the GWL observation data at Kalteng in Palangkaraya. Simulated area is nested by four domains; the largest domain is 31x31 mesh with 27km grid, the second domain is 31x31 mesh with 9km grid, the third domain is 31x31 mesh with 3km grid, and the smallest domain is 31x31 mesh with 1km grid. Central point of each domain is the same, Kalteng SESAME observation point. The soil type, topography, land use and so on are used as default of WRF ver.3.5.1.They got the WRF simulation results in August 2015, February 2017 and August 2017. The correlation between the GWL and the soil moisture contents is calculated with correlation analysis. Correlation is very good for each month. But, as parameters are different, the cross correlations of the three months are not good.
For future perspective, one-month simulation of the daily soil moisture contents need to be conducted to obtain the correlate equation between the GWL and the simulated soil moisture contents. Simulation of GWL in this time was based on one-point data. The distribution map of the GWL for 1km mesh will be simulated combined with WRF simulation in Indonesia.

Details of this estimation protocol are organized as a manual in the attached guidebook (See Annex 01).

Table 2-4 Appendix **Estimation of groundwater level by numerical weather model WRF**

Estimation of the Ground Water Level using numerical weather simulation *WRF (Weather Research and Forecasting Model)*

KIMURA,K., N.TAKANO (Nara University),
A.Sulaiman, and S. Awaluddin(BPPT)

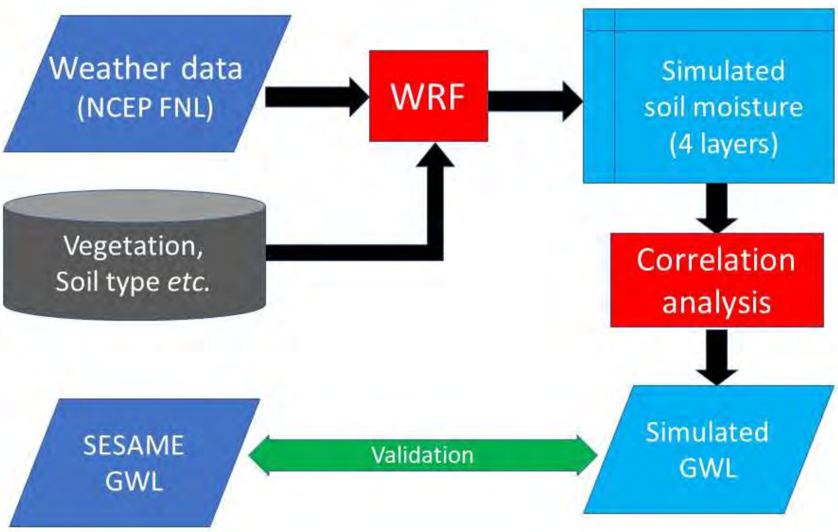
Introduction

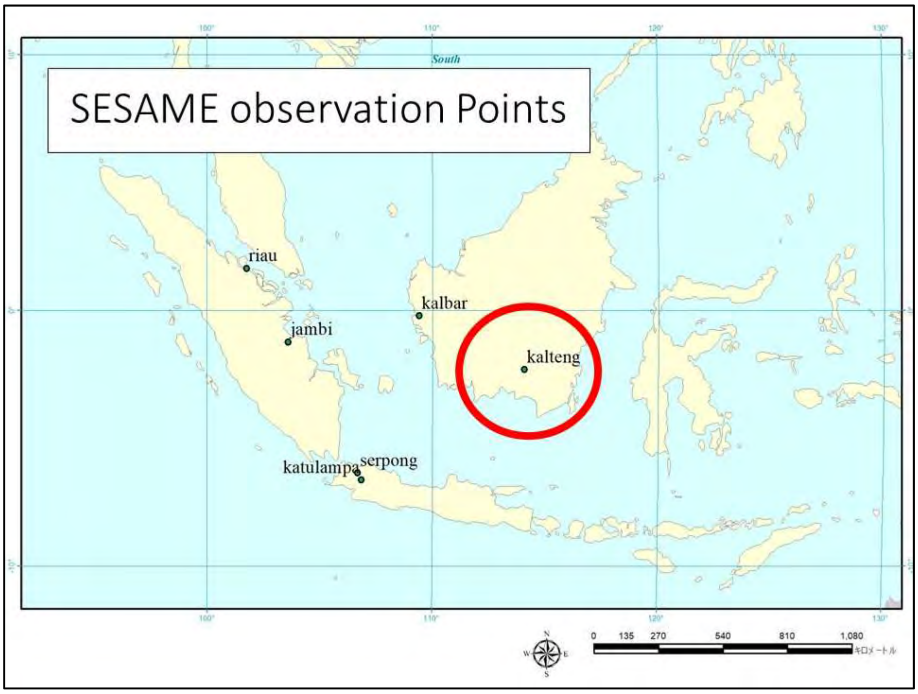
- Tropical peatland fire often occurs when the Ground Water Level (GWL) is under 40cm.
- In order to predict the GWL, the numerical weather simulation may be useful.
- WRF (Weather Research and Forecast Model) is often used for the local weather simulation.
- Now we analyze the WRF soil moisture and GWL of one SESAME point at Palangkaraya.

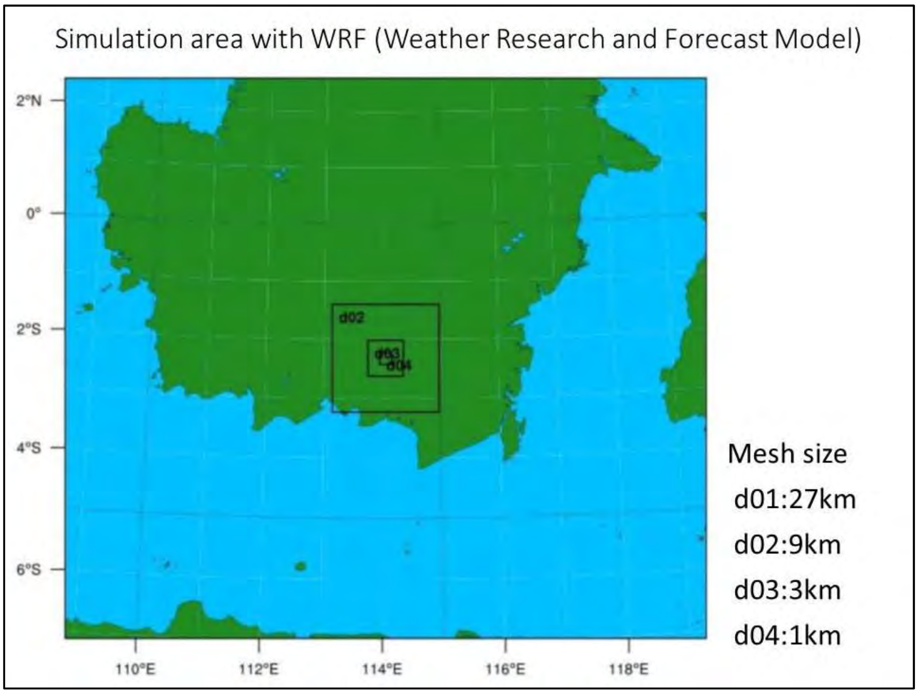
About numerical weather simulation

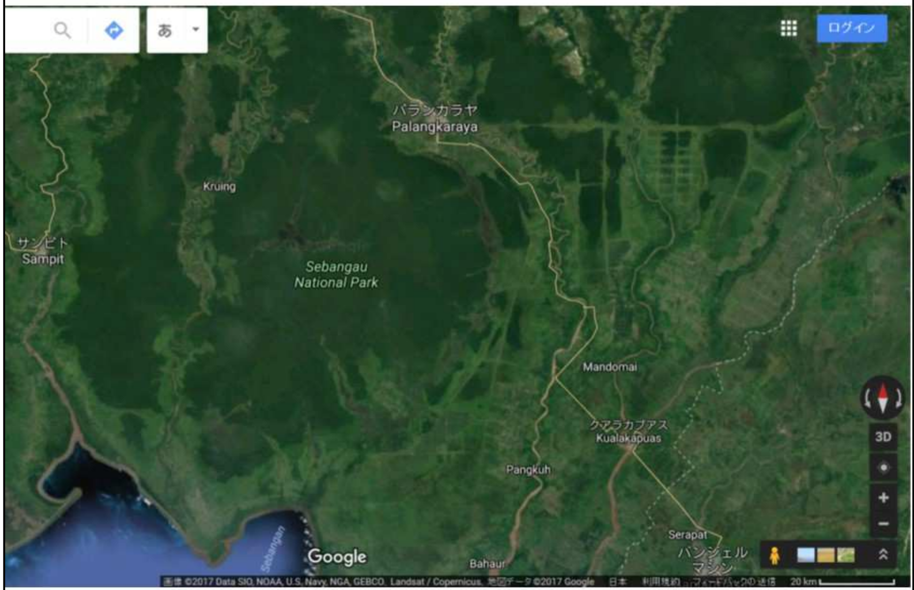
- We can use two simulation origines of the soil moisture.
  - ECMWF ERA-Interim (in Europe)
    - The precision and the resolution is better.
    - We can download only data more than three months ago.
      Today (on January 15, 2018), we can get the data until October, 2017.
    - As for the resolution, most detailed one is 0.125 degree.
    - We can use it for analysis and the variation.
  - NCAR FNL data (in U.S.A.)
    - We can download the data for a half day ago.
    - As the resolution, 1 degree.
    - We can use it for the simulation for forecast.
      Now, we can get the data until yesterday.

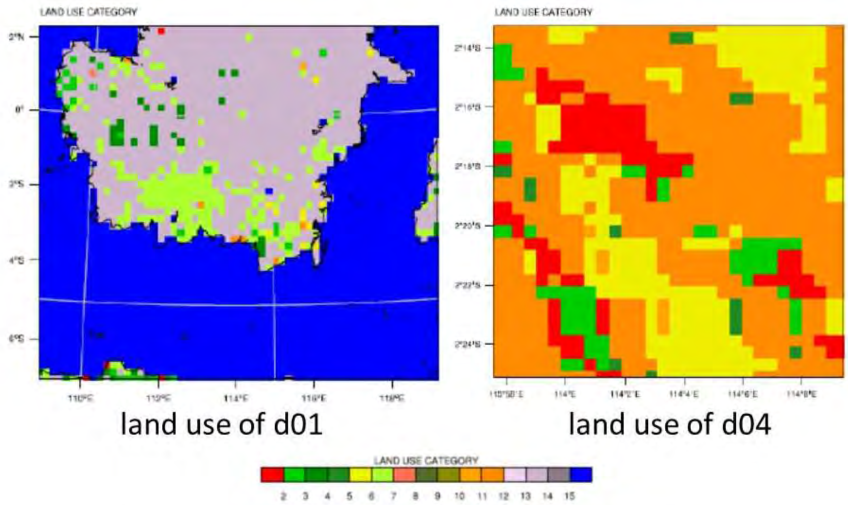
Ground water level prediction modelling




SESAME observation Points
South
riau
jambi
kalbar
kalteng
katulampa
serpong
0 135 270 540 810 1,080

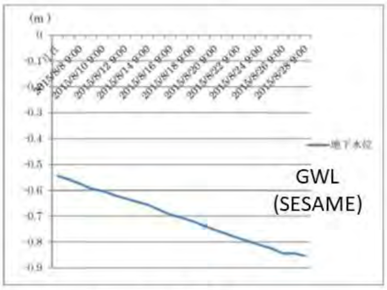

Simulation area with WRF (Weather Research and Forecast Model)
2°N
0°
2°S
4°S
6°S
110°E
112°E
114°E
116°E
118°E
d02
d03
d04
Mesh size
d01:27km
d02:9km
d03:3km
d04:1km

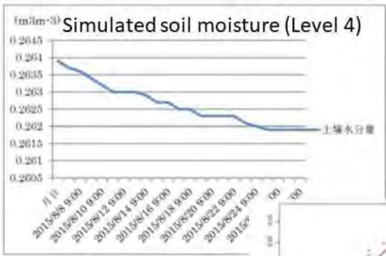


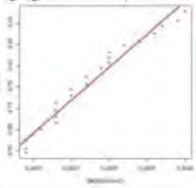


	Legend	
1_Urban and Built-up	2_Dryland Cropland&Pasture	3_Irrigated Cropland&Pasture
4_Mixed Cropland&Pasture	5_Cropland/Grassland Mosaic	6_Cropland/Woodland Mosaic
7_Grassland	8_Shrubland	9_Mixed Shrubland/Grassland
10_Savanna	11_Deciduous Broadleaf	12_Deciduous Needleleaf
13_Evergreen Broadleaf	14_Evergreen Needleleaf	15_Mixed Forest
16_Water Bodies		

Multiple Regression Analysis (MRA)





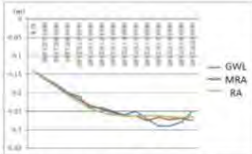


In August, 2015

(Dry season) at the point of SESAME

Correlation

variable	slope	intercept	t value	p value	judgement
Level1	-0.13646	-7.69361	-1.735	0.113	
Level2	0.3432		0.902	0.388	
Level3	-0.36807		-0.565	0.585	
Level4	25.31291		7.449	2.19E-05	***
Adjusted coefficient of determination	0.9187				
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1					

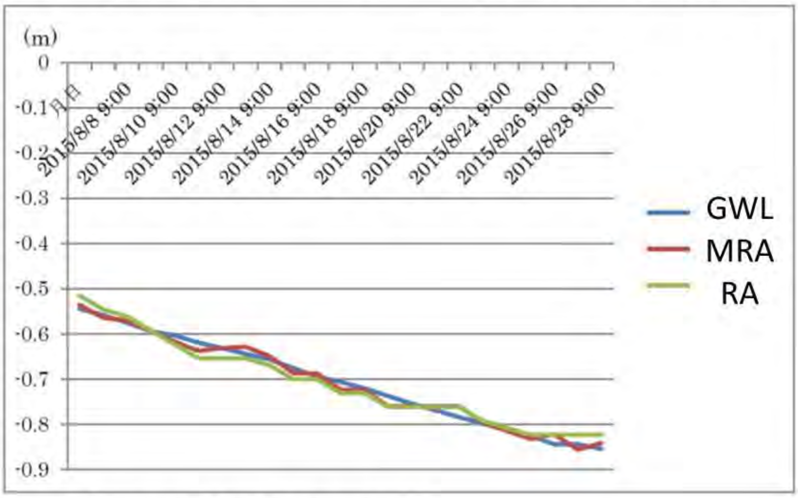


Ground Water Level(SESAME) and simulated soil moisture

Multiple Regression Analysis (MRA)

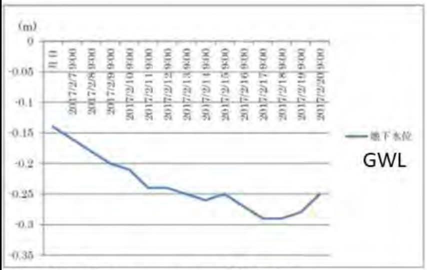
variable	slope	intercept	t value	p value	judgement
Level1	0.5877	-54.4165	1.918	0.070251	*
Level2	-1.952		-2.99	0.007526	**
Level3	25.6019		3.898	0.000968	***
Level4	181.4307		19.931	3.39E-14	***
Adjusted coefficient of determination	0.9826				
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1					

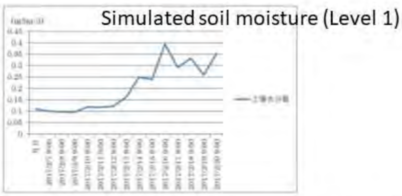
Comparation of the results (in August, 2015)

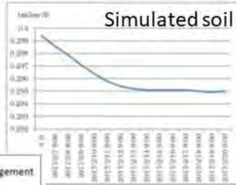


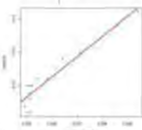
- Correlation is very good.

Multiple Regression Analysis(MRA)









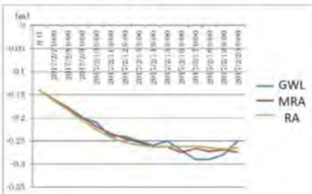
In February, 2017

(Wet season) at the point of SESAME

Correlation

variable	slope	intercept	t value	p value	judgement
Level1	-0.13646	-7.69361	-1.735	0.113	
Level2	0.3432		0.902	0.388	
Level3	-0.36807		-0.565	0.585	
Level4	25.31291		7.449	2.19E-05	***
Adjusted coefficient of determination	0.9187				

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

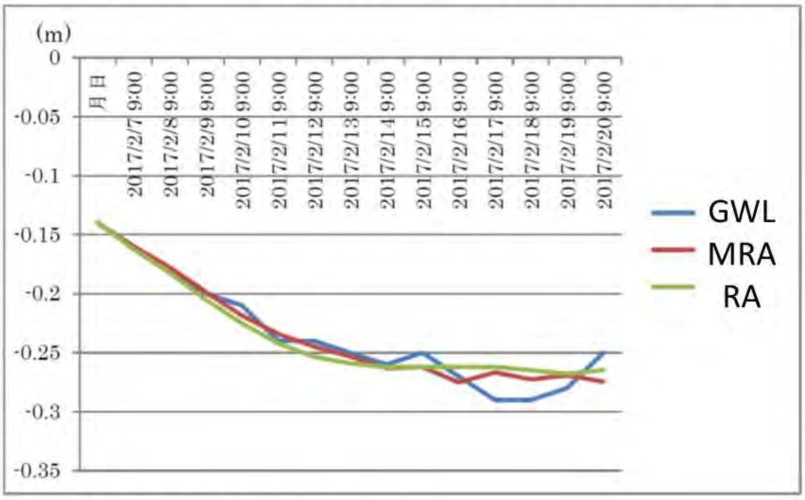


Multiple Regression Analysis (MRA)

variable	slope	intercept	t value	p value	judgement
Level1	-0.13646	-7.69361	-1.735	0.113	
Level2	0.3432		0.902	0.388	
Level3	-0.36807		-0.565	0.585	
Level4	25.31291		7.449	2.19E-05	***
Adjusted coefficient of determination	0.9187				
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1					

The result of MRA is better then that of RA.

Comparation of the results (in February, 2017)

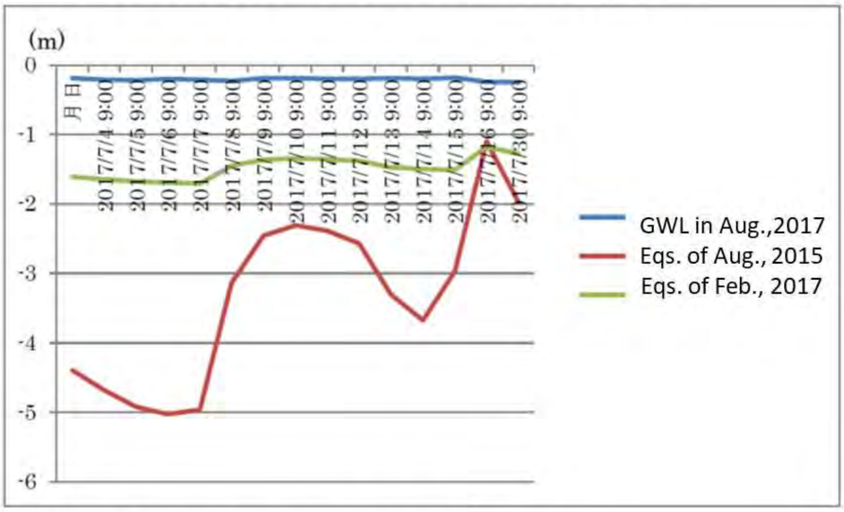


- Correlation is very good.

Discussion 1

- Each correction is very good.
- But… the values of slope and intercept are different.
- Is it the reason of the season or only that term?
  → Let's check!

Verification with another month



- Both equations are quite different!

Discussion 2

- Correction in short period is very good.
- The results fit to only short period.
- The results don't fit to other period:
  even if the month is the same of the different year.
- The reason why…
  the mechanism of the GWL change is not explained by the correlation of the soil moisture simulation.

Conclusion

- We can make the GWL prediction model with WRF (numerical weather simulation).
- The simulated results are very good for the real GWL at Palangkaraya.
- But, the parameters from the WRF results to the GWL change every time. It is not fix to even the season or the month.
- When we calculate the parameters and use them, the GWL is estimated very good, we found.
- We must compare as:
  - the GWL simulated with ECMWF data,
  - the different vegetation type (burnt forest and bare ground).
- In this study, the result is effective for only one point. We must make the simulated GWL map for whole Indonesia to predict the wild fire occurrence.

Presented by Keiji Kimura in International Workshop on "Forest Ecological Resources Security for Next Generation: Development and Routine Utilization of Forest Ecological Resources and their Domestication" 15th January 2017

(2) Creation of a detailed map of vegetation and microtopography

We conducted a field survey for a detailed evaluation of vegetation and microtopography of a peat dome, with photogrammetry technology using a drone (Phantom 4Pro, DJI) as a platform. The flight plan, which was prepared in advance, overlaps with the region of interest of the surveyed area. The drone took images with an overlap rate of 80% at an angle of 70 degrees. Then we created the microtopography model by the photogrammetry technology using overlapped images. With the detailed DSM of the microtopography and orthomosaic images, we extracted the channels and carried out mapping of vegetation regions..

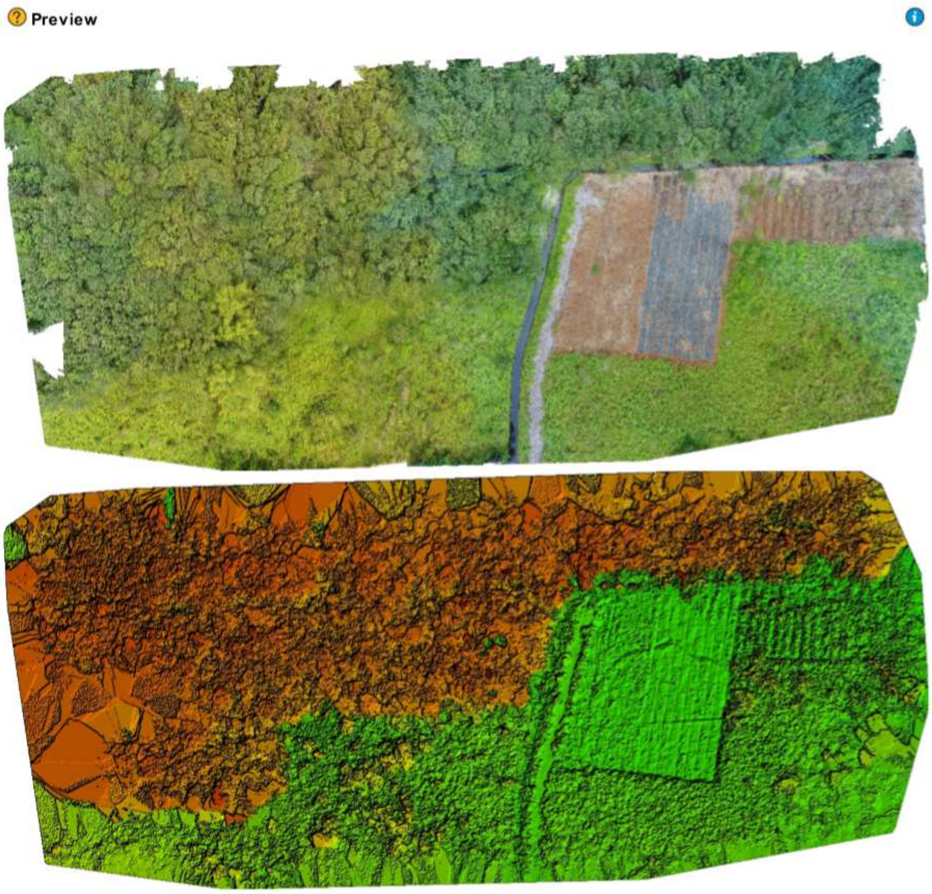


Figure 2-1 Orthomosaic images and digital surface model (DSM) extracted by photogrammetry

The accuracy of 3D mapping created from camera data by the photogrammetry technology using drones depends on the accuracy of flight, camera pixel size and focal length. We also conducted a study using more detailed microtopography LiDAR data. In order to extract secular changes in the targeted area, we obtained the microtopography maps created with the LiDAR data collected in said targeted area in 2011 and 2014..

Figure 2-2 LiDAR – DSM and – DTM for Block C as overview .(Projected by Global Mapper: UTM, Zone-49, WGS84, meters)

(3) A presentation of the summary for creation of fire frequency and intensity prediction maps.

In order to protect and properly manage peat soil, it is necessary to understand the behavior of peat soil by area exhaustively and in detail. In principle, the status of soil degradation in peatlands can be extracted as a variation amount on land surface, by differential interference wave analysis (DInSAR) of SAR (synthetic aperture radar). However, in reality, due to the characteristics of the microwave used for the interference SAR, vegetation coverage over the peat land and the geography could affect its feasibility and accuracy. This means that the shorter the microwave length used for the interference SAR, the greater the resolving power of the variation amount detection on land surface, however, this leads to difficulty in the interference with regards the impact of subtle changes in the vegetation on the ground. However, on the contrary, the longer the microwave length, the wider the area that can be interfered.

In this section, we organize the changes of the peat land detected in parallel with each frequency characteristic, discuss the effectiveness of the differential interference SAR analysis as the soil degradation index, and present a methodology to predict the frequency and intensity of fire. Much details are listed in the attached guidebook (See Annex 01).

1) Applicability of SAR satellite to peatland management

Although multitemporal behaviors of land surface can be captured as a whole area by the differential interference wave analysis (DInSAR), it was pointed out that there were some operational and technical issues to apply it to the management of peatlands.

Table 2-5 Operational issues of analysis using SAR satellites

	Operation Aspect	**Technical Aspect**
Issues	A large cost is required for obtaining the SAR data at various times covering a vast peat bog.	A comprehensive understanding of peat bog space is difficult due to the difference in the scale variation and the detectable subjects in response to the microwave frequency.
Solutions	Utilization of SAR satellite data (Sentinel) that is distributed for free.	An improvement of comprehensive understanding of space by the combination of detectors with different frequency.

2) Evaluation towards Impacts on Humans by Time-Series Comparison

The peat decomposition state becomes apparent as deposition phenomenon on the ground surface. Also, the time-series behavior is assumed to be fluctuated long termly as a result of a seasonality and land modifications by precipitation as well as occurrences of events such as fire. Therefore, it is possible to detect the variation amount of peat soil surface from the SAR data taken at various times (DInSAR analysis), as well as the effects of artificial land modifications and occurrences of fire on peat soil using the detection results from the occurrences of events.

3) Comparison of Variability on Peat Bog Surface at Different Locations

The peat soil decomposition reaction varies in proportion to the vegetation succession process after the fire breakout, the location in terms of microtopography, and the existence and the distance of open channels. Therefore, it is difficult to provide the representation of the space for the peat management from the value measured at several points. As a result, for the appropriate maintenance and management, it is necessary to comprehend the state of peat bog from the points of view of 1) vegetation, 2) microtopography, and 3) water utilization.

Using the mapping results for the water channel and the vegetation extracted in advance as well as the analytical results from SAR detectors in an integrated manner, it becomes possible to detect the variability of peat soil surface in accordance with the vegetation, the microtopography, and the water utilization by the analysis from wide area including the hydrological units.

(1) Guidebook creation

(2) In terms of the related items, mentioned in this chapter, for preparing a map for predicting fire risks using stochastic model for ground water level, the details have been compiled in the guidebook attached(Annex 01

3. Proposal of Model Pilot Project

The most difficult aspect of peatland restoration is the fact that there are no comprehensive knowledge or model for it. The solutions past projects adapted were based on the digging of drainage channel under the development program. Construction and implementation of a model pilot project with an innovative perspective that is not constrained by the common drainage channel digging is required.
There are some areas where restoration has been successful. However that is limited to areas that are 1) flood plain of a river or 2) along the coast (the tide supplies seawater [nutrition and water]). Such areas have soil with favorable nutrition condition and could maintain good organism production function. However, inland or inside a peatland waterway unit are degraded peatland with poor nutrition due to the lack of influence from rivers or the tide. Thus the abovementioned model cannot be applied at all. Therefore in collaboration with BRG, this project proposes a restoration method for degraded peatlands that is extremely difficult to restore.
Through consultation with BRG, the following areas were selected as the targets. Tebing Tinggi Island in Riau province, Kahayan Sebangau Rivers in Central Kalimantan province and West Kalimantan province.

3.1 Field Survey

Due to the global impacts of greenhouse gas (GHG) emissions from peat fires and peatland development, establishment of an appropriate management system has become an urgent issue. We should aim to achieve both peatland restoration to recover the original function of ecosystems and sustainable management to ensure economic activity. Over the last 20 years, Indonesian and international scientists have studied peatland ecosystems and methods for peatland restoration, with a number of publications expected to be used by policymakers. Yet, these scientific findings are usually produced on the basis of a single discipline and are not sufficiently integrated into multidisciplinary knowledge to be effectively referred to by policymakers. Conducting further research is urgent to achieve the conservation and sustainable management of peatlands in Indonesia.

The Peatland Restoration Agency (BRG) under the Deputy Research and Development cooperates with the Japan International Cooperation Agency (JICA) to conduct restoration and research activities and intends to conduct a field survey at an oil palm plantation company and a restoration test area. Prior to the upcoming large project on peatland restoration, this project aims to identify the most important target sites to be worked on from several perspectives within six months. According to this purpose, preliminary surveys in seven provinces designated as strategic target sites in Indonesia are being carried out. This report is one of the case studies conducted in the Riau province. Two recommended target sites in the BRG project are the oil palm company PT Meskom Agro Sarimas in Benkalis Island and an experimental plot for peatland restoration located in Tanjung Leban village (see the map below).

(1) Riau Province

We visited two places of BRC's project site, Riau Province Bencaris Island, Oil Palm Plantation and peat rebuilding base. The former is a field of oil palm company PT Meskom Agro Sarimas, the latter is a farm house in Tanjung Leban village and accepts testing and investigation of various researchers and research institutes as a peat revival test site. (See map)

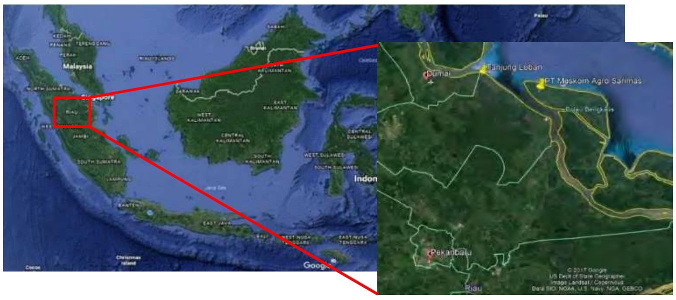


Figure 3-1 Bengalis Island, Riau

(2) . Survey schedule and members

The survey was conducted from 29th August 2017 to September 1st schedule. Details are summarized in the following table.

Table 3-1 Survey details

TIME (WIB)	ACTIVITY	INFORMATION
Tuesday, August 29, 2017		
08.35 – 10.20	Flight from Jakarta to Pekanbaru	
11.00 – 11.30	Travel to Riau Provincial Environmental Department office	Pick up Ms. Dilla
11.00 – 18.00	Trip from Pekanbaru to Bengkalis	Stay at Bengkalis
Wednesday, August 30, 2017		
08.00 – 08.15	Travel to Bengkalis District Environmental Department office	Meet Mr. Nurman
09.00 – 10.00	Trip from Bengkalis to PT Meskom Agro Sarimas	
10.00 – 15.30	Field survey in the oil palm plantation at PT Meskom Agro Sarimas	Accompanied by Ms. Dilla, Mr. Nurman, Mr. Hirawan, Mr. Reno
15.30 – 23.00	Trip from Bengkalis to Dumai	Stay at Dumai
Thursday, August 31, 2017		
08.00 – 10.00	Trip from Dumai to Desa Tanjung Leban	
10.00 – 10.15	Meeting at Tanjung Leban Village Office	
10.15 – 11.30	Field survey of the restoration experiment area at Tanjung Leban Village	Accompanied by Ms. Dilla, Mr. Nurman, Mr. Nur
11.30 – 18.00	Trip from Tanjung Leban Village to Pekanbaru	Stay at Pekanbaru
Friday, September 1, 2017		
11.10 – 12.55	Flight from Pekanbaru to Jakarta	

Surveyors

Prof. Mitsuru Osaki (Hokkaido University), Kayo Matsui, Ph.D (Hokkaido University), Weta (JICA-BRG)

Field guides

Ms. Dilla (Riau Provincial Environmental Department)

Mr. Nurman (Bengkalis District Environmental Department)

Mr. Hirawan (General Manager Plantation – PT Meskom Agro Sarimas)

Mr. Reno (Environmental Department – PT Meskom Agro Sarimas)

Mr. Nur (Farm Owner at Tanjung Leban)

(1)-4. Oil palm plantation PT Meskom Agro Sarimas

【Schedule】

Morning

- ■ Introduction of oil palm plantation management and facilities at the office by the manager Mr. Hirawan
- ■ Survey in a plantation site, observation of peat soil, discussion etc.

Afternoon

- ■ Presentation on nutrient, peat soil and water-table management by Prof. Osaki at the office
- ■ Survey in the company area (peat water purification/ packing process etc.)

【General Information】

- ■ Distance from the sea : 6.5 km
- ■ Peat depth : 12 m
- ■ Inti area : 3,705 ha
- ■ Plasma area : 3,889 ha
- ■ Production : 500 t 17-18 ha^{-1} day^{-1}
- ■ Fertilizer application
  - ➢ NPK: 6 kg $year^{-1}$ $tree^{-1}$ (N: P: K = 7: 6: 36)
  - ➢ Rock phosphate (P): 1 kg $year^{-1}$ $tree^{-1}$
  - ➢ Urea (N): 1.7 kg $year^{-1}$ $tree^{-1}$
  - ➢ Zn and Cu
  - ➢ B
  - ➢ Ash 7 kg $year^{-1}$ $tree^{-1}$
- ■ Water-table management : 50-70 cm
- ■ Measurement : Once every two months at 18 points
- ■ Precipitation monitoring has been conducted.
- ■ The processed oil is mainly sold to PT Wilmar (another large oil palm company).

- ■ They recommended us to visit another oil palm plantation company: PT Tabung Haji Indo Plantation(@Tembilahan subdistric) ※a huge 82,147.22 ha of peatland (98% of the island by area)

【Other business】

- Biogas (CH_4) and bio-fertilizer are produced from the oil palm residue for use in the company and re-selling.
    - Mineral water purified from peat water is produced and 6,000 t of peat water is processed in one day.

【Survey in the plantation site】

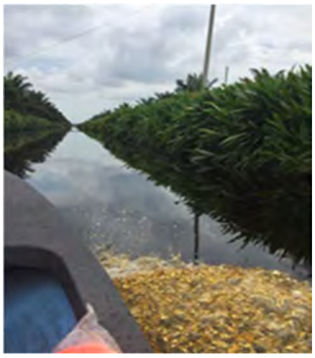


Fig. 2 Canal

Fig. 3 Water table measurement

Fig.4 Soil profile

- Canals between blocks (1200 m × 250 m).We traveled with a motorboat (Fig. 2)
  ※ 1 block = 30 ha, width of canal: 12 m, 8 m, 4-6 m
- 18 sites were set this year for measuring the water table
- A soil profile was made at 2 m from the base of an oil palm tree (0-40 cm)

Fig. 5 Soil mount

Fig. 6 Inside the mount with roots

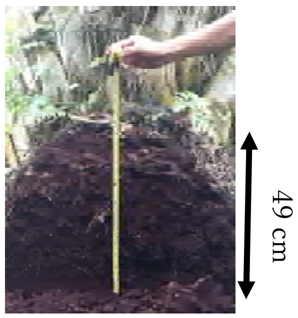


Fig. 7 Size of the mount

- Observation of soil mount (Figs. 4-7): Peat soil accumulated on the base of the tree. Many roots extended inside of the mount.
  ※Peat soil accumulated on the base of the tree from the adjacent canal. This soil mount played a role in supplying oxygen and nutrients to the tree. Although it was created by accident, it shows that a nutrient supply system at the surface may be

possible. The project team considers that this site could be a candidate for one of the target sites for establishment of an improved nutrient supply system.

- K^+ deficiency was found in some oil palm trees (Fig. 8). The company was also concerned by this issue and they have increased the amount of fertilizer (potassium and nitrogen) since this year.

Figure 3-2 Potassium deficiency symptoms on leaves

【Conclusion】

Although the company is making efforts under the recommendation of the government's 40-cm water level, they feel that the 10% reduction in yield is large. Currently they prefer a water level of 50-70 cm which is known as the water level with the best yield return. Following an explanation of peatland management by Prof. Osaki along with a tour of the plantation, Mr. Hirawan's attitude has changed slightly but we could not gain their intention to participate in the project during our visit. However, the company has set up a water gate for water-level adjustment (Fig. 8) and there are facilities that can be managed at the 40-cm water level. If the guarantee of production profit becomes clearer, it seems that they can shift to high water-level cultivation relatively smoothly. Regarding nutrient supply to oil palm trees, it is important to establish a system that promotes the distribution of roots to the ground surface and efficiently supplies nutrients and oxygen to trees while keeping the water level high and preventing yield decrease.

A message from the company stating that they are interested in collaborating with our project was delivered after the survey. The PT Meskom Agro Sarimas will be one of possible candidates who will join a pilot project on high water-table cultivation systems led by BRG. PT Tabung Haji Indo Plantation, located in the Tembilahan sub-district, may also be a candidate to call for collaboration. This company occupies 98% of the island (82,147.22 ha) according to PT Meskom Agro Sarimas.

Figure 3-3 Water Gate

(1)-5. Restoration test plot at Tanjung Leban Village

- History: The plot was used for an oil palm plantation, but after the 2008 fire, it has been used for planting non-oil palm trees since 2009.
- Land area: 2.5 ha
- Peat depth: 9 m (previous) > 7 m (current)
- Distance from the sea: 2.5 km

Figure 3-4 Site plot

Figure 3-5 Canal

【Conclusion】

The test site is very close to the coast and it is likely that sufficient nutrients are supplied to the soil from sea water and a tidal effect. In the peat restoration project, we concluded that establishing a model case on such land may not be appropriate because a system established in a fertile field cannot apply to the oligotrophic condition. However, this test site can be available for a field survey to understand the relationship between nutrient distribution and vegetation in peatlands.

3.2 Proposal of model pilot project

The Indonesian Peatland Restoration Agency targets 7 provinces in Indonesia in its peatland conservation project. However in this project, it was decided through the consultation with BRG that the focus will be on Riau province and Central Kalimantan province. As one could see from the inspections by companies managing oil palm plantations, the high water level necessary for peatland conservation leads to the reduction of oil palm yield in the current cultivation method and therefore difficult to be adapted. Thus, a new cultivation system that allows coexistence of conservation and economy is desired.

(1) Maintenance Method of High Water Level

The detail of water level control method model pilot project through canal blocking and pump up of groundwater that also includes fire control method is discussed here. The target area is a community plantation in Ketapang region in West Kalimantan province, and the detail of the cultivation plot design for the Pawan River peatland is discussed. The preparation of the plot was conducted through the consultation with the local government and the operation of the pilot site started in October 2017. This is an area where drainage is progressing through openings of waterways. However, a part of this area was dammed up through canal blocking, and this part was separated into the part for fire prevention treatment and the part for the continuation of drying with the previous drainage situation kept as it is. Moreover, a test area for digging a well and trying pump up of groundwater was installed in a part of the area that became wet after the construction of the dam in the waterway. The cultivated plant was decided for each block surrounded by the waterways. Furthermore, the biomass such as young and fallen trees that is found across the cultivated field was collected and turned into charcoal. They were then scattered throughout the field and thus were used effectively as charcoal functions as the matrix for water retention, circulation and microorganism, and contribution to carbon storage is expected. Moreover, in order to compare the difference in growth the usage of fertilizer causes, fertilizer was used in every other line.

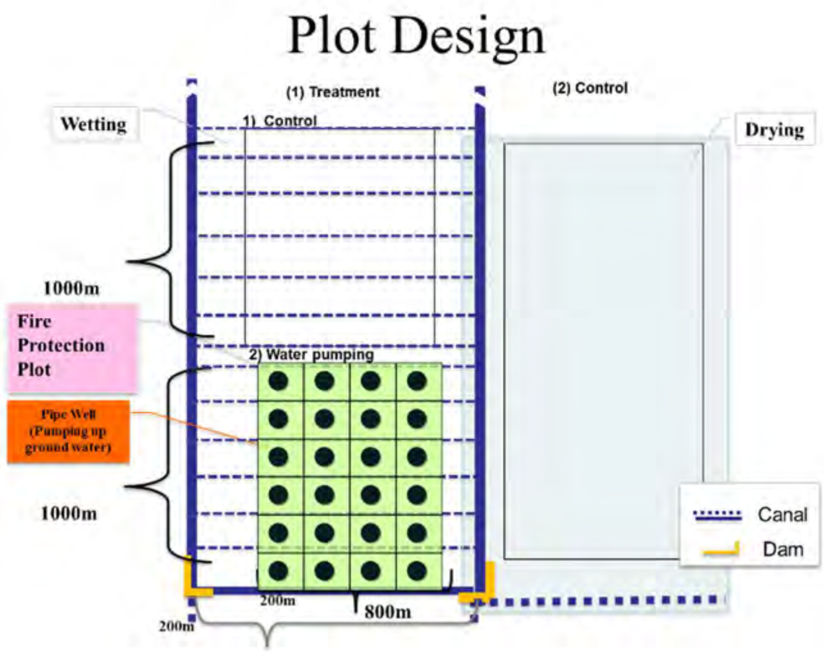
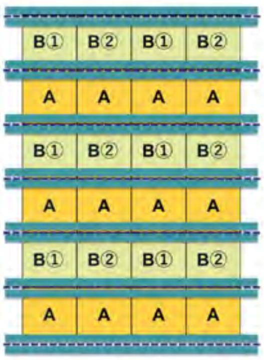


Figure 3-6 Plot Design of High Water Level Maintenance Method

Fire protection plot design



	A	B ①	B ②	C
Planting Species	Sengon Enterolobium cyclocarpum	Oil palm Elaeis		Bamboo
Planting Density	1m ×1m	5m ×5m		Ask local people
Wood pilling	○	○	○	-
Biochar	○	○	○	-
Fertilizer (Bag)	-	-	○	-

Contents of Bag
- Biochar
- Charcoal
- Coating….
- Natural peat from forest
- Chicken manure

Figure 3-7 Fire protection plot design

(2) High Water Level Cultivation Method

The establishment and verification of technologies for efficient cultivation on the surface layer of soil while maintaining a high water level is an urgent issue to meet the requirements of both the aspects of conservation of peat-lands and economic activity. Direct injection of chemical fertilizers into peat soils is highly inefficient as there is significant loss and flowing off of nutrient salts that are not preserved in the peat-lands due to the highly acidic soil.

In the high water level cultivation method, a mixed fertilizer of natural compost and manure (rich in nitrogen) is stacked in breathable bags (such as sandbags) and placed on the soil surface. It is a system in which the root of the plant is extended till the inside of such a bag and nourishment is supplied directly and efficiently to the plant without using peat soil. Further, a controlled release fertilizer test is also conducted. The aim, in particular, is to improve the efficiency of the supply of potassium ions which are required for all biological functions of plants. The benefits of this cultivation system are as follows, and it is expected that they will have a social impact.

1. Crop cultivation in peat-lands can be carried out while maintaining a high water level.
2. As there is no direct fertilization to the peat soils, it prevents the flowing off of nutrients and plants can use nutrients efficiently.
3. As the plant roots spread on the surface of the ground surface there is also adequate supply of oxygen.
4. It minimizes nutrient outflow from fertilizers and can prevent contamination of natural soils.

The first pilot project will be done on an oil palm plantation. With the leadership of BRG, the following three points have been listed at the proposed sites, and the plan is progressing.

1) KHG Sungai Kampar - Sungai Gaung (Riau)
2) KHG Sungai Sugihan - Sungai Lumpur (South Sumatra)
3) KHG Kubu Raya (West Kalimantan)

The project period is two years, and the improvement of symptoms of potassium deficiency seen in oil palm plant body is expected in the first half of the first year. Improvement of yield is expected to occur at the end of the first year. From the second year, various measurements are carried out to evaluate this cultivation method. If the method probability at the site is confirmed, the application at another location will be also planned. Moreover, the application test of the high water level cultivation method to another commodity crop other than the oil palm is planned to be carried out.

The following outcomes are expected in this pilot project.

・ Proposal of 'Innovative oil palm cultivation method' as an action plan for responsible management of tropical peat conservation
・ Establishment of a committee on pilot projects that will be deployed in Japan

(3) Effective utilization of biomass

Peatlands usually have high water conservation functions even in the dry season and can maintain high photosynthetic capacity by water supply. Therefore, they possess increased dry matter productivity. In this regard, we established a production system of sago starch and biomass, focusing primarily on sago palm, which is a plant adapted to peat ground, and proposed measures to spectacularly enhance the conservative and economic effect of peatland..

Figure 3-8 Biomass potential of Sago

Figure 3-9 Nutrient requirement of Sago

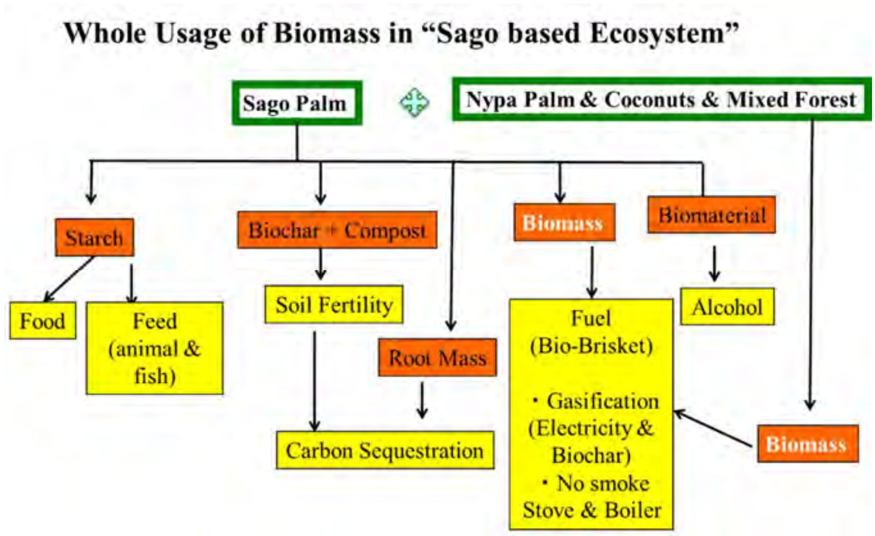


Figure 3-10　Proposal of biomass production system focusing on sago

(4) Complex economic system

Peatlands are very fragile ecosystems, and plantation systems are inherently unsuitable for such ecosystems. Therefore, the introduction of a complex management system centered on maintenance is required. Thus, we propose a model construction of Micro-Hydrological Unit concentrating into one unit the elements such as edible economic crop and fruit tree around the residence and village, grassland for livestock grazing, biomass forest and conservation forest.

The purpose of this project is to create a roadmap for improving economic values by utilizing estimation and application of natural capital such as 1) carbon/water problem related to COP 21 and SDG, 2) contribution to alleviation of, and adaptation to, climate change, 3) overcoming the food crisis. The improvement of the economic value of feed (starch utilization rate) and energy (biomass energy and renewable energy) covers the socioeconomic programs of the community by developing within the community, and it is expected that the program provides a key for the healing, restoration and protection of peatland.

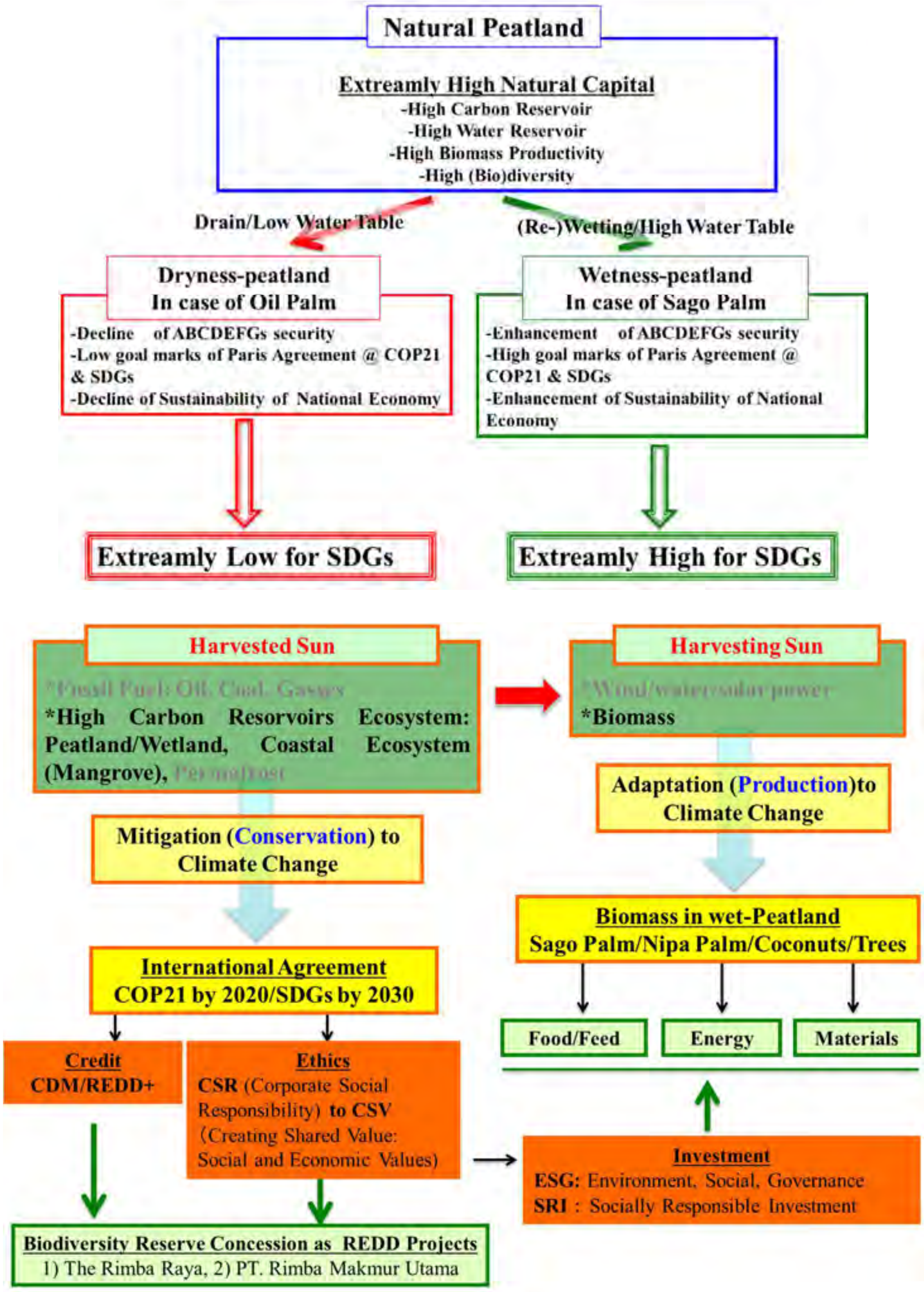


Figure 3-11 Complex Economic System in Tropical Peatland Ecosystems

Figure 3-12 Proposal of economic evaluation method for peatland ecosystems

(5) Evaluation of SDGs index

It is expected that conservation of peatlands under high water level conditions will result in achieving significantly higher SDGs. For that purpose, it is necessary to elaborate an evaluation method of SDGs index. As shown in the table below, from the viewpoint of security surrounding peatlands, we proposed the development of a method to carry out the following index evaluation (ABCDEFs Security) in cooperation with BRG..

Table 3-2 Proposal of evaluation index

項目	Evaluating methods
Aquatic/Water reservoir ecosystem	Water security
Biodiversity security	High Biodiversity by mix planting and nature conservation around peat dome
Climate Change security	Mitigation as Carbon Emission Reduction and Adaptation as high Biomass Production against El Nino.
Disaster security	Fire and Haze protection
Energy security	Biomass energy from sago starch and residuals, and other biomass materials in sago based ecosystem
Food/Feed security	Sago starch for food and feed (animal husbandry and fish culture)
Social Security	PES and CSR and CSV by several credit(REDD+ JCM)

4. Proposal of Capacity Building Method for Peatland Restoration Project

For the recovery, restoration and conservation of peatlands, a management/maintenance method based on correct scientific knowledge is necessary. Various trainings, workshops and educational curriculum are required for the enforcement of this knowledge. Moreover, manual and guideline for each level must be produced. Here, organization structure for the basis of this capacity building is proposed.

4.1 Peatland Restoration University Consortium

Fiver universities in Kalimantan (Kalimantan University Consortium) and five universities in Sumatra (Sumatra University Consortium) formed consortiums.

The purpose of these university networks is to establish the standardized methodology for field studies toward accumulation of scientific knowledge on peatlands. In this project, a joint research was conducted in Central Kalimantan province between January 17 and 27, and engaged with the standardization of peatland research method together with the researchers from Palangka Raya University of Kalimantan University Consortium and Riau University of Sumatra University Consortium. It resulted in the production of field research manual (appendix), which was proposed as the manual/guideline for education and workshops.

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4.2 Peatland Restoration Center

At the 1st Roundtable Discussion on Peatland held in November, establishment of an education center for peatland research in both Kalimantan and Sumatra on the occasion of the organization of Kalimantan University Consortium and Sumatra University Consortium was proposed. The notable point about this proposal was that its premise was to promote involvement of private sector in the peatland restoration project. The discussion paper argued that the operation of the education centers should be done through the collaborative structure of Ministry of Environment and Forestry (MoEF), Agency for the Assessment and Application of Technology (BPPT), Indonesian Institute of Sciences, universities, local municipalities and other various stakeholders in addition to BRG.

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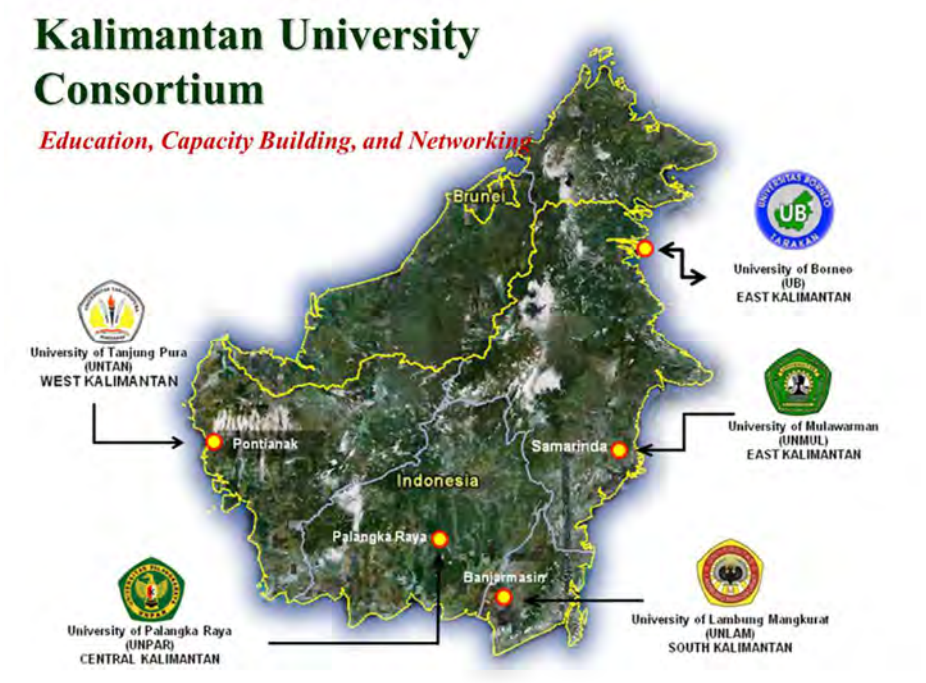

Figure 4-1 Kalimantan University Consortium

Figure 4-2Sumatra University Consortium

5. Support for Organization of International Committee for Peatland Restoration in Indonesia

For the collaboration of various stakeholders in the restoration/recovery project of peatland in Indonesia, the adjustment of various interests is arguably the most important factor for its success. Therefore, we support the establishment of "International Committee for Peatland Restoration in Indonesia". IPS and JPS will be its cores and BRG, in collaboration with JICA and Japan Science Association.

Concretely, the contractor will be responsible for the communication and coordination between various relevant organizations upon the establishment of this committee, will produce the proposal for the committee establishment plan, and support the gaining of approvals from the relevant organizations. Moreover, the committee will consist of 1) Executive Board, 2) Implement Group, and 3) Secretaries. We supported the requests made to relevant donors in order to receive international support for the establishment of this committee.

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5.1 Coordination among related organizations

In this project, we stablished the first peatland roundtable conference as a forum for discussion among related organizations as a step toward the establishment of the International Committee on Peatland Recovery in Indonesia. In holding the first peatland round table, we made prior adjustments with people affiliated with BRG, JICA, IPS, JPS, Nihon Gakujutsu Rengo, and other related organizations. We also disseminated information about the first roundtable and created the program in consultation with people affiliated with this project. In addition, we cooperated with Nihon Gakujitsu Rengo in requesting the Norwegian Embassy in Indonesia for assistance as we sought international support. We were able to procure a portion of the necessary funds through the United Nations Development Programme (UNDP).

5.2 Creation of a draft proposal for the committee's establishment

In this project, we drafted a proposal regarding the parent organization and the operating organization of the International Committee on Peatland Recovery in Indonesia toward the holding of the roundtable discussion. At the roundtable meeting, the participants, including BRG, JPS, Nihon Gakujutsu Rengo, released a joint statement entitled "the Jakarta Declaration on Responsible Management of Tropical Peatland." Afterward, we held several meetings and workshops with various stakeholders such as the Ministry of Environment Forestry (MoEF), the Ministry of Agriculture (MoA), the Agency for the Assessment and Application of Technology (BPPT), the Indonesian Institute of Science (LIPI), universities, local-government bodies, and private-sector companies to build cooperative relationships for the establishment of the International Committee on Peatland Recovery in Indonesia and the International Peatland Research Center. We were able to provid support in obtaining approval from related organizations.

5.3 Holding of roundtable discussion

We held the first roundtable peatland conference at a hotel in Jakarta on November 1 and 2 of 2017. IPS, BRG, and JPS hosted the conference and invited researchers of peatland and people invovled in peatland-realted work in Indonesia and elsewhere. We discussed issues realted to the establishment of the International Committee on Peatland Recovery in Indonesia and its framework. About 80 people participated in the event. The agreement was compiled as specific action plans in a joint statement called the Jakarta Declaration. From November 3 through 5, we took volunteers to Palangka Raya in the province of Central Kalimantan for field excursion.

(1) Summary of the event

The following is a summary of the first peatland roundtable and the field excursion:

1) 1st Tropical Peatland Roundtable

Date and Time
08:30~17:00 November 1st, 2017
09:00~14:30 November 2nd, 2017

Menara Peninsula Hotel, Jakarta, Jasmine 4 room, 3rd Floor
Jalan Letjen S. Parman Kav. 78, Jakarta
Telephone: (62-21) 535 0888
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Welcome dinner
Date and Time
18:30~20:00 November 1st, 2017

2) Field Excursion to Palangkaraya (Advanced registration is required)

Date and Time
November 3rd to 5th, 2017
Venue
(Refer to agenda for field trip)

Table 5-1 1st November: 1st Tropical Peatland Roundtable Day 1

Time	Agenda	PIC
08:30-09:00	Registration/Short movies about peatlands restoration will be played prior the opening	
09.00-09.05	Committee Report	Dr. Haris Gunawan (Deputy Research and Development of Peatland Restoration Agency
09:05-09:30	Opening Remarks	1) Ir. Nazir Foead MSc (The Head of the Peatland Restoration Agency) 2) Dipl.-Ing.Gerald Schmilewski (The president of International Peatland Society)
09.30-10.00	Press Conference and Coffee Break/ Photo session	
10.00-11.00	Panel Dialogue	Facilitator: Dr. Alue Dohong/ Dr. Abdul Wahib Situmorang 1) Prof. Azwar Maas : Situation of Indonesian Peatlands 2) Directorate General PPKL, KLHK: Sustainable Management of Indonesian Peatlands 3) Dr. Haris Gunawan: Restoring Degraded Peatland, The Potency of Promising Adaptive Crops.
11.00-11:45	Topics Presentation and Discussion 1 Restoration of Degraded Peatland in Different Land Uses	Facilitator : Hanni Adiati, MSc 1. Prof. Indratmo : Hydrological Restoration in Plantation Areas 2. Prof. Line Rochefort : The Development of Technology to Restoring Peatlands 3. Prof. Kosuke Mizuno : Restoration of Peatland in Community Lands
11:45 – 13:00	Lunch	
13.00 – 14.00	Topics Presentation and Discussion 2 Development Peatland Monitoring System	Facilitator: Dr. Budi Wardhana 1. Dr. Hidenori Takahashi: Developing System on Water Table Monitoring 2. Dr. Albertus Sulaiman: Building An Integrated Peatland Monitoring Through Modeling and Mapping Water Table 3. Bernd Hofer: Data collecting, data processing and peatland restoration planning – experiences from Europe 4. Vähäkuopus Tuija: Geological Survey of Peatland
14.00–14.30	Coffee Break	

Time	Agenda	PIC
14:30-17:00	Roundtable Discussion	Chaired by Dr. Haris Gunawan and Dr. Bambang Setiadi 1) "Discussion Paper" explanation by Dr. Mitsuru Osaki (President of Japan Peatland Society) 2) Short comments/presentation from participants
18:30-20:00	Welcome dinner party	Supported by BRG

Table 5-2 2nd November: 1st Tropical Peatland Roundtable Day 2

Time	Agenda	PIC
09:00-09.15	Registration and Coffee	
09.15-10.30	Topics Presentation and Discussion 3 Carbon Emission on Peatlands	Facilitator: Dr. Belinda Margono - Prof. Dr. Daniel Murdiyarso: Estimation of Carbon Emission on Tropical Peatland: Before and After Restoration Scenario - Prof. Dr. Eeva Stiina Tuittila: Ecology of Boreal Peatlands Including Methane and Carbon Dioxide Processes - Dr. Takashi Hirano: Long Term Monitoring of CO2 Flux in Tropical Peatlands
10:30-12:30	Action plan discussion	Chaired by Prof. Mitsuru Osaki, Prof. Azwar Maas - Proposing discussion points by Dr. Bambang Setiadi
12:30-13:30	Lunch	
13:30-15:00	Jakarta Declaration	- Discussion on draft of Jakarta Declaration - Signature with Gerald Schmilewski, Nazir Foead, Mitsuru Osaki (Witness by Haris Gunawan in the case of Nazir Foead) - Jakarta Declaration on Tropical Peatland by Gerald Schmilewski (The president of International Peatland Society)
15:00-15:15	Closing Remarks	Dr. Bambang Setiadi

1st Tropical Peatland Roundtable

2nd November 2017

"Jakarta Declaration" on
Responsible Management of Tropical Peatland

Truly effective Tropical Peatland Restoration in Indonesia will require substantial development of an integrated peatland management system based on scientific and technical knowledge and information. Achieving this requires the establishment of an International Committee for Technical Consultation to facilitate Tropical Peatland Restoration Action.

For this purpose, the IPS (International Peatland Society), BRG (Peatland Restoration Agency, Indonesia) and JPS (Japan Peatland Society) organized the 1st "Tropical Peatland Roundtable" on the 1st and 2nd November 2017 in Jakarta, supported by JICA (Japan International Cooperation Agency), Norwegian Embassy, UNDP (United Nations Development Programme), and BRG.

After two days of thorough discussion, a principal strategy of Responsible Management of Tropical Peatland was agreed. This includes five pillars of action:

- establish a "Tropical Peatland Center "
- organize an " International Committee for Technical Consultation"
- develop an "Integrated Monitoring System"
- conduct a "Model Project" for responsible management
- achieve capacity building

We release this "Jakarta Declaration" as a milestone for promoting action on "Responsible Management of Tropical Peatland", also as a basis for bridging Indonesian stakeholders and the international community.

Gerald Schmilewski	Nazir Foead	Mitsuru Osaki
The President of the International Peatland Society (IPS)	The Head of Peatland Restoration Agency (BRG)	The President of Japan Peatland Society (JPS)

Figure 5-1 Jakarta Declaration on Responsible Management of Tropical Peatland

6. Cooperation Activity on Peatland Restoration and Transmission of Information

We supported the dissemination of information to the international community by announcing the outcomes of 1st Tropical Peatland Roundtable at the Japan Pavilion JICA-BRG (Indonesia Peatland Recovery Agency), COP23 held in Germany, At the same time, the results of the 1st Tropical Peatland Roundtable (the 1st Tropical Peatland Roundtable) conducted in November 2017 for the establishment of the International Committee on Peatland Restoration in Indonesia was announced at the International Organization including IPS (International Peat Region Association) . In addition to sharing it to each person concerned, we provided feedback to support the establishment of the committee, including providing advice on the creation of a concrete framework.

6.1. JICA-BRG (Indonesia Peatland Recovery Agency), COP23 held in Germany

Mr. Hidenori Takahashi and Mr. Mitsuru Osaki attended to the United Nations Framework Convention on Climate Change Conference (COP 23) held at Bonn (Germany) from November 6 (Monday) November 17 (Fri) on July 17. At side events of Japan Pavilion held on November 8 (Japan, departing on the 17 th of the same month), they proposed the effective use of the real-time monitoring system from the contents of each country's pavilion I got information on the task. At the Indonesian Pavilion event held on the 9th, Mr. Wahjudi Wardoyo (Senior Advisor to the Ministry of Environment and Forestry), Nazir Foead (Headof BRG), Mr. Alue Dohong (Deputy of BRG) stated the national strategy for peatland restoration.

6.2. Discussion in IPS Executive Board Meeting

(1) Executive Board Meeting on October, 2017

Mr. Mitsuru Osaki participated in the Executive Board Meeting of IPS held at Poznan in Poland from October 10th to 11th. Here he reported about the agenda of a roundtable meeting planned to be held in November and discussed the session topic. As a result, the consensus on participants from IPS are gained

Table 6-1 Proposed Agenda

Agenda 1: Integrated MRV System
Agenda 2. Model Pilot Project
Agenda 3. Capacity Building
Agenda 4. International Program

(2) Executive Board Meeting on April 2018

At IPS Executive Board Meeting held in Vilnius, Lithuania, from 31 March to 8 April 2017, Mr.Mitsuru Osaki proposed and discussed on the holding of the second peat roundtable conference in Indonesia. As a result, agreement was reached on the holding in November 2018 organizing by IPS, JPS, Indonesian Peat Society, BRG, and Indonesian Ministry of Environment and Forestry (MoEF). The person who responsible to this event from IPS is decided to be Mr. Jack Rieley and Mr. Mitsuru Osaki.

Figure 6-1 IPS Executive Board Meeting

7. Summary of Proposal

Our proposal for this project will be organized as a recovery process of tropical peatland in Indonesia and proposed as concrete action plans contained in the “Responsible Management of Tropical Peatland” adopted in the Jakarta Declaration.

Tropical peatlands store gigantic amounts of carbon and water, and may be one of the most valuable ecosystems from the perspectives of natural capital assessment. However, the water levels of tropical peatlands are falling as they are drained for development, and colossal emission of carbon due to fires and degradation of microorganisms. This is a global crisis, and protecting tropical peatlands is crucial for protecting safety at global levels and would also contribute to global goals of 1)Aquatic /water Security and 2)Carbon Security. These important securities are also key elements to the targets of the 17 Sustainable Development Goals (SDG), thus the rehabilitation, restoration, and security of tropical peatlands contributes to SDGs at a global scale as well.

Keywords: aquaculture, nitrogen fixation, biomass production, aerial roots, mound roots

7.1 Introduction

Large amounts of carbon are stored in tropical peatlands. 70% of the world's tropical peatlands are distributed in Southeast Asia, the majority of which is in Indonesia. These areas of tropical peat have been exposed to the threats of development since the turn of the 20th century. The rapid excavation of water channels in these areas and cutting down of tropical peat swamp forests, plantations of oil palm and trees for pulp have progressed, and fires and degradation of microorganisms cause massive emissions of carbon dioxide.

High Carbon Reservoir Ecosystems were subject of debate at the United Nations Framework Convention on Climate Change (UNFCCC) workshop (UNFCC-SBSTA 38 Research Dialogue, 2012 and UNFCCC workshop, 2013) as recognized as “Technical and scientific aspects of ecosystems with high-carbon reservoirs not covered by other agenda items under the Convention,” which incited various measures to solve this problem. "Ecosystems with high-carbon reservoirs" as discussed here consist of

1) Peatlands/Wetlands
2) Costal Ecosystem (comprising mangroves/sea grass/coral)
3) Permafrost (permafrost)

Recently, carbon in coastal ecosystems and marine carbon are called blue carbon. According to this, well-conserved carbon in peatlands/wetlands started to be called gold carbon, and similarly, carbon in permafrost (primarily in the form of methane) is termed silver carbon, and black carbon is the term given to large amounts of carbon released from the ecosystem as a result of failed ecological management. That is, the restoration and rehabilitation of peatlands depend on how a system for assessing and converting black carbon into gold carbon can be developed. The super el Niño in 1997-8 was marked by outbreaks of forest fires around the world, which collectively emitted more than 24-66% of carbon dioxide released in the world (of this percentage, 60% was estimated to have been released from Southeast Asia), and the proportion of tropical peat swamp forest disappearance that this accounts for was estimated to be extremely high (Guido R. van der Werf, et al. 2004). During this time, normal el Niño's began to increase in frequency in 4-5 years interval, causing frequent tropical swam fires, haze, increasing the incidence of respiratory diseases and mortality in community residents. There have been major economic losses due to disrupted air and marine travel as well. Furthermore, Indonesia's neighboring countries of Malaysia and Singapore also suffered major damage as well, which have caused diplomatic conflicts and lawsuits as well. This is because in Indonesia, the development of tropical peatlands accelerated drastically in the 1990s, the majority of which involved drilling channels for drainage which has caused drying of tropical peatlands. Prior to the 1990s, even el Niño's did not cause severe peatland fires such as those we have seen after the 1990s. This makes it unarguably clear that the "tropical peatland fires (hot fires) and "microbial degradation of tropical peatlands (cold fires) caused by the "drying of peatlands due to drainage" is the scientific mechanism underlying swamp carbon degradation. In other words, the high water levels in tropical peat, with almost no dissolved oxygen causes poor oxygenation, which dramatically lowers microbial activity. This prevents the degradation of organic matter, thus allowing peat to accumulate in tropical regions, which is the scientific phenomenon complementary to peat generation.

The state of Indonesia (President Joko Widodo) announced the establishment of the Peatland Restoration Agency (Badan Restorasi Gambut: BRG) in the 21th United Nations Climate Change Conference Paris (COP21/UNFCCC) held in November 2015 to promote forest disaster prevention and reduce greenhouse gas emissions to counter these problems of tropical peatlands. The BRG was implemented in January 2016, and mandated to plan peat restoration and effective use of 2 million ha by 2020 through maintaining water levels and planting and cultivating economic crops. In response to this, Hokkaido University, Kyoto University, and the Research Institute for Humanity and Nature (RIHN) signed agreements for collaborative research with the BRG. To support these agreements, the Japan International Cooperation Agency (JICA) and BRG also signed agreements and starting a supporting program, the JICA-BRG Project, contracted to Hokkaido University, which has promoted 1)constructing and building models of sensing and monitoring systems, 2)designing and operating model pilot projects, 3)founding capacity-building systems, and 4)establishing an international tropical peat center (provisional name) for the innovative rehabilitation and management of peat. In particular, measurements and assessment and manual-making of innovative cultivation methods are crucial keys to promoting collaboration with international organizations as well.

7.2 Tropical peatlands as natural capital

Extremely complex systems and large volumes of research and surveys are necessary to assess tropical peatlands, and techniques to maintain and manage them makes the task even more troublesome. However, the ecology of tropical peatlands is extremely simple, from the perspective of tropical peatlands as natural capital. Tropical peatlands are "High Carbon/Water Reservoir Ecosystems" in which plants grow.

According to the global-scale analysis of a cluster of interconnected environment-related risks, the top-ranking risks are 1)"water crises" and 2)"failure of climate change mitigation and adaptation" (The Global Risks Report 2017 12th Edition). Tropical peatlands are high carbon/water reservoir ecosystems, and are beginning to be recognized as very specific ecosystems comprising the two greatest global environmental risks. Therefore, tropical peats will be analyzed as natural capital.

The restoration of destroyed tropical peatlands can effectively increase the value of natural capital, so that Indonesia with its vast peatlands in ruins can increase the various types of national security. Increased security by restoring degraded tropical peatlands consist of eight components abbreviated as the ABCDEFGs Security, and can be analyzed as follows:

-Aquatic /water security: Functions of water reservoir ecosystem
-Biodiversity security: Diversity and function of plants adapted to peatlands and wetlands
-Climate Change security: Global contribution to mitigating and adapting measures to climate change
-Disaster security: Mitigating peat disasters and smoke
-Energy security: Using massive biomass for energy
-Food/Feed security: Starch production mainly by cultivating the sago palm
-Global Partnership as global security: International contribution through standardization of measurement of tropical peatlands and international collaboration to develop a program for peatlands security, rehabilitation and restoration
-social security: Substantiation and valuation of natural capital through REDD+, PES, CSR&CSV and ESG&SRI

Recently, terrestrial water is noted as the biggest of the global risk factors (The Global Risks Report 2017 12th Edition). The drilling of channels to drain tropical peatlands for development has lowered the water levels, and they have been emitting large amounts of carbon due to biodegradation and fires, marking a global-scale crisis. In other words, the security of tropical peatlands can play a role in achieving security at global scales. Furthermore, achieving the ABCDEFGs Security of tropical peats potentially helps achieve many SDG. SDGs 2, 5, 6, 7, 8, 9, 11, 12, 13, 14, 15 and 17 encompasses F, s, A, E, s, s, s, s, A+C+D, A+B, B, and G, respectively. The destruction of tropical peats endangers many of the ABCDEFGs of Security, threatening the SDGs to extremely low levels. SDGs are starting to become indicators for banks and investors in making investments. For example, if oil palms are cultivated in tropical peats in low-water levels (under drained conditions), this leads to lower evaluations of Environment, Social, Governance (ESG) and socially responsible investment (SRI), which would lower the ABCDEFGs of Security in tropical peat markedly. Because of this, investments to the companies are remarkably restricted.

7.3 Tropical peatlands are “hydroponic cultivation systems”

Tropical peatlands are ecologically speaking, “high carbon/water reservoir ecosystems”, but from an even simpler agronomic view, they are “hydroponic cultivation systems”. Water is the basic element of hydroponics, and carbon (peat material) is the support material in hydroponic cultivation. Methods for hydroponic cultivation involve three basic elements: water, nutrients and oxygen. In tropical peatlands, water levels are often lowered for monoculture of palms, and many researchers believe high levels of aboveground water act almost like a poison to plants; however, the main issue is that oxygen solubility in water is extremely low, and when water is present, oxygen deficiency can easily occur in plants. A great deal of energy is required for nutrient absorption and when there is no oxygen, nutrients cannot be taken up by the absorptive roots, which in turn rot, and the plants wither. The main and other supporting roots can survive even in flooded peatlands of 10 m water depth because their main role is for respiration, and not nutrient absorption; thus, they are able to function and grow sufficiently with the amount of oxygen diffused through aboveground conductive tissues. Meanwhile, even in rice with developed conductive tissues, aeration (bubbling via air compressor) is essential in hydroponic cultivation to enable abundant nutrient absorption by lateral roots. Thus, for plants living in tropical peatlands, the primary limiting factor is “oxygen”.

The second limiting factor is the type and amount of “inorganic nutrients”. Delivery of inorganic nutrients to peatlands is mainly via clay minerals from rivers; there is also inorganic nutrient supply from the ocean, but it is limited by tidal action (Fig. 1). Meanwhile, water is delivered from rivers and oceans as well, but this is also restricted. Water supply to peatlands is mostly dependent on rainfall, however, most nutrients are not included in rainwater and due to its acidic nature (pH5.6), cations easily can be leached from peatlands. In particular, K^+ and Na^+ do not form compounds, and because they exist in ionic form, they are the most susceptible to leaching.

In tropical peatlands, peat is formed in islands surrounded by rivers or the sea and is known as a “peat hydrological unit”; the peat deepens toward the center to build dome-like structures (Figure 1). It is clear from this schematic that ample inorganic nutrient supply allows abundant plant growth along rivers and coasts, but the accumulation of peat (organic matter) is low; meanwhile, plant growth is suppressed on the top of domes due to oligotrophic conditions, but peat accumulation is high. In nutrient-rich zones, organic matter is quickly decomposed via high microbial activity, leading to little organic matter accumulation, whereas in nutrient-poor areas such as on the tops of domes, organic matter decomposition is limited by low microbial activity and organic matter accumulation occurs.

From the above, two important factors for accumulation of tropical peat are: 1) high water levels and 2) oligotrophic conditions. Thus, from the viewpoint of peatland conservation, lowering the water levels (thereby providing oxygen and encouraging microbial activity) and applying fertilizer (also encouraging microbial activity) such as for oil palm cultivation in particular, are detrimental practices.

Additionally, in tropical peatlands, leaching of inorganic nutrients, primarily cations, leads to oligotrophic ecosystems. When peat (organic matter) is around pH7, it adsorbs cations, but in acidic conditions below pH4, the major mechanism that occurs in peat is to desorb cations. Incidentally, in tropical peat, the pH is often around 3.5, thus it is basically an ecosystem where nutrients are leached out.

Thus, in tropical peatlands, 1) there is no nutrient supply system, and 2) nutrients are drained away, resulting in oligotrophic ecosystems. However, as will be described later, biomass production capacity is unexpectedly high despite low inorganic nutrient supply, thus the finding needs to be investigated further. Figure 1 shows a schematic and it is proposed that three nutrient cycling mechanisms are at work:

1) surface recycling (a): leaf litter and other organic matter are decomposed at the surface and is immediately taken up by microorganisms and roots, minimizing leaching of nutrients,
2) plant organ recycling (b): nutrients are recovered from older and no longer needed organs of the plant,
3) intracellular recycling (c): older intracellular compounds are decomposed and reused to increase plant resistance to low nutrient ratios.

The surface nutrient recycling system consists of a surface layer of available organic matter and microorganisms involved in decomposition; when this layer is disturbed due to desiccation (via drainage and deforestation), fires and land development, the role of surface nutrient recycling system is substantially reduced. When the nutrient recycling system is destroyed, there are cases where it may take more than 20 years for natural recovery of forests (unpublished data).

Oxygen/inorganic nutrient absorption systems

In tropical peatlands, nutrient absorption ability may be further decreased due to: 1) the nature of water supply (rainwater) and peat nutrient desorption (removal of cations at pH4 or less), leading to oligotrophic ecosystems, and 2) the water-rich environment, leading to oxygen deficiencies. In the end, the environment surrounding the peat is a major issue of the physical and chemical properties of the inorganic nutrient supply system. To address this, we investigated how natural tropical peatland ecosystems overcome these limitations. Basically, it depends on:

1) formation of aerial roots and

2) formation of mounds (root)

Due to the formation of aerial roots, oxygen can be absorbed from the atmosphere, and through mound formation, oxygen and nutrients can be taken up.

7.4 High productivity in natural forests of tropical peatlands

Data tracking of trunk diameters was conducted in one-hectare survey areas established in Central Kalimantan province peat swamp forests (PSF1, PSF2), heath forests (shallow peat layer overlying sandy soil) (HF1, HF2) (Rahajoe et al. 2003; Miyamoto et al. 2003; Nishimura et al. 2007; Atikah et al. 2014), and in West Kalimantan province lowland (mineral soil) mixed dipterocarp forests (MDF1, MDF2) (Kohyama et al. 2001, 2003). Data was obtained from two survey areas at each location, and included trunk diameter/tree height relationships, and harvesting survey of each forest type. From these, analyses were performed using the relative growth relationships of aboveground biomass (Yamakura et al. 1986; Miyamoto et al. 2007, 2016). Recruitment and mortality rates based on tree populations with trunk diameters of 5 cm or more were calculated. Additionally, production and mortality rates based on individual trees in the aboveground biomass were calculated. In both instances, vital rate estimation was conducted whereby differences in observation periods were not a factor (Kohyama, Kohyama & Sheil, 2017).

Peat swamp and heath forests were compared to mixed dipterocarp forests, and our survey data confirmed previous reports that the number of tree species, maximum tree height and aboveground biomass are small (Figure 3). Data from a successive survey was used to calculate production rates from individual growth and recruitment of trees in the aboveground biomass; similarly, death rates were calculated from data obtained on withering trees (Figure 4c, d). The production rate due to individual tree growth was reported to be approximately 40% of the net aboveground primary production rate which includes production rate of short-lived leaves (Malhi et al. 2004; Takyu et al. 2005). As a result, the two forest types of low wetlands were revealed to have 1.5 to 2 times the biomass turnover rate than mixed dipterocarp forests. The turnover rate of the number of individuals was also higher than in mixed dipterocarp forests. In low wetlands, while oligotrophic conditions result in high mortality of canopy trees, there is sufficient light and nutrient supply for replacement individuals, culminating in high biomass production rates.

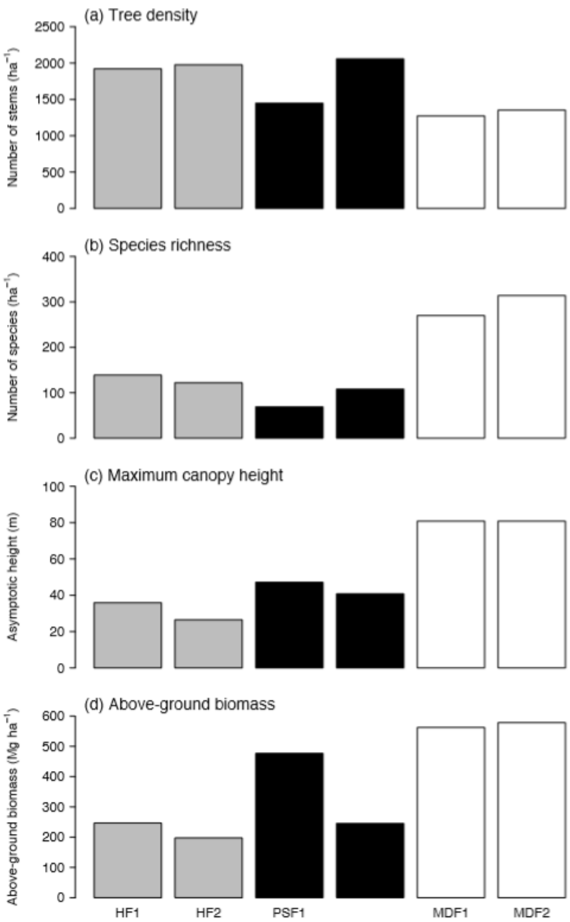


Figure 7-1 Configuration of 1-hectare survey areas established at two locations in each of heath forest (HF), peat swamp forest (PSF), and mixed dipterocarp forest (MDF) in Kalimantan. From census of all individuals with diameter at breast height of 5 cm or more. Maximum canopy height represents the maximum height from extended allometric equations.

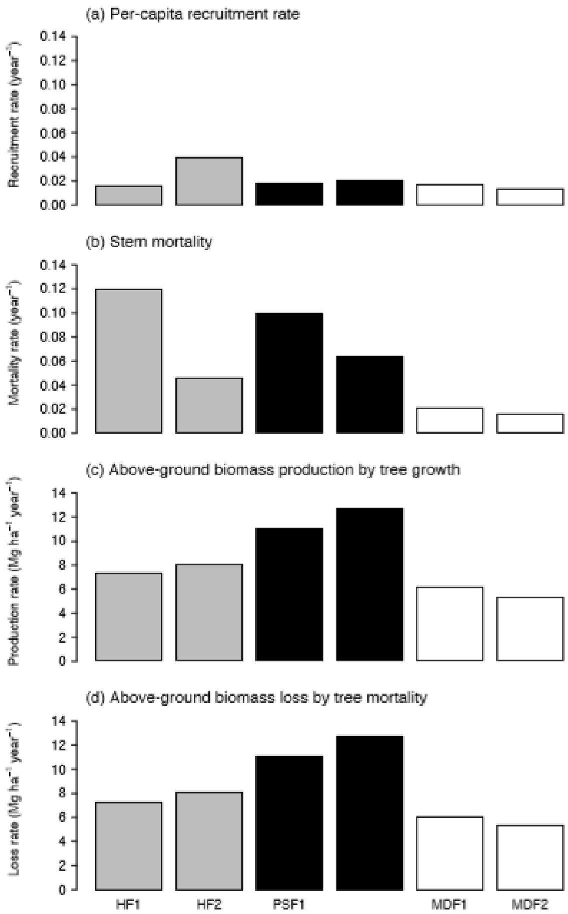


Figure 7-2 Biomass dynamics and number of individuals in 1-hectare survey areas in heath forest (HF), peat swamp forest (PSF), and mixed dipterocarp forest (MDF) in Kalimantan. From recruitment, growth and mortality data of individuals with diameter at breast height of 5 cm or more

From trunk diameter-tree height allometric relationships estimated in each survey area, it was revealed that small diameter trees have elongated shapes in heath forests whereas canopy trees exhibit elongated trunk shapes in mixed dipterocarp forests (Miyamoto et al. 2016). Aboveground biomass of peat swamp and heath forests is approximately 200 to 300 t/ha and is about one half to one third of mixed dipterocarp forests yet the production rate due to tree growth is 10 to 15 t/ha/y, surpassing that of mixed dipterocarp forests, and showing a greater than three times biomass turnover rate. The rapid mortality rate of the canopy appears to induce quick replacement by smaller diameter individuals, revealing potential production characteristics of a tropical peatland ecosystem. The rapid mortality of individuals in the canopy indicates that there is high material supply rate of woody peat in peat swamp forests.

Flux observations of peatland that was drained by human intervention and disturbed by forest fires yielded a carbon emissions rate of 5 t/ha/y from the net ecosystem carbon exchange rate (NEE) (Hirano et al. 2012). This value is fairly consistent with a carbon emissions rate of 6 t/ha/y reported when disturbance and irrigation of peatlands led to a surface sedimentation rate of 1 cm/y (H. Takahashi et al., 2018). These emission values are also consistent with dry weight-based biomass turnover rate due to tree growth and mortality. In undisturbed peat forests with high aboveground water levels, it was revealed that the amount of surface organic matter was retained by the rapid production and supply of wood carbon to the surface. Thus, for tropical peat restoration and management, it is important to maintain a high aboveground water level and vegetative cover to allow large wood carbon supply to the surface layer.

7.5 Nitrogen fixation capacity of tropical peatlands

We found that natural tropical peat forests can have thriving bioactivity even in low water tables. That is, they form aerial roots and mounds to absorb oxygen and nutrients. Furthermore, we found that tropical peatlands were ecosystems with surprisingly extremely high fixation capacity of atmospheric nitrogen.

A survey on the natural abundance of δ 15N of the peatlands of To Daeng in Narathiwat Province, in southern Thailand (Yanbuaban, M, et al, 2007) revealed that the soil δ ^{15}N (per mil) was ≥ 3.0, while that of various plant foliage was ≤ 3.0. This is because plants rely on the lighter ^{14}N with preference, thereby encouraging gaseous metabolism, and demonstrates that atmospheric nitrogen is the primary source of nitrogen. Furthermore, nitrogen compounds accumulated through nitrogen fixation are distributed to the ground level in the form of litter, and when it becomes denitrified through decomposition, the lighter weight ^{14}N disappears first, thus increasing the amount of soil δ ^{15}N over time. As such, there is little soil absorption of nitrogen in tropical peatlands, and the fixation of atmospheric nitrogen can be assumed to be active in these environments.

These trends have been confirmed in the tropical peatlands of Kalimantan in central Indonesia as well (Takeshi MATSUBARA, et al, 2002). In this area, soil δ ^{15}N was ≥1.0, while that of various plants was ≤ 1.0: the ecological system here also absorbs nitrogenous nutrients by fixation of atmospheric nitrogen in the same way as the tropical peatlands of Thailand.

Nitrogen-fixing is primarily done by legumes in symbiotic relationships with rhizobia (root nodule bacteria); however, tropical peat forests have few legumes. Furthermore, rhizobia are particularly sensitive to water (=oxygen deficiency), thus nitrogen fixation is not possible in tropical peatlands with their high water levels; with the possible exception of mound areas where they may form nodules for nitrogen-fixing. However, plants with low δ ^{15}N, i.e., nitrogen-fixing plants, 1)are not colonized by rhizobia, 2)have almost no endophytes, but 3)frequently secrete gel-like substances from the tips of their aerial roots, from which numerous nitrogen-fixing microorganisms can be isolated. Thus, nitrogen fixation is assumed to occur abundantly in the aerial roots of plants growing in tropical peats as well.

7.6 Innovative methods of tropical peat recovery and rehabilitation

Tropical peatlands are maintained when water levels are high, thus 1)oxygen supply is the first restricting factor, and 2)there is almost no supply of inorganic nutrients, and as a characteristic of peat (organic), under low pH conditions, inorganic nutrients tend to detach and wash away, thereby making nutrients the second restricting factor. That is, under these conditions, both plant growth and bacterial activity are inhibited and decomposition of organic substances is slowed, encouraging its accumulation. As such, to cultivate oil palm in tropical peatlands, they generally need to be drained, and large amounts of chemical fertilizers must be pumped, accelerating tropical peat drainage. Oxygen can be fed by lowering the water level, then large distribution of chemical fertilizers dramatically boosts bacterial activity,   inducing rapid degradation of tropical peat (cold heat=slow oxidation). This further accelerates drying, causing frequent fires (hot combustion= acute oxidation) in a cycle of tropical peat disappearance.

These tropical peatlands may appear as biological production ecologies with very low biomass production capacity; however, they exhibit extremely high biomass production capacity (see Fig. 4). In reality, in natural tropical peat forests, even in sub-high water levels, these ecological systems absorb oxygen and nutrients through aerial roots and mounds in the superficial peat layer. As such, functional maintenance of the superficial tropical peat layer is extremely important. If the function of this superficial layer is maintained, there is sufficient water and prevents the photosynthetic capacity of plants from decreasing even in dry seasons. There is no toxicity of aluminum dissolution due to low-pH environments, such as in mineral soils (unavailability of phosphorus due to the toxicity of the Al^{3+} itself and the generation of Al-P compounds), making it an ideal biomass production system.

Furthermore, as the analysis of $\delta\ ^{15}N$ values of the soil and plant foliage has shown, tropical peatlands are systems with fixation of atmospheric nitrogen. There are few legumes in this environment, and therefore no root nodules and stem tubercles. However, the tips of aerial roots secrete and are covered in mucigel and are a host to numerous nitrogen-fixing bacteria. Thus, the aerial roots are presumed to fulfill the roles of both oxygen absorption and nitrogen fixation.

Based on the above, tropical peatlands are extremely distinctive production ecologies, and can also be called a type of hydroponic culture system. Therefore, tropical peatlands with high water levels are 1)<u>AeroHydro culture systems</u> characterized by superficial layers that supply oxygen and nutrients, and 2)<u>atmospheric nitrogen-fixing systems</u> that supply nitrogen, the nutrient needed in the highest quantities, from the atmosphere. Within this system, the nutritive needs of phosphorous by plants is small and phosphorus is not released easily, so they circulate within the superficial recycling system, and there is a high release of potassium so that potassium becomes a restricting factor in the long term, and since micronutrients required for nitrogen fixation are rare in peat to begin with, it may be another restricting factor.

With these concepts in mind, the following two processes should be implemented as ideal techniques for recovering and rehabilitating tropical peatlands: 1)Supply oxygen and nutrients through superficial layers in high water-level AeroHydro culture (i.e., by implementing aerial root plants and mound forming plants), and 2)boost the atmospheric nitrogen fixation system (i.e., by planting aerial root-forming plants and inoculating applying nitrogen-fixing bacteria to seedlings). In particular, superficial layer function is lost in degraded peatlands, so it is recommended to 1)first recover the water level, 2)implement aerial root- or mound-forming plants, 3)artificially form mounds, 4)supply nutrients (particularly K) from the superficial peat layer with slow-release fertilizers and composting, 5)supply micronutrients to strengthen the nitrogen fixation system, and 6)plant mycorrhizal fungi to boost growth and phosphorus absorption. These techniques can be applied to peatland oil palms as well: supplying inorganic nutrients (in particular, phosphorus) to superficial layers in sub-high water levels encourages efficient phosphorus absorption to increase production capacity.

7.7 Conclusion

As a natural capital, tropical peatlands are potentially one of the most valuable ecological systems. However, enormous amounts of carbon are being emitted from tropical peatlands in a cycle of lowered water levels by digging draining channels for development, microbial decomposition, and fires. This is a global crisis, and it is not an understatement to say that protecting tropical peatlands achieves security at a global scale. In particular, sago palms are very promising crops to be cultivated in tropical peatlands because it enables 1)large biomass energy conversion for Energy security, and 2)increases Food/Feed security by supplying large amounts of sago starch as food and feed for livestock. Since sago palms thrive in high water levels (i.e., in water reservoir ecologies), they also play important roles in increasing 1)aquatic /water security and 2)carbon security. These important securities are key elements to the 17 SDGs, thus rehabilitation, recovery and security of tropical peatlands are linked almost directly to the achievement of global SDGs as well.

SDGs are also starting to become indices that banks and investors use in determining their investments: for example, they may stop investing in companies that are neglectful of Environment, Social, Governance (ESG) and socially Responsible Investment (SRI) that farm oil palms in tropical peatlands, plummeting their ABCDEFGs of Security.

Furthermore, self-sufficiency in food, energy and other measures in rural areas, which traditionally mirrored the urban model focused on high food-processing systems to increase energy efficiency, is now starting to shift, potentially placing it back in rural areas. Food and energy footprints are becoming increasingly crucial, and tropical peats may provide a new framework for building a new production system.

Table 7-1 Appendix 3

Proposal of Action Plan on International Tropical Peatland Center (ITPC)

Chapter I.

[Appointed Task of Proposal]

This **Proposal of Action Plan** has been mainly prepared for the **International Tropical Peatland Center (ITPC)**. However, the proposal will be upgraded as a working document along the ongoing Action Plan on "Peatland Restoration" in Indonesia. This Technical Document will serve as the base for several training manuals, guide books, text books, reports, papers, and books.

Finally, this Action Plan on "Peatland Restoration" in Indonesia aims to contribute to SGDs; therefore, the socio-economic impacts of peatland restoration should be described in other paper/documents on the topics of 1) economic and community benefits for locals, 2) natural capital conservation on the global scale, and 3) mitigation and adaptation to climatic changes.

Summary

Below are some points that must be considered while executing this project:

(1) Establish "Integrated Monitoring System":

Based on the scientific model developed in many previous projects for the estimation of greenhouse gas (GHG) emission from peatland, it is proposed that the structure of real-time ground level peatland estimation be established, the release and uptake of carbon dioxide (CO_2) be evaluated, and fire hazard projection map be created. For this, we must consider the convenience factor in data accumulation or comprehension of the "manual" without sacrificing the scientific validity or correctness.

(2) Conduct a "Model Project" for responsible management:

The BRG's target is to restore peatlands in seven provinces (namely, Riau, Jambi, South Sumatra, West Kalimantan, Central Kalimantan, South Kalimantan, and Papua). In this project, Riau and Central Kalimantan were considered as the main provinces for research. We plan to conduct the field work and elucidate the structure and components of local government peatland restoration programs and systems as well as create the necessary guidelines for developing model pilot projects (in 2–4 places).

(3) Achieve "Capacity Buildings":

The Capacity-Building Centers in Kalimantan and Sumatra will be placed with the aim to link these centers with universities. We will propose manuals and guidelines for education and training purposes in the study areas of model pilot projects (as mentioned in point 2). The target groups for the capacity-building plan are universities, private sectors, administrations, and local residents. We intend to develop specific step-wise approaches for each target group.

(4) Establish ITPC

This project will be mainly conducted in cooperation with BRG and the Ministry of Environment and Forest. However, we must take care in building cooperative relationships among various stakeholders in Indonesia, including the Ministry of Agriculture, the Agency for Assessment and Application of Technology (BPPT)/Indonesian Institute of Sciences (LIPI), universities, local governments, private-sector businesses, non-governmental organizations, among others, considering that we wish to encourage the participation of private-sector businesses in peatland restoration projects. **ITPC needs donors to support this cause.**

(5) Organize an "International Committee for Technical Consultation" (ICTC)

Peatland restoration in Indonesia involves various stakeholders. The coordination of interests among each stakeholder is extremely important because successful collaboration is the key to success in peatland restoration project. For this purpose, the International Peatland Society and Japan Peatland Society, and Indonesia Peatland Society were considered as the key actors in the **ICTC.**

Chapter II.

[Proposal Outline of Action

2-1. Background

Mr. Joko Widodo, the president of Indonesia, issued a presidential regulation in the early 2016 toward the establishment of the Peatland Restoration Agency (BRG), which bears the mandate of peatland ecosystem restoration for 2 million hectares in 5 years. This step was an evidence of the genuine concern about the criticality associated with peatland restoration in Indonesia. However, there are several other stakeholders involved in peatland management, including 1) oil palm and fast-wood plantation companies, 2) local communities, and 3) agro-industries that produce sago, nipa, coconut, coffee, cacao, or the native species for food/feed production as well as for biomass production as a source of bioenergy.

In addition to coordinating the interests of the multiple stakeholders involved, multiple elements need to be taken care of in the peatland ecosystem, including the 1) water level, 2) nutrient status in soil and water, 3) vegetation, 4) topography, and 5) economic system.

For more than 20 years, both Indonesian and international scientists have studied the peatland ecosystems and their restoration methods and published several documents for the same. The Government of Indonesia also issued ministerial regulations on peatland management, presumably using these study outcomes, for example, the practice of maintaining the ground water level at >40 cm below the ground and allocating 30% of total peatland areas for peat dome conservation (according to the Government Regulation No. 57, Year 2016 on the Protection and Management of Peatland Ecosystem). However, these scientific findings are normally based on a single discipline and not sufficiently integrated into the solid multi-disciplinary knowledge that can be referred to policy makers. Therefore, further actions are urgently required by scientists to actualize conservation and sustainable management of peatlands in Indonesia.

BRG has a basic concept on peatland restoration, as defined by the "Integrated Model 3RE," which includes *Re*wetting (water control-water sharing), *Re*vegitation (biodiversity-peatland ecosystem quality), and *Re*vitalization of livelihood (socio-economics). In rewetting, peat fire prevention should be included. It is an ambitious concept that is extremely difficult to achieve because of the following limitations: 1) disagreements among stakeholders and 2) limited experience of peatland restoration and rehabilitation. Therefore, it is proposed that **ITPC** be established under the guidance of **ICTC** that follow and function on a standard **"Action Plan"** within a short time period.

This Action Plan by ITPC is inspired by the "Jakarta Declaration" on Responsible Management of Tropical Peatland, which held its 1st Tropical Peatland Roundtable on November 2, 2017 at Jakarta (Fig. 1).

"Jakarta Declaration" was composed of the following **five pillars of action:**

1) **establish a "Tropical Peatland Center"**
2) **organize an ICTC**
3) **develop an "Integrated Monitoring System"**
4) **conduct a "Model Project" for responsible management and**
5) **achieve capacity buildings.**

1st Tropical Peatland Roundtable

2nd November 2017

@ Jakarta

"Jakarta Declaration"
on
Responsible Management of Tropical Peatland

Five pillars of action:

- **establish a "Tropical Peatland Center "**
- **organize an " International Committee for Technical Consultation"**
- **develop an "Integrated Monitoring System"**
- **conduct a "Model Project" for responsible management**
- **achieve capacity building**

1st Tropical Peatland Roundtable

2nd November 2017

"Jakarta Declaration" on
Responsible Management of Tropical Peatland

Truly effective Tropical Peatland Restoration in Indonesia will require substantial development of an integrated peatland management system based on scientific and technical knowledge and information. Achieving this requires the establishment of an International Committee for Technical Consultation to facilitate Tropical Peatland Restoration Action.

For this purpose, the IPS (International Peatland Society), BRG (Peatland Restoration Agency, Indonesia) and JPS (Japan Peatland Society) organized the 1st "Tropical Peatland Roundtable" on the 1st and 2nd November 2017 in Jakarta, supported by JICA (Japan International Cooperation Agency), Norwegian Embassy, UNDP (United Nations Development Programme), and BRG.

After two days of thorough discussion, a principal strategy of Responsible Management of Tropical Peatland was agreed. This includes five pillars of action:

- establish a "Tropical Peatland Center "
- organize an " International Committee for Technical Consultation"
- develop an "Integrated Monitoring System"
- conduct a "Model Project" for responsible management
- achieve capacity building

We release this "Jakarta Declaration" as a milestone for promoting action on "Responsible Management of Tropical Peatland", also as a basis for bridging Indonesian stakeholders and the international community.

Gerald Schmilewski	Nazir Foead	Mitsuru Osaki
The President of the International Peatland Society (IPS)	The Head of Peatland Restoration Agency (BRG)	The President of Japan Peatland Society (JPS)

Fig. 1. The statement of "Jakarta Declaration"

The detailed Action Plan is provided in Figure 2. ITPC will be established in FORDA, Bogor, which will function as the headquarters. The key structure will be decided by FORDA, and ICTC will support ITPC. Because an Action Plan is necessary for the functioning of ITPC, we proposed the three following pillars of Action Plan:

1) Water/Carbon Mapping and Special Dynamic Informatics
2) AeroHydro Culture System and Biomass Energy and
3) Capacity Building and Designate of Field Center.

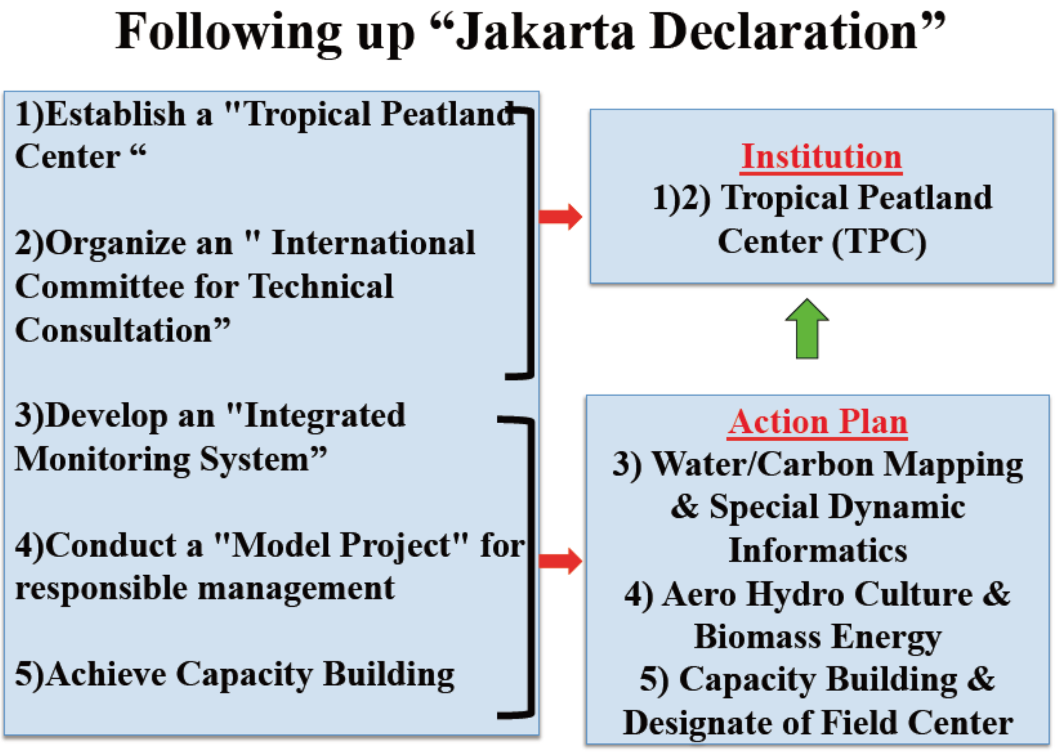


Fig. 2. Schematic description of the "Jakarta Declaration"

2-2. Outcomes

The Social System Innovation is required urgently as the base of SDGs. In the past, the society mainly depended on the **harvested sun energy** (fossil fuels such as oil, coal, and natural gases) and harvested sun-energy materials (high carbon reservoirs ecosystem and peatland/costal ecosystem/permafrost), together referred to as the "**Harvested Sun Society"** (Fig. 3). In the future, we desire that the society depend mainly on "**harvesting sun energy"** (**renewable energy** sources such as wind, water, solar power, and biomass and **natural capital** such as water cycle by solar energy), together referred to as the "**Harvesting Sun Society."**

Therefore, it is proposed that a national concept be established about how the "**Harvested Sun Society"** should transform into the "**Harvesting Sun Society."** In the "**Harvested Sun Society,"** climate change strategy mainly includes mitigation (conservation) to climate change, supported by credits such as clean development mechanism, reducing emissions from deforestation and forest degradation (REDD+), and Ethics Investment, such as corporate social responsibility, in creating shared value such as social and economic values. In addition, in the "**Harvesting Sun Society,"** climate change strategy mainly includes adaptation (innovation) to climate change, supported by investment systems such as environment, social, governance (ESG), socially responsible investment (SRI), and green bond (carbon bond and water bond).

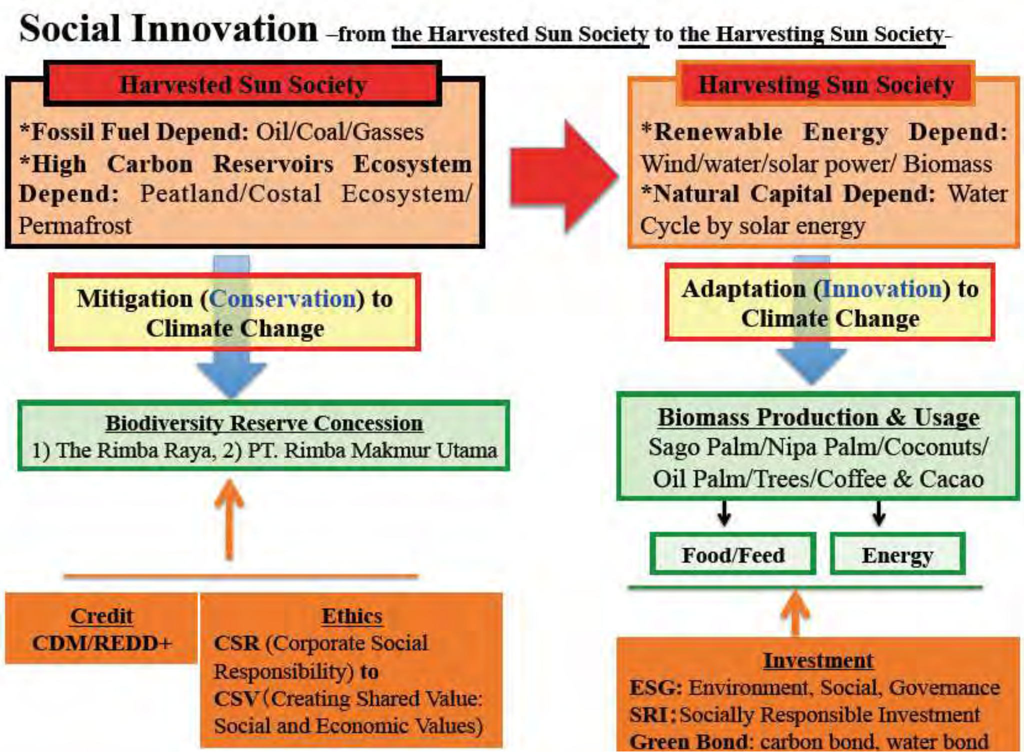


Fig. 3. Social innovation from the Harvested Sun Society to the Harvesting Sun Society

The "**Harvesting Sun Society**" in humid tropical regions should focus on Biomass Production and Usage because of the abundance of solar energy (photosynthesis) and through water cycle powered by the solar energy (one of the key elements of biosphere and human).

What is the optimal renewable energy source in the humid tropical region? The answer is biomass and biomass energy. The first reason for this answer is the energy profit ratio (EPR or EROEI), which is the ratio of output energy to input energy (Fig. 4). For example, if one unit of energy input is required to obtain energy and we receive 10 unit energy, the EPR comes to 10. Second reason is the energy storage function, which is a kind of natural battery. Solar/wind power shows a good score of EPR, but their need for battery instrument, energy use, and storage efficacy lowers their score. The third reason is the high transference efficiency (photosynthesis) of the solar energy. The photosynthetic system is cheaper than solar panels and causes no environmental pollution.

The use of fossil fuel is accompanied with two major issues: 1) CO_2 emission that causes climate change and 2) lower EPR (lower than that of renewable energy sources). Thus, it is important to transform the "**Harvested Sun Society**" concept into the "**Harvesting Sun Society**" concept for both environmental and economic reasons.

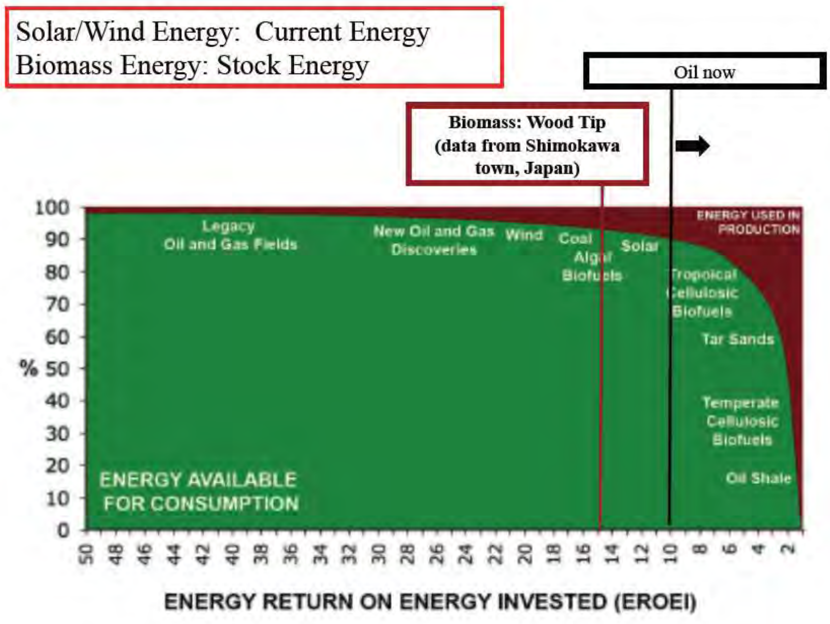


Fig. 4. Energy Profit Ratio (EPR) of several energy sources

EPR = output energy/input energy

Therefore, the "**Harvesting Sun Society"** in the humid tropical region should depend more on biomass and biomass energy. Thus, it is concluded that tropical peatland is one of the best regions for the "Harvesting Sun Society" because of the abundance of solar energy and water resources (Fig. 5). To achieve the "Harvesting Sun Society" in tropical peatlands, two types of technologies should be innovated, viz.:

1. Hardware (Technology) Innovation

-AeroHydro Culture System: High bioproductivity and conservation (National Security)

-Harvesting Sun System: Downsizing and wide-scattering energy (Biomass Energy)

-Special Dynamic Informatics

-Activation on Small- and Medium-sized Enterprises and Technology

2. Software (Social) Innovation

-Natural Capital Depend Society: The usage of water and carbon function (High SDGs score)

-Gold Carbon Mechanism: Branding of tropical peatlands (ESG and SRI Investment)

-Activation on Local Community

Fig. 5. The "Harvesting Sun Strategy" by tropical peatland restoration

2-3. Action Plan

The proposed Action Plan includes the three following phases (Fig. 6):

(1) Develop an "Integrated Monitoring System"

[Input]

1) Water Table Monitoring

2) New SESAME Monitoring

3) CO_2 Flux Measurement

4) Special Dynamic Monitoring

[Output]

1) Real-Time Carbon Accounting

2) Fire Prediction Model

3) Climate Prediction Model

4) Special Dynamic Informatics

[Outcome]

1) Upgrading NICAS

2) TIER3 into UNFCCC

(2) Conduct a "Model Project" for responsible management

[Input]

1) AeroHydro Culture System

2) Biomass Utilization for Energy

[Output]

1) Reduce CO_2 Emission

2) Food/Feed Security

3) Energy Security

(3) Achieve Capacity Building

[Input]

1) Field Center

[Output]

1) Manual/Guide Books

2) Outreach

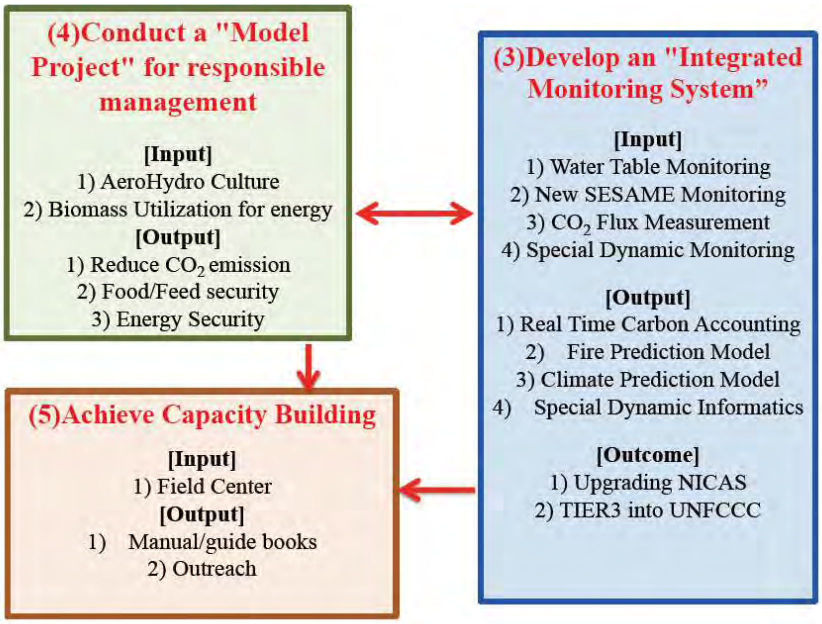


Fig. 6. Action plan for tropical peatland restoration

2-3-1. Develop an "Integrated Monitoring System"

The flow chart of the proposed "Integrated Monitoring System" in peatland ecosystem is given in Figure 7. In this system, the water table is one of the key factors for determining the status peatland ecosystem. We can develop further models of carbon emission mapping and fire prediction, which will contribute to the TIER-3 level CO_2 emission counting system of UNFCCC.

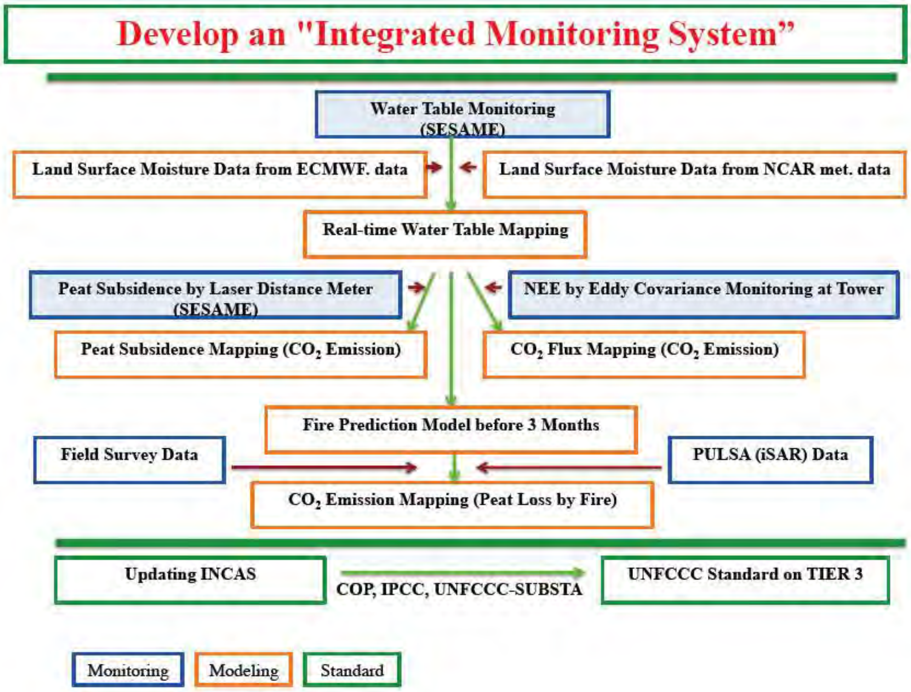


Fig. 7. Develop an “Integrated Monitoring System” based on water table monitoring

(1) Real-time Water Table Mapping

Model on real-time water table mapping was established based on 1) water table monitoring (SESAME) and 2) land-surface moisture data from NCAR MET data and from European Center for Medium-Range Weather Forecast (ECMWF) data (Fig. 8).

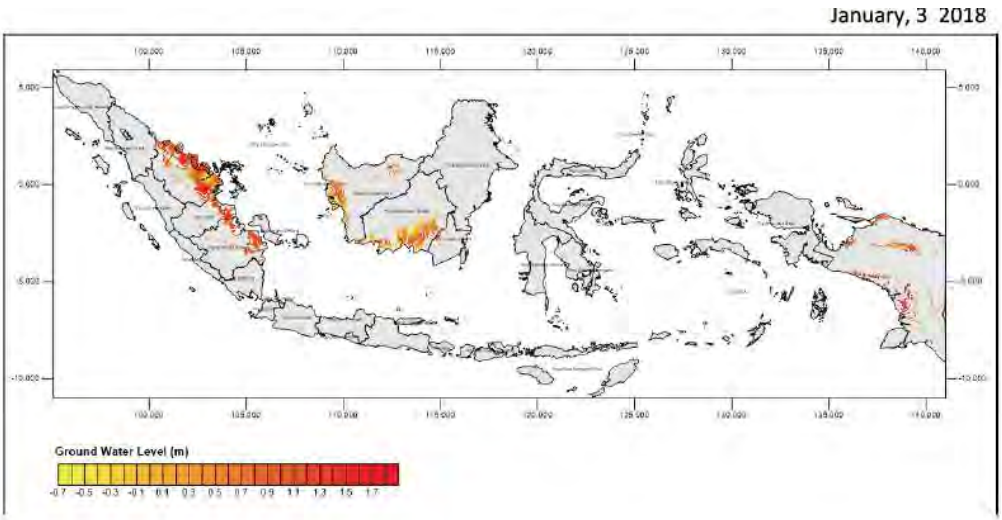


Fig. 8. A model on real-time water table mapping

(2) Real-time Carbon Emission Mapping

The net ecosystem exchange (NEE) is negatively correlated with ground water table; however, its correlation coefficient varies among the ecosystems, such as undrained forest peatland (native forest; UF), drained forest peatland, and drained and burned peatland (Fig. 9).

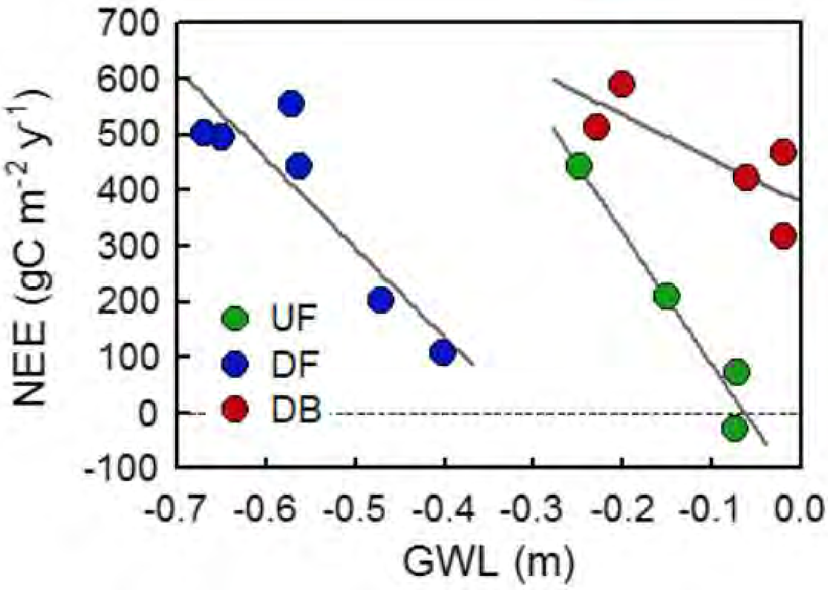


Fig. 9. The relationship between net ecosystem exchange (NEE) and ground water level (GWL)

Real-time carbon emission map was developed from water table map and the coefficients of NEE-ground water level (GWL) regression (Fig. 10). Because CO_2 emission has been monitored only in Palangkaraya, it is strongly recommended to undertake CO_2 flux monitoring in other regions, at least in Sumatra and Papua.

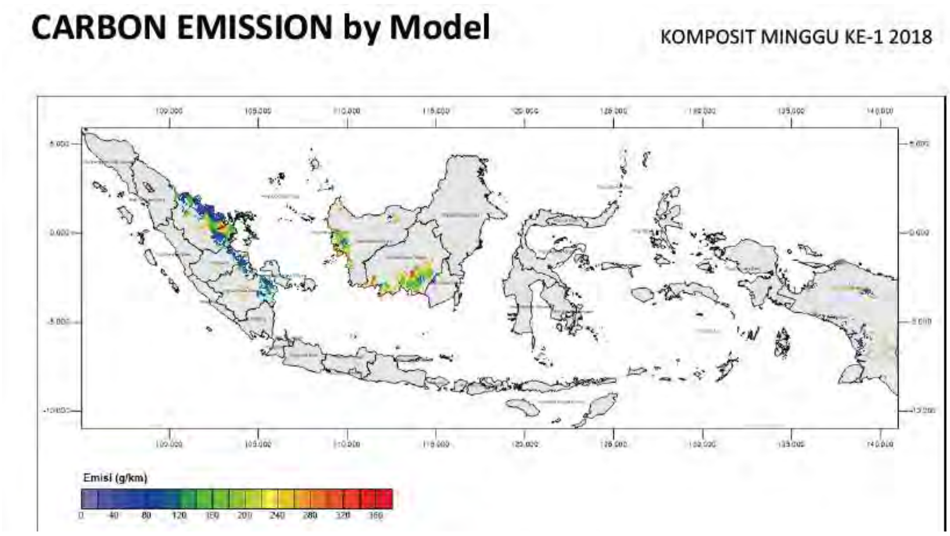


Fig. 10. Real-time carbon emission map

(3) Peat Fire Prediction Model

The peatland fire is usually of two types: 1) land-surface fire (fire on peatland surface) and 2) peat fire (fire into peatland). As hot spots data from satellite may refer to the mixed event of both situations, a system must be developed to identify individual causes.

Peat fire depends on water table and land-surface moisture level (covering vegetation) as well as some human activities (such as canal digging and canal blocking). Because water table and land-surface moisture strongly depend on rainfall, the **Peat Fire Prediction Model** should include a model of rainfall prediction, at least from 3 months ago.

A **Peat Fire Prediction Model** needs to be developed as soon as possible after ITPC is established.

2-3-2. Conduct a "Model Project" for responsible management

There are many misunderstandings about the peatland ecosystem. Therefore, it is fundamental to gain important basic knowledge about this ecosystem and understand the concept of peatland to develop appropriate management methods.

Oxygen as a limiting factor: Peatland is basically a water culture system, the peat materials accumulate above the ecosystem because peat itself cannot adsorb nutrients at low pH (<4.0). A peatland is composed of extremely simple elements such as water, nutrients, and oxygen (Fig. 11).

As oxygen has very low solubility in water, the presence of oxygen in peatland is an important limiting factor in the growth and activity of plant and microorganisms. In fact, the microbial activity is depressed in low oxygen presence in a natural tropical peatland. If the water table level reduces further, the oxygen supply would increase and peat decomposition would accelerate. This is the **first principal of peat accumulation and decomposition**.

Therefore, in a water culture system, aeration is an important aspect, for instance, rice crop is adapted to water condition. Because nutrients absorption depend on active absorption mechanisms, oxygen is essential for the production of energy in the roots required for the absorption of nutrients.

As nodule formation is extremely sensitive to water, it is extremely difficult to form nodulation even in aerating water culture. Nodules are formed above the water level. As nitrogen fixation is an electron transportation process, micronutrients (such as Fe, Zn, Mn, and Co) are more essential in nodulation plants than in non-nodulation plants.

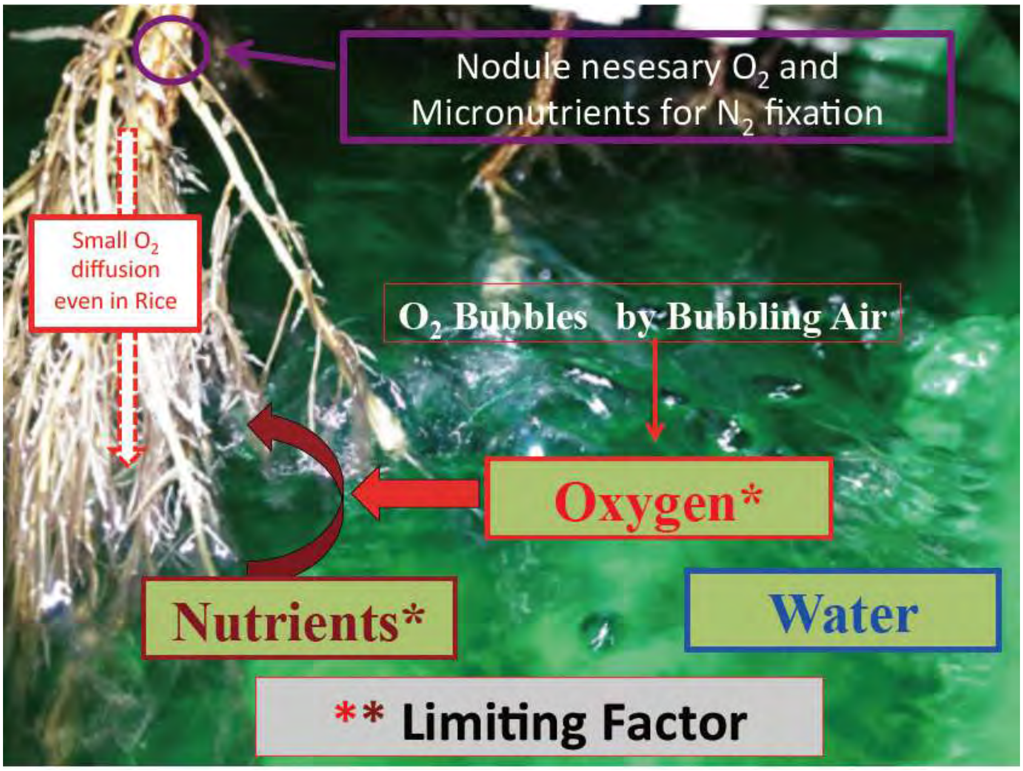


Fig. 11. Limiting factors in hydroculture as a model of peatland
Water: enough
Oxygen: very limited by enough water because oxygen solubility is extremely low in water

What are the adaptation strategies of plants in native tropical peatland? How do these plants obtain oxygen? In response, there are two strategies known: 1) aerial root formation and 2) mounding root formation (Fig. 12).

Fig. 12. Strategy on oxygen/nutrients absorption through the formation of aerial roots and mound roots

Nutrients as a limiting factor:

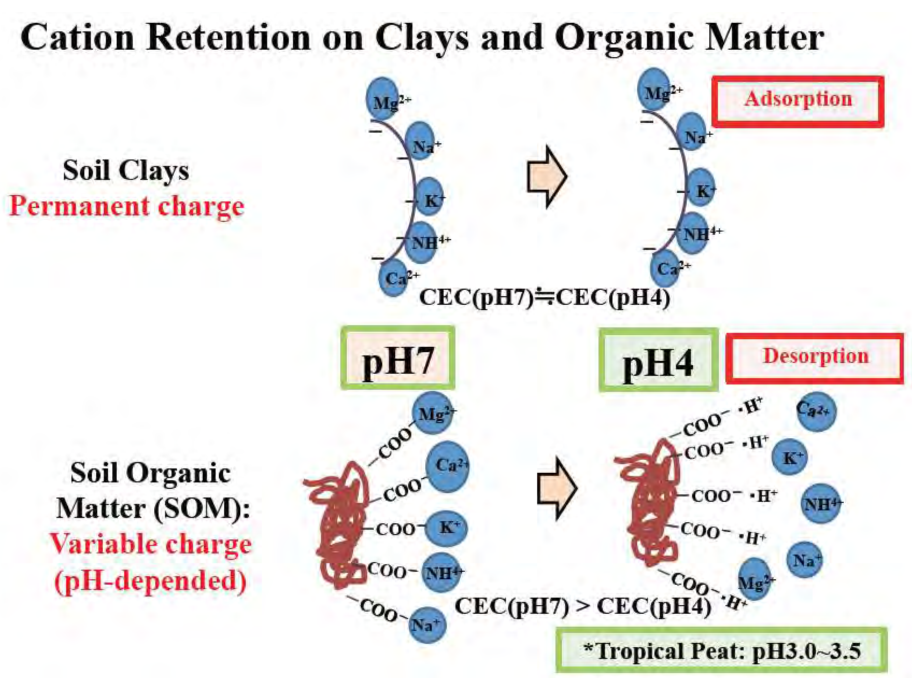


Fig. 13. Cation-retention ability on peat (organic soil) and clay

Cation retention on clay is stable at different pH; however, cation retention on peat (organic soil) decreases drastically at low pH, indicating the difficulty in retaining nutrients, particularly K^+ (always forms an ion and not chemical compounds) (Fig. 13). Therefore, if a potassium fertilizer is applied, K^+ leaches quickly.

Nutrient availability is extremely poor in inland peatland, because there are no mechanisms for supplying nutrients and nutrients are leached by rain water, particularly at the peat dome (Fig. 14). River side is supplied with nutrients through clay and a sea side through the sea via the tidal effect. Therefore, nutrient recycling is an important concept for plant growth in peatlands. However, the low availability of K+ remains a limiting factor in long term.

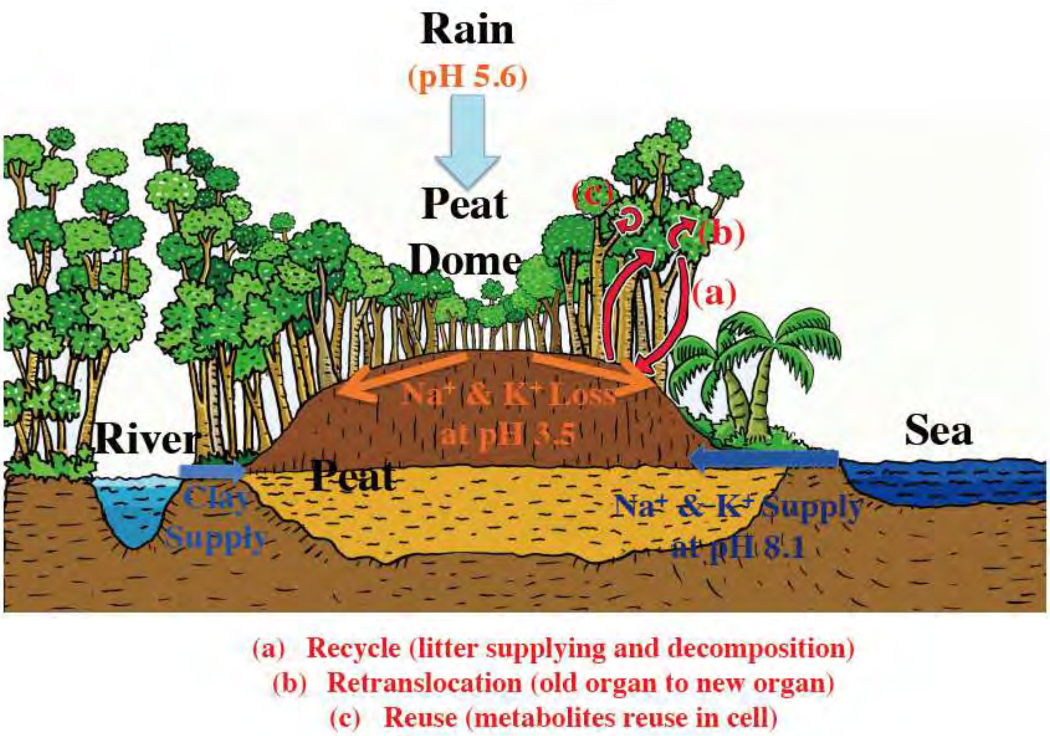


Fig.14. Nutrient supplying system and nutrient recycling in peatland

Peat fire restricts the nutrient recycling system (by restricting microbial activities) and leaches nutrients, particularly micronutrients (Fig. 15), from the soil. Therefore, in order to rehabilitate or restore a burned peatland, we must recover the deficient nutrients by nutrient application or recycling via microbial activity on the land surface.

Legume plants are good candidate to rehabilitate heavily damaged peatlands owing to the following attributes:

1) Nodulation and N_2 Fixing: Oxygen supply (land-surface management) and micronutrients (such as volcanic ash)
2) Mycorrhizal fungi: P nutrient and growth stimulation
3) K nutrition: K or Na application for root activation (carbohydrate transportation to the roots)

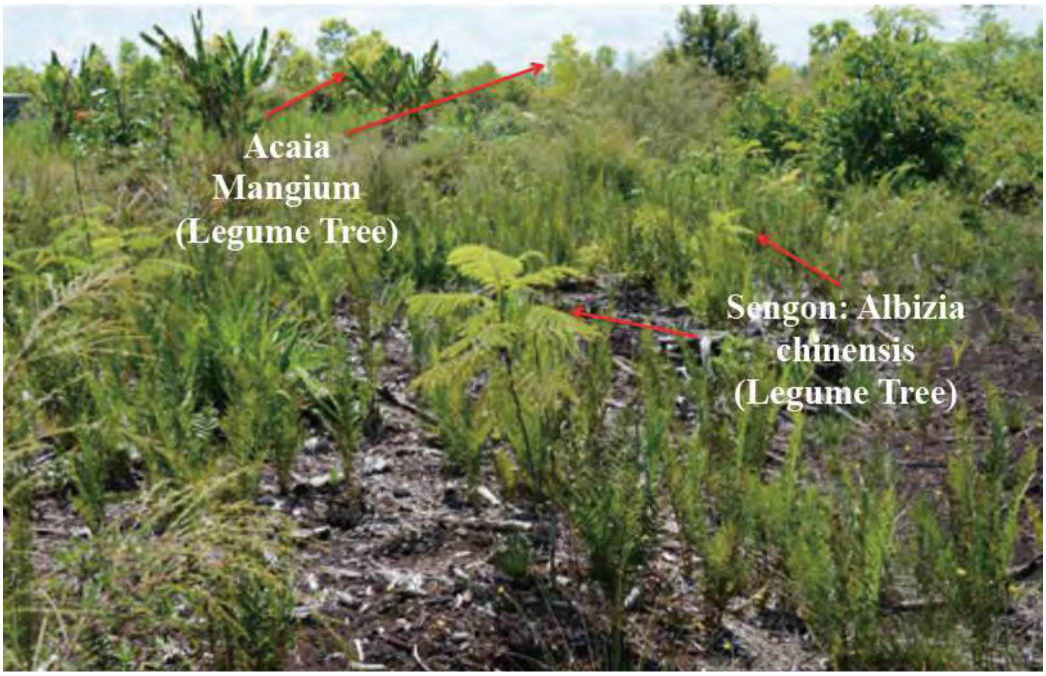


Fig 15. A typical symptom of micronutrient deficiency is reduced nodulation due to reduced N_2 fixation. Micronutrients are leached by heavy peat fire.

AeroHydro Culture System:

We propose an innovative culture system of oil palm in high water table condition. We found that the key limiting factors in high water table in tropical peatlands are oxygen and nutrient supply.

Therefore, we recommend the application of AeroHydro Culture System, which involves the supply of oxygen and nutrients from the land surface to the peatland. Oil palm growth is improved by the application of natural compost even in high water table conditions, indicating that water table itself is not a limiting factor for plant growth, particularly for oil palm growth (Fig. 16).

The key concepts of **AeroHydro Culture System** are as follows:

1) High water table level
2) Natural composts by frond and cover crops

3) Slow release of K^+ nutrients by coating fertilizer that also includes N, P, Ca, Mg, and other micronutrients

4) Biochar

5) Nutrients recycling system for heavily damaged land surface (victim of dryness and fire)

Fig.16. The AeroHydro Culture System in oil palm under high water table condition

2-3-3. Achieve Capacity Building

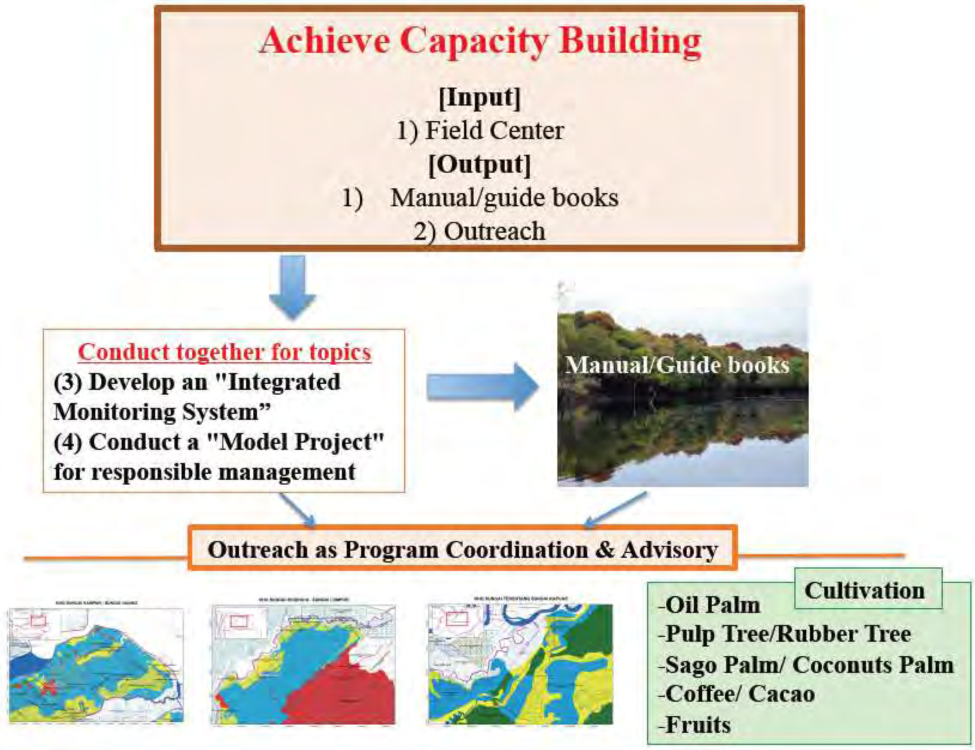


Fig. 17. Capacity building for peatland restoration in local areas

It is recommended to establish a field center in at least Sumatra, Kalimantan, and Papua (Fig. 17). These field centers can host the “Model Project” for responsible management through “Integrated Monitoring System.”

Chapter III.

[Proposal Detail of Action

3. Scientific base: Principles on peatland formation and degradation

3-1. Principle of Peatland Formation/Degradation

Tropical peatlands have a unique ecosystem, even when compared to temperate and boreal peatlands which are formed under the effects of water and low temperature conditions. Tropical peatlands are characterized by oligotrophic conditions, which is a similar environment to water culture ecosystem with poor nutrient level.

(1) Water

The water culture (hydroponic culture) system is a good model to understand tropical peatlands. In a water culture, there are three key elements: water, oxygen, and nutrients (Fig. 1).

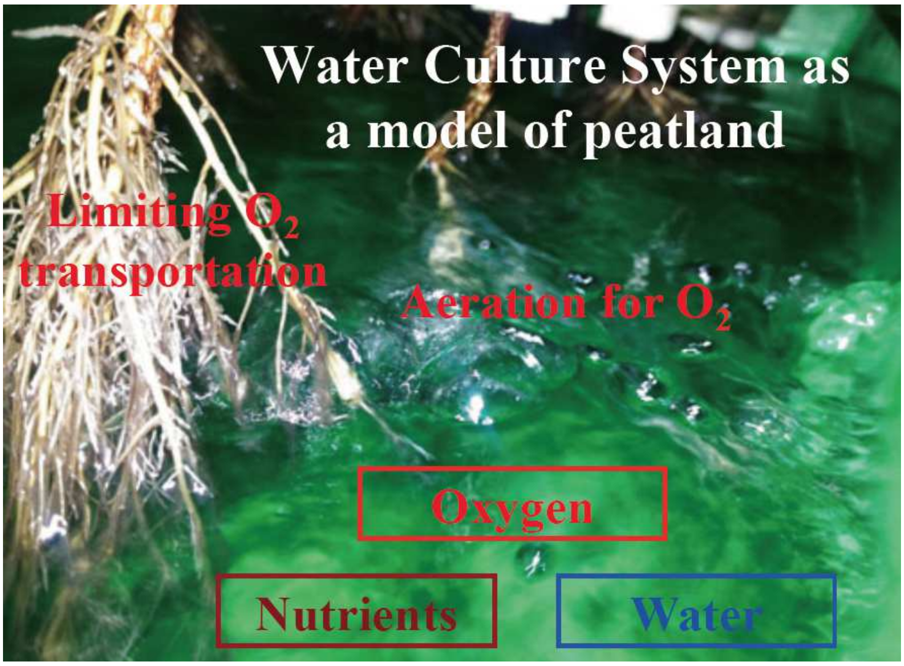


Fig. 1. The water culture system as a model of oxygen limitation

(2) Oxygen

Oxygen is an essential limiting factor in high water condition because oxygen only slightly dissolves in water. For instance, the redox potential in air and dried peatland (the upper zone of water table) is +600 mV, while it is 0 mV in water and wetness peatland (the lower zone of water table).

Methane (CH_4) emission is low in native peatlands, because the microbial activity is extremely poor under low nutrient condition, the redox potential in water and water-saturated peatland is 0 mV even at 10-m peat depth (Fig. 2). CO_2 emissions mainly occur from a highly dried peatland condition, where a large amount of O_2 is supplied from the air. In addition, once chemical fertilizers are applied to a dried peatland, the activity level of microorganisms increases and O_2 is rapidly consumed by respiration. In such situations, the redox potential reaches -300 mV in underwater table zone, leading to the emission of CH_4. Moreover, N_2O emission is accelerated in the upper dried peatlands, with +300 mV redox potential.

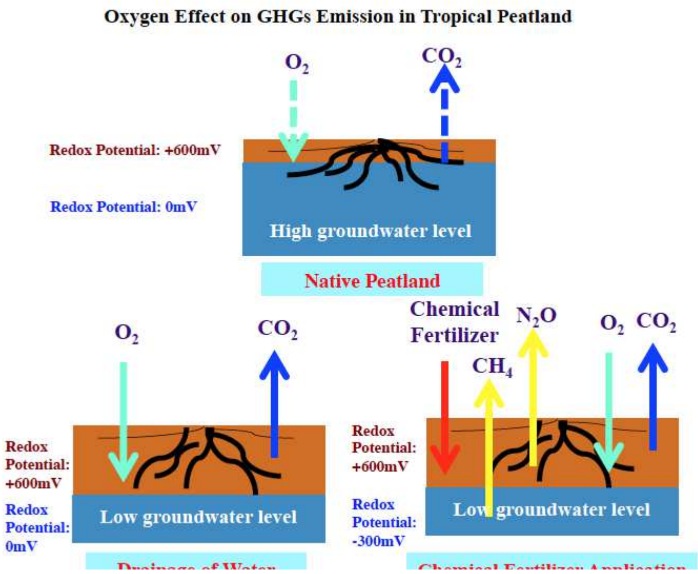


Fig. 2. Oxygen as an essential factor to produce GHGs in tropical peatlands

(3) Nutrients

Peat and peat water contain extremely low nutrient quantity. If sufficient nutrients are supplied, an active microbial decomposition will impede peat development even in flood plains or in places with high water table level.

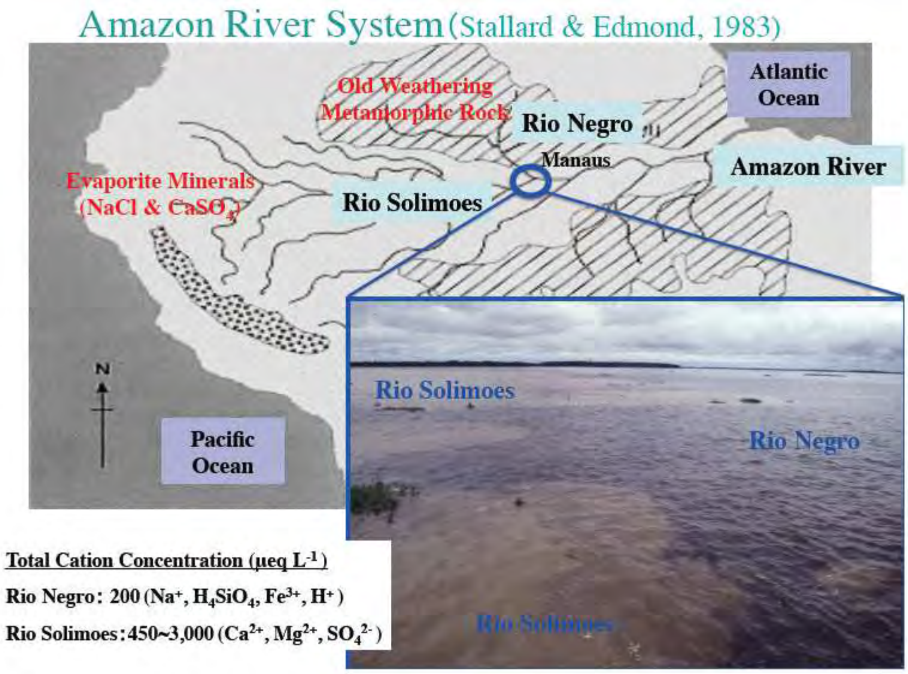


Fig. 3. Amazon river system showing reduced peat formation

Although the Amazon river is a large flood area with a potential to accumulate a large amount of peat, peat development is poor in this river basin. The reason for this was revealed from an investigation of the nutrient content of peat water at the junction points of Rio Negro and Rio Solimoes (Fig. 3). Although the total cation concentration in Rio Negro was low (around 200 μeq L^{-1}), it was found that a high content of nutrients (450–3,000 μeq L^{-1} of total cations) was being supplied in Rio Solimoes through clay from the Andes, leading to poor development of peat.

The nutrient contents of peat-discharged water (similar to that of peatland water) in the Kya (deep peat) canal of Sebangau, Central Kalimantan are extremely low. Under such conditions, even trees, which do not require high nutrition, do not grow (Table 1). Therefore, peatland forests can only be sustained by recycling nutrients supplied from the surface litter.

Table 1. Nutrients property of peatland water and river water

	Area	Site	pH	EC mS/m	TOC mg/l	Cl^- mg/l	NO_3^- mg/l	PO_4^- mg/l	SO_4^{2-} mg/l	Na^+ mg/l	NH_4^+ mg/l	K^+ mg/l	Mg^{2+} mg/l	Ca^{2+} mg/l
River water	Kahayan	Bridge	5.15	4.31	46.20	2.93	0.00	0.00	1.22	2.17	0.63	2.05	0.30	2.32
Peat discharged water	Sebangau	Kya canal	3.70	6.43	75.68	0.58	0.23	0.00	0.37	0.65	0.00	0.25	0.11	0.20
Sea salt affected	Sebangau	Paduran canal	2.60	104.50	12.87	3.76	0.00	0.00	675.73	3.86	1.14	2.60	12.40	5.77

The nutrients (particularly cations) contents of the Kahayan river water are poor, but still greater than that of peatland water. In this analysis, we found that when clay is filtrated, the nutrients of food area substantially increase. In fact, sometimes even rice can be grown in such areas.

The nutrient (particularly cations) contents of Paduran (shallow peat) canal water in Sebangau are affected by sea water and are rich. Therefore, the coastal area is adapted to plant growth, because of the nutrients and water supplied by the tidal effect. As sea water intrudes into the bottom of peatlands with high pressure for fire protection, it is expected that pumped-up ground water (which contain nutrients) will enrich the surface of peatland in coastal areas.

(4) Microorganisms Activity

Why do large water (poor oxygen) and poor nutrients are required for peatland development in the tropical areas?

The principle of tropical peatland formation is very simple. Basically, it includes two elements, high water table and poor nutrients, for the formation of peatlands. When the water table level reduces and oxygen is supplied to the soils through drainage and when sufficient nutrients are fed to the dried peat soils by chemical fertilizers, the activity of soil microorganisms dramatically increases, thereby accelerating peat decomposition. Thus, maintaining high water table level and avoiding the application of chemical fertilizers (except for organic fertilizers and slow-release fertilizers) are the key factors to restore peatlands.

(5) Diagram of Peatland Hydrological Unit

Figure 4 depicts the peatland hydrological unit, showing the dynamics of water and nutrients in two seasons: rainy and dry seasons.

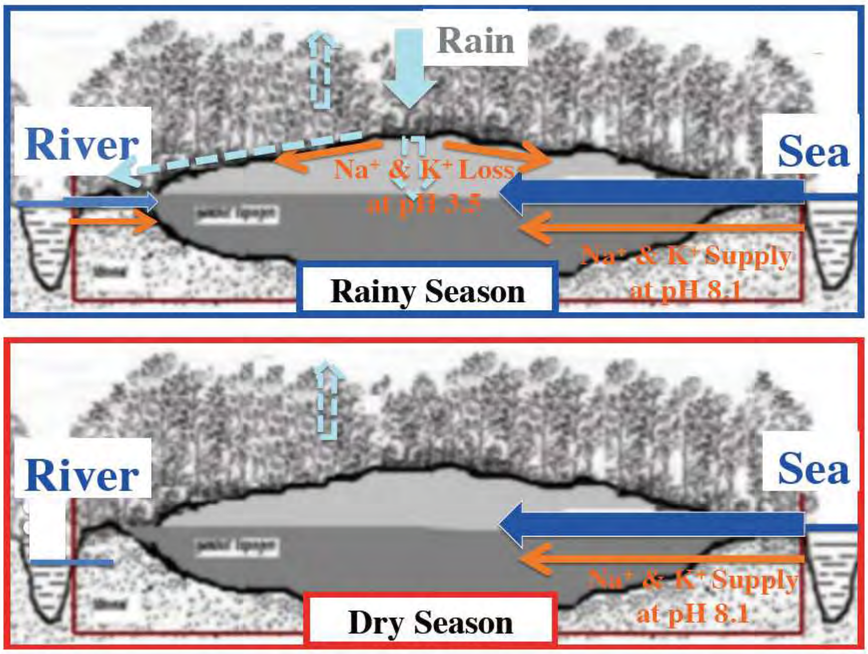


Fig 4. Peatland Hydrological Unit

Inside Peatland:

Unlike the peatlands in other climatic zones, the tropical peatlands are built on a remarkable balance between specific microbial ecosystems and nutrients and moisture conditions. In order to suppress the emissions of GHGs such as CO_2 and CH_4 emitted due to disturbance of the tropical peatlands, it is necessary to manage this balance with complete understanding of the underlying mechanism.

In the rainy season, water is supplied by rainfall. Nutrients are also supplied, but leaching due to rains exceeds the supply rate. Oxygen deficiency in the water and oligotrophic condition greatly suppress the bacterial activity, resulting in only little carbon emission from the peatlands. On the other hand, since the inside of peatland has a high oxidation–reduction (redox) potential ($\Delta E'_0$) at around ±0 V, a small amount of oxygen can dissolve into peat to create an environment that inhibits the activity of anaerobic microorganisms (such as methanogen), which requires a low redox potential of <−0.33 V. Under such conditions, the CH_4 emission rate is also very small.

Costal-side peatland: Sea water containing rich nutrients (K^+, Na^+, Ca, Mg, P, and micronutrients) is supplied to the bottoms of peatlands and rivers by tidal effect (intruding around 50-km inland),

Riverside peatland: The river water supply is limited inside of a peatland. River water is a source of mineral soil (mainly clay) to the areas located at a short distance from the river.

Peat Dome: Plant growth is extremely poor because of scarce nutrition (little supply and excessive leaching loss). Low microorganism activity due to poor nutrient condition result in a deep accumulation of peat.

(6) Peat Definition

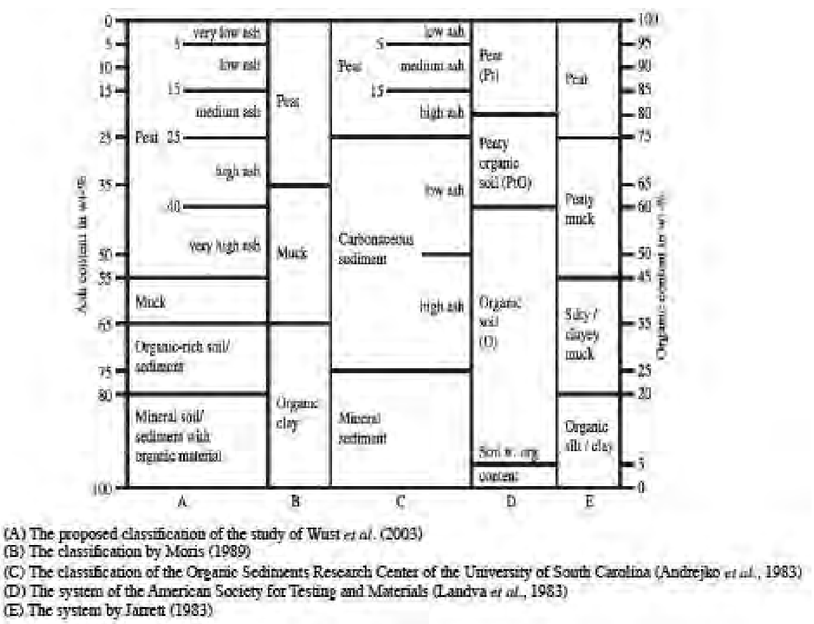


Fig. 5a.Various classification systems of peat and organic soils

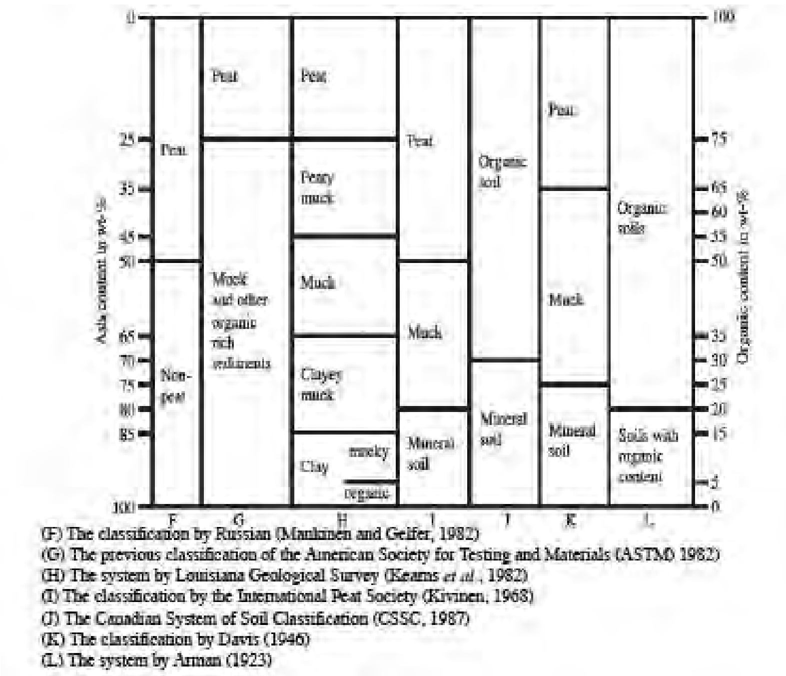


Fig. 5b. Various classification systems of peat and organic soils

Peat formation is a true carbon sink, with the carbon being sequestered out of the system and converted into peat through biological activities (Sorensen 1993). Peat is a heterogeneous mixture of decomposed organic matter and inorganic minerals. The various classification systems of peat and organic soils are shown in Figures 5a and b.

As per Ramsar, peatlands are the ecosystems wherein peat is accumulated with or without vegetation. Peat is a sediment material that consists of dead plants and more or less decomposed plants that accumulates *in situ* under water-logged conditions. The term “peatland” is inclusive of active peatland or “mire.” A mire is a peatland on which peat is continuously forming and accumulating. Peatlands where peats are no longer forming are not considered as active peatlands. The presence of peat or vegetation that potentially contributes to peat formation is the key characteristics of peatlands.

Most schemes for common use in fields and laboratory classifications of peats were developed in the boreal and humid temperate regions; these schemes cannot be directly applied for the distinctive features and specific uses of tropical peats. Wust et al. (2003) suggested that these schemes failed to fully characterize and classify the tropical organic deposits of Tasek Bera (Malaysia) peatland (which was selected as an example of tropical peat deposit to evaluate different classification systems, as it is ideal for testing the applicability of peat classification systems for lowland tropical peats), for the following reasons: 1) temperate and boreal peats are often dominated by bryophytes/moss and shrubs; 2) the existing classification schemes for temperate and boreal peats are based on selected characteristics for specific uses in the fields of agriculture, engineering, energy, etc., rather than having a generic approach; and 3) classifications of organic soil for agricultural purposes (e.g., CSSC, 1987; Soil Survey Staff, 1990; Paramananthan, 1998) are based on control section (Figs. 4 and 5).

Fig. 6. Various peat textures of the tropical lowland mire system of Tasek Bera (Malaysia) peatland

Therefore, the important aspects of peat texture (morphology of constituents and their arrangement) and laboratory ash content (residue after ignition) need modification for consideration in classifying tropical peat deposits. Wust et al. (2003) proposed a 3-group (fibric, hemic, and sapric) field texture classification system applicable to tropical organic deposits, which is based on the classification system proposed by Esterle (1990); the latter was modified from the US Soil Taxonomy and developed for tropical low ash, ombrotrophic peat deposits and soils (Fig. 6). This field texture classification was made on the basis of 1) visual examination of the morphology of the peat constituents (texture) and 2) estimation of the fiber content and matrix.

Typically, peat is composed of ash (0%–55%), muck (55%–65%), organic-rich soil/sediment (65%–80%), and mineral soil/sediment (80%–100%). The peat class is subdivided by ash content into the following five subclasses: 1) very low ash (0%–5%); 2) low ash (5%–15%); 3) medium ash (15%–25%); 4) high ash (25%–40%; and 5) very high ash (40%–55%).

The generally recognized definition of peatland is as follows:

> **Peatland is an area with an accumulation of organic matter that is partly decomposed, with ash content of ≤35%, peat depth ≥50 cm, and organic carbon content (by weight) of at least 12%**.

Ash Content of Peat

The US Soil Taxonomy classifies organic soils as having >12–18% organic C content. In tropical peat deposits, the C content often ranges between 40% and 60% (Andriesse, 1988; Moris, 1989; Phillips, 1995; Neuzil, 1997). Tie (1990) reported the C content values of 35–44% in the tropical peat deposits of Malaysia. On the other hand, Wust et al. (2003) reported that the peat of the Tasek Bera Basin (Malaysia) contains 20%–54% C. Therefore, ICCC proposed the US Soil Taxonomy definition of at least 12% organic C content to classify peat.

Ash content is expressed with percent of ignition residue after the combustion of organic elements (C, O, and H). As ash content reflects the original plant type, a plant's mineral composition is useful in applying peat definition. Ash content of peat depends on the vegetation type, bedrock composition, and hydrology. The lower the ash content, greater is the organic content (Fig. 7). According to the system defined by Moris (1989), most of the organic materials in the *Tasek Bera* Basin (tropical peatland) can be classified as peat as they contain an ash content of 0%–35%. Meanwhile, several peat scientists describe organic soils as "peat," although they have ash contents of >25%. Wust et al. (2003) defined peat as organic soils with ash content of 0%–55%. As per this definition, organic soils with <55% ash content have >18% C content.

However, for adoption in Indonesia, the ash content of 55% indicates organic content of approximately 45% only. Therefore, ICCC recommends "peat" as an organic soil with an organic content of ≥65% (Rieley and Page, 2005; Sorensen, 1993; Andriesse, 1974), which is same as the ash content value of ≤35%. Based on the research of Wust et al. (2003), the ash content of 35% in tropical organic soil contains 28%–32% C (Fig. 7).

In conclusion, it is extremely important to make a zoning of peatland based on the ash content, because soil with high ash content cannot be defined as peat soil, rather as muck or organic soil. Rice can be grown in muck or organic soil, but not in peat soil. This misunderstanding

led to the tragedy of Mega Rice Project (MRP) in peatland.

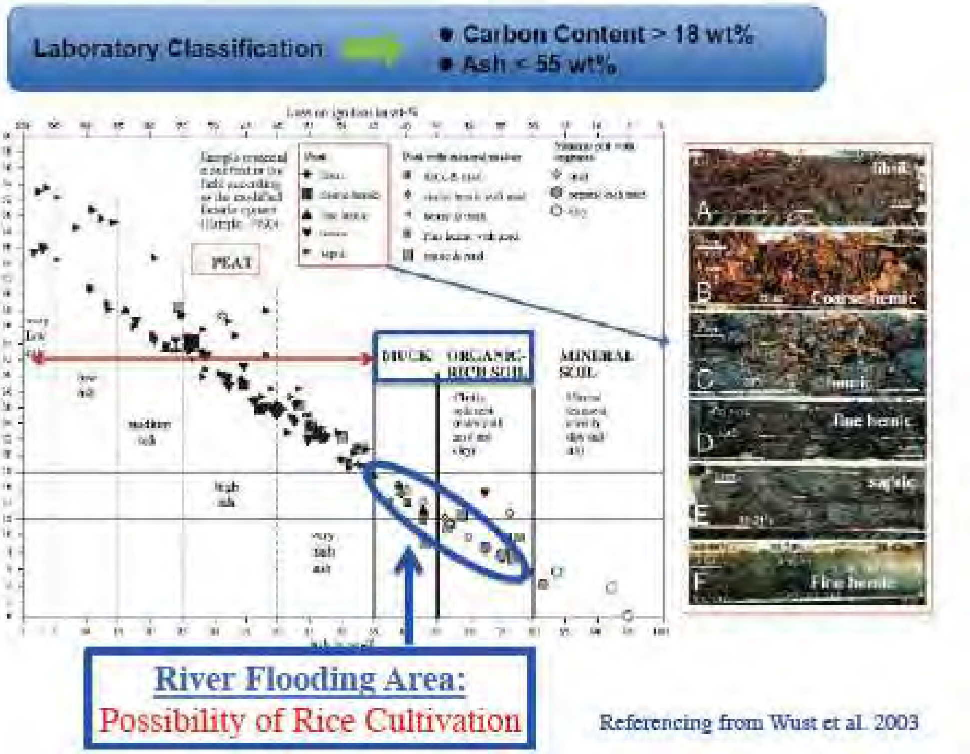


Fig. 7. The relationship between ash content and carbon content in soil

Peat Depth

Peat depth should be considered while defining peat. Different scientists have described different depth categories while defining peat. Peat was defined as having a depth of >80 cm by Andriesse (1988), >40 cm by Jansen et al. (1985), and >30 cm by Joosten and Clarke (2002). In addition, Sorensen (1993) stated that peatland forests in Indonesia occupy at least 17% of the forests with a peat thickness of 50 cm to 20 m. Paramananthan (1998) suggested that the agricultural system in peatlands of Malaysia require sufficient organic soil of at least 40–120-cm depth. The Second International Congress of Soil Science in 1930 declared peat as an organic soil that accumulated >50-cm depth (Tie, 1982; Rieley and Page, 2005; The Research Center of Land, 1990). Moreover, Hardjowigeno and Abdullah (1987) defined peat as an organic deposit that is partly decomposed and having a depth of ≥50 cm. As several studies describe "tropical peat" as having a minimum of 50-cm thickness, ICCC recommends considering a of ≥ 50 cm for defining peat.

Examples of the worst case induced by peatland degradation

High water table level and low nutrient level are the most essential factors affecting sustainable peatland hydrological unit. If peatland is drained and chemical fertilizers are applied, the peat will quickly decompose by the action of microorganisms. As shown in this clear mechanism, the worst case of peatland management was, namely, "o**il palm plantation"** (low water table management by digging huge drainage canals) and "**MRP,"** in which it was impossible to grow rice under the poor nutrient conditions of peatlands.

Learning from the past experiences, it is recommended that, in peatland restoration, native plant species adopting to high water table level and poor nutrition should be mainly used.

(7) Water-Oxygen-Nutrient Model in Peatland

Peatland represents remarkable balance of water-oxygen-nutrient. In particular, tropical peatlands are sustained by low concentration of dissolved oxygen (around 0-mV redox potential), which is the most important condition for peatland sustainability, because 0-mV redox potential in native peatlands can maintain 1) low CO_2 emission due to low microorganism activity and 2) low CH_4 emission due to low methanogen bacteria activity (<-300 mV). To understand this balance of water-oxygen-nutrient in tropical peatlands as well as to establish the best management system of tropical peatlands, it is necessary to apply the "Water-Oxygen-Nutrient Model" for simulation, supported by data monitoring and sensing on field.

The examples of approaches in peat soil process research can be seen across various relationships between an environmental component and peat soil with crops, such as nutrient-level relationships with soil/year/garden productivity or from each soil component, such as the relationship among the following (Fig. 8):

-nutrient level
-water
-soil structure
-organic structure
-depth of soil
-other properties related to the soil productivity levels

In constructing both static and dynamic models, several inputs are necessary in advance, such as the following:

A. Collection and analysis of data

B. Scope of problem

C. Structuring the concept of the problem

D. Formulation of the mathematical model

E. Algorithm development, logic, and manipulation procedures with mathematical equations

F. Testing algorithms with hypothetical calculations

G. Programs with understandable language

H. Parameter estimation from and to the real system

I. Running the "Run" program

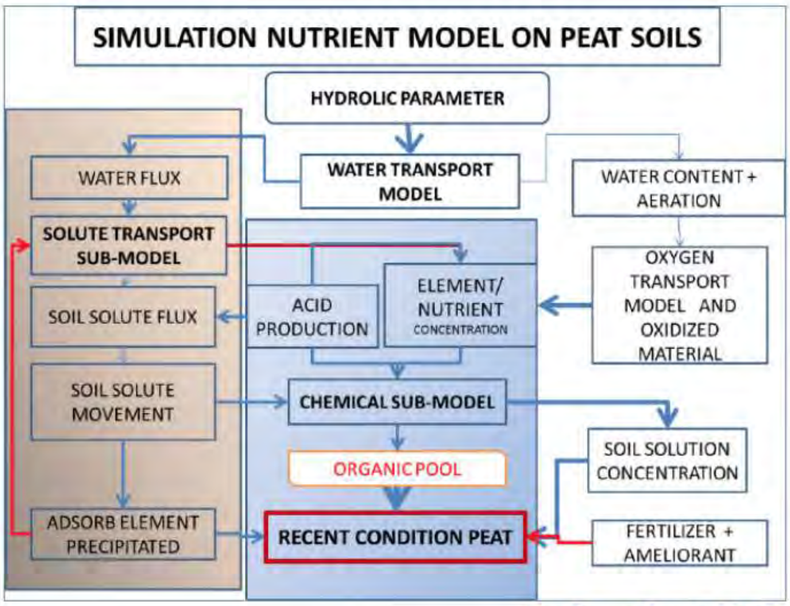
J. Sensitivity tests, for non-permanent, very diverse, and able to set things beyond the ability to be understood

K. Plan and perform simulation experiments to test in real-time in order to observe signs not yet known

L. Analysis of the simulation data and estimations

M. Verification through comparison with the estimates obtained from other studies or empirical data

N. Modifications, if possible, in accordance with the development of models tailored to newly emerging data or concepts can be considered from both appearance and theoretical content



From Kusumo Nugroho, ICALRD

Fig 8. Simulation of nutrient model on peatland

3-2. Principle of Peatland Micro-Hydrological Unit Managemen

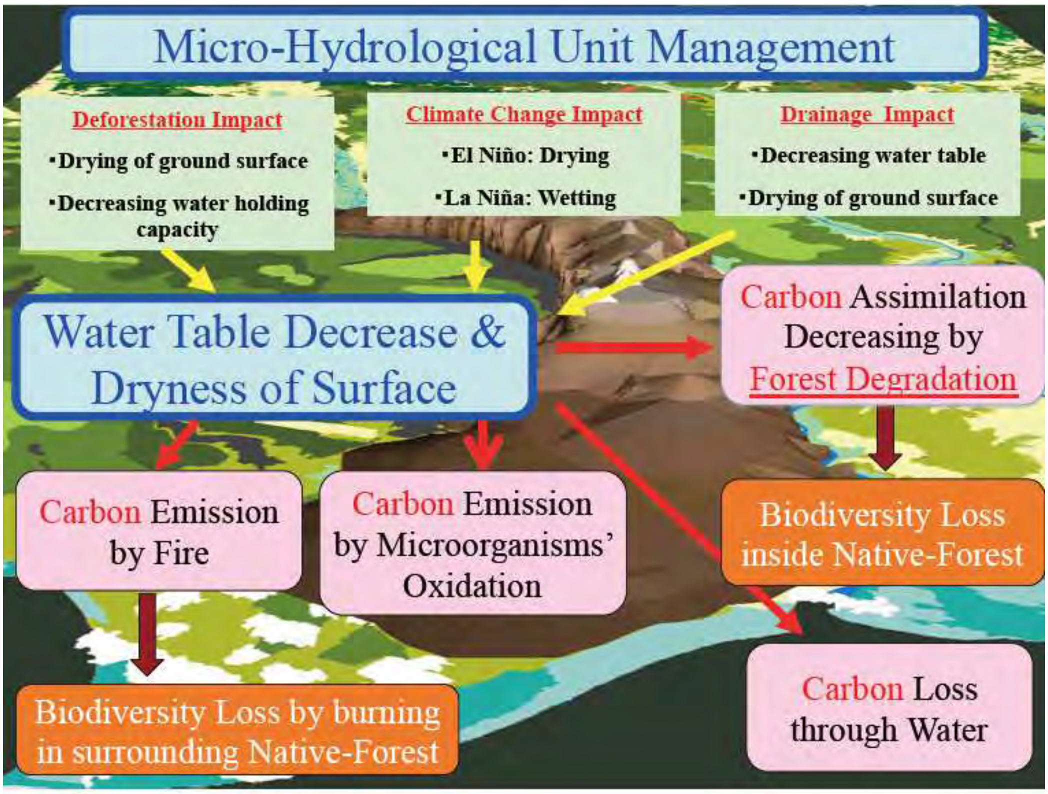


Fig. 9. Principle of peatland micro-hydrological unit management

There is a global consensus that water resource is the most important factor in terrestrial ecosystems. Global Risks (World Economic Forum, 10th Edition, Switzerland, 2015; www.weforum.org/risks) reported the "top 10 risks in terms of global impact," with water crises topping the rank. The function of wet peatland as a large reservoir offers great benefits. It can be called the natural capital water supplier in dry seasons, which mitigates the impact of food/feed shortage in the year of El Niño as well as reduces CO_2 emissions (Fig. 9). In this way, the natural function of wet peatland on the global climate is inevitable to mitigate the negative impacts of global warming derived from CO_2 emissions and to appropriately adjust the water supply to plants.

(1) High Carbon/Water Reservoir Ecosystem

Natural wet peatlands are defined as ecosystems with high carbon/water reservoirs that assimilate and sequestrate a large amount of carbon. However, once this ecosystem is disturbed by 1) deforestation, 2) Land Use, Land Use Change, and Forestry (LULUCF), 3) drainage for plantations, or 4) climate change, the capacity of reservoirs is catastrophically decreased by drastic change in the water regime. As a result, carbon emission will accelerate due to fire resulting from microbial decomposition of organic matter. Carbon loss through water drainage and reduction in carbon assimilation by forest degradation will also have a major negative impact on the ecosystem.

(2) High biomass productivity in High Water Table (HWT)-peatland

Biomass productivity is greater in HWT-peatlands because of the high turnover, necessitating theoretical model analysis.

The agroforestry system should be studied with various combinations of plant species, such as sago palm, sago palm-natural forest trees, sago palm-natural forest trees-rubber trees, sago palm-rubber trees-betel nut palms, sago palm-rubber trees, sago palm-betel nut palm, and sago palm-homegarden crops. The specialty of sago palm is that it produces stolon from the main stems so that, a few years later, these stolons can produce more stems, making the entire growing system continuous. After 1 year of harvesting the first main stem at maturity, the second main stems can be harvested, making this system sequential. Thus, once sago palm canopy is established, this unique production system can continuously produce huge amount of starch and biomass. Therefore, theoretical analysis to optimize the cultivation for maximum yields is required.

High productivity in intact peat-swamp forest (by Takashi KOHYAMA): In comparison with tall tropical rain forests in hilly topography, peat-swamp forests in flat lowland are characterized by a low-canopy stature and low above-ground biomass. However, repeated censuses on intact forests have suggested that peat-swamp forest shows high net production rate irrespective of its low-living biomass storage (Fig. 10). This is because of the high mortality in canopy trees and the high growth rate of understory trees. Peat-swamp habitat prevents the survival of large trees, which in turn facilitates the regeneration and high productivity of the forest. High canopy-tree mortality contributes to the supply of woody debris as peat materials. Specific plant species that are indigenous to lowland habitat with HWT level meet the purpose of reforestation, restoration, and sustainable land use.

Adaptive cropping system in peatland (by Takashi KOHYAMA): Based on the high biomass productivity of peat-swamp ecosystems, it is recommended to develop an adaptive cropping and harvesting system for motivated households and societies. Indigenous commercial plants in HWT habitat, such as sago palm and timber species, would be ideal for encouraging local livelihood generation. For sustainable management and land use of peatlands, selective harvesting of canopy-layer plants by enhancing natural regeneration is essential. The development of sustainable and optimal harvesting system model is expected to provide an incentive to the local society.

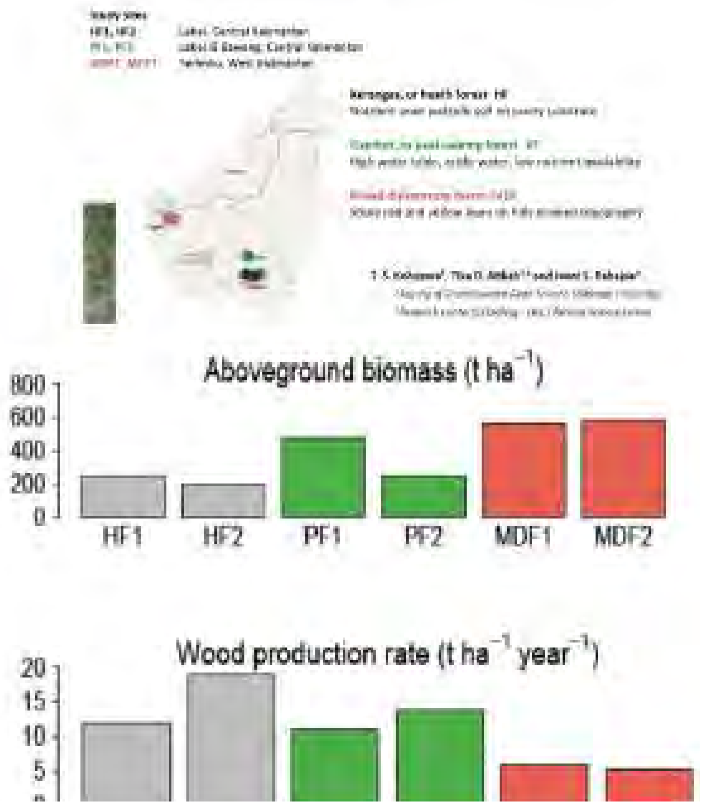


Fig. 10. High productivity of biomass in peatland

(3) Zoning for Peatland Micro-Hydrological Unit Management

Peatlands can be classified into the following three zones on the basis of their distance from the coast: coastal, intermediate, and inland peatlands. The coastal peatland is affected by high salinity, particularly high Na^+ concentration, from the sea water and by the tidal effect. Plant species with a tolerance for salinity are suitable for plantation in the coastal peatland. On the other hand, inland peatland has insufficient nutrients for plants, particularly K^+, which is essential in large quantities for plant growth (Fig. 11). Therefore, zone-specific management is essential from the perspective of soil nutrient condition for plants.

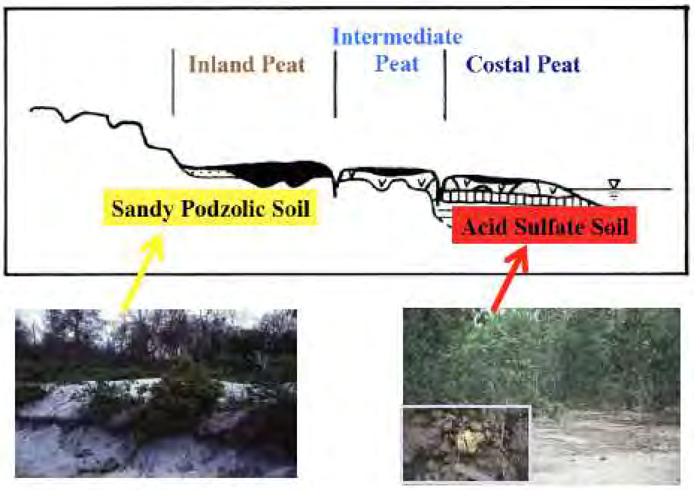


Fig. 11. Peatlands are classified as costal, intermediate, and inland peatlands, including sub-soil property

The zoning of peatlands according to their nutrient condition is given in Figure 11. (Fig 12). A peatland is usually deficient in most nutrients; however, Na^{+}/K^{+} are the dominant deficient elements because of excessive leaching. Other nutrients in a native peatland are recycling nutrients from the litter. Because seawater is rich in nutrients, the coastal areas have a potential of rehabilitation with the use of high commercial values crops. On the other hand, inland peatland, where nutrients are mostly deficient, should be rehabilitated by native trees tolerant to poor nutrients that can dissolve organic matter for nutrient recycling.

Costal Peat (High Na^{+}/K^{+}*)*: Sago palm, nipa palm, coconut palm/mangrove/melaluca

Intermediate Peat (Medium or Low Na^{+}/K^{+}*)*: Sago palm/*Combretocarpus rotundatus*/ *Shorea* sp.

Inland Peat (Extremely Poor Na^{+}/K^{+}*)*: Native trees such as *C. rotundatus*/*Shorea* sp.

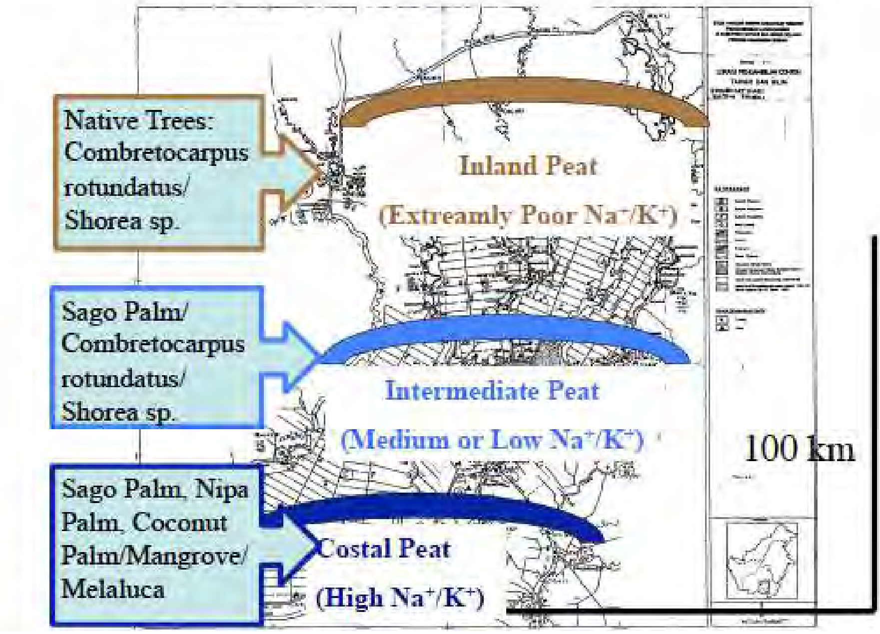


Fig. 12. The zoning and key species for peatland restoration

3-3. Purpose

We propose to establish an "**International Committee for Technical-Advisory on Tropical Peatland Restoration in Indonesia (ICTTroP),**" with the aims to 1) provide science-based advice on peatland restoration activities that are oriented by Peatland Restoration Agency (BRG), Ministry of Environment and Forest (MoEF), and other related agencies; 2) support the development of assessment criteria for peatland restoration activities; 3) support capacity building of concerned personnel through the university network, and 4) establish an international network on peatland restoration and the standardization of the Measurement, Reporting, and Verification (MRV) system under IPCC and UNFCCC.

ICTTroP is obligated to establish a "**Center for Tropical Peatland Restoration" (CENTroP).** This project will be conducted in cooperation with BRG. However, we must ensure building flexible and cooperative relationships among the various stakeholders in Indonesia, including the MoEF, BPPT/Indonesian Institute of Sciences (LIPI), universities, local governments, private-sector business, NGOs etc., particularly considering the need for promoting the participation of private-sector business in peatland restoration projects. CENTroP needs donors to support this project.

Some of the action plans to be conducted in this project are as follows:

(1) Establishment of MRV System:

Based on the scientific model developed in several previous projects for the estimation of GHG emission from peatland, we propose the implementation structure of real-time ground level peatland estimation, evaluate the release and uptake of CO_2, and create fire hazard projection map. In this work, we must consider the factors of convenience in data collection and comprehension of the manual, without sacrificing scientific validity or correctness.

(2) Model pilot project proposal:

BRG's target is to restore peatlands in seven provinces (Riau, Jambi, South Sumatra, West Kalimantan, Central Kalimantan, South Kalimantan, and Papua). In this project, Riau and Central Kalimantan were considered as the main provinces for research. We will conduct the field work and elucidate the structure and components of local government peatland restoration programs and systems that BRG will initiate to create the necessary guidelines for developing model pilot projects (in 2–4 places).

(3) Economic Value Enhancement:

Carbon/water issues related to COP21 and SDGs and the economics of implementing peatland restoration/rehabilitation activities have been discussed.

(4) Capacity-building techniques related to peatland restoration operation proposal:

By placing the Capacity-Building Centers in Kalimantan and Sumatra, we will create a proposal for research institutes, such as the Indonesian universities, and provide assistance through technical support for the establishment of these centers. Furthermore, we will support the consortium concept of these centers by networking with universities and propose manuals and guidelines for educational and training purposes in places of model pilot projects mentioned in point 2. The target groups for the capacity-building plan are universities, private sectors, administrations, and local residents. We intend to create specific step-wise approaches for each target group.

3-4. Proposed Actions

To realize the restoration/rehabilitation of 2-Mha disturbed peatland in a short period, the restoration/rehabilitation program should be based on scientific knowledge and technology, which is supported by Integrated MRV System, Model Pilot Restoration Program, Capacity Building, and Operational Institution/Platform.

3-4-1. System of Measurement, Reporting, and Verification (Integrated MRV System)

(1) Overall design

One of the key factors in successful tropical peatland restoration is to establish a system on MRV. MRV is necessary for project planning and evaluation. Because of the complexity of tropical ecosystems, precise estimation of the dynamics of GHGs flux and water statuses is difficult, which is one of the reasons for disagreements among several stakeholders, including scientists, that has failed to generate common consensus. To overcome this problem, **ICTTroP** will establish an integrated MRV System by applying real-time data monitoring data and data mapping of important parameters into the improved system. In addition, this system will guarantee transparency and open-access environment.

To estimate the water and carbon statuses in peatland, the Tropical Peatland MRV System is being developed (Fig. 13).

As shown in Figure 12, the elements covered in the system include 1) CO_2 flux (NEE), 2) fire spots and CO_2 loss, 3) forest degradation, 4) deforestation, 5) water level and soil moisture, 6) peat thickness and peat structure, 7) peat subsidence, and 8) water-soluble organic carbon.

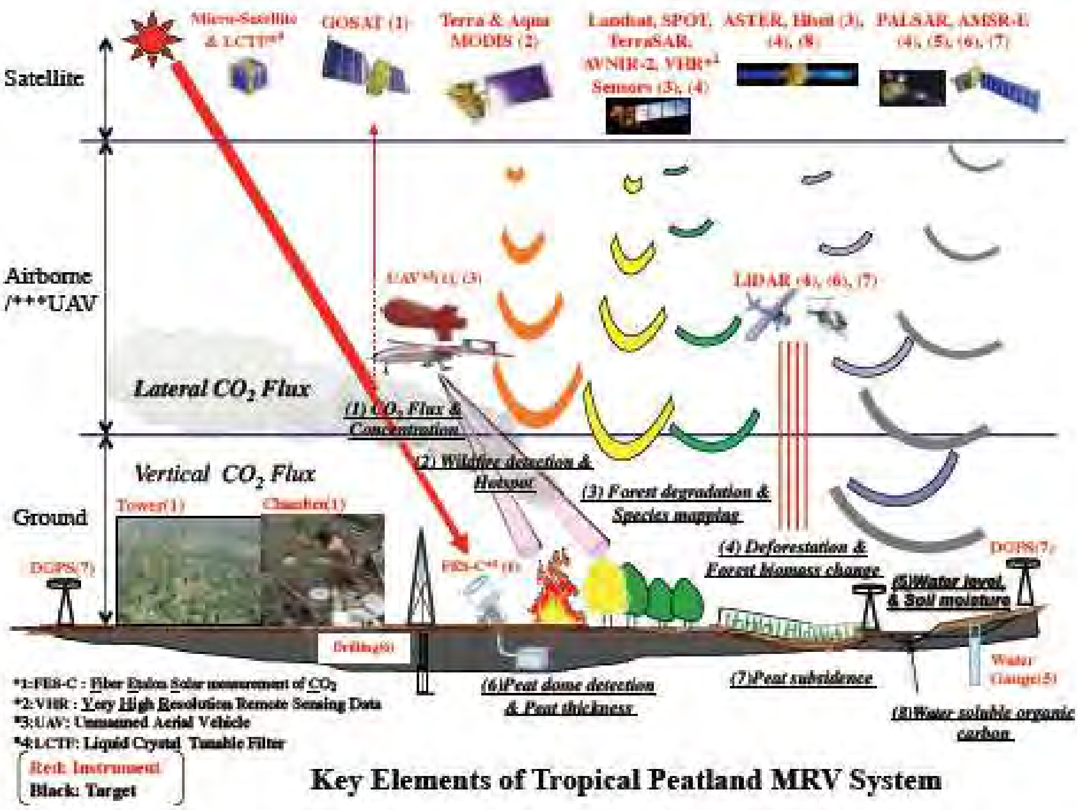


Fig. 13. Tropical Peatland MRV System for estimating water and carbon statues in peatlands

These eight items form the key elements in understanding peatland ecosystems and designing peatland restoration (including rehabilitation, reforestation, afforestation, and conservation). From the aspect of peatland restoration and presidential regulation, the following Restoration Maps are important:

For Peatland:

1) Water table map (model) is necessary to maintain the water table depth at 40 cm
2) Peatland depth map (model) is necessary to limit the peatland usage to within 3-m peatland depth
3) Peatland border map (model) is necessary to clarify the peatland borders (0-m peatland depth)

For Vegetation:

1) Biomass map (model) is necessary to estimate carbon budget and utilization of biomass
2) Plant species map (model) is necessary to estimate biodiversity on zoning peatlands

These eight elements are composed of 1) gases (CO_2, N_2O, and CH_4), 2) liquids (water), and 3) solids (plants and peat). It is impossible to directly observe the dynamics of gaseous CO_2 and liquid water in the peatland ecosystem. Therefore, a mapping model is required for the precise estimation of this ecosystem.

The estimation and evaluation of peatland ecosystem by GIS information revealed the importance of the following items: 1) geo-information (including dome structure), 2) peat depth, 3) bordering peatland, 4) peatland subsidence, 5) moisture level of the peatland surface, 6) flooding, 7) dissolved organic carbon (DOC), 8) canal constriction, 9) fire spots, 10) peat loss by fire, 11) deforestation and forest degradation, 12) LULUCF, 13) biomass, 14) vegetation, and so on.

Therefore, advanced novel sensing by satellites and drones is warranted in this situation. ICTTroP will contribute to establishing an international platform on this so-called “One Map Platform.”

(2) Components

1) Real-time monitoring of ground truth by Sensory data transmission Service Assisted by MIDORI Engineering (SESAME)

The new field data transmission system using a universal mobile telecommunication network, SESAME system, was developed and applied to monitor the items related to global warming in tropical peatlands of Indonesia (Fig. 14). The transmission system is mainly composed of a sensor, a data logger, a data communication module, and a battery system. The sensors for measuring water-depth, distance, moisture tension, and the circumference were combined with SESAME and used to measure the groundwater and ground surface levels in peatlands; the water levels in river, dam, and lake; and the soil moisture and growing process of trees in a plantation in Indonesia. The interval of monitoring was 10 min, and the data were transmitted successfully to the data server in Japan at 3–6-h interval. The data in the server was downloaded in Japan and Indonesia through the domestic internet network and was processed.

In the SESAME system, the following items were measured; 1) water table, 2) water quality, 3) soil properties (chemicals, moisture, and temperature), 4) ground surface subsidence, 5) diameter of the tree (tree growth), and 6) micro-climate (wind, rainfall, solar, temperature, and humidity) (Fig. 14).

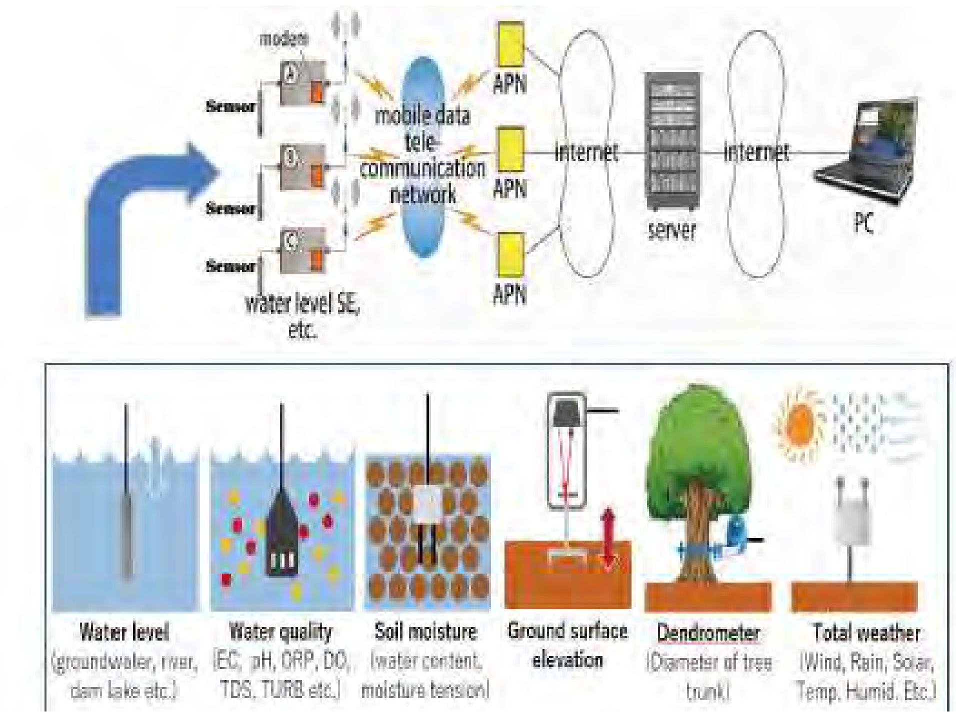


Fig. 14. Diagram of real-time monitoring system by SESAME

2) Water table Modeling

The GWL of peatlands differs by factors such as the land use, land cover types, and the extent of disturbance. Since each peatland has a specific characteristic in these factors, it is expected that GWL would distinctively vary under the classification system based on these factors. Each peatland type must clearly be defined as UF, DF, or DB. First, forest and non-forest areas in the target area (if both the areas exist) can be defined. The canopy-loss areas may be classified as DB land. Second, drained and undrained forest areas in the target area (if both the areas exist) can be defined. The drained and undrained forest areas can be identified based on the relative dry tendency of the dense forest surface. Lower dry classes can be classified as UF and higher dry classes as DF.

Regression analysis between satellite-based soil moisture data and observed GWL data

The SESAME system can monitor GWLs at remote locations in real-time (Fig. 15). The SESAME systems must be installed at locations that satisfy the following conditions: 1) physical accessibility and legitimacy for the installation and maintenance of the system, 2) coverage of GSM/GPRS/Q-CDMA network, 3) representative of distinctive peatland types identified by remote-sensing imagery, and 4) safety from theft.

Volumetric soil moisture data was obtained from the open-access database provided by the ECMWF (URL: http://apps.ecmwf.int/datasets/ data/interim-full-daily/). Before downloading the data, the applicable time-series (i.e., daily), coordinate system (e.g., WGS 84), coordinates (the boundaries of the target area), and grid size (0.125° at minimum) need to be set.

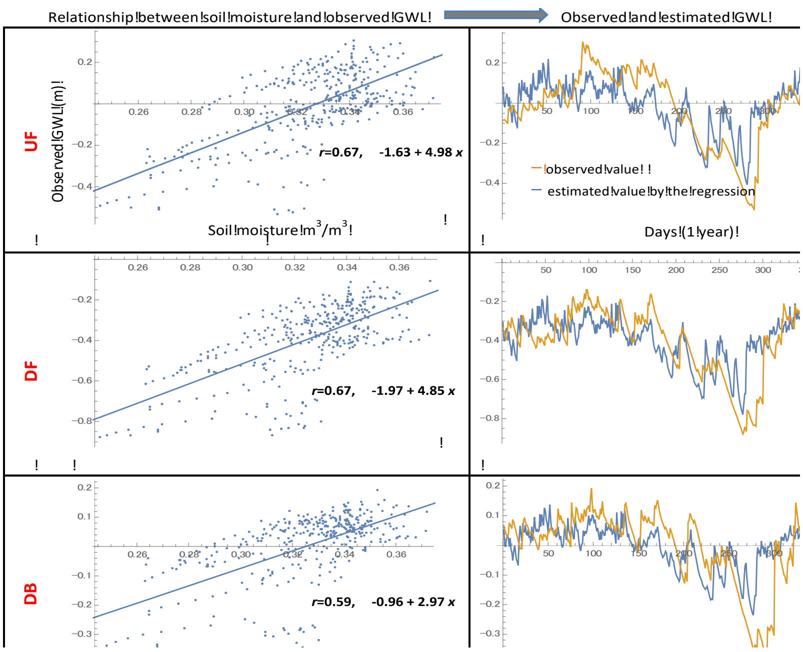


Fig. 15. GWL Model estimated in each peatland type based on the relationship between soil moisture and observed GWL data

Y-axis shows the plotting of the observed (measured) daily average GWLs by SESAME,

Water Table Model (Map)

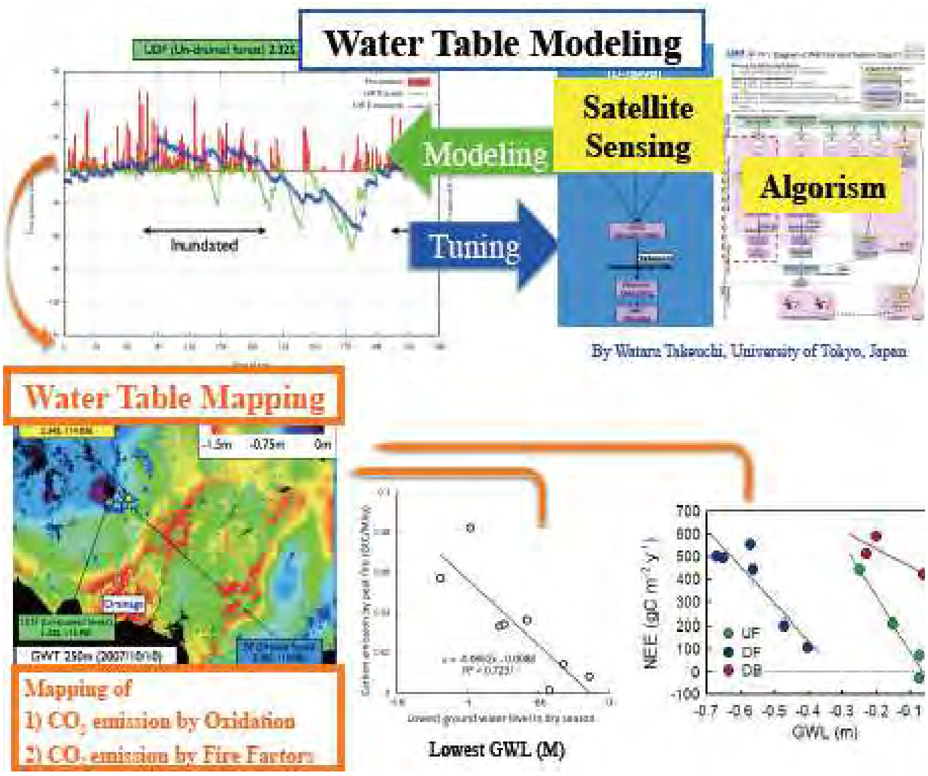


Fig. 16. Water Table Model (Map)

Water table model (Map) is a milestone for several parameters of “Tropical Peatland Ecosystem,” MRV for ICTTroP. For instance, it showed that water table correlates with CO_2 emission by oxidation (peat decomposition) and CO_2 emission by fire (fire spots and intensity) as shown in Fig. 16.

3) Peatland Geo-information Model

Depth Map (Model)

more description

Peatland Bordering Map (Model)

more description

4) Peatland Bio-information Model

Biomass Estimation Map (Model)

more description

Plant Species Map (Model)

more description

5) Road map on Integrated MRV System on “Tropical Peatland Ecosystem”

Integrated MRV System: Figure 17 shows a road map (model) for Integrated MRV System on “Tropical Peatland Ecosystem,” which is semi-real-time model, as follows:

1) Water Table Model (Map): Simulation based on the relationship between water table monitoring (SESAME) and (peat) land-surface moisture data from NCAR MET data. As peatland surface moisture (or water table) is strongly influenced by rainfalls, we should develop this model to estimate the real-time precipitation in Indonesia.

2) CO_2 Emission Model (Map) for peatland degradation: CO_2 emissions caused by peatland

degradation will be estimated by simulation based on relationship with water table model as well as with 1) NEE by Eddy covariance monitoring at tower and 2) peatland subsidence by laser distance meter (SESAME).

3) CO_2 Emission Model (Map) for peatland fire: CO_2 emissions caused by peatland fire will be estimated by simulation based on the relationship between water table model and 1) field survey for peat loss estimation and 2) PULSA (iSAR) analysis.

4) Fire Prediction Model (Map): As peatland surface moisture (or water table) is strongly influenced by rainfalls, we should develop "Rainfall Prediction Model (Map)" combined with the field observation data of rainfall event. By using this model, a 3-month forecast of fire prediction can be established.

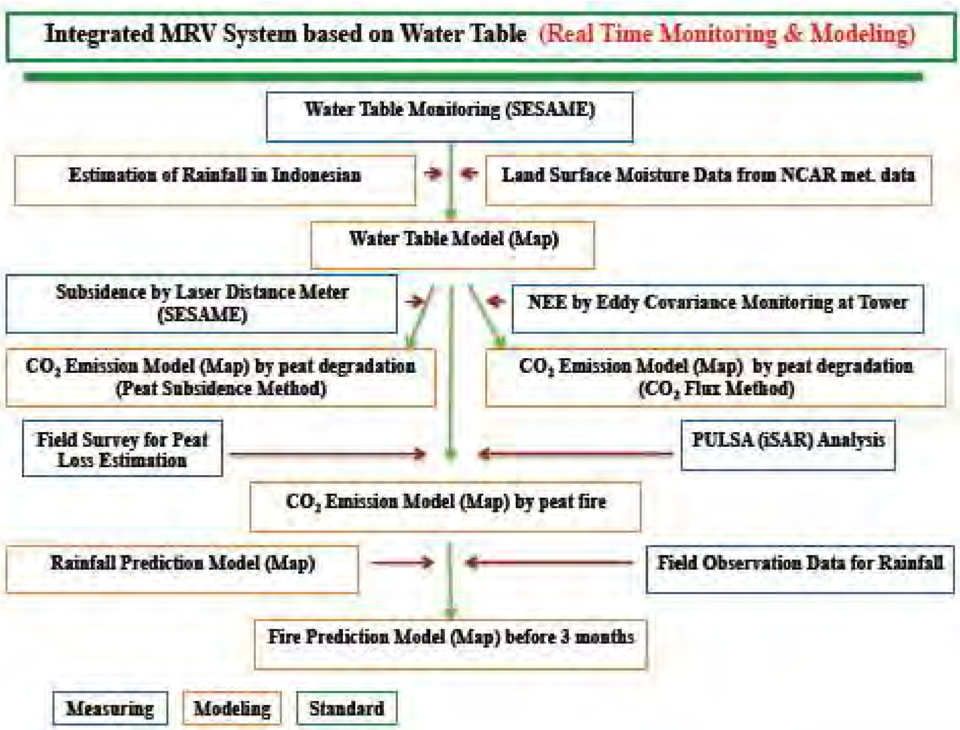


Fig. 17. Road map (model) for Integrated MRV system on "Tropical Peatland Ecosystem"

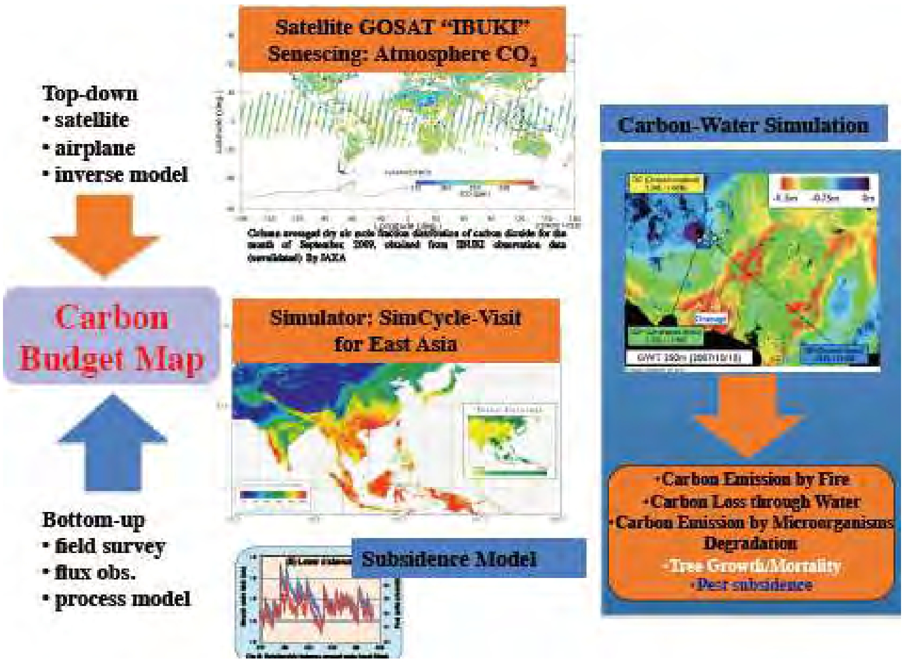


Fig. 18. Crosscheck of Carbon Emission Model

Crosscheck of Carbon Emission Model: Integrated MRV System is a set of model (map) of "Tropical Peatland Ecosystem," which contributes mainly to CO_2 budget, flux, and loss such as 1) carbon emission by fire, 2) carbon loss through water (not yet included in the Model, but related to water table), 3) carbon emission by microbial decomposition, 4) tree growth/mortality, and 5) pest subsidence (Fig. 18).

Inverse model is being developed using atmospheric CO_2 by satellite GOSAT "IBUKI" senescing. The CO_2 budget model in terrestrial ecosystems is also being developed as "Simulator: SimCycle-Visit for East Asia." Each model is now being crosschecked

(3) Contribution to *IPCC Methodologies*

The IPCC guideline for carbon inventory is tiered to three categories given below:

Tier 1: Simplest method and activity data available to all countries

Tier 2: Technology-specific emission factor

Tier 3: More detailed or country-specific methods

It is recommended that carbon inventory methodology be upgraded from Tier 3 to Tier 1. The Carbon Emission Model by ICTTroP contributes greatly to Tier 3 of Indonesia, but has a potential for further upgrade to match the international standards.

3-4-2. Model Pilot Projects

(1) Overview

Principal of Rewetting

Rewetting is required for peat fire prevention and, ultimately, for peatland restoration with the following three steps:

1) HWT
2) High Moisture at the Peatland Surface
3) Reforestation

The results of long-term observation and measurement of water table and fire showed that "HWT" is the optimal condition to prevent peatland fire. "High Moisture at the Peatland Surface" comes second because only few peat fire have been observed in natural peatland forests that suffered from serious reduction in water table level in the El Niño year. Water table, even in natural peatland forest, reduce to 1-m depth in the El Niño year (Fig. 19). This fact indicates that peat fire can be prevented not only with HWT but also with high moisture at the peatland surface (high moisture condition in forest even in El Niño year because sunshine radiation to the peatland surface is prevented by the forest canopy).

"Reforestation" strategies for fire prevention in wide areas are different from long-term strategy of reforestation, because the purpose of managing these forests is to retain high moisture content on the peatland surface. Therefore, trees species with the following attributes must be selected: 1) fast growing, 2) tolerance to submergence, and 3) fire tolerant.

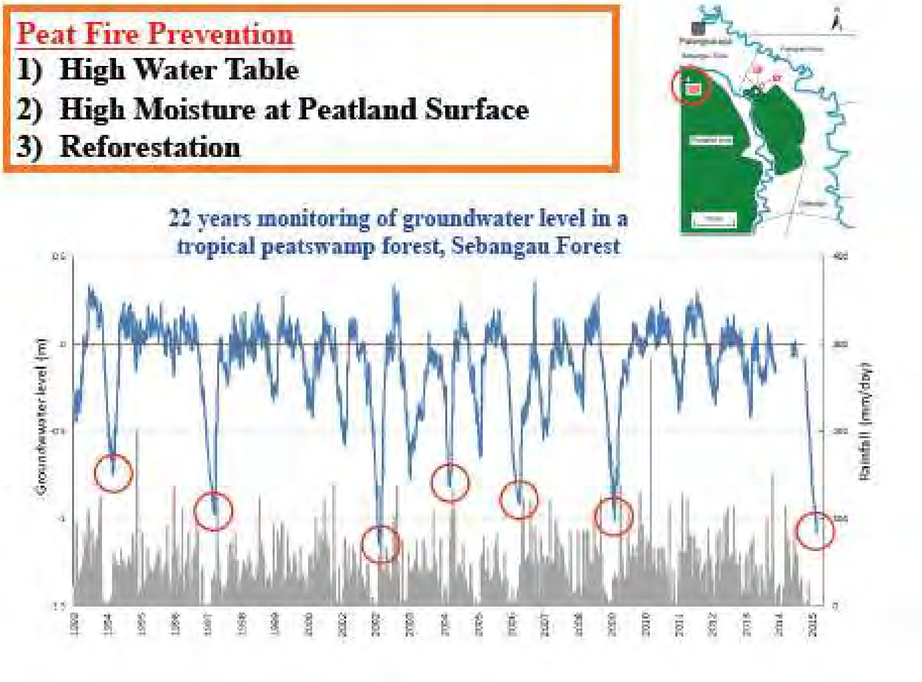


Fig. 19. Groundwater level monitoring in the Sebangau Natural Forest

(2) Rewetting and fire prevention

1) Rewetting

Big Canal Blocking and Pumping-up: There have been a few incidences of big canal blocking and pumping-up in Indonesian peatlands. For instance, during peatland rewetting of U Minh Tuong National Park (of area around 10,000 ha) in Vietnam, the drained peatland was seriously burned out by Super El Niño in 1997-8 U Minh Tuong National Perk (Figs. 20a and b). Then, the drained canal was blocked by water gate and pumping-up water from the outside river. In a few years, the pumping-up machines were in full operation, but gradually, the water loss almost stopped, after which the pumping-up machines stopped working.

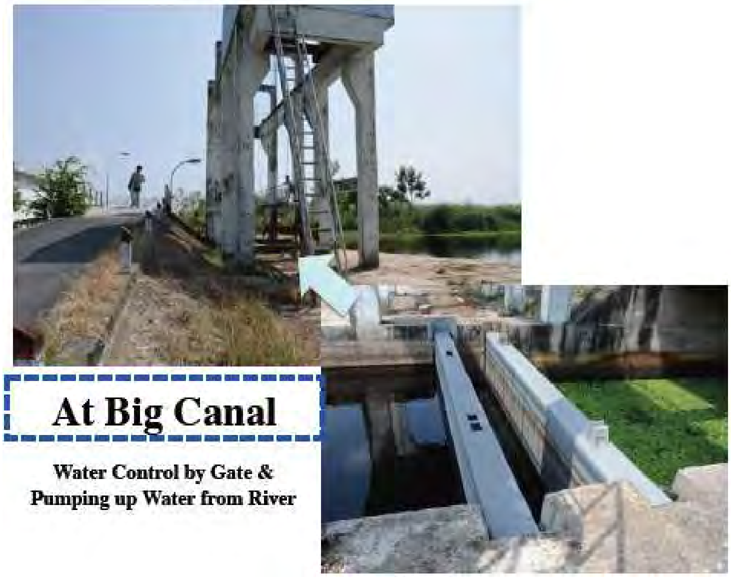


Fig 20a. Water control by gate

Fig. 20b. Water pumping-up from the river side

Rewetting in the MRP Area

Rewetting MRP Area in Central Kalimantan is expected to be the most difficult, because huge drainage canals were constructed more than 20 years ago, from which water is gradually being drained year after year (Figs. 21a and b). It is expected to take more than 5 years for recovering the water level after canal blocking and pumping-up.

Fig. 21a. Big canal blocking (from Bambang Setiadi)

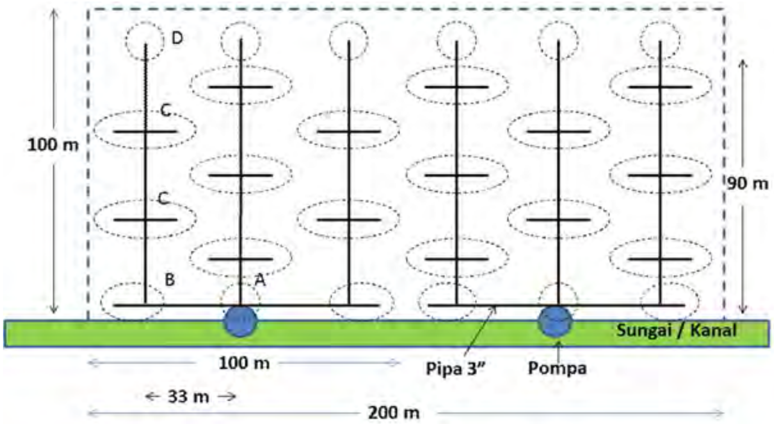


Fig. 21b. Irrigation system in big canal blocking (from Bambang Setiadi)

Small Canal Blocking

Interval of canal blocking depend on topography (Fig. 22).

Fig. 22. Small canal blocking

Rewetting in a village farming area

In local farming villages, small canal blocking and peatland surface wetting are necessary, because, to grow only low economic value tree is difficult for covering land surface (to protect land-surface moisture). Figure 23 illustrates the case of a small scale (100-ha area) rehabilitation of disturbed and frequently fired peatland.

This rewetting model is expected to achieve not only protection of fire but also land farming after the fire protection system is established.

1) Weed transform into natural compost with biochar (made from border tree and bamboo)

2) Pumping-up water will supply nutrients if the well is located in proximity to the sea

3) Pumping-up water is useful for the irrigation of crops, vegetables, and fruits during the dry season

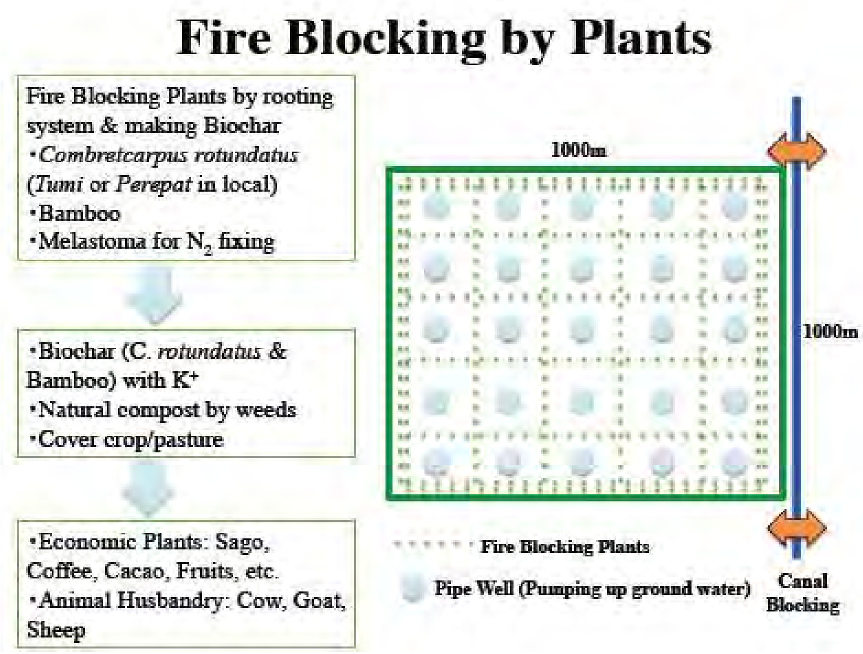


Fig. 23. Rewetting in the village-farming area

The proposed plot design as given below:

Facility

- Pipe for well: 25
- Pumping engine and hose (150 m): 5 sets
- Weeding machines: 5 sets
- SESAME: 2 sets
- Canal blocking: 2–3 points
- Chemical matters: Soap and gel pack

Activity

- Blocking canal and maintaining HWT
- Slashing weeds
- Wetting (spry water by 1–3-days interval according to the dryness)
- Check quality (nutrients) of groundwater
- Peat depth map

Planting HWT adapted plants

- *Combretcarpus rotundatus* (*Tumi* or *Perepat* in local) and bamboo (for fire prevention and biochar)
- Natural composting by weed

- Sago, coffee, cacao, fruits, etc.
- Cover crops as pasture

2) Peat Fire Prevention

Peatland Fire Information System: The Peatland Fire Information System is proposed as given in Fig. 24.

Fire Management System in Peatland

			Comments
Mapping and Prediction	1	Peatland Map and Channel map	Basic information
	2	SST (sea surface temp.), and long-range forecasted SST by meteorological bureau (1-2 months)	Long-term prediction of El Niño
	3	Daily GWL prediction model by ECMWF Data from Europe (in two month ago)	Middle-term prediction
	4	Daily GWL prediction model (in one week ahead)	Short-term prediction
Fire Detection	5	Fire Detection in large area by Satellite (MODIS, VIIRS), and in spot by UAV/drone with IR detector	Remote Sensing
Evaluation	6	CO2, CO, and PM2.5 emission by GOSAT II and FES-C column spectrometer	Direct estimation of C emission
	7	Burnt depth estimation by PARSA II, and iSAR	Indirect estimation of C emission

Fig. 24. The Peatland Fire Information System

Mapping and Prediction

1) Peatland map and channel map

2) SST (sea-surface temperature) and long-range forecasted SST by meteorological bureau (1–2 months)

3) Daily GWL prediction model by ECMWF Data from Europe (2 months ago)

4) Daily GWL prediction model (1 week ahead)

Fire Detection

5) Fire detection in large areas by satellite (MODIS, VIIRS) and in spot areas by UAV/drone with IR detector

Evaluation

6) CO_2, CO, and PM2.5 emissions by GOSAT II and FES-C column spectrometer

7) Burned depth estimation by PARSA II and iSAR

3) Fire-Fighting System at (Fire) Site-Local Community Level

In establishing the peat fire-fighting system at the local community level, it is important to protect (1) private houses and public buildings (such as government offices and schools) and (2) farmlands from the peat fire.

Strategy 1 Fire-fighting for Peat Fire Equipment by Local Community Level: It is important for each local community to be prepared with at least the minimum fire-fighting equipment using water from ditches, canals, ponds, and deep wells (Fig. 25a).

Strategy 2. Effective Firebreak by Ditch and Clear-Cut for Prevention of Peat Fire Spreading: To protect buildings and farmlands from the spread of peat fire, it is effective to create a firebreak by ditch and clear-cut or by planting plants at the border of the field (Fig. 25b).

Fig. 25a. Fire-fighting equipment in local farmer

Fig. 25b. Fire-fighting zone

(3) Zoning

The plant cultivation methods are different among different peat zones:

1. Costal Peatland: Rich nutrients supplied from the sea water
2. Riverside and Delta-side Peatland: Rich nutrients supplied by clay mineral from the river
3. Inland and Inside Peatland: Extremely Poor Nutrients

As nutrient content is different among different peatland zone, nutrient management and design are the most basic strategy in peatland restoration.

"Sago-based ecosystem" in Costal Peatland

A sago-based ecosystem established in 200-Mha fields of Indonesia is expected to become both ecologically and economically beneficial. It will also have a huge positive impact globally. In an ideal wet peatland condition at the Sei Tohor village, the Meranti district, Riau province, starch production is 20–30 ton starch/ha/year (more than 10-times the rice production), and biomass productivity of 50–100-ton biomass/ha/year (Fig. 26a). Once sago canopy is established, it is expected that starch and biomass productivity will be maintained at extremely high levels for 8–10 years.

Fig. 26a. Sago based-Peatland Restoration

Sago palm has unique characteristics for adaptation to peatlands (Fig. 26b), some of which are given below:

1) Submergence tolerance through aerial root
2) N_2 fixation by aerial roots
3) Low P requirement for starch synthesis process
4) Na tolerance (saline tolerance) and Na accumulator
5) Acid soil tolerance (growing even in acid sulfate soil)
6) Perennial crop (8–10 years)
7) K^+ is required in a large amount, but K^+ is extremely poor in peatlands, except for at the riverside and tidal-effect areas, which is the main limiting factor.

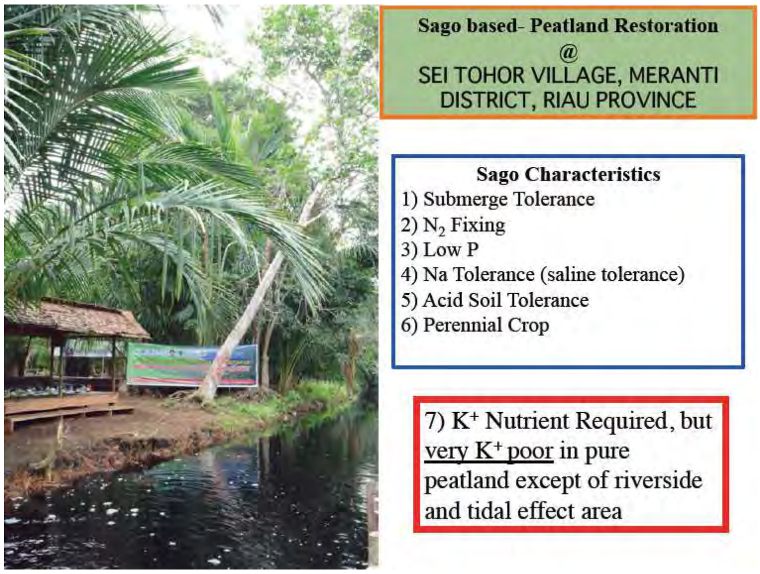


Fig. 26b. Unique characteristics of sago palm grown in peatland

A large amount of starch and biomass produced in an ideal "sago-based ecosystem" can be processed into high additional-value materials such as functional foods, bioenergy and organic materials (Fig. 27). Thus, sago usage is an excellent model in producing starch (food/feed) and biomass (bioenergy), which enhances the economic values together with those of other plants like coconut (coconut shell is a good biofuel, and coconut plantation conserves the coastal lines).

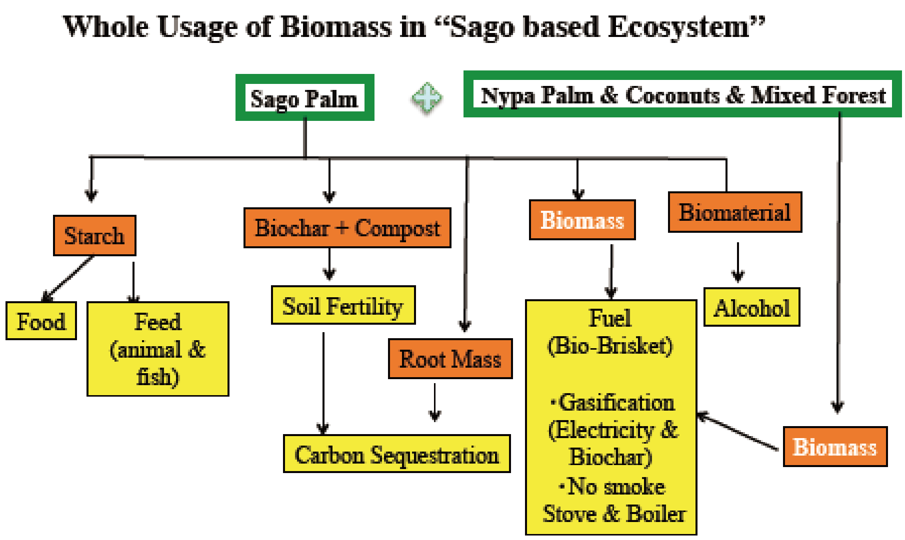


Fig. 27. Innovating biomass-oriented ecosystem Management-economic implementation with high benefits

To ensure the flow diagram of biomass usage, it is recommended to develop an efficient collection methods of biomass resources from the local lands, that is, by using "LiDAR, SAR, and Hyper Spectra-Sensors" (natural scientific approach) as well as by establishing a waste-management system in each village (social science approach).

More scientific researches are required on "sago-based ecosystem," practical guidelines on the best practices of "sago-based ecosystem," and strategy to maximize social and national economy benefits.

It is important to know the potential productivity (starch and biomass) of sago palm for determining the limiting factors in other areas and designing solutions for improvement in cultivation and management system. It is recommended to study the best practice area (or case) of "sago-based ecosystem" in the following regions to develop a "manual" of best practices. A guideline is also necessary in surveying the study areas (or cases). The guideline should include conducting of water table monitoring at least once a year.

"Organic soil-based ecosystem" in riverside and delta side close to a peatland

The main reason for failure in the MRP comes from the misunderstanding and mismanagement of soils. Soils in the riverside and delta side should be considered as organic soil (because of the high clay and mineral content) rather than as peat soils. A crop like rice can grow very well in organic soils, but not in true peat (which is extremely poor in nutrients).

These misunderstandings may create serious issues, because the management principles in these areas are not typical as those applicable to large topical peatland areas. We must ensure that rice cannot grow in normal peatlands due to extremely poor nutrients.

By sallow development, peat soils disappear and unfavorable features in the subsoils emerge, such as acid sulfate soil (extremely low pH of <3.5) and sandy podzolic soil (extremely poor nutrients). Rehabilitation of these soils is necessary as a part of peatland restoration.

Acid Sulfate Soil:

Sago palm and Melaluca can be grown in acid sulfate soil (Fig. 28).

Fig. 28. Plants grown in acid sulfate soil

Sandy Podzolic Soil:

Pasture/fiber crops and coconut palm can grow in sandy podzolic soil (Fig. 29).

Fig. 29. Plants grown in sandy podzolic soil

3) "Tree-based ecosystem" in Inland Peat

According to the manual of best practices for "sago-based ecosystem," it is possible to analyze the limiting factors of sago-based ecosystem in each area. Then, it is prescribed and practiced for the best practice of "sago-based ecosystem."

The XMRP area is the area that has been mostly discarded and damaged by decreased water-holding capacity of the soil, dryness, fire damage, biodegradation (decomposition), and decreasing soil biodiversity. In most disturbed peatlands, special solutions are necessary for restoration, including the following:

1. **Recover high groundwater table (0–20 cm) by** canal blocking and fire prevention
2. Plant HWT adapted species (HGWT species) and
3. Establish "sago-based ecosystem" among HGWT species.

HGWT species will be selected from the native species grown in peatlands (Fig. 30). In the field observation on the sample plots that were affected by fires in 2015, the dominated pioneer species after fires were Kalakai (*Stenochlaena palutris*), Karamunting (*Rhodomyrtus tomentosa*), Pakis (*Osmunda cinnamomea*), and Tumih (*Combretocarpus rotundutus*). These species (except for Tumih) can be categorized as shrub/bush vegetation. The abundance of seeds and favorable environmental conditions in the tropical peat-swamp forest in Kalimantan partially accounts for such rapid vegetation-coverage recovery, even in severely damaged areas. Tumih (*C. rotundatus*, family: Anisophyllaceae) is extremely hardy, fire-resistant, and fast-growing species. Seed dispersal by wind and water is common throughout forests and deforested areas.

Fig. 30. *Combretcarpus rotundatus* (Tumih or Perepat in local) and aerial roots

C. rotundatus grows naturally in Sumatra, Peninsular Malaysia and Borneo (Fig. 30). Its habitat is swamp and kerangas forests. *C. rotundatus* grows as a tree of up to 40-m height, with a trunk diameter of up to 1 m. The fissured bark is gray-brown to brown. The bisexual flowers are yellow. The fruits have three or four wings and measure up to 3-cm long. It is hard and heavy wood is used in heavy construction for indoor floors and paneling. *C. rotundatus* can grow in water-logged soils of peat-swamp forest and in kerangas, which is a type of moist, heath forest formed on acidic, sandy soils low in nutrients, particularly in nitrogen content. In addition, since its tree coppices vigorously, the regeneration of logged-over forest poses no problems. The fallen trees of *C. rotundatus* usually develop adventitious shoots from the bole and eventually develop into new trees, thereby regenerating.

C. rotundatus has unique characteristics such as aerial roots, which contribute to the O_2 absorption. These aerial roots exudate gel-like polysaccharides, which contribute to the growth of nitrogen-fixing bacteria. Delta ^{15}N techniques have confirmed that the nitrogen nutrient of *C. rotundatus* are mostly derived from the air.

(4) Integrated micro-hydrological unit management

The ideal Integrated Micro-Hydrological Unit Management is based on a self-supply system of energy and food. A society that achieves this system can be described as a "low carbon society," or a “recycling society,” and a “society in harmony with nature.”

The livelihood system is necessary in peatland restoration. Households are surrounded by vegetable gardens, fruits gardens, animal husbandry, and fish culture, as well as agroforestry of sago (or several other tree species), timber planting, and native forests for conservation (Fig. 31). To establish the livelihood system, zoning is required to categorize food-production area, economic plant-growing area, timber-growing area, and nature-conservation area.

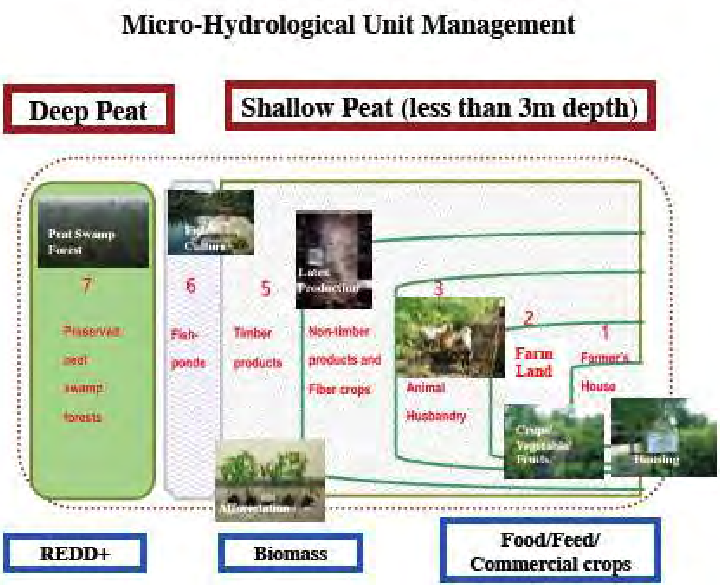


Fig. 31. Integrated Micro-Hydrological Unit Management

(5) Land-surface management

1) Mound structure

Micro-topography of tropical peatland was uneven and rough at the ground surface (Fig. 32). There were numerous mounds in peatlands formed from plant roots, litters, and other materials. It is assumed that a mound is the site for aerial root formation.

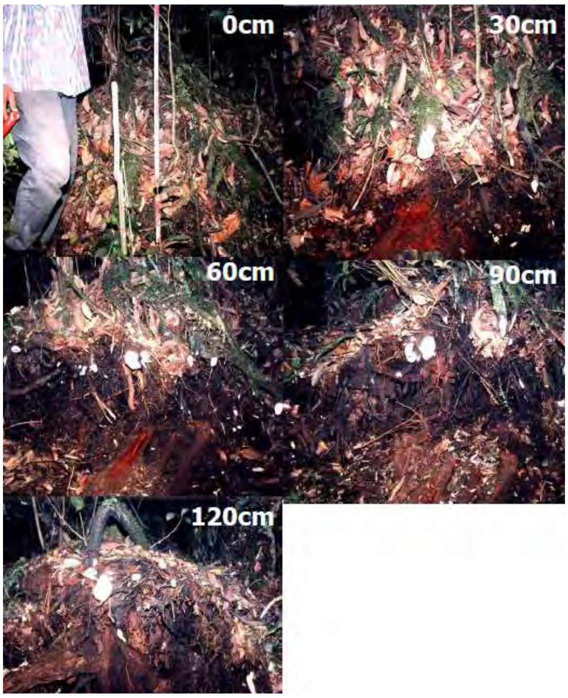


Fig. 32. Mound structure in a tropical peatland

The mound surface surrounded by open water has very high Eh (almost similar to that of the atmosphere) (Fig. 33). Although non-mound peat surface has low Eh, the value is still greater on the surface of peatlands than in water (around 0 mV) in peatlands.

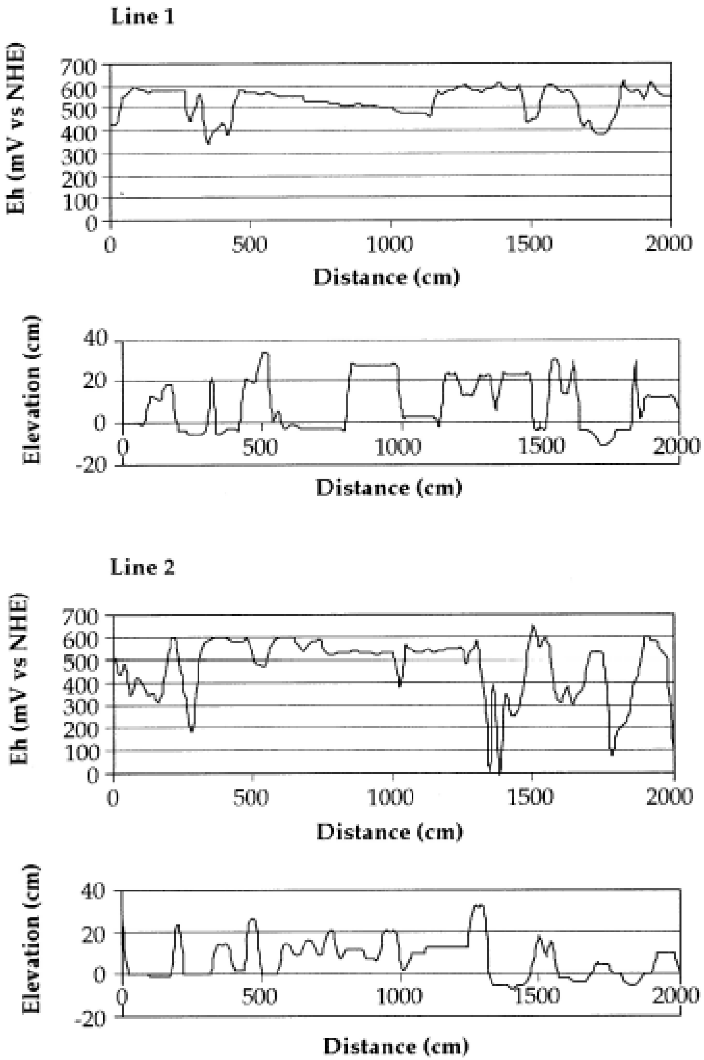


Fig. 33. Distribution of the redox potential (Eh; mV) at the soil surface (within 2 cm from the surface; upper panel) and the surface elevation relative to the water table (lower panel) along two transect lines in a shrub wetland community in Lahei, Central Kalimantan, Indonesia. Measurements were made on September 3, 1998 (Haraguchi & Yabe, TROPICS 11: 91-100, 2002).

2) Aerial root formation

The root system of sago is extremely unique. It has two root systems, axillary (white color) and aerial (pink color) (Fig. 34). In submerged (flooded) condition, the axillary root mass spreads from 0- to 30-cm peat depth (the scale in Fig. 34 shows the peat surface line), aerial roots spreads over the peat layer.

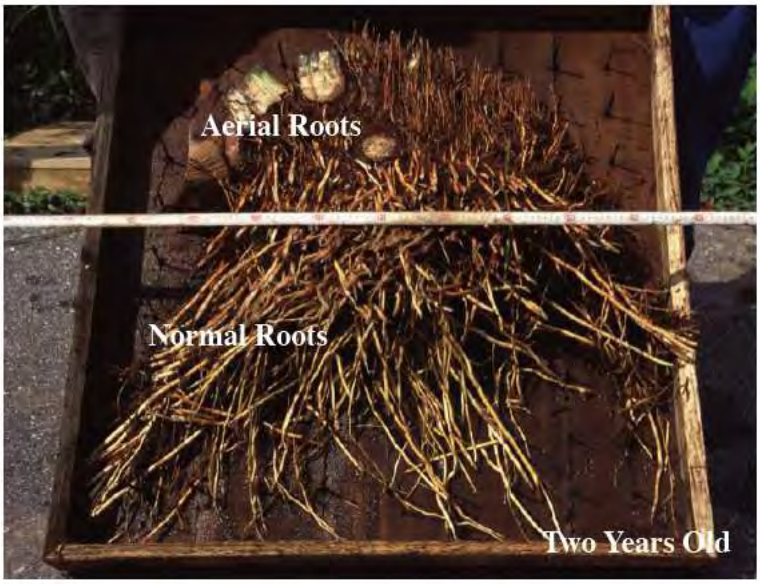


Fig. 34. Axillary and aerial roots of sago palm

The aerial roots of sago palm grow well in HWT (Fig. 35a) and they develop from the trunk of the tree (Fig. 35b).

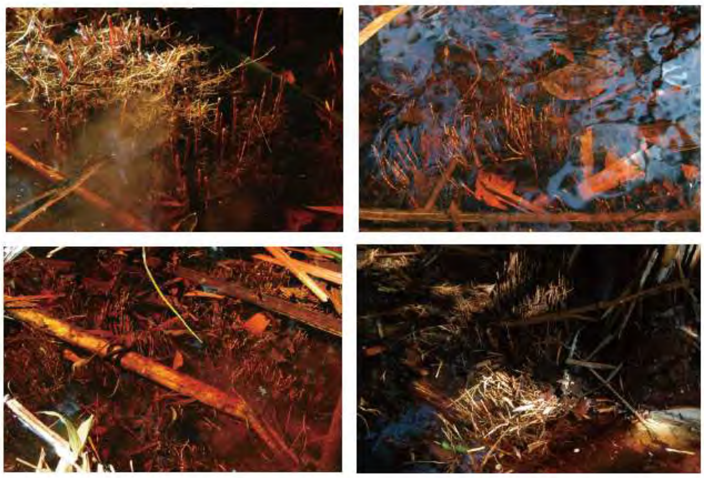


Fig. 35a. The aerial root of sago palm in high water table

Fig. 35b. The aerial root from the trunk of sago palm

The aerial root has two important functions: i) O_2 absorption and ii) N_2 fixation.
According to the experimental results obtained from Sarawak, Malaysia, the application of **N-P-K fertilizer (Fig. 36a, left panel)** showed **no aerial root** development, but n**o fertilizer application (Fig. 36, right panel)** showed **aerial root** development.
This observation was confirmed in field experiments as well (Fig. 36b). Sago growth was better in "no fertilizer application" (left panel) than in "Fertilizer Application" (right panel), and a large number of aerial roots was observed in "no fertilizer application" in a 2-m circular distance from the trunk.

Thus, it is hypnotized that the aerial root plays a role in N_2 fixation in addition to that in O_2 absorption. It is easy to isolate several N_2-fixing bacteria species from the aerial roots of sago palm.

Fig. 36a. Aerial root formation of sago palm without fertilizer application (right panel)

Fig. 36b. Good sago growth and aerial root formation occurred without fertilizer application (left panel)

It can thus be concluded that sago growth was better under wet conditions and HWT level, as it led to better aerial root development. Under dry conditions, the growth of aerial roots reduced and the N_2-fixation ability also weakened.

3) Land-surface function

If once the top peat layer has been seriously damaged by dryness (canal construction or deforestation), fire, and removal of the top layer, it is extremely difficult to perform recovery, rehabilitation, or reforestation (Fig. 37). The figure shows rehabilitation process after the top peat layer (1–2 m) was removed. The peat mining project (Finland Project in Kalanpangan, Central Kalimantan) was stopped, and the rehabilitation program was started in 1985, during which acacia trees were planted. However, the trees did not grow anymore despite application of chemical fertilizers. However, *C. rotundatus* trees started to grow naturally in around 2000; as a result, the biodiversity increased immediately surrounding the *C. rotundatus* trees in around 2006. Thus, it was assumed that the top peat layer improves over a period of time as a result of microbial activities.

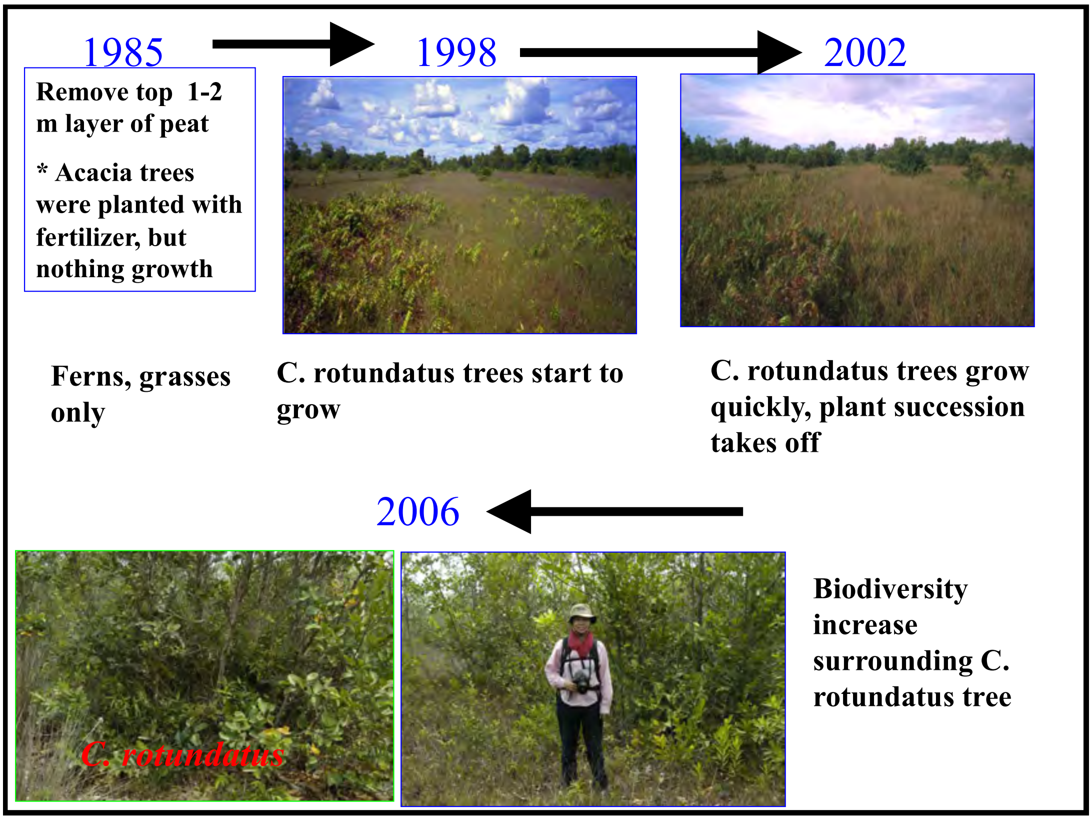


Fig. 37. Vegetation transition after heavy disturbance of peat (top-layer removing)

C. rotundatus is a pioneer tree in the peatland of Central Kalimantan (Fig. 38). *C. rotundatus* can develop aerial roots under wet conditions and HWT levels and start fixing N_2. It is very interesting that once the aerial roots of *C. rotundatus* start to grow; its seed can germinate in the areas surrounding the aerial roots and grow into seedlings. If Cyperus sp. and Fan sp. cover a peatland, it is difficult to germinate the seeds of *C. rotundatus* and of other species. Thus, it was assumed that once the microflora is improved, the germination of seeds and the growth of tree are promoted immediately with microorganisms symbiosis, probable by N_2-fixing bacteria.

Fig. 38. The aerial roots of *C. rotundatus* and competition with Cyperus sp.

In the burned fields of peatlands, restoration of the vegetation is difficult, even in sago plants with HWT level (Thailand peatland) (Fig. 39). The left panel of this figure shows the heavily burned area with vigorous growth of *Fimbristylis umbellaris*, while the right-panel figure is not a burned area. Thus, the loss of the top layer of peat is important to restore the ecosystem, probably to promote the function of microflora.

Fig. 39. Sago growth in heavily burned area (left panel, poor growth) and slightly burned area (right panel, excellent growth)

4) Zoning criteria of plants-related peat depth

As deep peatland (of depth >3 m) has very poor nutrient composition, tree plantation is better. As the nutrient content of shallow peat is slightly more than that of deep peatland, economic plants can be grown with proper land-surface management. Thus, the zoning criteria is given below:

Deep peatland (>3 m): Trees (main composition: **lignin**)

Shallow peatland (<3 m): Economic plants (main composition: **sugar, starch, cellulose, hemicellulose, lipids, or carbohydrate and lipid**)

Lignin plants grow slowly and require only a small amount of nutrients when compared to carbohydrate and lipid plants. Thus, for zoning, the main chemical composition of the plant is an important criteria. The zoning can also be presented as follows:

Deep peatland: lignin plants (mainly tree)

Shallow peatland: carbohydrate and lipid plants

5) Peatland surface management as innovated farming system in shallow peatland

The farming system in shallow peatlands is essential for peatland management. Because nutrients are poor, the application of nutrients is necessary in farming. However, if a chemical fertilizer is applied to peat soils, these nutrients quickly decompose the peat. Thus, nutrients must be applied only to the peatland surface and must be released slowly to avoid nutrient pollution of the peat. Thus, sallow peat management must be adopted on land surface.

A model presented on the left panel of Figure 40 is a conventional oil palm tree growing in low water table level after heavy chemical fertilization. A model on the right panel of this figure is an innovated model that is “HWT, Artificial Aerial Root on peatland surface, and Sallow Root,” which gives higher yield of oil fruits due to its improved photosynthesis ability even during the dry season. In the right-panel model, nutrients are supplied from mainly the peat surface; therefore, HWT do not reduce the oil palm growth and productivity. For surface peat management, the compost and biochar are important elements.

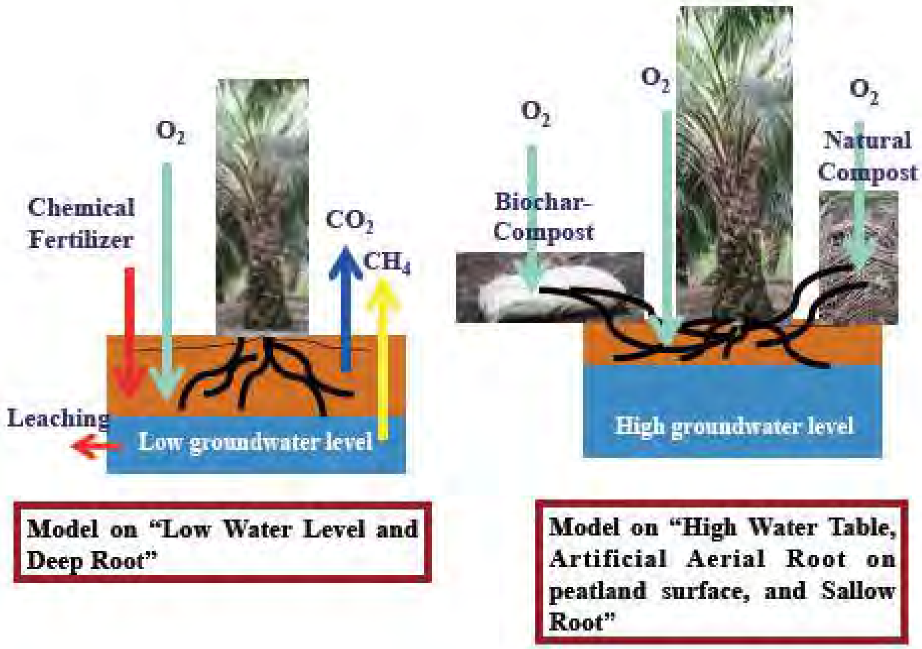


Fig. 40. Peatland surface management as an innovated farming system

Natural compost: In disturbed peatlands, weeds grow strongly and cause a fire in a dry season. These weeds should be cut, piled, and filed under wet conditions. Then, the bottom of piled weeds degrades gradually and mixes with the natural compost (Fig. 40, right panel).

Mycorrhiza: In disturbed peatlands, the peatland surface is strongly damaged and most nutrients are lost. As the dome area is originally nutrient-deficient, the peatland surface management is the key for its successful restoration, provided that the microflora is recovered.

Tropical peatland forests in Indonesia are being rapidly deforested, which has led to disturbance of the hydrology, wildfires, and carbon loss. Cost-effective methods are needed to promote the restoration activities on a large-scale of degraded peatland. One method is to inoculate seedlings with their corresponding local mycorrhizal fungi species to increase the performance during nursery stage under field conditions. Numerous studies on tropical forests have indicated that several native tree species are colonized by arbuscular mycorrhizal fungi (AMF) and ectomycorrhizal fungi (EMF). The diversity of mycorrhizal fungal is greater in the tropical forests than in other forests, and the colonization of mycorrhizal fungi improves plant growth of several species in a tropical forest. The survival rate of colonized seedlings of tree species is higher than that of non-colonized seedlings. The symbiotic fungi called AMF are common and found in major terrestrial plants, including cycads, conifers (except for the pine family), and most trees and crop plants, including palms. As is known, date palm (*Phoenix dactylifera*) and oil palm (*Elaeis guineensis*) were reported to be significantly colonized and showed a high growth performance by AMF. On the other hand, there was no report on the role of mycorrhizal fungi in sago palm (*Metroxylon sago*). Inoculation of mycorrhizal fungi at the nursery stage is a useful technique for large-scale restoration program of degraded tropical peatland forests. The selection of appropriate combinations of native tree species and mycorrhizal fungal species is also important for the restoration of degraded peatlands (Fig. 41). The combination of mycorrhiza selected and biochar could achieve high productivity and assure good quality of sago-based ecosystem.

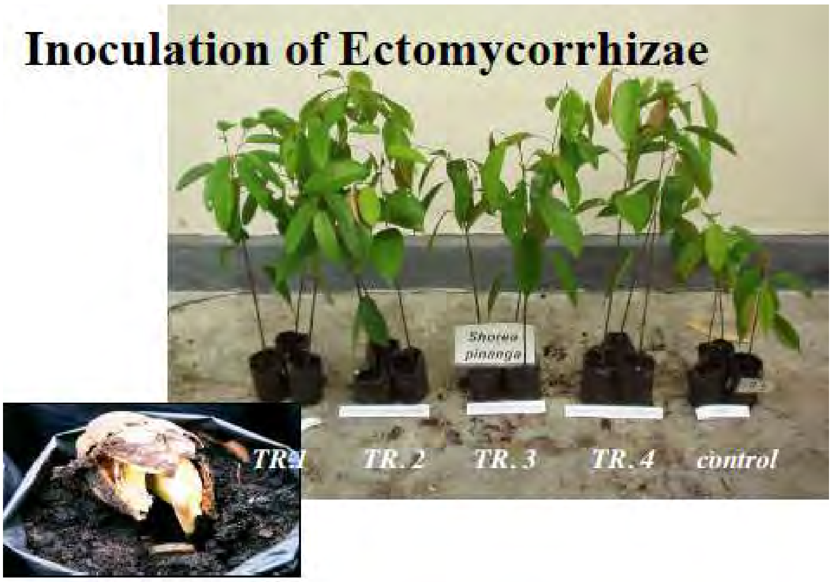


Fig. 41. Plant-growth promotion by ectomycorrhizae inoculation

N_2-fixing bacteria: Nitrogen is the key element of plant nutrients; however, nitrogen content in pea is extremely low. Therefore, it is hypothesized that plants adapted to tropical peatlands can fix nitrogen. In tropical peatlands, several plants develop aerial roots at high ground water table level. The rhizosphere or mucilage (polysacalids) of the aerial roots was found to contain N_2-fixing bacteria. Thus, it was hypothesized that aerial roots have O_2 absorption and N_2-fixation functions.

Melastoma malabathricum L. can grow in nitrogen free-water culture, which is an extremely rare case, because no other plant (even in endophytic nitrogen-fixing bacteria symbiotic sorghum or maize) grows in the same culture. Based on this fact, we may conclude that *M. malabathricum* L. possess endophytic nitrogen-fixing bacteria in the roots, shoots, and leaves but not in the plant tissues (Fig. 42). Nitrogen-fixing bacteria live on the rhizosphere and in mucilage exudated from the roots.

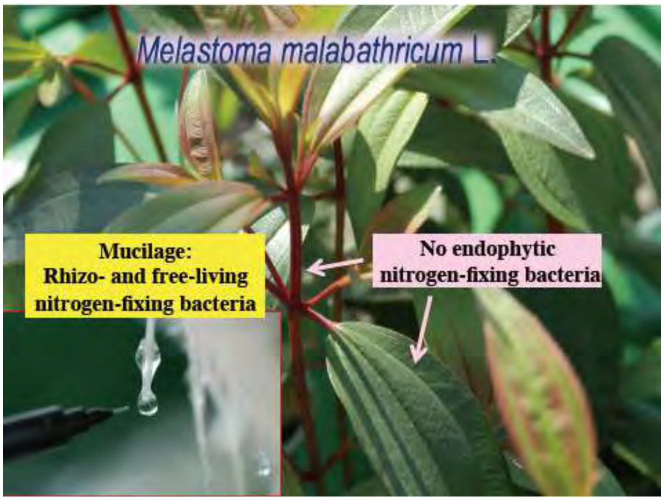


Fig. 42. Nitrogen fixation by *Melastoma malabathricum* L.

Isolated nitrogen-fixing bacteria were inoculated in aseptic culture and found to promote plant growth (Fig. 43). Nitrogen-fixing bacteria also promote plant growth in peat soils (Fig. 44).

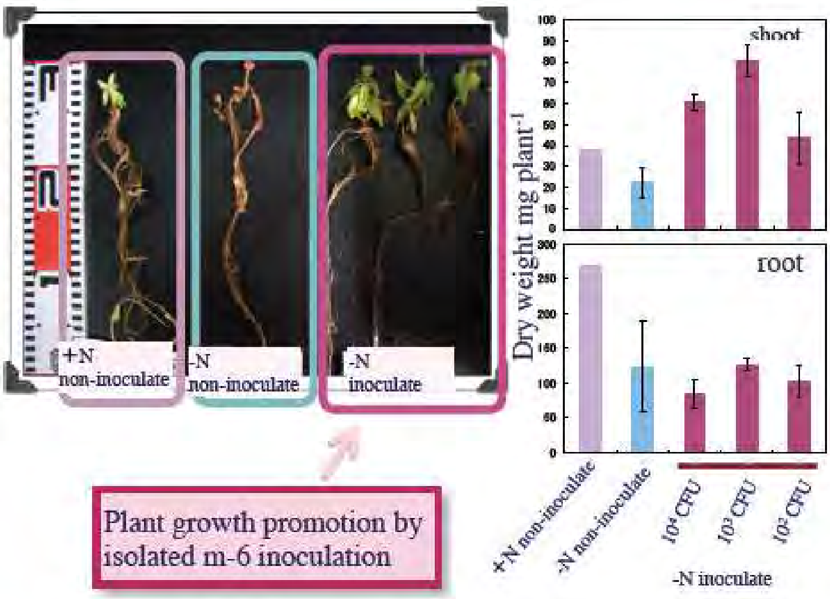


Fig. 43. Plant-growth promotion by inoculation of isolated nitrogen-fixing bacteria in aseptic culture

Fig. 44. Plant-growth promotion by inoculation of isolated nitrogen-fixing bacteria in peat culture

Biochar:

Tropical peat soil is extremely oligotrophic due to the poor nutrient content of its subsoil, strong leaching under acidic conditions, and low cation exchange capacity (CEC). To improve the fertility of tropical peat soils, mineral soil application may be the most fundamental solution. However, it is very expensive and excessive mineral soil is required to improve a large area. Another possibility is to increase the organic matter in soil. However, since the matter easily decomposes, this method is also not a feasible solution for the remediation of tropical peat soils.

Biochar, which is a charcoal made by pyrolysis of biomass, is the best material to apply to peat soil for remediation purpose as well as to mitigate peat degradation. Adding biochar to soil fixes and maintains soil fertility (Laird 2008) by mainly increasing its CEC and microorganisms' activity. Since biochar can sequester carbon in the soil for hundreds to thousand years (Winsley 2007), it is considered to be the ideal tool to slow down global warming. As peat is a good material for biochar, and only a small amount is required to make biochar by pyrolysis, biochar usage is expected to help conserve the precious peat in the future.

Another research group reported changes in the chemical properties of soil and increase crop yields by applying bark charcoal of the Acacia Mangium developed from pulp waste (Yamato et al., 2006). It was applied for soil amendments to cultivate maize, cowpea, and peanut in Sumatra, Indonesia. The yields of maize and peanut increased significantly by charcoal application to the infertile acidic soil. The amount of root and colonization rate of mycorrhiza increased, especially in maize crop. Root nodule formation in leguminous plants was also stimulated by charcoal. The application of charcoal improved the chemical properties of soil by neutralizing the soil's pH and increasing its (i) total nitrogen content, (ii) available phosphate content, (iii) CEC, (iv) amount of exchangeable cations, and (v) base saturation. Moreover, it induced reduction of the dissolved exchangeable Al ions in soil, which retards the root growth.

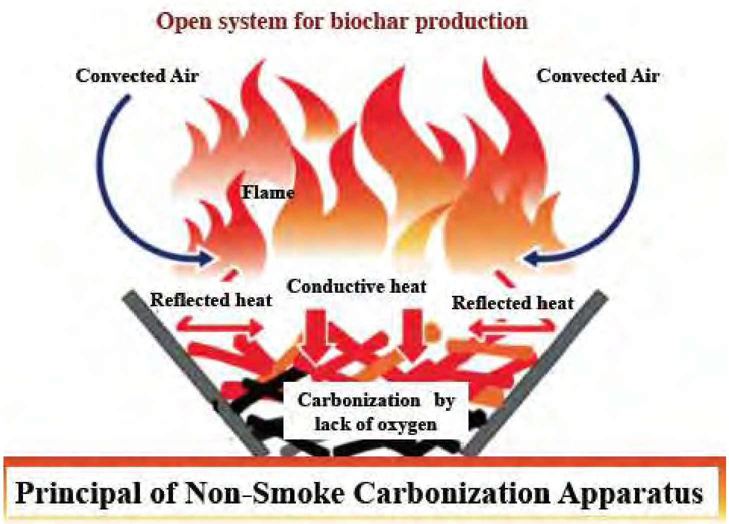


Fig. 45. Open system of biochar production

Fig. 46a. Demonstration of making biochar and compost using grass and bamboo materials in peatland of Central Kalimantan

Fig. 46b. Demonstration of biochar and compost production using grass and bamboo in peatlands of Malaysia

It is recommended to produce biochar by open system using non-smoke carbonization apparatus (Fig. 45). By using this system, biochar can be easily produced and transported (Figs. 46a and b).

Volcanic Ash: Volcanic ash is also a good material for nutrient supply and adsorption. This material can be used to improve the peatland surface soil without applying it into the peat.

(5) Food and environmental security

Peatlands Ecosystem Management on HWT must be developed for innovating economic value chains. Natural HWT-Peatland Ecosystem has high natural capitals such as i) High Carbon Reservoir, ii) High Water Reservoir, iii) High Biomass Productivity, and iv) High Biodiversity, which suggest that the conservation and restoration of these lands contribute globally to i) COP21 Paris agreement for mitigation and adaptation to climatic change and ii) sustainable development goals agreed by the UN assembly meeting in 2015.

Natural HWT-Peatland Ecosystem achieves rewetting (water control-water sharing), revegetation (biodiversity-peatland ecosystem quality), and revitalization of livelihood (Socio-economics) among the "Integrated Model 3RE" of BRG strategies.
"Sago-based ecosystem" in HWT-Peatland has low topical vulnerability and high resilience because it includes a High Water Reservoir that contributes to the supply of water to plants even during the dry seasons and adjusts the temperature and humidity level (protection of dryness), acts as a High

Carbon Reservoir, facilitate high productivity of starch and biomass, and serves as a high biodiversity platform by mix-planting.

1) Enhancement of ABCDEFGs Securities and SDGs

SUSTAINABLE DEVELOPMENT GOALS
17 GOALS TO TRANSFORM OUR WORLD

Goal 1. End poverty in all its forms everywhere
Goal 2. End hunger, achieve food security and improved nutrition, and promote sustainable agriculture
Goal 3. Ensure healthy lives and promote well-being for all at all ages
Goal 4. Ensure inclusive and equitable quality education and promote life-long learning opportunities for all
Goal 5. Achieve gender equality and empower all women and girls
Goal 6. Ensure availability and sustainable management of water and sanitation for all
Goal 7. Ensure access to affordable, reliable, sustainable, and modern energy for all
Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
Goal 10. Reduce inequality within and among countries
Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable
Goal 12. Ensure sustainable consumption and production pattern
Goal 13. Take urgent action to combat climate change and its impacts*
*Acknowledging that the UNFCCC is the primary international, intergovernmental forum for negotiating the global response to climate change.
Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development
Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
Goal 17. Strengthen the means of implementation and revitalize the global partnership for sustainable development

United Nations Department of Economic and Social Affairs, Division for Sustainable Development, "Outcome Document - Open Working Group on Sustainable Development Goals" URL:http://sustainabledevelopment.un.org/focussdgs.html

Fig. 47a. Sustainable Development Goals (SDGs)

Wet peatland naturally has a high potential of owning natural capitals such as i) High Carbon Reservoir, ii) High Water Reservoir, iii) High Biomass Productivity, and iv) High Biodiversity. If a wet peatland transfers into dry peatland by drainage (or canal construction), these natural capitals will degrade quickly, causing severe damage to climate, economy, and the social system on a global scale.

On September 25, 2015, some countries adopted a set of goals to **end poverty**, **protect the planet**, and **ensure prosperity for all** as a part of a new sustainable development agenda. Each goal had specific targets to be achieved over the next 15 years (Fig. 47a). Thus, restoration of wet peatland will be economical and beneficial, especially to the locals.

If wet peatland is managed by “sago-based ecosystem,” ABCDEFGs securities will be highly achieved. The ABCDEFGs securities are listed below: (Fig. 47b).

-Aquatic/water security: Water-reservoir ecosystem

-Biodiversity security: High biodiversity by mix-planting and nature-conservation around peat dome

-Climate Change security: Mitigation as Carbon Emission Reduction and Adaptation as High Biomass Production (enough water) against El Niño

-Disaster security: Fire and Haze Protection

-Energy security: Biomass energy from sago starch and residuals, and other biomass materials in sago-based ecosystem

-Food/Feed security: Sago starch for food and feed (animal husbandry and fish culture)

-Global Partnership as global security: International safety networks on Peatland/Wetland

-Social security: REDD+, PES, CSR&CSV, and ESG&SRI

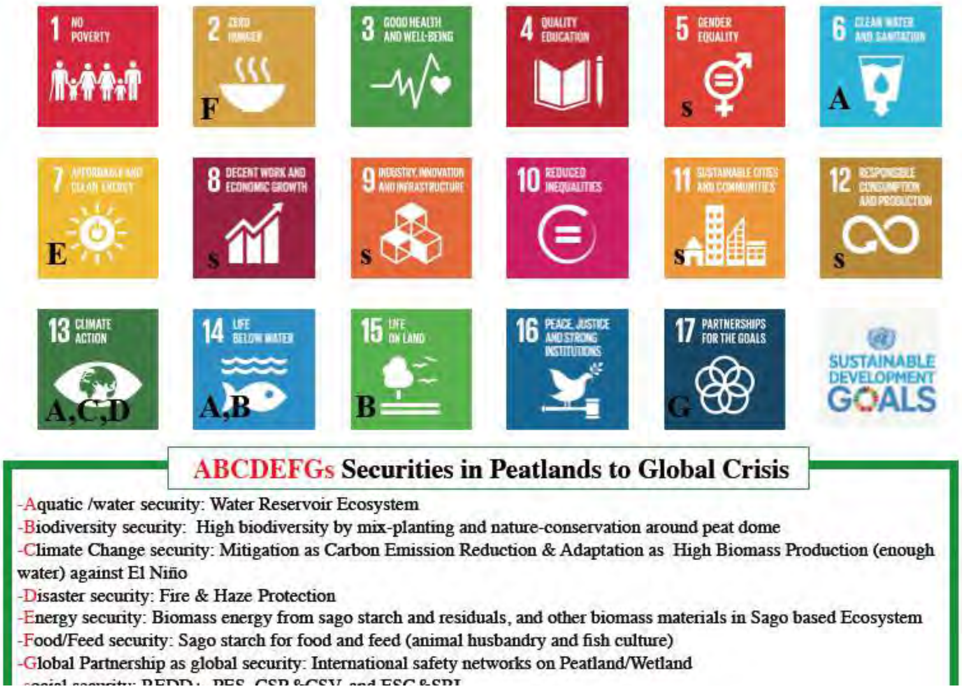


Fig. 47b. Relationship between Sustainable Development Goals (SDGs) and ABCDEFs Securities

"Sago-based ecosystem" is the only system that can achieve all ABCDEFGs securities in peatlands while maintaining full water-reservoir level. Considering that sago palm grows well in submerged peatlands (wet peatlands) with a high yield of starch and biomass, "sago-based ecosystem" can function as a High Carbon Reservoir, a High Water Reservoir, and a High Biodiversity system.

The recommended "sago-based ecosystem" is composed of at least two elements in wet-peatland: HWT and semi-natural mixed forest (like biodiversity in agroforestry), which is simple and effective for ABCDEFGs.

Water reservoir is the key element in peatlands. Especially, High Water Reservoir contributes to maintaining high biomass production even during super El Niño. If water-reservoir function is weakened by drainage, frequent fires and drastic decrease in biomass production can lead to carbon assimilation, and the carbon emission increases on a global scale. Therefore, water reservoir is the most important factor for mitigation (carbon emission by peat fire and peat degradation by microorganisms) and adaptation (high biomass production) to climate change, especially to super El Niño.

In conclusion, to be compatible with both Sustainability and Profit, "sago-based ecosystem" has been proposed, because sago grows well in HWT level and poor nutrition conditions (such as low N and P, high Na, and acidic conditions) and produces high amount of starch and biomass.

2) High EPR of Biomass in Tropical Peatland Ecosystem

The concept of EPR is one of the basic criteria to understand the energy quality. EPR originates from the idea of "rabbit limit" that is based on the case of rabbit hunting (Fig. 48).

In explanation, when you have to chase a rabbit to obtain food, you need to consume energy for hunting. If the energy spent in hunting the rabbit is greater than the energy obtained from eating the rabbit, rabbit hunting cannot be considered sustainable. EPR is determined using the following equation (Amano, 2008):

$$EPR = \text{yielded energy}/\text{consumed energy}$$

EPR must be >1 when the activity is sustainable. The greater the amount of EPR, greater is the efficiency of an energy resource.

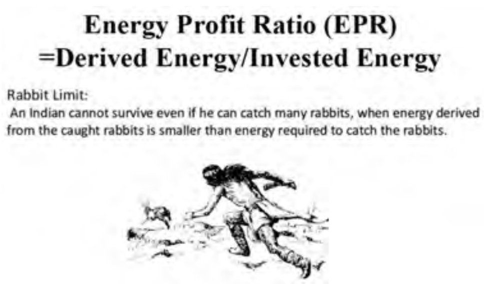


Fig 48. Energy Profit Ratio (EPR)

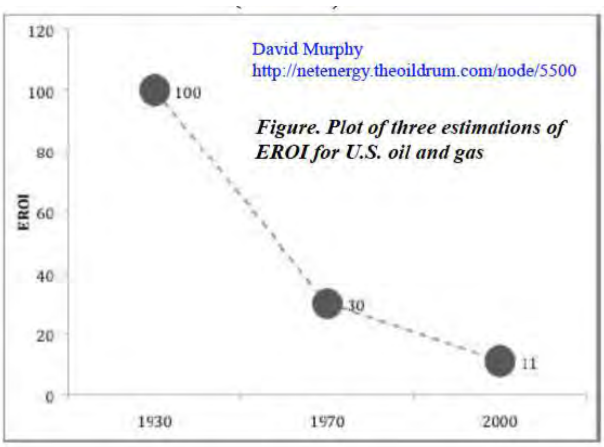


Fig. 49. Decreasing Energy Return on (Energy) Investment (EROI)

Energy Return on Investment (EROI) is quite a similar concept of EPR. How much energy is obtained by 1 unit of energy input? Cutler Cleveland of Boston University reported that the EROI of oil and gas extraction in the USA has decreased from 100:1 in 1930's to 30:1 in the 1970's to roughly 11:1 in 2000s (Fig. 49). However, beyond this fact, the society receives currently around 11 barrels of oil for every one barrel of energy input.

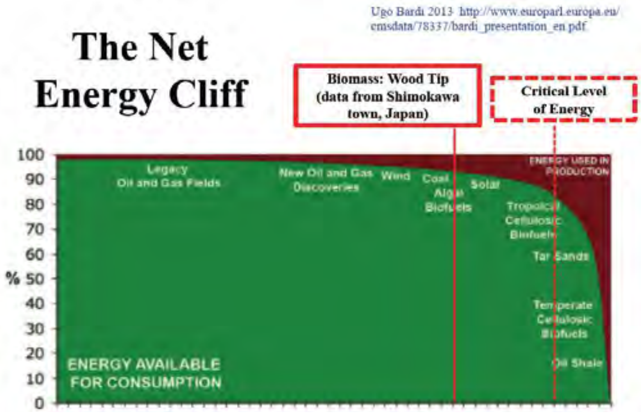


Fig. 50.   Diagram on Net Energy Cliff of various energy

Table 2. EPR of various energy

Generation type	EPR	Location	Reference
Coal thermal power generation	6.6	Japan	Amano, 2008
Oil thermal power generation	7.9	Japan	Amano, 2008
LNG thermal power generation	2.1	Japan	Amano, 2008
Atomic power generation	6.7-16.9	Japan	Amano, 2008
Small/ medium size hydro power generation	15.3	Japan	Amano, 2008
Geo thermal power generation	6.8	Japan	Amano, 2008
Solar power generation	5.2	Japan	Amano, 2008
Wind-mill power generation	3.9-11	Japan	Amano, 2008
Wood energy for Boiler or CHP* power generation	20.5	Finland	NEDO oversea report, 2006 No.983
Wood energy for Boiler or CHP* power generation	15.5	Sweden	NEDO oversea report, 2006 No.983
Wood energy for Boiler or CHP* power generation	4.5	Date, Japan	Tsuji,2009
Wood energy for Boiler or CHP* power generation	10	Akagi, Japan	Tsuchiya & Karasawa, 2009
Wood energy for Boiler or CHP* power generation	5.8	Ashoro, Japan	Tsuji,2009
Refused-Derived Fuel (RDF) for Boiler or CHP* power generation	10	Furano, Japan	Tsuji,2009

*CHP: combined heat & power

EROI has decreased drastically to around 6.0, which is called as the Net Energy Cliff (Fig. 50). In fact, in energy crisis, we can depend on energy of less than the 6.0 EROI, such as that obtained from tropical cellulose biofuel (alcohol), temperate cellulose biofuel (alcohol), tar sands, and oil shale.

If the EPR estimation includes the facility cost (construction and destruction), it will become <10, which is close to the Net Energy Cliff. Even by using solar power generation, wind-mill power generation and/or geo thermal power generation, the EPR remains nearly 6.0.

The EPR of wood energy for boiler or combined heat and power generation and small/medium-sized hydropower generation are >10 (Table 2). Wood energy is sometimes evaluated at <10, because the process of making pellet consumes much energy (Figs. 51 and 52).

Fig. 51. Wood chip production (high EPR)

Fig. 52. Wood Pellet Production (low EPR)

3) Biomass and high financial return products

Oil palm in peatland is a high financial return crop, but it is a non-native species that requires drainage, and hence the SDGs mark drops extremely. It is therefore recommended that oil palm cultivation be reduced in peatlands. Alternative native crops should be cultivated in peatlands such as sago, illipe nut, and candlenut, which give high financial returns through products and biomass (Fig. 53).

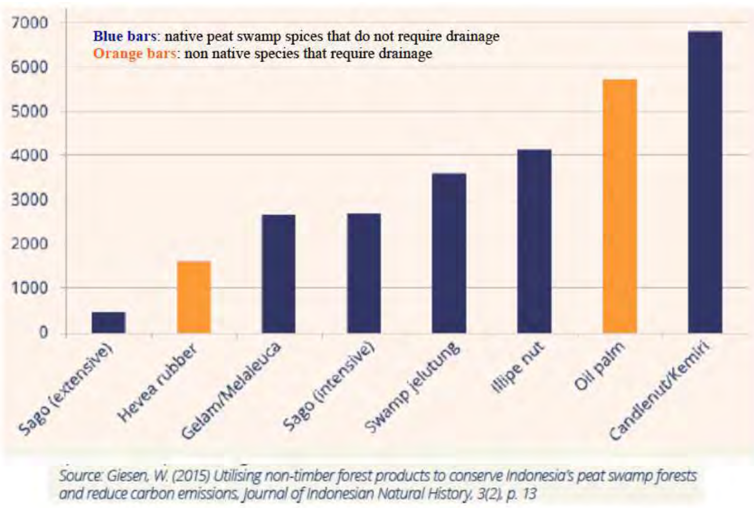


Fig. 53. Financial returns for a range of agricultural commodities on peat

(6) New economic paradigm (including palm oil)

Oil Palm Plantation in the LWT-Peatland Ecosystem (dry peatland) is basically a **high vulnerability and low resilience system**, because the function as water reservoirs in oil palm plantation is poor, which causes peat fire and peat degradation by microorganisms and accelerates land dryness by using a large amount of water for oil palm trees (Fig. 54). Thus, to cultivate oil palm in peatlands, an improved methodology in which oil palm can grow in 40-cm water table level needs to be developed.

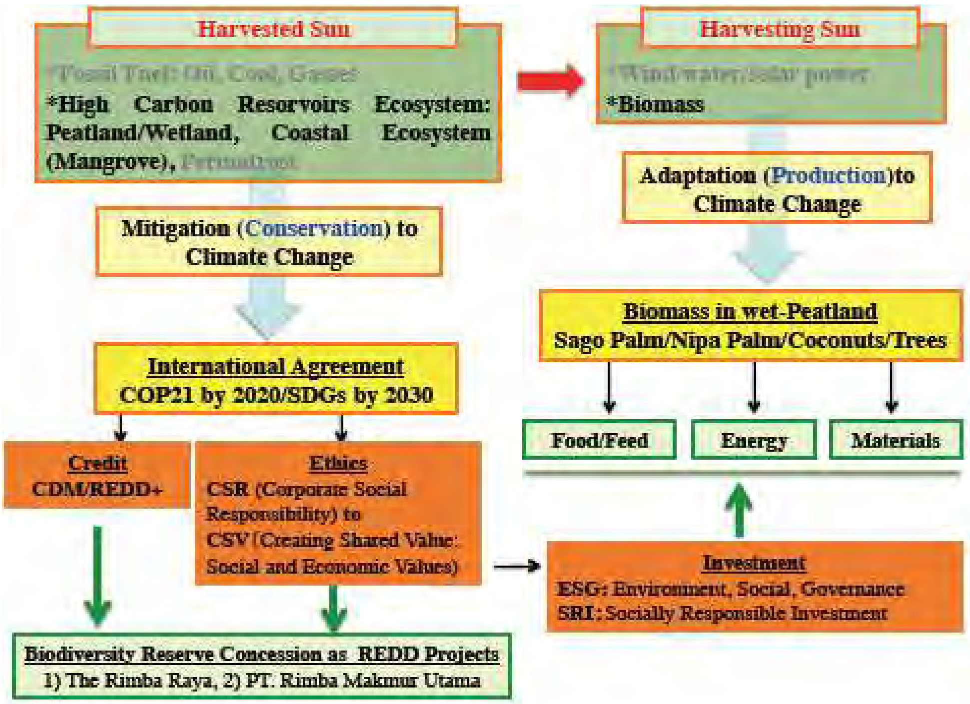


Fig. 54. New Economic Paradigm on Peatland Restoration

1) Negative Impact on national security by conventional Oil Palm Plantation in peatland

In conclusion, oil palm growth in dry peatland can cause serious damages to the environment thorough carbon emission and Water Resources Losses (Fig. 55). Oil palm plantation encounters international restriction and binding, some of which are listed below:

a) <u>Mitigation of Climate Change</u>: "High Carbon Reservoir Ecosystem" (especially peatland and mangrove (costal ecosystem in tropical regions) by COP21 agreement and SDGs agreement

b) <u>Company Ethics CSR to CSV:</u> Social and Economic Values): Restriction of Investment following ESG or

SRI

c) Consumer boycott: Consumer request stronger stoppage of oil palm plantation in peatland.

d) Filing suit: Soybean Oil producer in USA should file a suit against palm oil companies.

e) Haze issues: As ASEAN and APEC argue about peat fire, the Indonesia Government must follow these decisions.

2) ABCDEFs Securities on Oil Palm

As discussed, oil palm in peatland has encountering eight serious bindings, indicating that oil palm in peatland has achieved the symbol of ABCDEFGs Securities Crisis. To avoid corruption of all oil palm or palm oil companies, it is recommended to reduce oil palm plantations in peatlands and concentrate on investing in oil palms on mineral soils.

Oil palm plantation reduces both ABCDEFGs Securities and SDGs evaluation (Fig. 45).

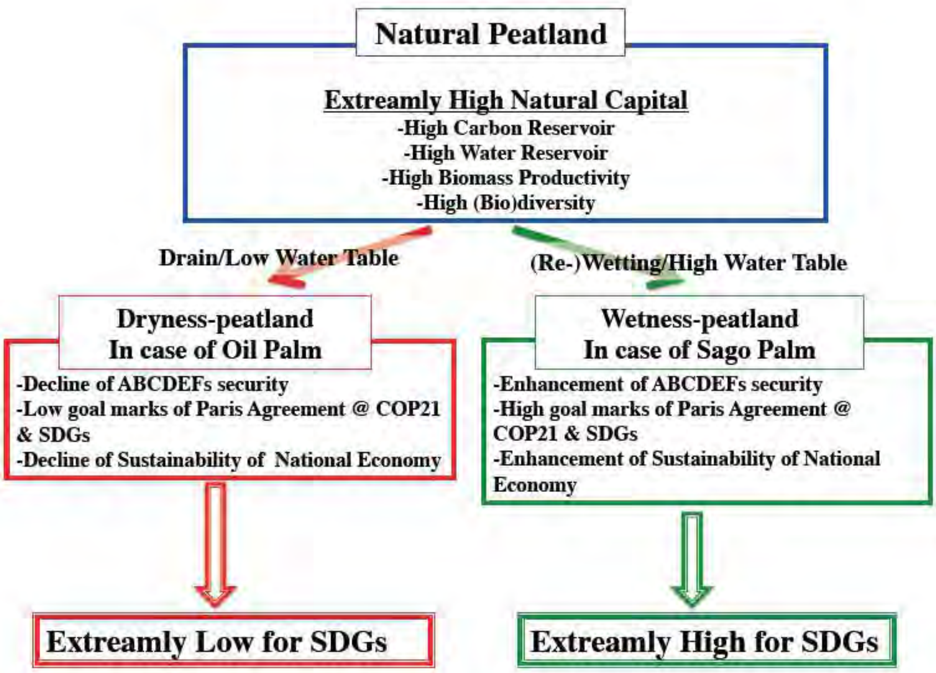


Fig. 55. SDGs value by different peatland management

3) Oil palm growth at 40-cm ground water table

The paper "Best Management Practices for Oil Palm Planting on Peat: Optimum Groundwater Table" (Othman et al., 2010) is a good reference that highlights the issues in the relationship between oil palm growth (Fresh Fruit Bunches, FFB) and high groundwater table (Fig. 56). According to this paper, the following are some of the best water management practices:

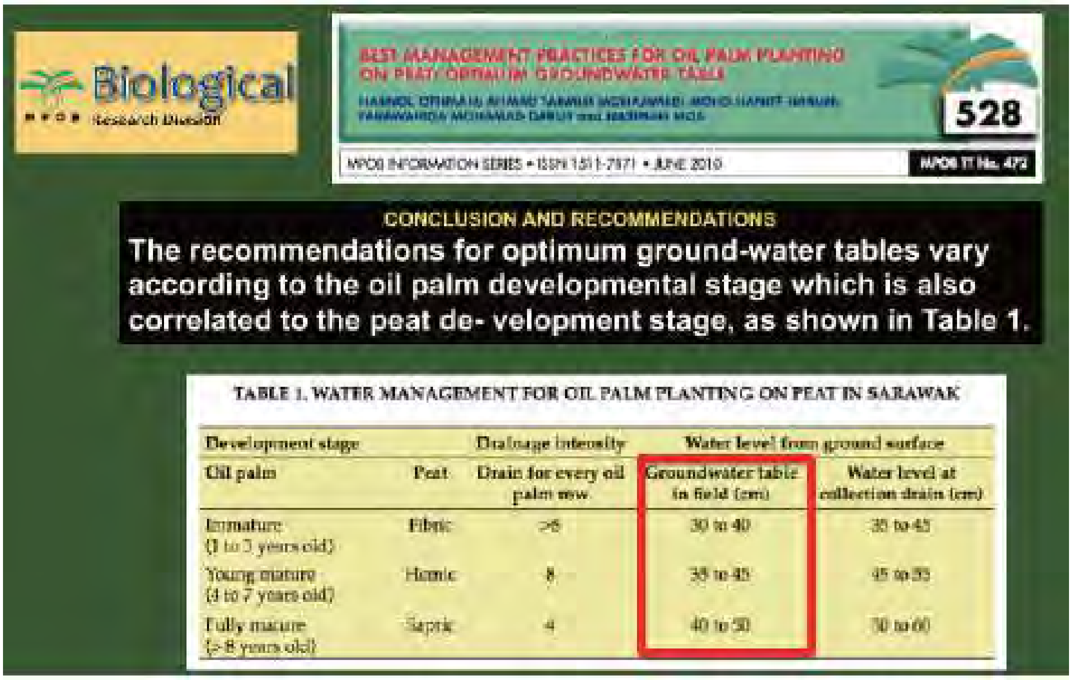
1. The field design needs to provide space to accommodate maneuvering of machinery used for the maintenance of collection and main drains

2. The intensity of field drains needs to be differentiated by the peat decomposition stage, i.e., higher intensity is required for an area with sapric peat materials as compared to that with fibric peat materials

3. The peat surface topography must be considered

4. The groundwater table must be monitored regularly by checking the water levels in the collection drain and by checking the piezometers installed in the planting block and

5. The drainage system must maintain water quality by flushing out stagnant water in the field drains during the wet seasons.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CONCLUSION AND RECOMMENDATIONS

The recommendations for optimum ground-water tables vary according to the oil palm developmental stage which is also correlated to the peat de- velopment stage, as shown in Table 1.

TABLE 1. WATER MANAGEMENT FOR OIL PALM PLANTING ON PEAT IN SARAWAK

Development stage		Drainage intensity	Water level from ground surface	
Oil palm	Peat	Drain for every oil palm row	Groundwater table in field (cm)	Water level at collection drain (cm)
Immature (1 to 3 years old)	Fibric	>6	30 to 40	35 to 45
Young mature (4 to 7 years old)	Hemic	8	35 to 45	45 to 55
Fully mature (>8 years old)	Sapric	4	40 to 50	50 to 60

Fig. 56. Water Management for Oil Palm Planting on Peat in Sarawak

The mean monthly groundwater table levels in the three blocks were different (Fig. 57).

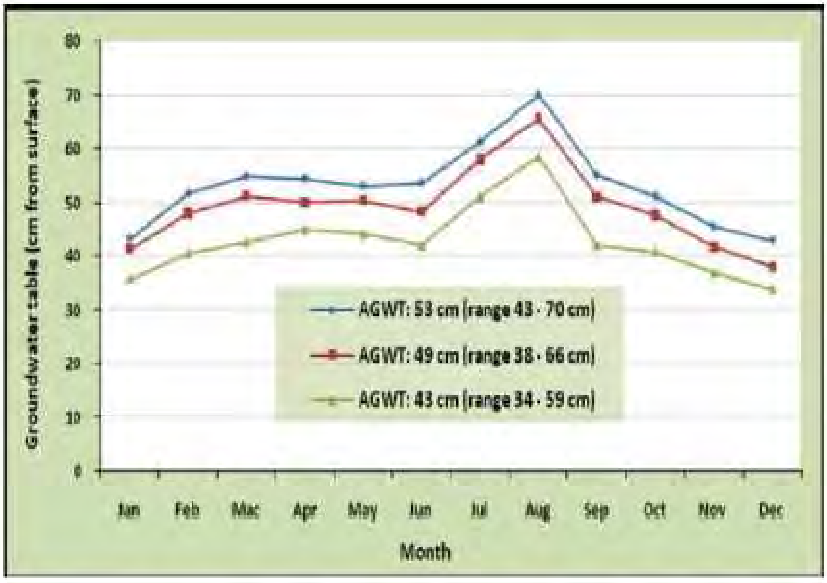


Fig .57. The mean monthly groundwater table in 3 different blocks planted with oil palm (AGWT: average groundwater table)

The estimated CO_2 emission was greater in lower groundwater table. AGWT 43 cm was a better water table management method to reduce CO_2 emission, while AGWT 50–60 cm was the worst (Fig. 58).

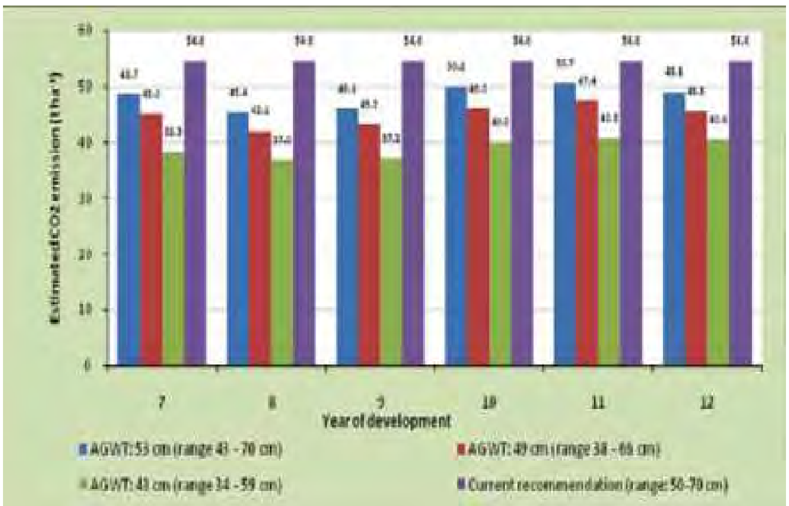


Fig. 58. Estimated CO_2 emission at different groundwater tables after 7 to 12 years of peat development

Although FFB yield was different among the 3 AGWLs at 6^{th} to 8^{th} years of harvest, the difference is only 15% (maximum) and there is no difference during the other harvest years (Fig. 59).

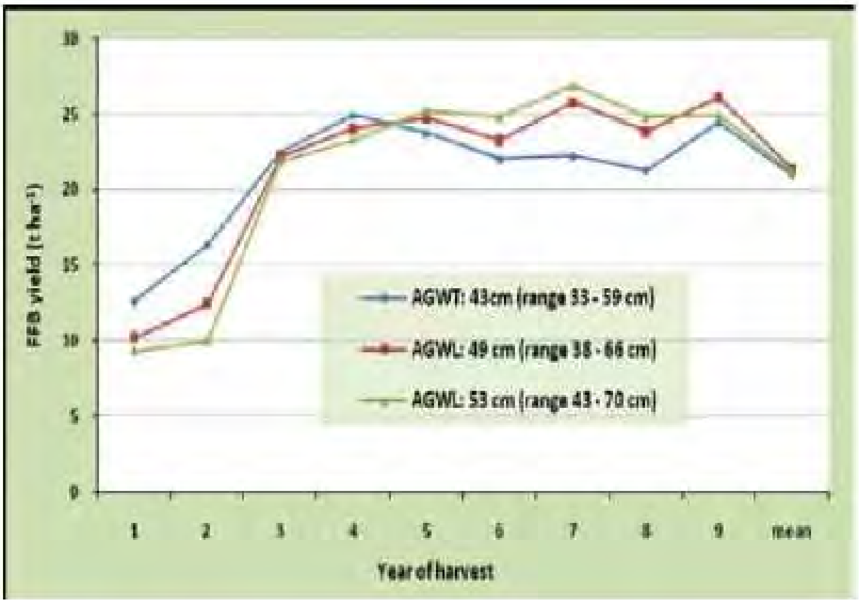


Fig. 59. Fresh Fruit Bunches (FFB) yield profile of 3 blocks with different groundwater table levels

In conclusion, 43 AGWL cm is a good criteria for oil plant cultivation.

Innovated Technology for peatland surface management

As shown in Figs. 60–62, oil palm can grow well even in HWT level, with new technologies such as "Artificial Aerial Root Formation on Peatland Surface". In this method, the nutrients are supplied from mainly the peat surface; therefore, HWT level does not reduce the oil palm growth and productivity, which gives greater yields of oil fruits because of high photosynthesis ability even in dry seasons. For surface peat management, compost and biochar are important elements (Figs. 40 and 60).

Fig. 60. A case study of oil palm growth in high water table (around 20–30-cm water table level)

Fig. 61. A case study of oil palm growth conditions in high water table level

Fig. 62. “Artificial Aerial Root Formation” on a peatland surface

Fertilizer components in the plastic bug method are composed of the following:

1) Biochar (or coal), composts (weeds), rock phosphates

2) Microorganisms: N_2-fixing bacteria, VAM (mycorrhiza), and

3) Slow-release K^+ nutrient by the coated fertilizer.

As K^+ is a limitation in soil nutrient in inland and inside of peatlands, it is necessary to design the application method for K^+ nutrient. On approach is to use a coated fertilizer (slow-release fertilizer) (Fig. 63). However, this method cost 2-times more than that used for normal fertilizers, but has high efficiency (2–3-times) as compared to normal fertilizers, the cost performance is compatible with the others.

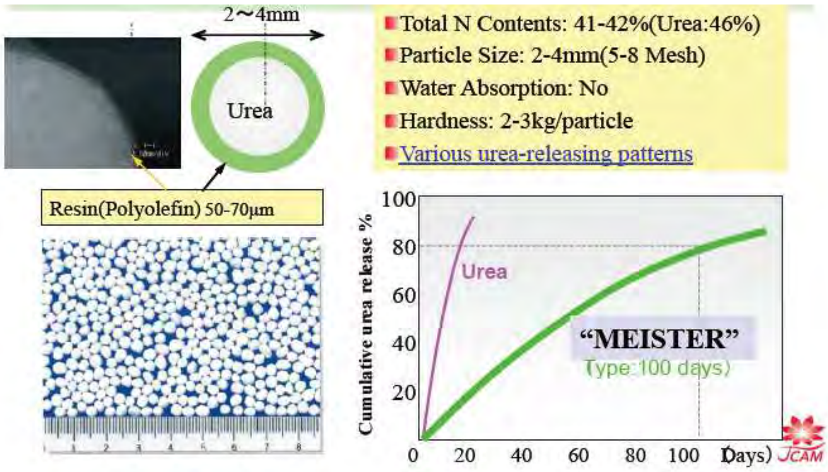


Fig. 63. Coated-fertilizer composition

(7) Socio-economy

Peatland restoration/rehabilitation activities should be performed in collaboration with local communities. The following information needs to be collected before initiating the peatland restoration/rehabilitation with several stakeholders:

-Survey the land poverty: Prepare land poverty condition such as "Hutan Desa"

-Cooperate with "Bumdes (Village Business Body)": Supporting independent social economic system by communities

-Evaluate groundwater level

-Monitor groundwater level and growth of seedlings

-Design and schedule rewetting and reforestation: small canal blocking that do not require opening and closing, sago forest mix with peatland forest

1) Land Rights

One of the key issues in peatland restoration is the land rights of state forests and communal forests. A stronger right of the locals would mean better care of peatlands (Fig. 64).

The land near the sea are privately owned land, while those far from the sea are state land in the study area, where extensive land is already degraded and abandoned. On a private land, rewetting is not difficult, but it is difficult on a state land because they are far from water resources. For rewetting in these areas, a collaboration with private companies would be helpful as they possess heavy equipment. Thus, rewetting should be performed in accordance with the difference in the social and ecological conditions.

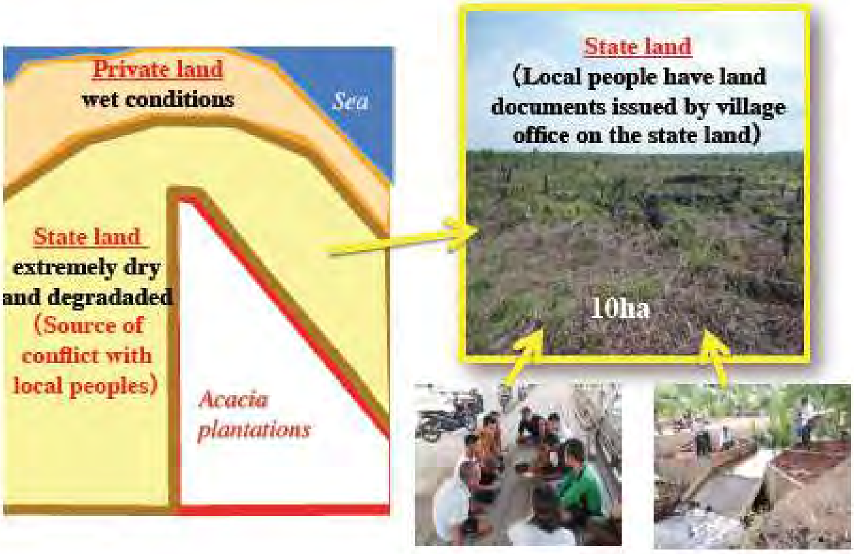


Fig. 64. Land rights issues on peatland restoration

2) Socio-economic development of Sago-based ecosystem

First, it is necessary to understand the socio-economic conditions of sago farmers, sago wet starch producers, and sago-dried starch producers at each level and understand them as a part of the sago agro-industry (Fig. 65). For each group, it is essential to understand from the capital, labor, land, and technological point of view.

For the present scenario, we found that the division of labor among farmers and producers at the cluster worked.

The analysis of productivity/income flow will be conducted at each level to understand the income of farmers, producers, and laborers involved. Technology, capital, labor, and lands will be analyzed at each level to clarify any bottlenecks. Methods to increase production would be studied As well to increase the demand of domestic and international markets for the products. Marketing analysis will be conducted and new sago-based product development would be initiated in collaboration with private companies or through international collaboration among producers/farmers. The welfare/livelihood of farmers, producers and laborers would be focused, both from sago planting/producing perspective and from a household economy perspective that includes occupations of the laborers beside sago plantation and production, such as fishery, agro-forestry, and off-farm/non-agricultural sectors. International certification system or PES will be incorporated in this analysis.

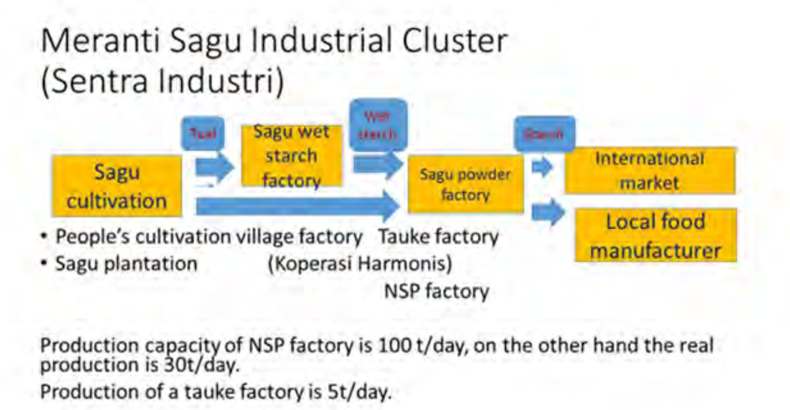


Fig. 65. Sago Industrial Cluster in Meranti

(8) Proposed pilot micro-hydrological units

Candidate Locations as Model Pilot Project Areas for Peatland Hydrological Units (PHU) (Kesatuan Hidrologi Gambut, KHG) are as follows:

1) **Tebing Tinggi Island: Riau Province, Sumatra, Indonesia**
2) **Kahayan-Sebangau Rivers: Central Kalimantan Province, Kalimantan, Indonesia**
3) **Musi Banyuasin District and Ogan Komering Ilir District: South Sumatera Provine, Sumatera, Indonesia**

1) Tebing Tinggi Island: Riau Province, Sumatra, Indonesia

The Tebing Tinggi Island is a sub-district in the Kepulauan Meranti of Riau Province (Fig. 66). The Kepulauan Meranti belongs to one of the priority restoration districts set by Peatland Restoration Agency (BRG). The criteria of areas that are set as a priority restoration districts include the existence of peatlands, drainage system as a canal indicator, and the post-fire, forest/land cover, and land statuses. The classification of restoration priority is as follows: i) post-fire 2015, ii) peat dome with canal (protected zone), iii) peat dome with no canal (protected zone), and iv) peatland with canal (cultivation zone).

The study area consisted of peat soil of depth up to 10 m. Until 2016, the condition of peatland in the Tebing Tinggi Island was degraded due to the conversion of land for agricultural or plantation activities. The land fires in 2013 to 2015 led to degradation of the peatlands in the Tebing Tinggi

Island. Based on the Landsat data analysis, the burned areas degraded from primary peat-swamp forest to disturbed/regrowth peat-swamp forest. The other areas that were not exposed to the fires remained safe as a primary peat-swamp forest. The existence of peatlands in the Tebing Tinggi Island was vulnerable to disasters when not maintained and managed properly.

Fig. 66. Model pilot project area in the Tebing Tinggi Islan Rivers Hyrlogical Unit

2) Kahayan-Sebangau Rivers: Central Kalimantan Province, Kalimantan, Indonesia

Kahayan and Sebangau are the two sub-districts in the Pulang Pisau district of Central Kalimantan Province. The Pulang Pisau districts belongs to one of the priority restoration districts set by the Peatland Restoration Agency (BRG). The Pulang Pisau district has the largest restoration priority area of 660,140 Ha in Central Kalimantan. The Pulang Pisau district has two large peat domes, mostly in the central and southern regions, with peat depth ranging from 0.5 cm to >2 m.

Fig. 67. Model pilot project area in Kahayan-Sebangau Rivers Hydrogical Unit

Pealand degradation in the Pulang Pisau district caused by the Peatland Development Project (PLG) in 1995 through the conversion of 1 million ha of peatlands into rice fields. Hundred kilometers of canal was built and have become the major cause of serious environmental problems and fire. The project failed because the land was not suitable for rice crops. Based on the hotspot cluster analysis data (KLHK), the area that was exposed to fire in 2015 in the Pulang Pisau was 98,784 ha, including Kahayan Tengah, Jabiren Raya, Kahayan Hilir, Maliku, Pandihbatu, Sebangau-Kuala, and Kahayan-Kuala (Fig. 67).

Palangka Raya University (UNPAR) applies Peatland Restoration Concession, wherein several model restoration programs will be implemented in this area (Fig. 68).

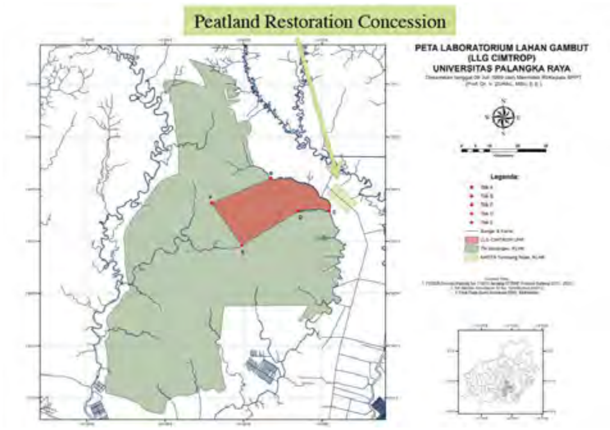


Fig. 68. Peatland Restoration Concession of Palangka Raya University

3) Musi Banyuasin District and Ogan Komering Ilir District: South Sumatera Provine, Sumatera, Indonesia

Based on the data of the Ministry of Environment and Forestry, Ministerial Decree Environment and Forestry Number SK. 129/MenLHK / Setjen / PKL.0 / 2/2017, there are 32 KHG (peatland hydrological unit/PHU) in South Sumatra (Fig. 69). The target of peat restoration in South Sumatra Province within 2016–2020 is expected to reach 848,325 ha spread across five districts. Most of the restoration targets are located in the cultivation areas (legal), while the remaining areas fall in some protected areas and cultivation areas (illegal).

In 2017, BRG prioritized peat-restoration activities at 9 KHG (KHG Sugihan river–Lumpur river, KHG Hitan Laut river - Buntu Kecil, KHG Lalan river - Merang river, KHG Merang river–Ngirawan river, KHG Ngirawan river–Sembilang river, KHG Saleh River - Sugihan River, KHG Sei Lalan - Bentayan River, KHG Bentayan River–Penimpahan river, KHG Penimpahan river–Air Hitam river) in three regencies—Ogan Komering Ilir Regency, Musi Banyuasin Regency, and Banyuasin Regency.

The main focus of the restoration sites in South Sumatera is in the Musi Banyuasin District and Ogan Komering Ilir districts. These areas are quite large and prone to burning. Planning and implementation priorities, as referred in the Presidential Decree No. 1 2016 shall start from these two districts as well as from two other districts that have been already mentioned in the previous section.

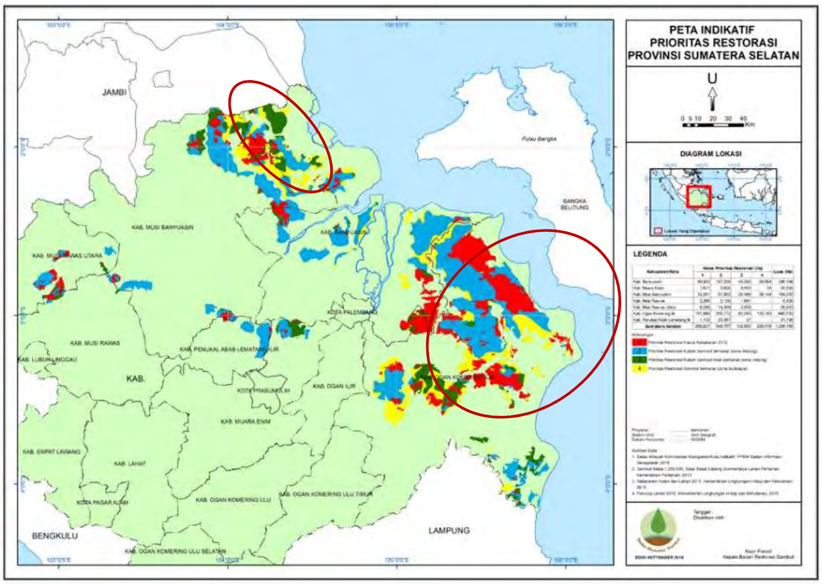


Fig. 69. Model pilot project area in Musi Banyuasin district and Ogan Komering Ilir district.

3-4-3. Capacity Building

(1) University consortium

1) BRG Program of University Network

We collaborate with BRG-University Network

2) Kalimantan University Consortium

Purpose/Objective: Facilitating communication and collaboration among core universities and research institutes on topics related to climate change; coordinating internal, external, and international research cooperation and collaboration; exchanging research outputs for broader dissemination of information; promoting necessary trainings to improve research workers' skills, up taking and applying research outputs (in education, research, and service to society), including regulations at the national and regional levels; establishing new ideas, opportunities, and inputs; and facilitating policy makers in scientific decision-making.

Background: The recent environmental issues arising from climate change are dominantly focused on the tropical areas. To eliminate the impacts of climatic change in these areas, strategic managements to combat issues in tropical areas is important. The Indonesian Kalimantan Region plays an undoubtedly important role in reducing the carbon emission by sustaining its ecosystem

function while supporting the need for local and regional social life.
Borneo, which is the third-largest island in the world, is composed divided of three countries, viz., Brunei, Malaysia, and Indonesia. Approximately 73% of this island is Indonesian territory, called Kalimantan. The Borneo rainforest is 130 million years old, and hence the oldest rainforest in the world, 70-million years older even to the Amazon rainforest. Borneo is extremely rich in biodiversity than other areas of the world, with about 15,000 species of flowering plants, 3,000 species of trees (267 species are dipterocarp), 221 species of terrestrial mammals, and 420 species of resident birds (MacKinnon et al. 1998).

Activity: Kalimantan has five state universities (UNPAR, UNMUL, UNTAN, UNLAM, and UB), which are the center for research, education, and extension. The roles of local universities are important in (i) executing research supervision, ii) coordinating, iii) socializing, iv) providing science-based advice, and v) engaging in various CC-related Working Groups. While sharing the surrounding tropical rain forest ecosystem, these five educational centers need to work toward improving their role by enhancing coordination, communication, collaboration, and cooperation among themselves in executing research, education, and extension works. The need for an institution to cater to this idea is, therefore, necessary. Establishing the Trans Kalimantan Universities Network is expected to scale-up the roles of these universities, particularly in addressing climate change. The tentative aims of the network are as follows: (further discussion is needed to establish concrete objectives):

a) Facilitation of communication and collaboration among core universities and research institutes on topics of climate change;
b) Coordination of internal, external, and international research cooperation and collaboration;
c) Exchange of research outputs for broader dissemination of information;
d) Facilitation of the necessary training to improve research workers' capacity, uptake, and application of research outputs;
e) Establishment of new idea, opportunities, and inputs;
f) Advising policy makers for scientifically based decision.

The participating universities: The initial participating universities of this network will be five core state universities located in Kalimantan (i.e., Tanjungpura University, Palangka Raya University, Lambung Mangkurat University, Mulawarman University, and Borneo University (Fig. 70). Research activities and information sharing may also be established with other national universities and local private universities that undertake climatic change-related activities.

Fig. 70. Kalimantan Universities Consortium

3) Sumatra Universities Consortium

Fig. 71. Sumatra Universities Consortium

(2) Training program

Training program will be developed with i) CIMTROP (Palangka Raya University), ii) Research Center of Tropical Peatland (Riau University), iii) CENTRE FOR FORESTRY RESEARCH PALEMBANG, etc.

1) CIMTROP (Palangka Raya University)

2) Research Center of Tropical Peatland (Riau University)

3) CENTRE FOR FORESTRY RESEARCH PALEMBANG

3-4-4. Establish "Research-Training-Extension Center" (RTEC) for Tropical Peatland Restoration

RTEC is a platform for i) training and extension, ii) project collaboration, iii) documentation, iv) data sharing, and v) networking.

In the past, several scientific studies were performed and reported through papers, reports, books, manuals, guidebooks, etc. on stoking data and information and developing new technologies. However, once a project finishes, all data are generally scattered and lost.

For example, in our long-term collaboration research in Central Kalimantan, we obtained long-term monitoring data, which is extremely useful to understand the method by which peatlands can be rehabilitated, restored, and conserved 2) to develop models and maps with remote-sensing data, and to exchange ideas and information on peatland management based on science and technology.

Following is a case of our long-term collaboration projects at the MRP site in Central Kalimantan, Indonesia. The key projects started from i) JSPS Core University Program (1997–2006) "Environmental Conservation and Land Use Management of Wetland Ecosystem in Southeast Asia", and then continued as ii) JST-JICA Project (SATREPS) (2008–2014) "Wild Fire and Carbon Management in Peat-Forest in Indonesia", iii) JICA Project as a follow-up of SATREPS (2015–2016) "Formulation of a Manual and Trial Calculation of GHG Emission from Peatland in Central Kalimantan", and iv) JICA-BRG program (2016–) "Collaboration with Tropical Peatland Restoration" (Fig. 72).

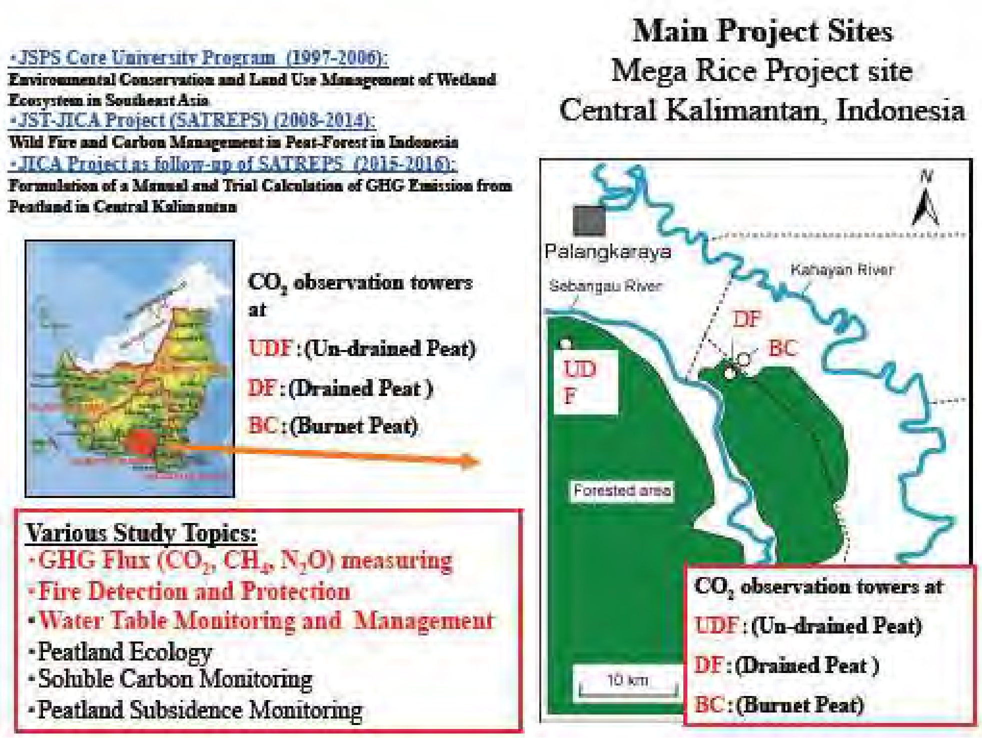


Fig. 72. A case of Hokkaido University Project in Central Kalimantan from 1996

During these projects, various topics were studied, some of which are stated below:

- GHG Flux (CO_2, CH_4, N_2O) measuring
- Fire Detection and Protection
- Water Table Monitoring and Management
- Peatland Ecology
- Soluble Carbon Monitoring
- Peatland Subsidence Monitoring

Training Program

The training program will be developed with i) CIMTROP (Palangka Raya University), ii) Research Center of Tropical Peatland (Riau University), iii) CENTRE FOR FORESTRY RESEARCH PALEMBANG, and others.

Data Sharing Program

1) Develop data server (retrospective data collection and real-time data management)
2) Develop iLibrary (all peatland information on several papers, reports, books, manuals,

guidebooks, and TV documents).

Action plan on model pilot project

1) MRV System development: At this stage, the main focus is on measuring system, but there is a need to develop reporting and verification systems as well.

2) Estimation of SDGs effort: As SDGs has several criteria, the criteria for peatland restoration should be standardized for evaluation of projects, programs, production activities by new SDGs criteria in a uniform manner.

International Networking

1) Collaborate with international organization such as CIFOR, ICRAF, FAO, and others
2) Collaborate with NGOs such WWF and WI
3) Collaborate with donors such as????

Table 7-2　Appendix 2

Pilot Project Proposal for "Innovative Oil Palm Cultivation at High Water Level in Tropical Peatland" -AeroHydro Culture System for the Responsible Management of Tropical Peatland-

Background

Based on the UNFCCC workshop entitled "Technical and scientific aspects of ecosystem with high-carbon reservoirs not covered by other agenda items under the Convention," in the context of wider mitigation and adaptation efforts, climate change mitigation strategies should include tropical peatland because it is a carbon-rich ecosystem. The Blue Carbon Initiative has already been established to focus on mitigating climate change through the conservation and restoration of coastal and marine ecosystems and Silver Carbon for permafrost ecosystems; additional promotion is now required for a Cold Carbon Initiative for peatland ecosystems. This initiative will contribute to the Paris Agreement (COP21), SDGs, Natural Capital, and National Security.

It is estimated that more than half of the tropical peatland areas are located in Southeast Asia, particularly Indonesia. Tropical peatlands have unique formations compared to others. However, they are under a tremendous threat due to extensive degradation, draining, and deforestation of these areas.

For more than 20 years, Indonesian as well as international scientists have collaborated on the study of peatland ecosystems and restoration methods, and these studies resulted in numerous publications. The results of some studies have been used for Indonesian ministerial regulations on peatland management. Examples of such regulations include the requirement that ground water levels in peatland plantations must be maintained at ≤40 cm below ground level or that 30% of any peat dome must be allocated for peat dome conservation (according to Government Regulation No. 57 Year 2016 on Protection and Management of Peatland Ecosystem). However, further studies are still required to convince many stakeholders to accept these regulations.

In early 2016, Joko Widodo, the President of the Republic of Indonesia, issued a regulation establishing the Peatland Restoration Agency (BRG) and mandating the restoration of two million hectares of peatland ecosystem in 5 years. While there is an urgency to achieve peatland restoration in Indonesia, it faces challenges from the presence of multiple stakeholders, such as oil palm and pulp wood plantation companies and other agro-industries (i.e., Sago palm, Nipa palm, Coconut palm, Coffee, Cacao, Pineapple, Rubber, and other native species for food and produce the biomass for bio-energy), because these stakeholders do not wish to increase the water table or keep it at a high level.

Peatland management is complex not only because of the presence of multiple stakeholders but also because of the natural characteristics of peatland ecosystems. There are multiple elements that should be considered in managing peatland, such as 1) ground water level, 2) nutrient status of peat soil and water, and 3) oxygen availability. The primary cause of plant growth restriction in high water tables is the lack of oxygen supply, followed by a lack of nutrients. Therefore, here we propose an innovative plant culture system called "AeroHydro Culture System" (i.e., plant culture under high water table conditions, with oxygen/nutrients supplied from the land surface).

If this cultivation system is successful, it will have a huge impact on the responsible management of tropical peatland. Herein, we propose a pilot project in the oil palm plantation; it is believed that oil palm growth and fruit productivity are extremely sensitive to the water table level: water table level of 50–70 cm below land surface is recommended. Because of the complex problems, three locations have been selected for these studies: 1) KHG Sungai Kampar - Sungai Gaung (Riau); 2) KHG Sungai Sugihan - Sungai Lumpur (South Sumatera); and 3) KHG Sungai Terentang - Sungai Kapuas (West Kalimantan). The duration of the experiment will be 3 years; however, it is expected that K+ deficiency will recover in the first 6 months and fruit productivity will increase after 1 year. Best practice methodology will then be established during the next 2 years. Once the AeroHydro Culture System is established and successful, it may be applied on different locations or to other food crops/cultivation crops.

Objectives

The ultimate objective of this pilot project is to establish the AeroHydro Culture System, which is a new and innovative cultivation method for oil palm under high water table conditions, while obtaining nutrients and oxygen from the land surface.

Principle of Peatland

What are the key limiting factors of plant growth in tropical peatlands (Fig 1)?

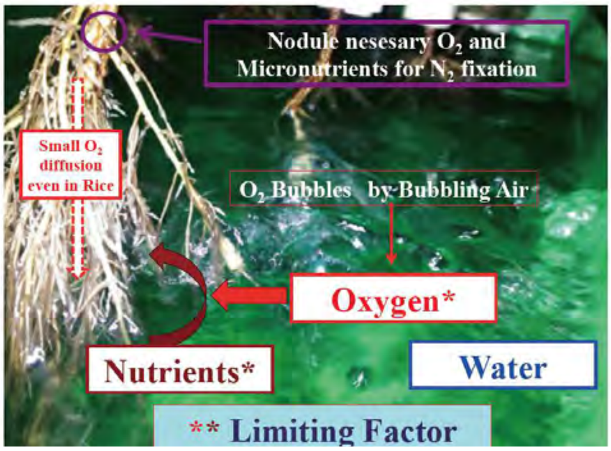


Fig 1. Limiting factors in Hydro Culture as a model of peatland

Limiting factors: oxygen (low solubility in water) and nutrients

1) **Limited oxygen in water:** Extremely low oxygen solubility in water

2) **Limited nutrients in peat soil:** a) Extremely low nutrient adsorption ability in low pH (pH < 4.0) soil, thereby causing nutrient leaching even with a high rate of fertilizer application and b) water supply mainly from rain (no nutrient content)

3) **Oxygen is required by roots for nutrient absorption:** Oxygen supply must be sufficient to accommodate rapid consumption because oxygen is required for the energy-dependent process of nutrient absorption (i.e., if no oxygen is present, no nutrients will be absorbed)

4) **Oxygen is required by root nodules for N_2 fixation:** The oxygen supply must be sufficient to accommodate N_2 fixation in legumes

What are growth strategies of plants in natural peatland (high water table) (Fig 2)?

1) **Aerial root formation**: Oxygen is absorbed from the air

2) **Mound root formation**: Oxygen is absorption from the air and nutrients are absorbed from plant litter on the mound

Fig 2. Aerial Roots and Mound Roots for oxygen and nutrients absorption

Field Observation

1) Conventional cultivation

Conventional and typical cultivation of oil palm is at low water table (50–70 cm) using a high fertilizer application rate, particularly K^+. However, oil palm leaves show very serious symptoms of K+ deficiency, indicating that almost all K^+ fertilizer applied gets leached (Fig 3).

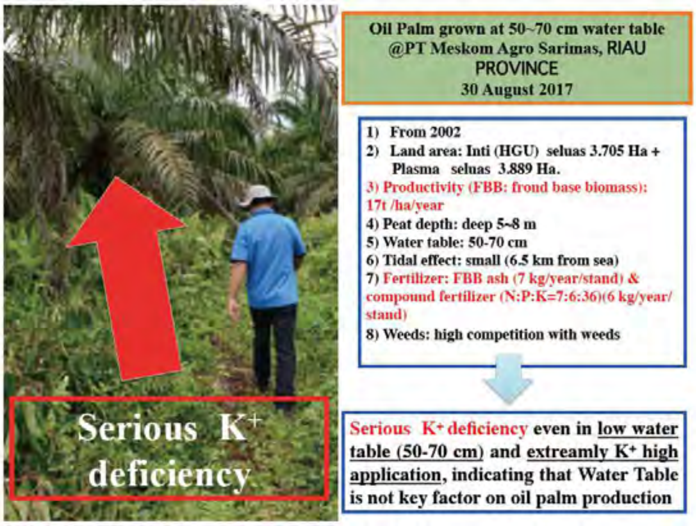


Fig 3. Serious K+ deficiency symptoms under conventional cultivation methods in oil palm planation even at a low water table of 50–70 cm and extremely high rate of K+ application

K^+ leaching mechanisms: Why does K^+ act as a limiting factor? Because the organic matter (peat soil) has a very low pH (pH < 4.0) and the cation content is also very low, if fertilizer is applied to peat soil, all nutrients, particularly K^+, leach immediately by desorption mechanisms. As K^+ is always present in ionic form (it does not react to form new compounds), it leaches easily (Fig 4). As other nutrients are absorbed, some accumulate in microorganisms and produce additional chemical compounds. These chemical compounds are then retained and decompose slowly in peat.

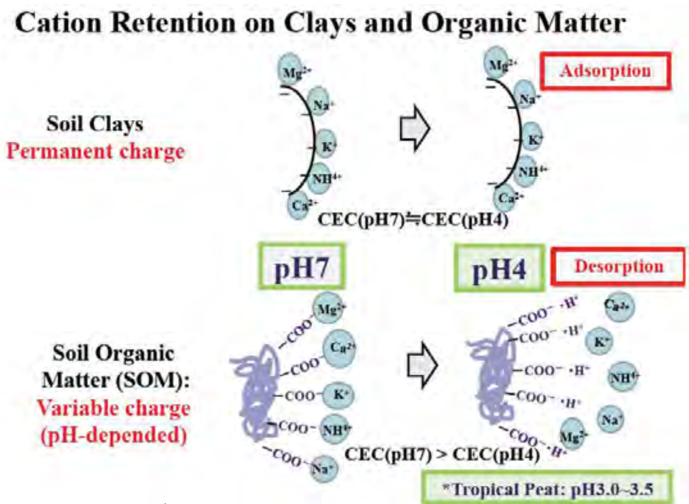


Fig 4. K^+ leaching mechanism by K^+ desorption in peat (organic soil) at low pH (pH < 4.0)

Poor root growth: When K^+ is deficient, root growth is poor because K+ functions in photosynthate translocation into the roots. Ultimately, because root growth is poor, nutrient absorption decreases, thereby establishing a negative feedback loop (Fig 5).

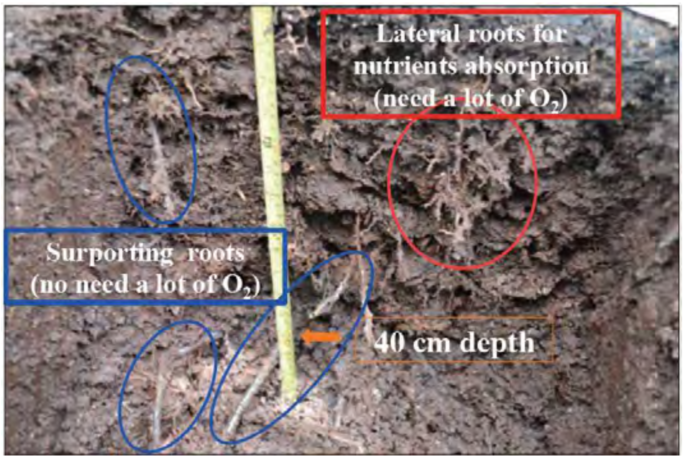


Fig 5. Poor root growth produced by negative feedback of K^+ deficiency

2) Water Level Recommendation:

A detailed study on drainage and water management for oil palm cultivation was reported by HASNOL OTHMAN et al (2010) (Fig 6). Good groundwater and water table management practices for good productivity in the field are as follows:

1) Immature (1–3 years old): 30–40 cm
2) Young mature (4–7 years old): 35–45 cm
3) Fully mature (> 8 years old): 40–50 cm

Thus, maintenance of the water table at 40 cm is acceptable for good water management practices for good productivity.

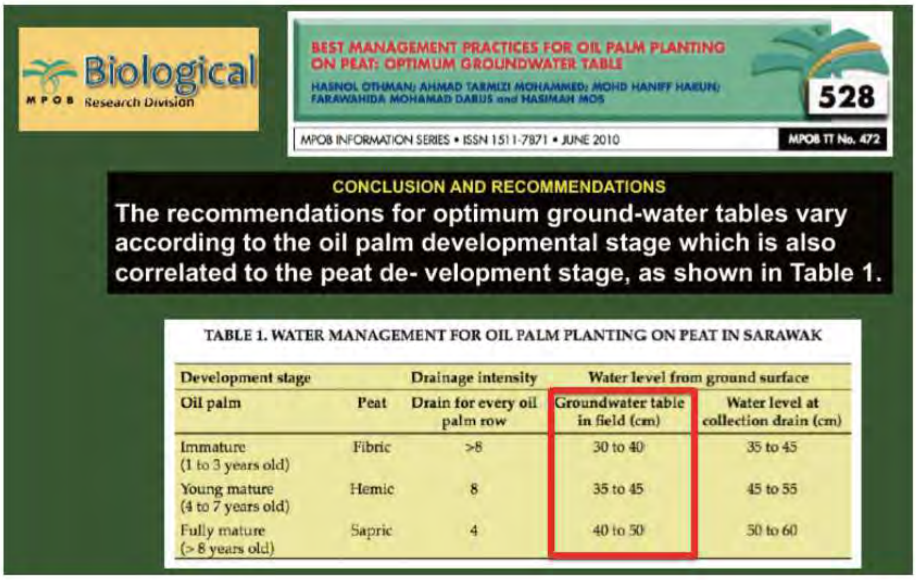


TABLE 1. WATER MANAGEMENT FOR OIL PALM PLANTING ON PEAT IN SARAWAK

Development stage		Drainage intensity	Water level from ground surface	
Oil palm	Peat	Drain for every oil palm row	Groundwater table in field (cm)	Water level at collection drain (cm)
Immature (1 to 3 years old)	Fibric	>8	30 to 40	35 to 45
Young mature (4 to 7 years old)	Hemic	8	35 to 45	45 to 55
Fully mature (> 8 years old)	Sapric	4	40 to 50	50 to 60

Fig 6. Recommendations for optimum groundwater tables (HASNOL OTHMAN; AHMAD TARMIZI MOHAMMED; MOHD HANIFF HARUN; FARAWAHIDA MOHAMAD DARUS; and HASIMAH MOS: BEST MANAGEMENT PRACTICES FOR OIL PALM PLANTING ON PEAT: OPTIMUM GROUNDWATER TABLE, MPOB INFORMATION SERIES, MPOB TT No. 472, ISSN 1511-7871, June 2010, Malaysian Palm Oil Board, Ministry of Plantation Industries and Commodities, Kuala Lumpur, Malaysia)

3) Growth in near-coastal regions:

Oil palms can grow in coastal intertidal zones, indicating that the water table is high and seawater supplies nutrients, particularly K^+ (Fig 7). Oil palms are tolerant to high osmotic pressure because they are adapted to dry land conditions. It is strongly suggested that water itself is not a limiting factor nor are toxic compounds. Oil palm plantations in peatlands are in near-coastal regions, particularly in Malaysia, which provokes the misunderstanding that oil palms can grow well in all peatlands.

Thus, it is concluded that toxic compounds are not present in water, but nutrients are the greatest limiting factor.

Fig 7. Oil palm growth near mangrove zone without K+ deficiency symptom

4) Case study on cultivation under high water table conditions:

“United Plantations Berhad” Oil Palm Plantation in Malaysia (Fig 8):

1) High Water Table (>30 cm)
2) High Yield
3) Land surface management (Natural Compost and Grass Mulching)
4) The world’s first certified producer of sustainable palm oil by “The Roundtable on Sustainable Palm Oil” on August 26, 2008

This planation recommend maintaining the high water table and land surface management using green manure for fertilizer and natural compost formation in the field (Fig 8). Therefore, oil palm roots grow at the surface and maintain good root activity because they are able to absorb oxygen from the air and nutrients from the land surface.

Fig 8. Good practice of oil palm cultivation under high water table in Malaysia

7.8 **Oil Palm grown under high water table conditions in Mega Timur Village, Sungai Ambawang District, Kubu Raya Regency, Pontianak (Fig 9):**

1) Palm produced for 8 years over 14 ha by Mr. Suparjo (farmer)
2) High productivity: 40 ton/ha/year (very high productivity)
3) Sallow peat (1–2 m depth)
4) High water table (10–20 cm from surface)
4) Final stage of peat
5) Tidal effect
6) Soil surface management using organic matter

The water table is very high (>30 cm) and productivity is very high (approximately 40 t/ha/year) (Fig 9). This farmer utilizes very unique technology for nutrient application: 1) Natural Compost in the field (only composting old fronds of oil palm) and 2) chicken manure fertilizer and composts in netted plastic bags. Oil palm roots grow into natural compost and netted plastic bags, allowing them to absorb nutrients and sufficient oxygen. Roots look like aerial roots. In addition, a slight tidal effect is present in this location, which facilitates the supply of K^+ from sea water.

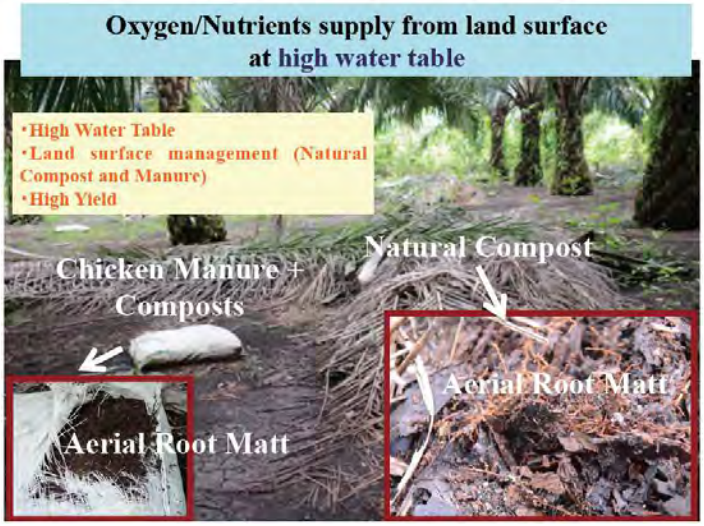


Fig 9. Good practice of oil palm cultivation under high water table conditions in West Kalimantan

Proposal on AeroHydro Culture System

It is concluded that sufficient nutrients/oxygen availability is key in peatlands with high water tables. We have developed a new and innovative culture system maintaining 1) a high water table and 2) nutrients/oxygen availability from the land surface, which is called AeroHydro Culture System. This system utilizes:

1) High water table
2) Natural composts by frond or cover crops
3) Slow release of K^+ and other nutrients from the coated fertilizer
4) Biochar

Expected Outcomes

It is expected that the pilot project will result in the following outcomes:

1) A proposal outlining an action plan for the responsible management of tropical peatland for "Innovative Oil Palm Cultivation"
2) Establish a committee who will be involved in the pilot project

Field Design

Water Table: 1) 50–70 cm (conventional), 2) 30–40 cm (for 1 year) and 10–20 cm (after 1 year)

Fertilizer application: 1) conventional application and 2) land surface application
Replication: 3
Size: 10 ha each

Field information: soil profile, pH, EC, nutrient concentration
Field monitoring:

Plant: leaf color, frond number, fruits productivity, root distribution

Soil: SESAME (water level, soil moisture, pH, EC, O_2, and micro climate)

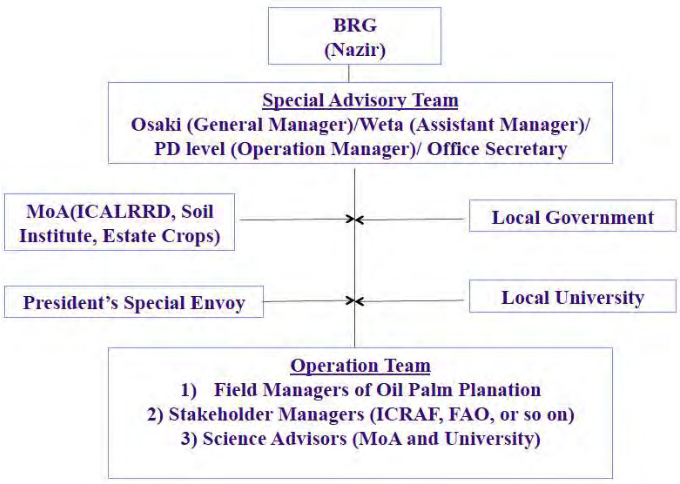
Water: DOC, pH, EC

CO_2 emission: Eddy covalence

Capacity Building

1) Training in Field
2) Production of a training manual

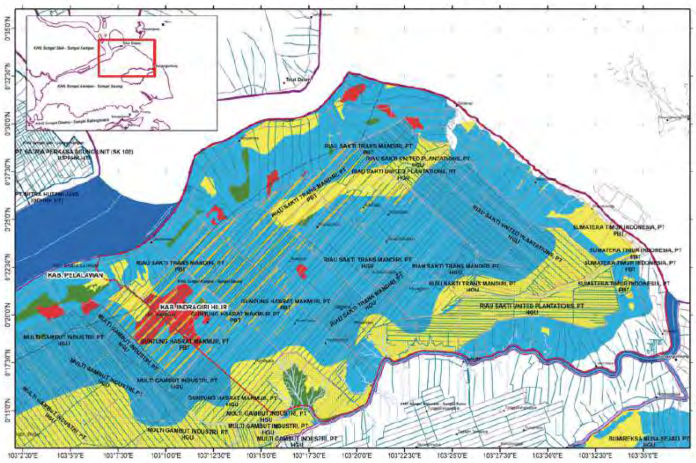
Organization



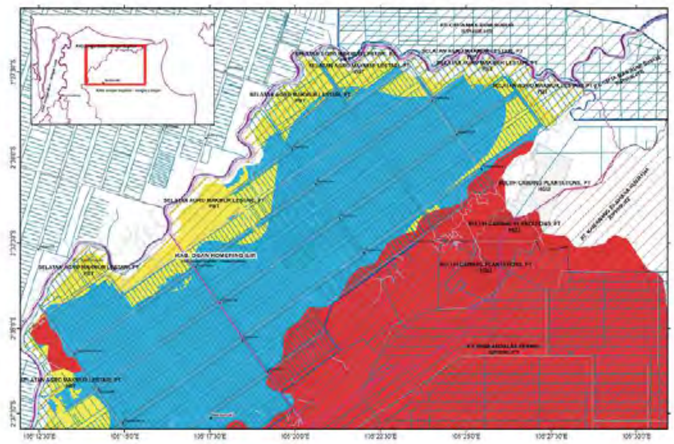
Field Sites

1) KHG Sungai Kampar - Sungai Gaung (Riau)
2) KHG Sungai Sugihan - Sungai Lumpur (South Sumatera)
3) KHG Sungai Terentang - Sungai Kapuas (West Kalimantan)

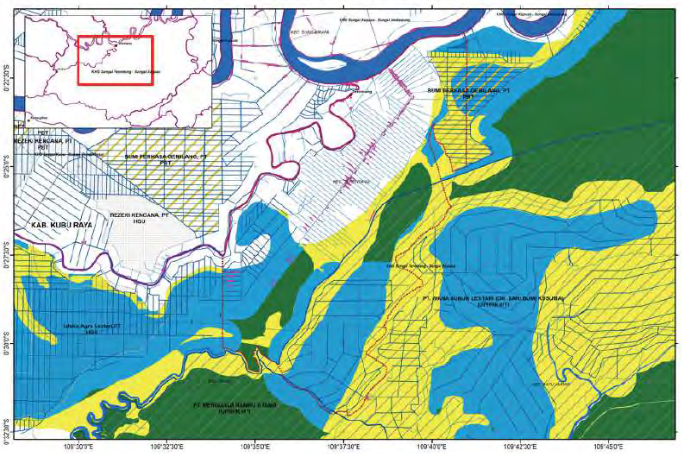
KHG SUNGAI KAMPAR - SUNGAI GAUNG



KHG SUNGAI SUGIHAN - SUNGAI LUMPUR



KHG SUNGAI TERENTANG SUNGAI KAPUAS



Budget

<Monthly Cost for **Community-based** AeroHydro Culture System Activities>

Human Resources:

Technical Advisor	USD 2000 × 1 person (based at Jakarta)
Field coordinator	USD 1000 × 3 persons (KHG based at three provinces)
Field facilitator	USD 700 × 3 persons (KHG based at three provinces)
Field administrator	USD 600 × 3 (KHG based at three provinces)
Field office cost	USD 1000 × 3 (KHG based at three provinces)
Transportation	USD 1000
Activities	USD 2000 × 3 KHG

(Total USD 18,900/month = USD 226,800/year)

Field Management for 100 ha

Fertilizer --

Canal Blocking --

Wetting --

Table 7-3 Appendix 3

Action Plan on Tree Cultivation Applying AeroHydro Culture and Nitrogen-Fixing Ecological System

Heavily damaged peatland restoration to prevent fire using the following strategies:

1) Canal blocking: As high a water table as possible

2) Canopy covering: Fast-growing trees (2 m growth in 6 months)

Action plan for quick restoration comprising two innovative methodologies:

1) AeroHydro Culture System
- High water table
- Oxygen/Nutrient supply from the land surface

2) Nitrogen-Fixing Ecological System
- Leguminous trees: Nodulation and nitrogen fixation in nodules
- Nonleguminous plants: Nitrogen fixation in aerial roots

1. Establish AeroHydro Culture System

Here we propose an innovative culture system of oil palms and leguminous plants (because they are very sensitive to water or low oxygen supply) in a high water table condition. The key limiting factors we found for a high water table in tropical peatland are oxygen supply and nutrient supply.

Therefore, we recommend AeroHydro culture system, which supplies oxygen and nutrients from the land surface. A case study shows that oil palm growth is improved by natural compost and nature, even in high water table conditions, indicating that the water table itself is not a limiting factor for plants, particularly oil palms (Fig. 0-1).

AeroHydro culture comprises the following:

- A high water table
- Natural compost by fronds (or litter) and cover crops
- Slow-release K^+ nutrients as coated fertilizer and also N, P, Ca, and Mg
- Ash for micronutrients
- Biochar
- Nutrient recycling by microorganisms (nitrogen-fixing bacteria and mycorrhizae) in the case of heavy damage of the land surface (dryness and fire)

Fig. 0-1. AeroHydro culture system in oil palms under high-water-table conditions.

2. Nitrogen-Fixing Ecological System

Heavy damage of peatland by fire leads to loss of land surface functions (e.g., nutrient content, nutrient cycling by microorganisms, high moisture condition, high water-holding capacity, and covering of weeds), inducing competition between ferns and trees for nutrients and water and induction of fire into the peatland and not just at the surface.

Nodule plants (leguminous, nitrogen fixation by nodules, sensitive to water) and aerial root plants (nitrogen fixation by free-living bacteria in aerial roots, tolerant to water) are candidates for rehabilitation of heavily damaged peatland. The following factors are important, particularly in the early stage:

- Aerial root formation: Establishment of a nitrogen-fixing ecosystem
- Mycorrhizae: Plant growth promotion and P nutrients
- K nutrition: K or Na application for root activation (carbohydrate transportation to roots)

For a nitrogen-fixing ecological system, seedling management is essential. Seedling pots should be designated as follows:

Vesicular-arbuscular mycorrhiza (VAM)*
Nitrogen-fixing bacteria*
Slow-release fertilizer (N:P:K = 1:1:10)
Volcanic ash for micronutrients (B, Mo, Co, Fe, Mn, and Zn)
Compost (for bacterial growth)
Biochar (matrix for microorganisms and water-holding capacity)

2.1 Field nursery for mycorrhizae and nitrogen-fixing bacterial inoculation

Because mycorrhizae and nitrogen-fixing bacterial inoculation is difficult, it is proposed that a cultivation nursery of mycorrhizae and nitrogen-fixing bacteria be established in the field, with no shading and sprinklers.

Candidate plants for microorganism culture in peat soil are as follows:

- *Melastoma malabathricum* L.: Strong nitrogen fixation by free-living bacteria
- *Combretcarpus rotundatus*: Strong nitrogen fixation by free-living bacteria
- *Acacia crassicarpa* or others: Mycorrhizae increasing

These plants grow in a mix-planting system.

3. Cultivation

Trees are planted in high density. After one year, the trees in the middle are cut for biochar. Biochar contributes to improving the land surface layer.

4. Verification of the Culture System

If this restoration methodology is adapted to a heavily disturbed peatland, plants grow quickly: up to 2 m growth within six months (Fig. 0-2). Thus, it is possible to quickly cover land. Culture system verification is quick in the short term, at least for half a month. If plant growth is slow, the cultivation system should be improved quickly following a scientific study on the cause of slow growth.

Fig. 0-2. Different sengon growth under different growth conditions (topography, nutrient imbalance, fire damage intensity, grass competition, etc.), even in the same location in six months.

I. Introduction

1-1. Serious Problems in Heavily Burned Peatland

Heavy draining leads to a low water table and low soil moisture, and frequent, heavy burning of peatland causes the following issues (Figs. 1-1 and 1-2):

- Nutrient leaching
- Low water-holding capacity
- Fern and grass vegetation (competition with trees)
- Dryness of land surface by direct solar radiation
- Flooding in the rainy season (peat loss by fire)

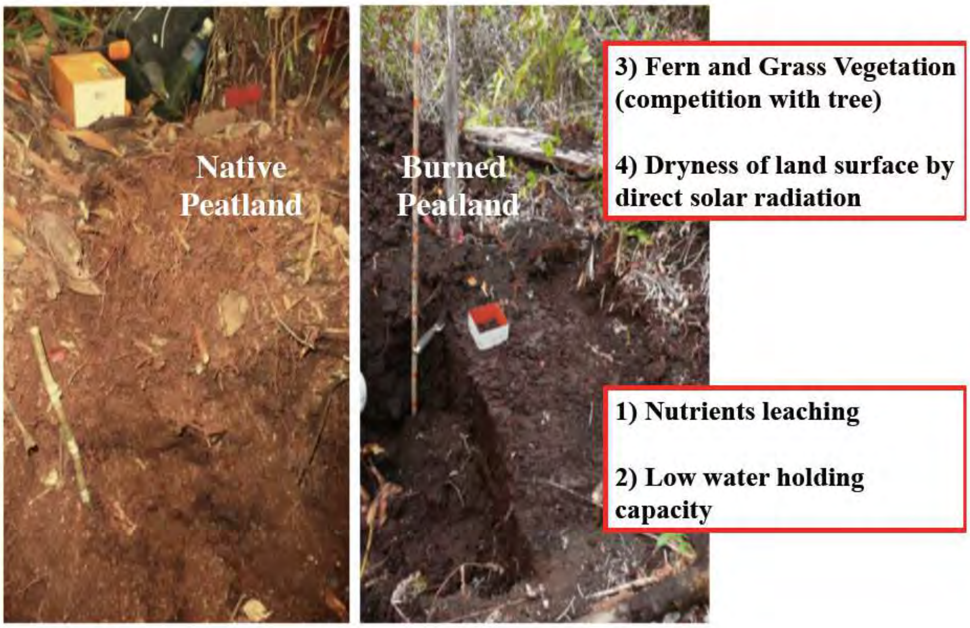


Fig. 1-1. Peatland profile of native and burned peatland in Central Kalimantan. Photo: Jyrki Jauhiainen.

Fig. 1-2. High water table owing to loss of peat by heavy fire at the FORDA site in Tumbang Nusa. This needs drainage in the rainy season and canal blocking before the dry season.

1-2. Frequent Peat Fires in Once-Burned Areas

Once peatland is burned, it is difficult to control further fires because of the following reasons:

- It is difficult to fill enough water by canal blocking (low water-holding capacity of burned peat, high water leakage through balk and path) and by pumping up (expensive)
- Weeds' roots, particularly fan roots, lead the fire into the peat
- The water table is mainly balanced by precipitation and evapotranspiration, and the inflow inside the peatland is less (Fig. 1-3).

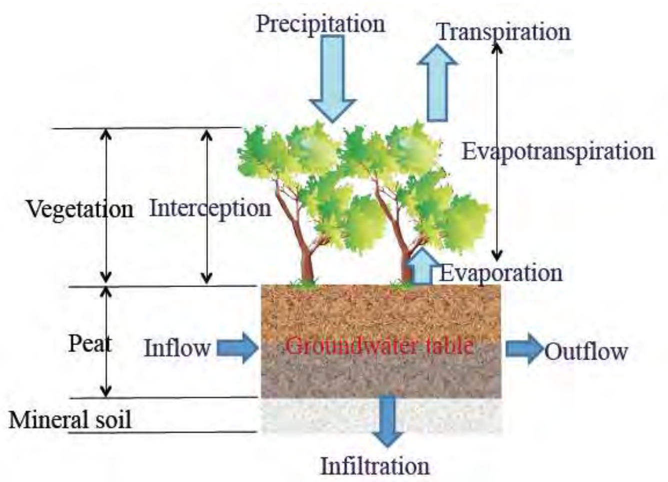


Fig. 1-3. Diagram of water balance in peatland.

1-3. Fire Prevention by High Soil Moisture

Land surface moisture next to the groundwater table (GWT) is also important because:

- Even in natural forests, the GWT comes to approximately 1 m low in an El Niño year (Fig. 1-4).
- Even in an El Niño year, few fires occur in natural forests because of high moisture in the soil surface and high humidity inside the forests.

Thus, not only a GWT but also land cover by trees (land surface moisture) is very important to prevent peat fires.

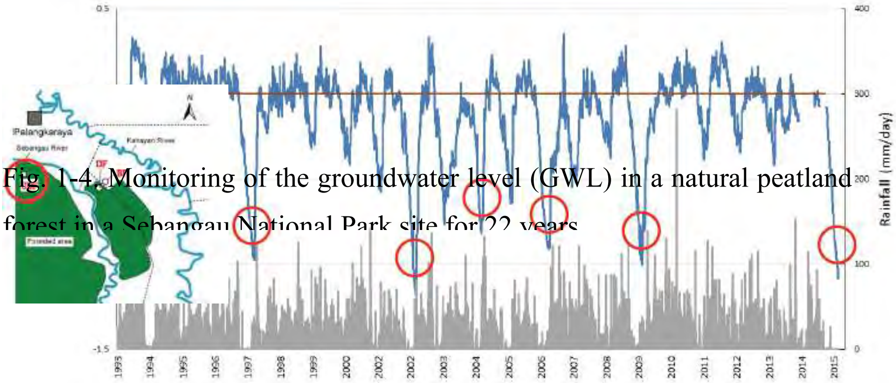


Fig. 1-4. Monitoring of the groundwater level (GWL) in a natural peatland forest in a Sebangau National Park site for 22 years

1-4.

Nitrogen Fixation Ecosystem in Peatland

Nitrogen is the most important nutrient for plant growth. We found that peatland ecosystem functions are highly dependent on nitrogen-fixing ability.

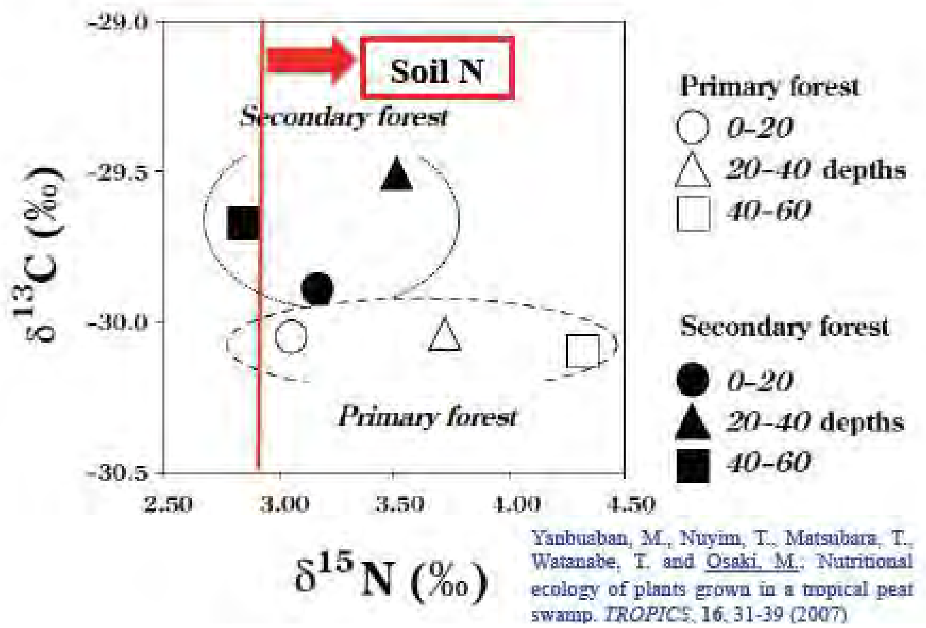


Fig. 1-5. Natural abundance of stable isotope ^{15}N ($\delta^{15}N$) and ^{13}C ($\delta\,^{13}C$) in peat soils of primary and secondary forests in tropical peatland (Thailand).

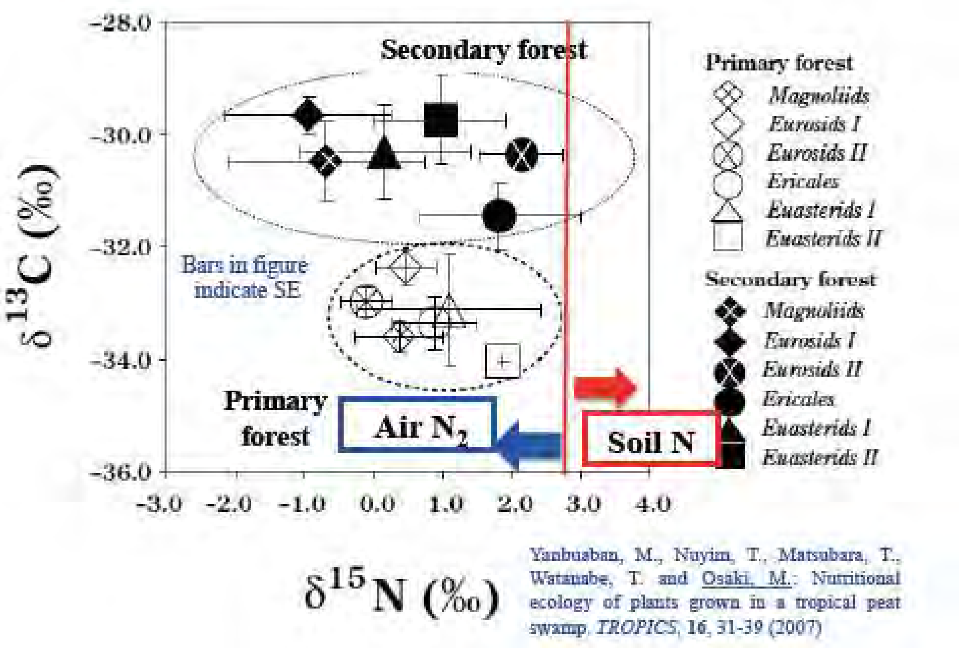


Fig. 1-6. Natural abundance of stable isotope ^{15}N ($\delta^{15}N$) and ^{13}C ($\delta^{13}C$) in leaves of plants grown in primary and secondary forests of peatland (Thailand).

In peatland in Thailand, (i) most plant species fix nitrogen from air, and soil nitrogen source contributes little to plant growth because $\delta^{15}N$ of leaves is less than $\delta^{15}N$ of the soil (>2.75) (see Figs. 1-5 and 1-6). The photosynthetic rate of plants in secondary forests is higher compared to primary forests because $\delta^{13}C$ of secondary forest species is higher than $\delta^{13}C$ of primary forest species.

In Central Kalimantan, $\delta^{15}N$ of the soil is lower in Kalanpangan than in Lahei (Kelangas: sallow and sandy podzolic soil under peat) and Setha Alam (natural forest), indicating that old accumulated nitrogen in peat decomposes and leaches out (Fig 1-7). As $\delta^{15}N$ of leaves of several plant species is less than $\delta^{15}N$ of the soil (approximately 1.0), except for Kalanpangan 4, dominant species in Central Kalimantan peatland may fix nitrogen from air. Kalanpangan 4 is a drained and burned peatland (fern and grass) with sallow peat and with sandy podzolic subsoil, indicating nitrogen fixation is low because of heavy leaching nutrients, particularly nitrogen (Fig. 1-7) and micronutrients (low nitrogen-fixing ability; Fig. 1-8).

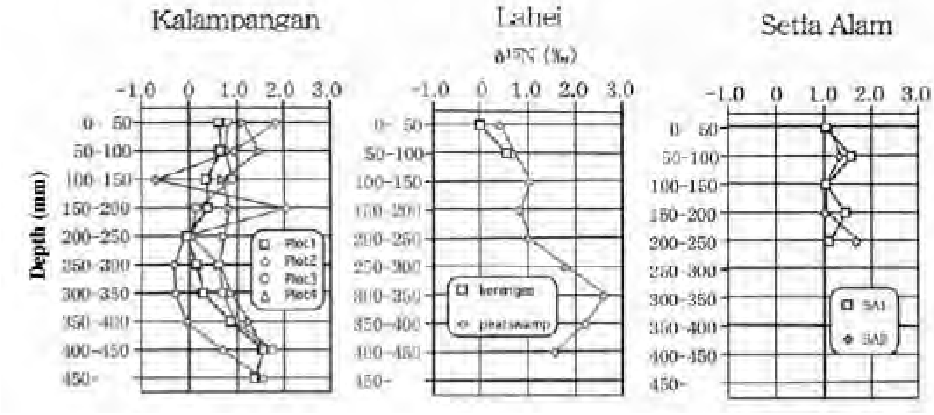


Fig. 1-7. $\delta^{15}N$ profile in peat soil at different locations of Central Kalimantan (from Takeshi Matsubara, Sehat J. Tuah, Suwido H. Limin & Mitsuru Osaki: Nitrogen source for common tree species in peat swamp forests, Central Kalimantan inferred from δ15N analysis, In Proceedings of the International Symposium on LAND MANAGEMENT AND BIODIVERSITY IN SOUTHEAST ASIA, Eds. by Mitsuru OSAKI et al., p.59-64, Bali, Indonesia, 17-20 September 2002).

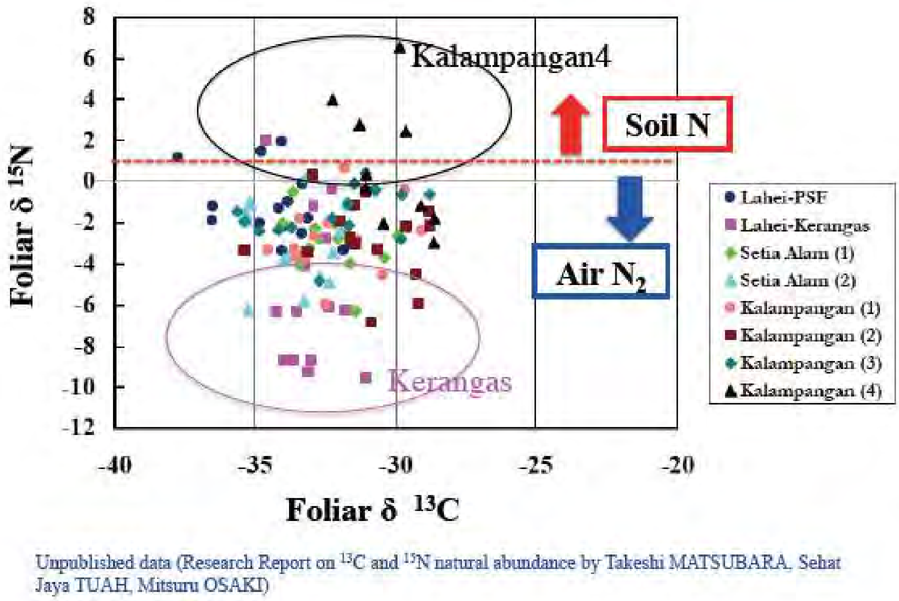


Fig. 1-8. Relationship between natural abundance of stable isotope ^{15}N ($\delta^{15}N$) and ^{13}C ($\delta^{13}C$) in leaves of plants grown in Central Kalimantan.

Kalampangan 1: Drained forest

Kalampangan 2: Drained and burned peatland (fern and grass)

Kalampangan 3: Drained secondary forest

Kalampangan 4: Drained and burned peatland (fern and grass) with sallow peat and maximum dryness (sandy podzolic subsoil)

1-5. Micronutrient Deficiency by Heavy Fire

In the Kalanpangan area, serious micronutrient deficiency is observed in leguminous plants (Figs. 1-9 and 1-10). Green stripes on leaves are a typical symptom of micronutrient deficiency. When micronutrients are deficient, chlorophyll is formed only in vine cells and the vine become slightly green.

It is hypothesized that heavy fire leaches all nutrients, which affects nodulation and nitrogen fixation:

- Micronutrients (B, Mo, Co, Fe, Cu, Zn) are necessary to fix nitrogen.
- A serious nitrogen deficiency leads to no nodulation and nitrogen fixation.

- Also, K^+ deficiency leads to poor root growth and poor nodulation.

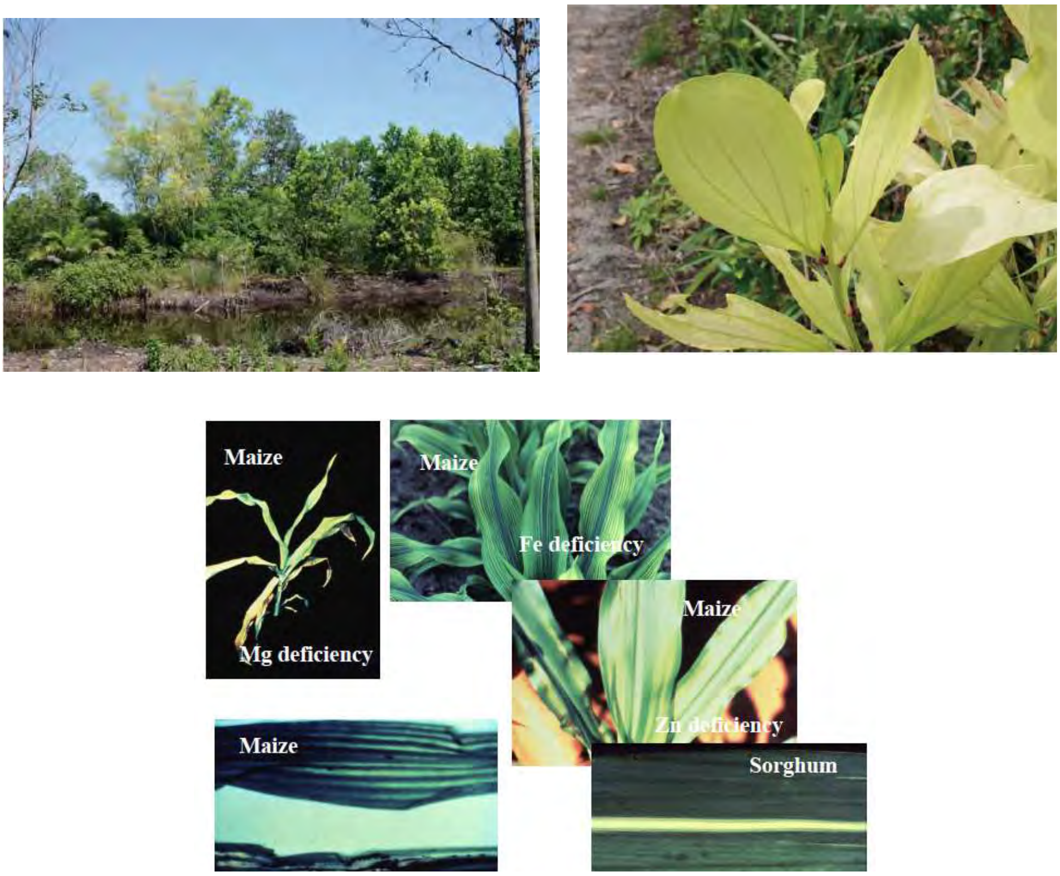


Fig. 1-9. Symptoms of micronutrient deficiency in strongly burned peatland in the Kalanpangan area of Central Kalimantan.

Fig. 1-10. Serious nutrient (micronutrients, nitrogen, and potassium) deficiency in leguminous trees grown in heavy-fire-damaged peatland, Kalanpangan.

5. Hypothesis of Nitrogen Fixation in the Peatland Ecosystem

Nodules are very sensitive to high water levels because oxygen supply is most important for nodulation and nitrogen fixation. Therefore, in peatland, free-living, nitrogen-fixing bacteria around the rhizosphere, not nodulation, are the nitrogen-fixing strategy.

Thus, it is hypothesized that aerial roots fix nitrogen.

- Nitrogen-fixing bacteria: Nitrogen is a key element of plant nutrients; however, nitrogen content in peat is extremely low. Therefore, it is hypothesized that plants adapted to tropical peatland have nitrogen-fixing ability. In tropical peatland, many plants develop aerial roots under high GWT conditions. The rhizosphere or mucilage (polysacalids) of aerial roots contains nitrogen-fixing bacteria. Thus, it is hypothesized that aerial roots have oxygen absorption and nitrogen fixation functions.

- Sago palm: Sago forms aerial roots under high water table conduction and no nitrogen fertilizer application, indicating that aerial roots have two functions, oxygen absorption and nitrogen fixation (Figs. 1-11 and 1-12).

Fig 1-11. Aerial root formation with high water table and no nitrogen fertilizer application in sago plant

Fig. 1-12. Aerial root formation and good growth without fertilizer.

- *C. rotundatus* (tumih or perepat in local language): *C. rotundatus* fixes nitrogen (Fig. 14) possibly in aerial roots exuding mucigel (Fig. 1-13).

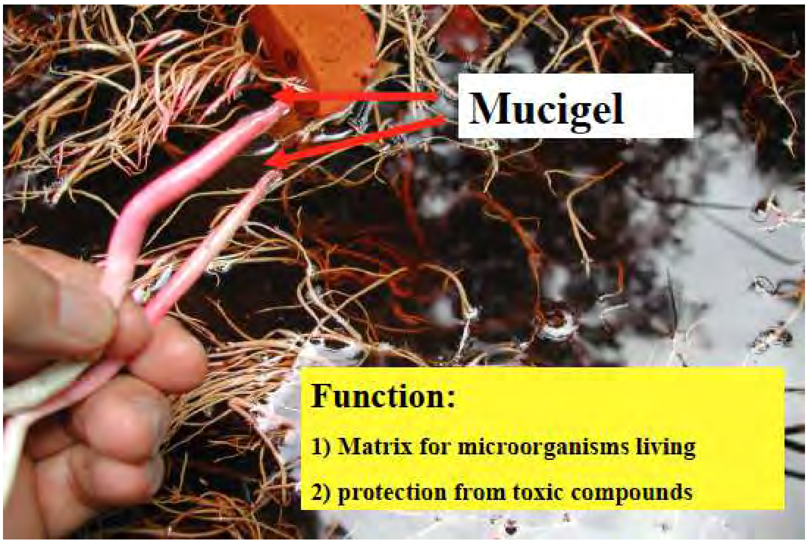


Fig. 1-13. Aerial roots coated with mucigel.

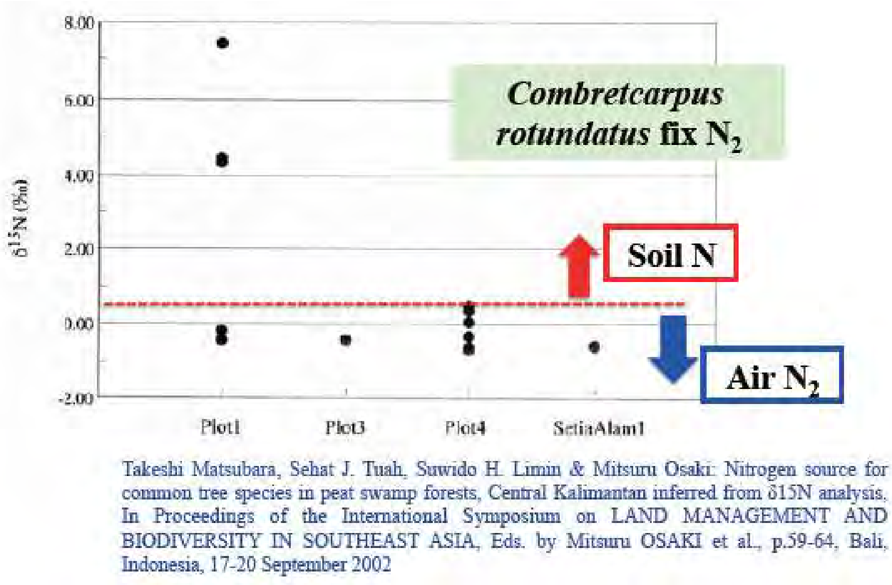


Fig. 1-14. Leaf $\delta^{15}N$ of *C. rotundatus* (tumih or perepat in local language) in peatland in Central Kalimantan.

- *M. malabathricum* L.: *M. malabathricum* L. can grow in nitrogen-free water culture, which is rare because we never find any other plants (even in endophytic nitrogen-fixing bacteria symbiotic sorghum or maize) growing in the same culture. Therefore, we may conclude that *M. malabathricum* L. has endophytic nitrogen-fixing bacteria in its roots, shoots, and leaves but not in tissues (Fig. 1-15). Nitrogen-fixing bacteria live in the rhizosphere and in mucilage exuded from roots.

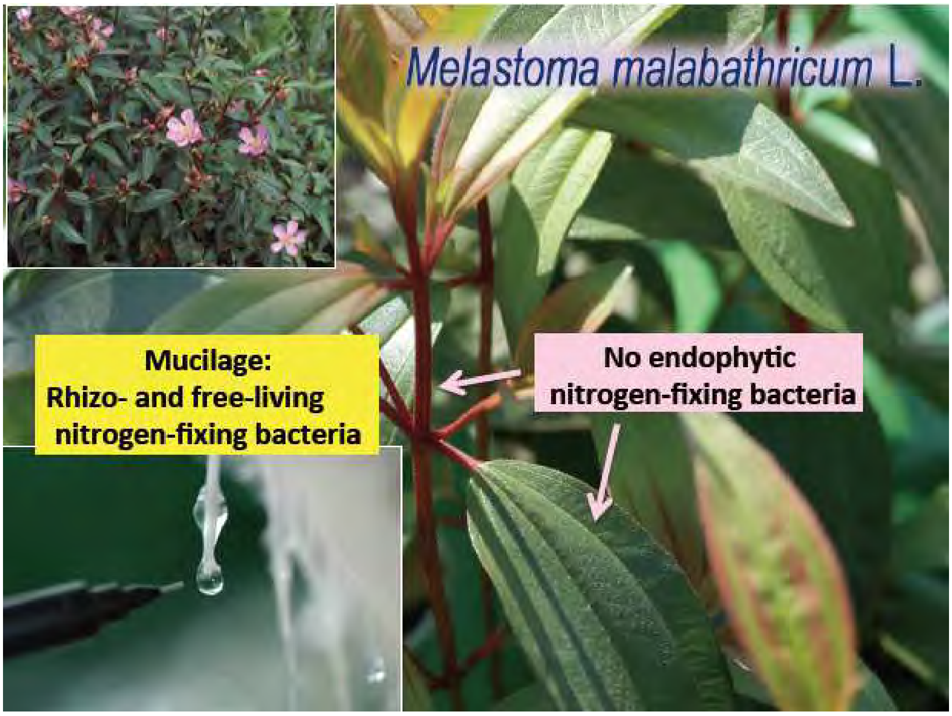


Fig. 1-15. High nitrogen-fixing ability of *M. malabathricum* L.

M. malabathricum L. roots were inoculated with nitrogen-fixing bacteria isolated in an aseptic culture, and the nitrogen-fixing bacteria were proved to promote plant growth (Fig. 1-16).

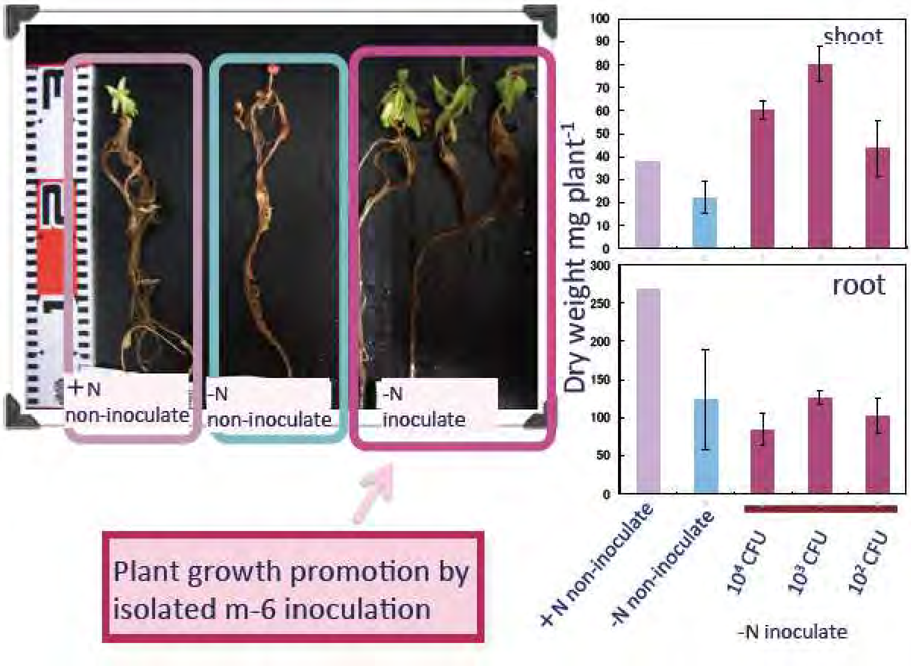


Fig. 1-16. Nitrogen-fixing bacteria (isolated from the rhizosphere of *M. malabathricum* L.) inoculation to *M. malabathricum* L. roots.

II. Proposal

2-1. Water Management

- Block the canal for a high water table as much as possible.
- Recover peatland surface moisture by quick land cover.
- Pump up groundwater in serious cases.

A high water table is most essential to prevent fires and peat degradation, which is the principle of peatland formation and protection.

Also, a forest canopy is important because dryness of the peatland surface induces peat fires.

Thus, reforestation should start quickly with canal blocking and forest canopy formation.

2-2. Nutrient Management (Fig. 2-1)

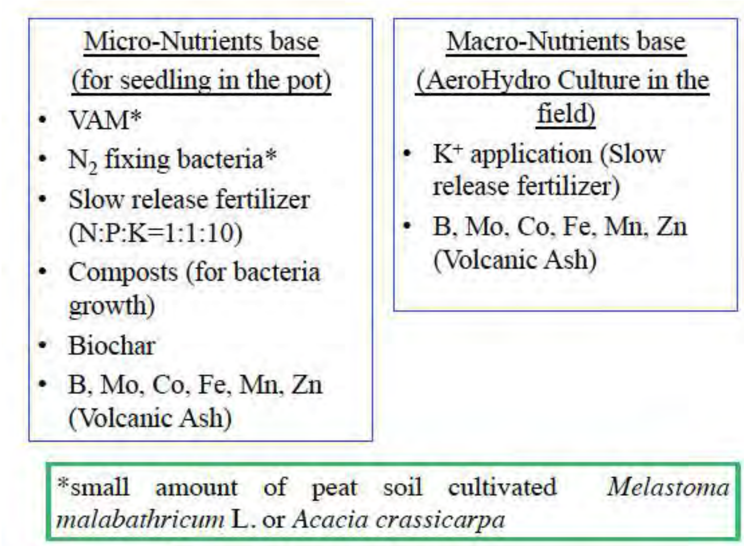


Fig. 2-1. Nutrient design depending on establishing a nitrogen-fixing ecological system.

2-3. Tree Species (Fig. 2-2)

- Nodulation tree: Nitrogen fixation but high water sensitivity (oxygen deficiency)
- Aerial root formation Tree: Nitrogen fixation and high water table tolerance
- Mound root formation tree: Nutrient cycling using litter and high water table tolerance

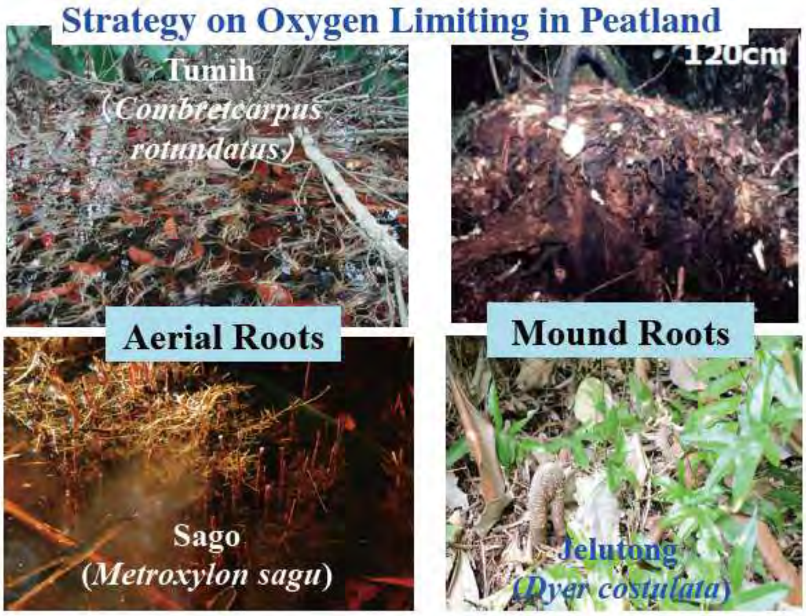


Fig. 2-2. Introduction of tree species having nitrogen fixing and/or oxygen absorption ability.

2-4.

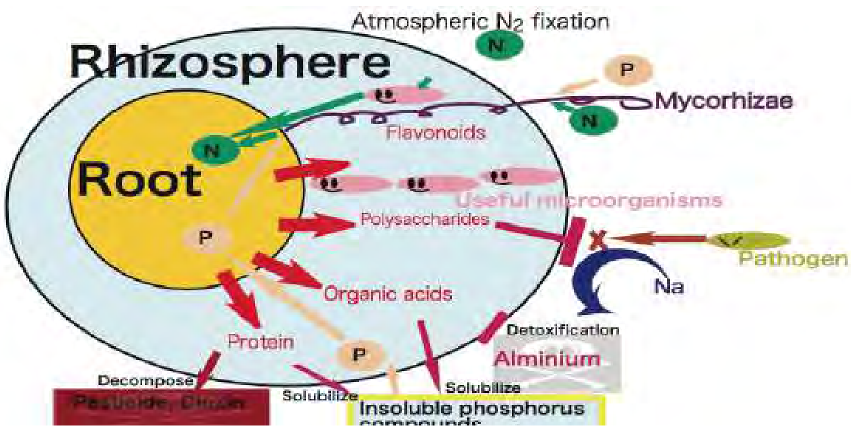
Rhizosphere Control

Nitrogen fixation:

- Nodulation: Leguminous
- Rhizosphere/(Entophyte?): Nonleguminous

Mycorhizae symbiosys:

- Plant growth promotion (like a safety net for growth)
- P nutrient absorption



III. Action Plan

The action plan for heavily damaged peatland restoration comprises the following:

- High water table management
  - Canal blocking
  - Pumping up of groundwater in serious cases

- Land cover management

3-1. Leguminous Plant Cultivation

Leguminous plants are candidate for rehabilitating heavily damaged peatland, and the following factors are important, particularly in the early stage:

- Nodulation and nitrogen fixation: Oxygen supply (AeroHydro culture: nodulation and nitrogen fixation are extremely sensitive) and micronutrient supply (volcanic ash?)
- Mycorrhizae: P nutrients and growth stimulation
- K nutrition: K or Na application for root activation (carbohydrate transportation to roots)

Peat fire damages the nutrient-recycling system (microorganism activity) in the land surface and leaches all nutrients, particularly micronutrients (Fig. 3-1). Thus, to rehabilitate or restore burned peatland, we must be careful about recovering nutrients that are deficient using nutrient application via nutrient recycling by microorganism activity in the land surface.

Fig 3-1. Different sengon growth under different growth conditions (topography, nutrient imbalance, fire damage intensity, grass competition, etc.), even in the same location in six months.

3-2. AeroHydro Culture System

Here we propose an innovative culture system of oil palms and leguminous plants (because they are very sensitive to water or low oxygen supply) in a high water table condition. The key limiting factors we found for a high water table in tropical peatland are oxygen supply and nutrient supply.

Therefore, we recommend an AeroHydro culture system, which supplies oxygen and nutrients from the land surface. A case study shows that oil palm growth is improved by natural compost and nature, even in high water table conditions, indicating that the water table itself is not a limiting factor for plants, particularly oil palms (Fig 3-2).

An AeroHydro culture comprises the following:

- A high water table
- Natural compost by fronds (or litter) and cover crops
- Slow-release K^+ nutrients as coated fertilizer and also N, P, Ca, and Mg
- Ash for micronutrients

- Biochar
- Nutrient recycling by microorganisms (nitrogen-fixing bacteria and mycorrhizae) in the case of heavy damage of the land surface (dryness and fire)

Fig 3-2. AeroHydro culture system in oil palm case under high-water-table conditions

3-3. Symbiotic System

(1) Mycorrhizae

Seedlings are prepared using the following mixture: charcoal + manure + fresh forest soil (microorganisms). This induces a symbiotic system of plants and microorganisms, which stimulates plant growth, even with high competition with grass (Figs. 3-3 and 3-4).

Fig. 3-3. Breakthrough in competition with grass by symbiotic system formation in mineral soil.

Fig. 3-4. Sesbania growth stimulated by vesicular-arbuscular mycorrhiza (VAM) inoculation in extremely poor soil.

We can conclude that mycorrhizae and bacterial symbiosis has two key functions: (i) plant growth promotion and (ii) nutrient absorption, particularly N and P nutrients. Once the top peat layer is seriously damaged by dryness (canal construction or deforestation), fire, or removal of the top layer, it is very difficult to perform recovery, rehabilitation, or reforestation. Figure 3-5 shows the rehabilitation process after the top peat layer (1–2 m) is removed. A peat mining project (Finland project in Kalanpangan, Central Kalimantan) was stopped, the rehabilitation program started in 1985, and Acacia trees were planted, which, however, did not grow, even when chemical fertilizers were applied. However, *C. rotundatus* started to grow naturally around the year 2000, and then the biodiversity immediately surrounding *C. rotundatus* increased around 2006. Thus, we can assume that the top peat layer improves microorganism activity.

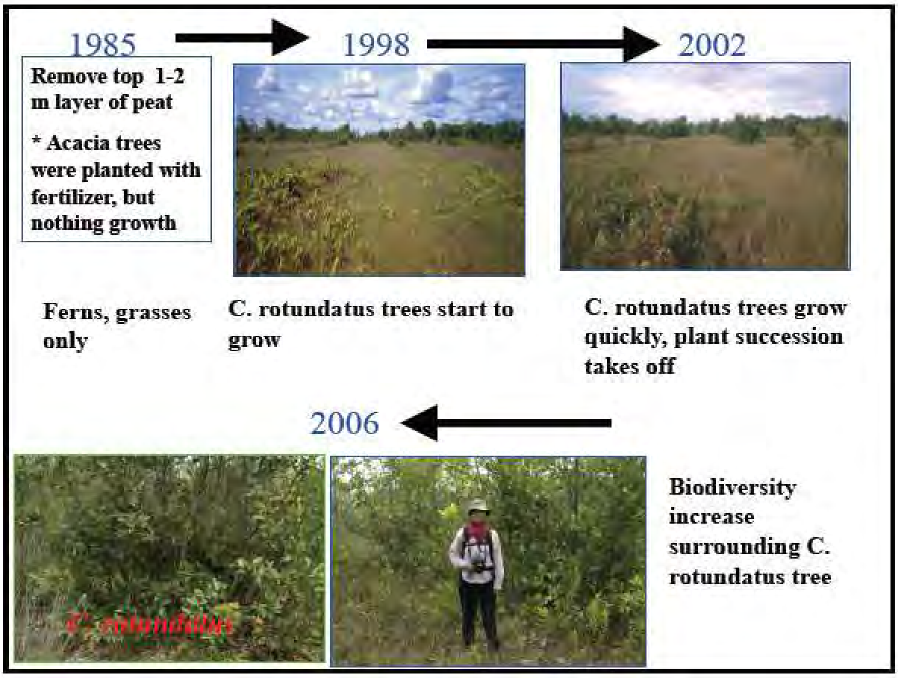


Fig. 3-5. Long-term natural regeneration of vegetation in top-soil-removed peatland.

C. rotundatus is a pioneer tree species for peatland in Central Kalimantan (Fig. 3-6). *C. rotundatus* can develop aerial roots under wet and high water table conditions and start fixing nitrogen. Interestingly, once the aerial roots of *C. rotundatus* start to grow, the plant's seeds can germinate surrounding the aerial roots and grow into seedlings. If, however, *Cyperus* sp. and *Fan* sp. cover peatland, it is difficult for seeds of *C. rotundatus* and other species to germinate. Thus, we can assume that once the flora for microorganisms is improved, seed germination and tree growth are immediately promoted with microorganism symbiosis, possibly with nitrogen-fixing bacteria.

Fig. 3-6. Competition between *C. rotundatus* and weeds.

3.4. Land Surface Management by Biochar

Tropical peat soil is extremely oligotrophic because of poor nutrient content in the subsoil, strong leaching under acidic conditions, and low cation exchange capacity (CEC). Mineral soil application might be the most fundamental solution to improve the fertility of tropical peat soils. However, it is expensive and a large amount of mineral soil is required to improve the entire area. Another possible solution is to increase the organic matter in the soil. However, because organic matter decomposes easily, this method is not feasible for remediation of tropical peat soils.

Biochar, which is charcoal created by pyrolysis of biomass, is the best material to remediate peat soils and mitigate peat degradation. It is known to fix soil and maintain soil fertility (Laird, 2008) by mainly increasing CEC and microorganism activity. Because biochar can sequester carbon in the soil for hundreds to thousands of years (Winsley, 2007), it is considered an ideal tool to slow down global warming. As peat is good material for biochar, and only small amounts are required to make biochar by pyrolysis, biochar usage will serve to conserve precious peat in the future.

A research group reported changes in the chemical properties of soil and increase in crop yields by application of bark charcoal of *Acacia mangium* made from pulp waste (Yamato et al., 2006). The bark charcoal was applied to the infertile acidic soil for soil amendments in order to cultivate maize, cowpea, and peanut in Sumatra, Indonesia. The maize and peanut yields increased significantly. The amount of roots and the colonization rate of mycorrhizae increased, particularly in maize. Root nodule formation in leguminous plants was also stimulated by bark charcoal. In addition, the chemical properties of soil were improved by neutralizing soil pH and increasing (i) total nitrogen, (ii) available phosphate contents, (iii) CEC, (iv) amount of exchangeable cations, and (v) base saturation. It also induced the reduction of dissolved exchangeable Al ions in the soil (Al is harmful for root growth).

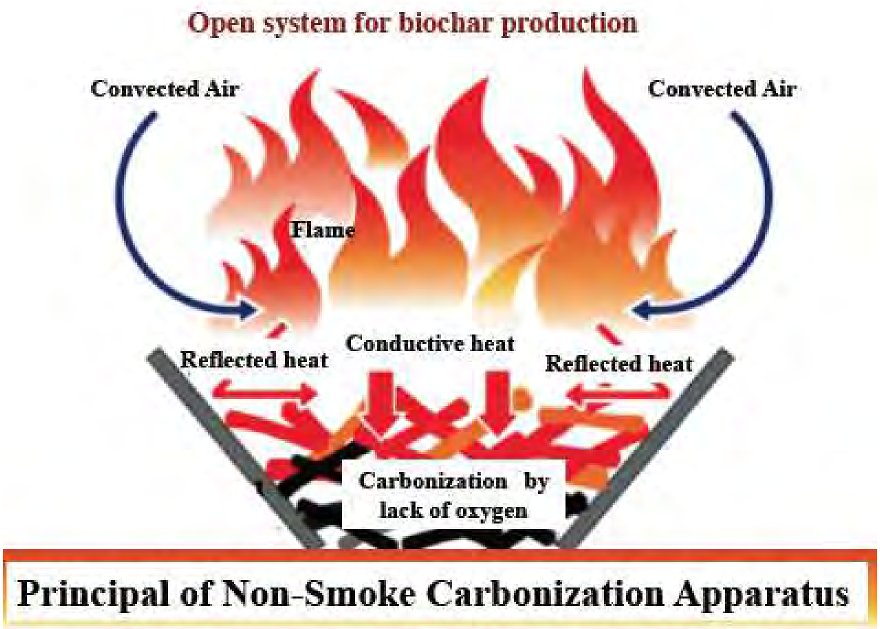


Fig. 3-7. Open system of biochar production.

Fig. 3-8. Demonstration of making biochar and compost using grass and bamboo materials in peatland in Central Kalimantan.

Fig. 3-9. Demonstration of making biochar and compost using grass and bamboo in peatland in Malaysia.

It is recommended that biochar be produced by an open system using a nonsmoke carbonization apparatus (Fig. 3-7) so that biochar can be easily produced and sent everywhere (Figs. 3-8 and 3-9).

8. Acknowledgement

This project has been carried out with support from the JICA-BRG (Peatland Restoration Agency, Indonesia) Project (headed by Takashi Inoue) in partial cooperation with the JST-JICA's SATREPS (headed by Mitsuru Osaki) of the JST-JICA and the Environment Research and Technology Development Fund of the Ministry of the Environment (4-1506 headed by Shigeo Kobayashi and 2-1504 headed by Takashi Hirano).

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UNFCCC Workshop: 24-25 October 2013, Bonn, Germany

Annex.01

GUIDEBOOK FOR ESTIMATING TROPICAL PEATLAND ECOSYSTEM
- Carbon and Water Dynamics-

2nd Edition

BRG-JICA PROJECT
Peatland Restoration Agency – Japan International Cooperation Agency Project for The Elaboration of Peatland Restoration

IJ-REDD+ PROJECT
Indonesia-Japan Project for Development of REDD+ Implementation Mechanism

GUIDEBOOK FOR ESTIMATING TROPICAL PEATLAND ECOSYSTEM
- Carbon and Water Dynamics-
2nd Edition

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PREFACE

Hokkaido University and Palangka Raya University have a long history of cooperation in research on tropical peatland ecosystems dating back to 1997. The Japan International Cooperation Agency (JICA) and the Japan Science and Technology Agency (JST) have also supported this cooperation through the Science and Technology Research Partnership for Sustainable Development (SATREPS) program, a Japanese government program that promoted international joint research with the title “Wild Fire and Carbon Management in Peat-Forests in Indonesia” from 2009 to 2014. These cooperative programs have generated important research on tropical peatland ecosystems in Central Kalimantan and many outcomes of this cooperation have been included in a recently published book edited by M. Osaki & N. Tsuji (2016), “Tropical Peatland Ecosystems”, 651 p. This is the world’s first complete book on this topic and it contains 41 scholarly articles that describe various aspects of tropical peatland ecosystems.

In line with these research advances, one of the recommendations that emerged from a joint workshop between the SATREPS program and the IJ-REDD+ Project in January 2014 was to develop methodologies to mitigate climate change due to carbon emissions. To this end, translating research results into a guide that can be easily understood by all stakeholders at the provincial government level was necessary. The IJ-REDD+ Project has coordinated and facilitated with stakeholders the preparation of this guidebook on estimating carbon emissions from peatlands in Indonesia, particularly with stakeholders from Central Kalimantan.

After these projects and the first version of the guidebook, Mr. Joko Widodo, the president of Indonesia, issued a presidential regulation in early 2016 to establish the Peatland Restoration Agency (BRG) which bears the mandate of peatland ecosystem restoration for two million hectares in five years. This is the evidence of genuine concern that peatland restoration is an urgent task in Indonesia. Many stakeholders are involved in peatland management, such as oil palm and fast-wood plantation companies, local communities, and agro-industries which grow sago, nipa, coconut, coffee, cacao, and native species for food and feed production and biomass production as a source of bioenergy. In addition to coordinating the interests of multiple stakeholders, multiple elements in peatland ecosystems need to be managed including water levels, nutrient status in soil and water, vegetation, topography, and the economic system.

The Peatland Restoration Agency (BRG) must restore disturbed, degraded, and damaged peatlands over a period of five years. Hence further collaborations between Japanese and Indonesian scientists are urgently required to implement the conservation and sustainable management of peatlands in Indonesia. The BRG-JICA Project was conducted from October 2017 to March 2018 in collaboration with Hokkaido University and founded by the JICA. The BRG-JICA Project has updated its methodologies so the second vesion of the guidebook that is published here.

We wish to express our appreciation to all parties who have supported this cooperation.

31 March 2018

Mitsuru Osaki
Leader of the JICA-BRG Project

ACRONYMS

AVHRR	Advanced Very High Resolution Radiometer
BIG	Geospatial Information Bureau of Indonesia
C	Carbon
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon dioxide
DB	Drained and Burned Land
DEM	Digital Elevation Model
DF	Drained Forest
DOC	Dissolve Organic Carbon
EC	Eddy Covariance
ECMWF	European Center for Medium-Range Weather Forecast
ER	Ecosystem Respiration
GHG	Greenhouse Gas
GIS	Geographic Information System
GOI	Government of Indonesia
GPS	Global Positioning System
GWL	Groundwater Level
GWP	Global Warming Potential
IJ-REDD+ Project	Indonesia-Japan Project for Development of REDD+ Implementation Mechanism
INDC	Intended Nationally Determined Contribution
JICA	Japanese International Cooperation Agency
LiDAR	Light detection and ranging (an optical remote sensing technology)
MODIS	Moderate Resolution Imaging Spectroradiometer
MRV	Monitoring, Reporting and Verifying
N_2O	Nitrous Oxide
NDVI	Normalized Difference Vegetation Index
NEE	Net Ecosystem Exchange
NEP	Net Ecosystem Production
NOAA	National Oceanic and Atmospheric Administration
OP IRGA	Open-Path CO_2 Infra-Red Gas Analyzer
PALSAR-2	Phased Array type L-band Synthetic Aperture Radar
PAR	Photosynthetically Active Radiation
PM	Particulate Matter
RAN-GRK	*Rencana Aksi Nasional Penurunan Emisi Gas Rumah Kaca* (National Action Plan for Reducing GHG Emissions)
REDD+	Reducing Emissions from Deforestation and Degradation Plus Carbon Stock Enhancement
SAR	Synthetic Aperture Radar
SAT	Ultra-Sonic Anemometer-Thermometer
SESAME	Sensory data transmission Service Assisted by Midori Engineering

SRTM	Shuttle Radar Topography Mission
UNFCCC	United Nations Framework Convention on Climate Change
WI	Wetlands International

I INTRODUCTION

1.1. Background

Indonesia holds approximately 15 million hectares of peat soil, which represents 50% of the world's total tropical peatland area (DNPI, 2014). Peatlands store a huge amount of carbon in the form of organic matter accumulated in waterlogged and anaerobic conditions. In natural conditions when peatland hydrology is intact, peatlands are capable of providing multiple environmental benefits including water regulation, carbon storage, and biodiversity maintenance.

Despite such ecological functions, peatlands have been utilized for economic development for decades. Peatland development often involves the construction of drainage canals, which inevitably lower water levels and put hydrological integrity at risk. Once peat soils are exposed to the air, they start to decompose and become dry and vulnerable to fires – which are major sources of greenhouse gas (GHG) emissions. In 2010, emissions from peat decomposition and burning contributed to 44 percent of Indonesia's total GHG emissions (DNPI, 2014).

For this reason, sustainable peatland management must be a central component in Indonesia's strategy to combat climate change and its devastating impacts on its land and people. The important role of peatlands is also reflected in the recent Ministry of Environment and Forestry decree (No S.661 /MenLHK-Setjen/Rokum/2015), as well as the national action plan for GHG (RAN-GRK). The decree not only bans the issuance of new business licenses on peatlands, but also requires concession holders to halt peatland clearing and maintain the minimum groundwater level (GWL) at 40cm.

Groundwater level is the most important environmental factor in peatland management (Shigenaga et al., 2016). This guidebook aims to provide practical methods for estimating carbon emissions from peat decomposition and burning by using real-time GWL data as a key parameter. It also provides a method for predicting GWLs for several days into the future. These models can be used for various purposes in practice, including developing science-based national and regional development strategies and early fire warning systems.

1.2. What is this guidebook about?

This guidebook provides step-by-step procedures to:

- Collect spatial information from remote sensing data sources
- Collect field sampling data of GWL and other parameters
- Estimate GWL distribution based on the field samples and remote sensing data
- Establish a linear relationship (model) between carbon emissions and GWLs
- Predict GWLs several days into the future based on field sampling data.

Although the methods outlined in this guidebook were initially developed in Central Kalimantan during the JICA-JST Project from 2010 to 2014 (see Preface for the project background), this guidebook provides general procedures which are replicable for peatlands throughout Indonesia.

1.3. Guidebook Organization

This guidebook is organized into four parts: **I.** Introduction, **II.** Field surveys, **III.** Ground Water Table, **IV.** Carbon Emissions, and **V.** Future Considerations.

Part I of this guidebook provides introductory information including information on guidebook structure.

Part II of this guidebook explains how to conduct field surveys to obtain basic information on peatlands.

Part III of this guidebook explains how to predict Ground Water Level (GWL) several days in advance based on daily average GWL data observed in the field. Figure 17 illustrates the framework of the GWL Prediction Model.

Part IV of this guidebook introduces a protocol to estimate the amount of carbon emissions from peatland due to microbial decomposition and peat burning. It is divided into four sections: 1) Data collection and processing, 2) Data analysis, 3) Carbon emission modeling from peat decomposition, and 4) Carbon emission modeling from peat burning. Based on the framework presented in Figure 1, each section provides step-by-step procedures in sub-sections.

Part V of this guidebook suggests further developments for an Integrated Sensing System to understand models introduced in Parts III and IV. Part V also discusses potential applications of these models.

1.4. Who is this guidebook for?

This guidebook is intended to be used by a wide range of stakeholders in Indonesia who wish to develop and implement sustainable management practices on peatland by knowing the amount of carbon emissions from land use and land use change, and by preventing peatland fires. These stakeholders include:

- Policy makers;
- Peatland managers (such as concession holders);
- Researchers; and
- Local authorities.

Peatlands can be classified into three zones based on the distance from the coast; coastal peatland, intermediate peatland and inland peatland. Coastal zone is affected by high salinity from the sea water and the tidal effect. On the other hand, inland peat is an oligotrophic environment. We need to apply an efficient cultivation system for restoration as well as agricultural demands. From the point of soil nutrient spatial conditions, zone-specific management is necessary. Different peat zones have different properties in water quality, soil and vegetation. Aiming at a large-scale application of zoning in the future, it is necessary to monitor several associate factors that determine the peatland properties, which leads establishment of an improved model system for tropical peatlands monitoring.

2.1. What needs to be measured for field survey

Soil properties and water quality and condition determine the types of vegetation. In field survey, these environmental factors related to each other are measured. There are established methodology and description methods for each measurement, which are introduced 2.3 Analytical items.

The general information is needed to record at each plot such as:

• date of measurement and sampling
• crew members present
•location of plot (e.g. management district, etc.)
•plot identification – name and/or number of the sampled plot or stand/GPS information and precision (± X m)
•plant community/site type: e.g. intact forest, logged forest, grassland, oil palm or other (if other, describe)
• geomorphic setting: river banks, peat dome, interior or basin, etc.
• ecological condition – evidence of any recent or past disturbances such as:
  - timber harvest
  - hydrological status (e.g. drained or undrained
  - recent wildfire and other disturbances such as natural (e.g. disease, insects, etc.) or anthropogenic (e.g. roads, trails, nontimber harvest or use, etc.)
  - plantations/restoration sites (e.g. age of planted trees)

• topography
• soil surface description: wet, dry, litter presence, etc.

In addition to descriptive data, it is valuable to establish permanent photo points in plots.

2.2. Survey Design

Survey plan can be designed by the following steps, which must be carried out in a transparent and consistent manner. Opinions and ideas from the crew members who are experienced in each survey need to be reflected and well-justified.

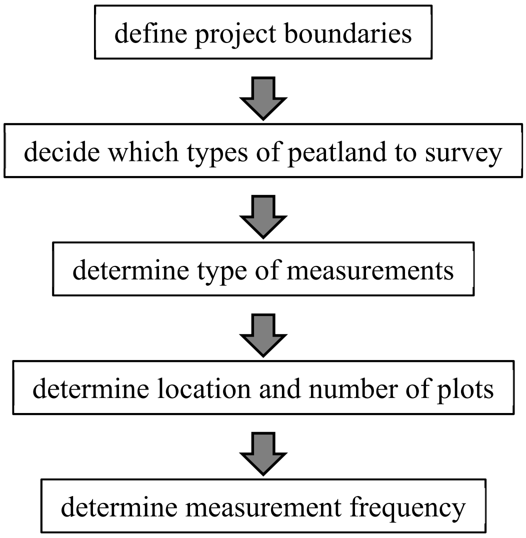


Figure1 Suggested steps in the preparation of measurement plan.

Based on the purpose of survey, site selection, types of survey (e.g. transect survey, area survey, etc.) and sampling design including analytical items (e.g. water quality, soil, vegetation, etc.) can be determined. Seasonal changes should also be considered in tropical peatlands, which has a big seasonal difference in water and soil condition.

2.3. Analytical items

Not all the analytical items are necessary or infeasible at field survey. Therefore, some of them will be selected based on the project purpose. The accuracy of measurement devices used at field also needs to be considered. The measurement values given by devices for outside use are usually less accurate than those analyzed under well-equipped condition in laboratory. If a high accuracy is required, sample collection as well as field measurement needs to be carried out for detail analysis in laboratory.

Following analytical items are useful to determine each plot.

- Soil physical properties
  - Soil texture (simple diagnosis at field / lab analysis)
- Soil chemical properties such as
  - EC (field measurement / lab analysis)
  - pH (field measurement / lab analysis)
  - Concentrations of exchangeable cations (K^+, Na^+, Ca^{2+}, Mg^{2+}) (lab analysis)
  - CEC (lab analysis)

- Ground water
  - Water level (field measurement)
  - Water qualities such as:
    - pH (field measurement / lab analysis)
    - EC (field measurement / lab analysis)
    - Concentrations of cations and anions (K^+, Na^+, Ca^{2+}, Mg^{2+}, PO_4^{3-}, NH_4^+) (field measurement / lab analysis)
    - BOD, COD, DO (field measurement / lab analysis)

2.4. Specific measurements

2.2.1 WATER

Several measurements such as pH and EC etc. will be conducted at field by using portable devises for each analytical item. To obtain water samples to apply for measurement, firstly a well will be established in each sampling site.

A long plastic pole, an electric drill, tights and plastic cable ties are the main materials for establishment of a well. The pole should be cut according to the depth of water table at each site, which needs to be checked in advance. One end of the pole will be drilled to make some holes on the side. Two layers of tights will cover the end of the pole with holes (a). It must cover all holes and be tied with a rubber band so that ground water be filtrated through them into inside of the pole (a). The covered tights will be band with a plastic cable tie (b). Wood piece is processed to put into the end of the pole, which is useful to penetrate peat (c). The pole is penetrated straight to peat and ground water can be taken from inside of the pole. It is better to put a cap on the pole end to avoid contamination of ground water inside the pole (d).

(a)

(b)

(c)

(d)

Using a tube and a syringe, ground water will be withdrawn into the syringe (e). Then, a filter is put on the syringe to collect water samples and apply to the measurement devices such as pH, EC and DO meters (f). Note that calibration must be done before measurement for each devise following the devises' manuals. When analyze a new sample, wash a residue adhering to the inner surface of a devise with a liquid to be analyzed next, then discard the liquid and dispense a new liquid to be analyzed. At least triplicate is necessary to obtain a data value.

(e)

(f)

2.2.2 SOIL

Soil samples will be collected by an auger at the points of determined intervals along a transect line. However, when a rapid change is expected on a transect, appropriate subdivisions should be set between the intervals. At field survey, observation of site and soil collected will be recorded.
Peat monitoring sheet is shown in appendix, which will be useful for recoding all the necessary information of sampling plot and survey area (see appendix. Peat Monitoring sheet).

For collecting soil samples, the depth of soil sampling will be decided based on the purposes of survey (i.e. 0-15 cm, 15-30 cm, 30-50 cm, 50-100 cm, 100-200 cm, 200-300 cm, 300-500 cm and > 500 cm). A soil sample is packed into a plastic bag. Air must be removed from the plastic bag before sealing as shown below. Also, peat soil water will be collected into plastic bottles by filtration at the depth of water level of each soil sampling points as explained in 2.4.3. WATER chapter.

Air is removed from a soil sampling bag.

2.2.3 VEGETATION

A tree survey contains all kinds of detailed information about the trees. The survey will reveal information such as species of the tree based on scientific name, physical measurements of the tree such as height and diameter, age of the tree etc.

Firstly, survey plot will be set by area measurement (a). The plots for tree survey should be representative, so the places that are specifically disturbed are not recommend to be set a survey plot. Three or four people are recommended to conduct tree survey in one square plot. At least one of them must be the experienced in identifying tree species. Each crew member is responsible for measurement, tree identification or recording.

(a) A survey plot is set by area measurement.

For the purposes of survey, the minimum size (cm) in stem diameter of mature trees to be measured will be decided. (i.e. trees with over 10-cm stem diameter). The main stem (trunk) diameter must be measured at 1.3 m above the soil surface (Kauffman et al., 2016). Within the individual plots, trees of each species are counted. All trees need to be tagged with special tags and numbers (b). These results are then expressed as percentages of the total for that area (i.e. Lithocarpus dasystachys makes up 15% of all the trees).

(b) A tree stem is measured and tagged with special tags and numbers

If possible, trees that are measured should be identified to the species or genus level. For the tallest tree of each species in an area, its height was measured using a clinometer. However, it is usually difficult in forests with a high tree density. The example of result table is shown in Table below.

Table 1 Results of tree survey

Species	Number of trees	Basal area (cm2)	Basal area (%)
Lithocarpus dasystachys	62	16157	15.32
Tetractomia tetrandra	36	8750	8.30
Combretocarpus rotundatus	4	6557	6.22
Xylopia fusca	8	5345	5.07
Cratoxylon glaucum	10	5083	4.82
Syzygium sp.	23	4849	4.60
Shorea teysmanniana	20	4446	4.22
Horsfieldia crassifolia	7	4195	3.98
Lithocarpus gracilis	1	4137	3.92
Mezzettia parvifolia	7	4130	3.92
Elaeocarpus mastersii	10	3529	3.35
Dactylocladus stenostachys	3	3513	3.33
Stemonurus secundiflorus	5	3426	3.25
Ilex hypoglauca	10	2767	2.62
Mezzettia umbelliflora	4	2757	2.61
Santiria griffithianum	11	2718	2.58
Neoscortechinia kingi	5	2652	2.51
Diospyros pseudomalabarica	8	2301	2.18
Gymnacranthera farquhariana	12	2209	2.09
Shorea balangeran	1	1304	1.24
Grewia sp.	10	1265	1.20
Garcinia sp.	3	1077	1.02
Others (35 sopecies)	67	12297	12
Total	**327**	**105466**	**100.00**

Reference

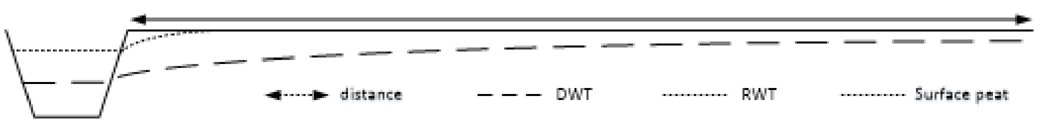
Kauffman et al. (2016) Protocols for the measurement, monitoring, and reporting of structure, biomass, carbon stocks and greenhouse gas emissions in tropical peat swamp forests. Working Paper 221.Center for International Forestry Research. DOI: 10.17528/cifor/006429

Annex.01

Appendix

	Name of surveyor		Peat profile
1	Date, Time		
2	Code / Number of sampling		
3	Administrative location		
4	GPS coordinate		
5	Peat maturity	Sapric/Hemic/fibric/Mineral/Charcoal(S/H/F/M/C) write in 'Peat profile'	
6	Peat thickness (cm)		
7	Depth of substratum (cm)		
8	Depth of charcoal (cm)		
9	Substratum soil type	Clay/sand	
10	Drainage pattern / type	natural/artificial (describe) . . .	
11	Distance for nearest canal (m)	primary/secondary/etc.	
12	Canal water table (WT) (cm) (Interview and/or observation)	Present ___ (cm); wet season ___ (cm); dry season ___ (cm)	
13	GWT of sampling point (cm) pH / EC (μS/cm)/DOC ※2		
14	Landuse		
	Year of canal construction		
	Previous landuse		
	Year of converting landuse		
15	Soil classification		
16	Number of samples	(total)	
	From auger		
	From core (undisturbed)		

Sketch:



Peat profile: Necessary information from soil observation, which are recorded in the tables will be drawn in the right space.

Sketch: in a transect survey, record general information in a visually understandable way such as site names, water level in dry season (DWT) and in rainy season (RWT), peat depth etc.

Reference of peat monitoring sheet

	Name of surveyor	Write the name who records
1	Date, Time	Write the date and time you conduct sampling in this point.
2	Code / Number of sampling	Write the code of sampling point.
3	Administrative location	Write administrative location. (Ex: name of village, district etc.)
4	GPS coordinate	Record GPS (X; Y) data at this point.
5	Peat maturity	Rapid assessment of peat maturity by squeezing amount of sample at field. For further explanation, see BBLSDP 2014(page 4, pdf page 9).
6	Peat thickness (cm)	The depth of mineral soil layer from the surface by auger measurement
7	Depth of substratum (cm)	Measure the depth where the mineral soil appeared
8	Depth of charcoal (cm)	Record the depths where charcoal is observed during collecting samples. Usually an artificial place has more charcoal layers than natural forests. Charcoal tents to appear in the upper layers in Natural forest due to the frequent fires in current decades.
9	Substratum soil type	Define mineral soil type. (Mineral Soil Classification: Clayey, Sandy, Loamy, etc.)
10	Drainage pattern / type	Describe drainage pattern / type (natural, artificially built, etc.)
11	Distance for nearest canal/stream (m or km)	Measure the sampling point to the nearest canal around, and recognize the canal (primary/secondary/branch etc.)
12	Canal water table (WT) (cm)	Measure the water table level from ground surface at the nearest canal. By interview (if possible). Difference between rainy season and dry season.
13	GWT of sampling point (cm)	Measure water table level at the sampling point using after you dig peat soil or make a well. Measure pH, EC and DOC as a site representative water quality)
14	Landuse	Describe present vegetation cover (forest, bare land, plantation etc.).
	Year of canal construction	Record when canal was built. (Interview)
	Previous landuse	Record the previous landuse / land cover. (Interview)
	Year of converting landuse	Record the year of converting land use to the present condition. (Interview)
15	Soil classification	Classify soil type of the samples using common soil taxonomy system or local taxonomy system (WRB USDA, FAO, etc.)
16	Number of samples	Total number of samples taken from auger and cores
	From auger	The number of samples taken from auger.
	From core (undisturbed)	The number of core samples.

Peat profile: Necessary information from soil observation, which are recorded in the tables will be drawn in the right space.

Sketch: in a transect survey, record general information in a visually understandable way such as site names, water level in dry season (DWT) and in rainy season (RWT), peat depth etc.

2.5. Peat Thickness Estimation with a Phenology Classification Method

Hypothesis

According to studies of Central Kalimantan peatlands (Shimada et al. 2017), peat thickness is predictable by forest phenology type above the peat layer. Peat swamp forest (PSF) phenology type in Central Kalimantan was classified into eight major types (PHIL, W1, W2, W2D-A, W2D-Z, W1D, PHOB-Z, PHOB-V) using multi-temporal (1992−1993) monthly National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Radiometer (AVHRR) data. Specifically, fluctuation patterns of the vegetation index among three seasonal periods (i.e., the former half of the five-month rainy season, the latter half of the five-month rainy season, and the two-month dry season) were classified.

Tropical peatlands are characterized by high groundwater levels and their seasonal fluctuations. High groundwater level usually leads to a decrease in vegetation activity owing to anoxic stress to plant roots. Considering the hydrological buffer function of the peat layer, we focused on phonological difference due to the hydro-periodical difference of PSF and its relation to peat thickness. Riverine PSF and PSF fringing on shallow peat layers have greater water flow and seasonal groundwater level fluctuations in comparison to inner forests on deeper peat layers which tend to have permanently high groundwater levels that moderately fluctuate. Since the hydroperiod is a seasonal characteristic of peatlands in Southeast Asia, PSF phenology was hypothesized to be a predictor of underlying peat thickness. The result of the association of ombrophobous PSF phenology types (PHOB-Z and PHOB-V [Remark 1]) with significantly shallower peat layers (Table X. 1) indicates the influence of flooding stress due to a waterlogging in the rainy season. This supports a part of the hypothesis (Figure 2-1).

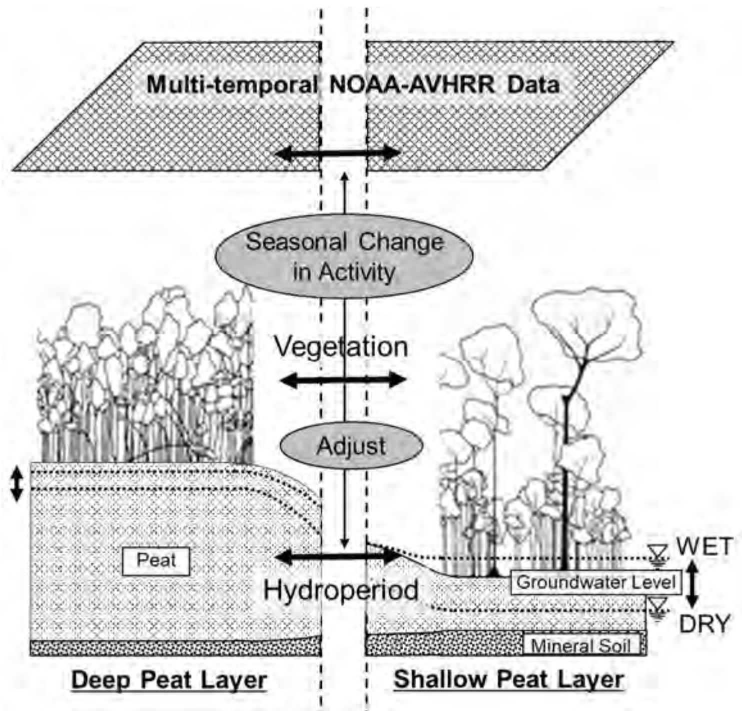


Figure 2-1: Phenological pattern, mean peat thickness, and percentage of areal extent among eight peat swamp forest types in Central Kalimantan (cited from Shimada et al. 2017)

PSF phenology types that have maximum vegetative activity during the latter rainy season (i.e., W2 and W2D-A) occur on relatively deeper peat layers (Table X. 1). The root mean square error (RMSE) for the peat thickness estimation map was derived by assigning each associated mean peat thickness value (Table X. 1 and Figure X. 6) to PSF types in Central Kalimantan and was found to be 2.49 m. Individually, the phenology types on deeper peat layers (i.e., W2, W2D-A, and W2D-Z) tend to have greater errors (RMSE = 2.33 m, RMSE = 3.17 m, and RMSE = 2.77 m, respectively) in peat thickness estimation.

Table 2-1: Phenological pattern, mean peat thickness, and percentage of areal extent among eight peat swamp forest types in Central Kalimantan (cited from Shimada et al. 2017).

Phenology type	Phenological pattern*					Mean peat thickness (m)	Percentage of areal extent (%)
	WET1	→	WET2	→	DRY		
PHIL	1	(+) (−)	1	(−)	0	0.75	0.5
W1	1	(−)	0	(+)(−)	0	–	0.8
W1D	1	(−)	0	(+)	1	1.56 [bc]	9.1
W2	0	(+)	1	()	0	4.70 [ab]	6.4
W2D-A	0	(+)	1	(-)	1	4.59 [a]	13.6
W2D-Z	0	(+)	1	(+)	1	2.64 [b]	47.2
PHOB-Z	0	(+)	0	(+)	1	1.35 [c]	13.3
PHOB-V	0	(−)	0	(+)	1	0.84 [c]	9.1

*WET1: former half of the rainy season (September 1992 to January 1993)
WET2: latter half of the rainy season (February to June 1993)
DRY: dry season (July to August 1993)
0: Normalized Difference Vegetation Index (NDVI) during a seasonal period < annual mean NDVI
1: NDVI during seasonal period > annual mean NDVI
(+): positive gradient between seasonal periods
(-): negative gradient between seasonal periods
a > b > c: values followed by the same letter are not significantly different at a significance level of $P < 0.05$ (Sheffé's test)

2.2.2. Peat Thickness Estimation Method

Here, we explain the steps involved in the derivation of the phenological classification map (i.e., the prediction map for peat thickness).

Step 1. Preparation of time-series satellite imagery data

- Acquisition of time-series vegetation index data product or raw reflectance imagery data which are to be calculated into a vegetation index. High temporal resolution image data such as Terra/Aqua-Moderate Resolution Imagery Spectroradiometer (MODIS) and NOAA-AVHRR are preferable since the elimination of contamination from noise or clouds can be more easily achieved.

- Vegetation index time-series imagery products can be freely acquired through various web archive data center portals, e.g., United States Geological Survey (USGS) Global Visualization Viewer (GloVis: https://glovis.usgs.gov/), USGS EarthExplorer (https://earthexplorer.usgs.gov/), National Aeronautics and Space Administration (NASA) Earthdata Search (https://search.earthdata.nasa.gov/search), and Global Land Cover Facility (GLCF: http://www.landcover.org/).

- A dataset of more than one year is required for analysis.

- The vegetation index can be the NDVI (eq (1)), the Enhanced Vegetation Index (EVI: eq (2)), or the Temperature Adjusted Vegetation Index (TAVI: eq (3) and eq (4)). TAVI, which includes not only vegetation chlorophyll activity but also vegetation transpiration activity, can be a more sensitive indicator than NDVI in the tropics (Foody et al. 1996).

$$\text{NDVI} = \frac{NIR-Red}{NIR+Red} \qquad \textbf{eq (1)}$$

$$\text{EVI} = \text{G} \times \frac{NIR-Red}{NIR+C_1 \cdot Red - C_2 \cdot Blue + L} \qquad \textbf{eq (2)}$$

$$\text{TAVI} = \frac{NDVI}{T_s} \times 100 \qquad \textbf{eq (3)}$$

Where,
NIR: reflectance in the wavelength of near-infrared,
RED: reflectance in visible red,
Blue: reflectance in visible blue,
L: canopy background adjustment,
G: gain factor,
C_1, C_2: the coefficients of the aerosol resistance term,
T_s: surface radiation temperature calculated by the split window algorithm using two thermal bands (Price 1990) [eq (4)].

$$T_s = \frac{[T_x + 3.3(T_x - T_y)](5.5 - \varepsilon_x)}{4.5 - 0.75 T_x (\varepsilon_x - \varepsilon_y)} \qquad \textbf{eq (4)}$$

Where,
T_x, T_y: brightness temperature (K) at thermal bands *x* and *y*,
ε_x, ε_y: emissivity at the wavelength bands *x* and *y*.

In the estimation case of Shimada (2001), datasets of 10-day composite NOAA-AVHRR data products on NDVI and channel-4 and channel-5 radiation temperature (T_x and T_y, respectively) over the Sumatra-Kalimantan area were collected from the Earth Resources Observations Systems (EROS) Data Center (Shimada et al. 2001). T_S was calculated using eq (4) by assuming the surface emissivity (ε_x, ε_y) to be 0.96 (Nemani et al. 1993). The image data period was set as April 1992 to September 1993 to avoid the effects of the large-scale forest fire in 1994
.

Step 2. Preprocessing of time-series satellite imagery data

- Monthly composite imagery data (e.g., NDVI, EVI, T_S, and other indices) should be prepared from shorter time period composites such as eight-day, 10-day, or 16-day composite data by maximum filter so as to reduce the effects of cloud contamination.

- Monthly composite data should be smoothed by the three-month moving median filter to eliminate remaining contamination due to clouds and noise (Fig. X. 2).

- TAVI, if adopted for the phenological classification, should be calculated using median-smoothed monthly images.

- The monthly vegetation index imagery dataset which was trimmed into a one-year period should be aggregated into three seasonal index images with a one-year mean image. The concept of the discrimination method of the seasonal period within a year is shown in the next step (Step 3).

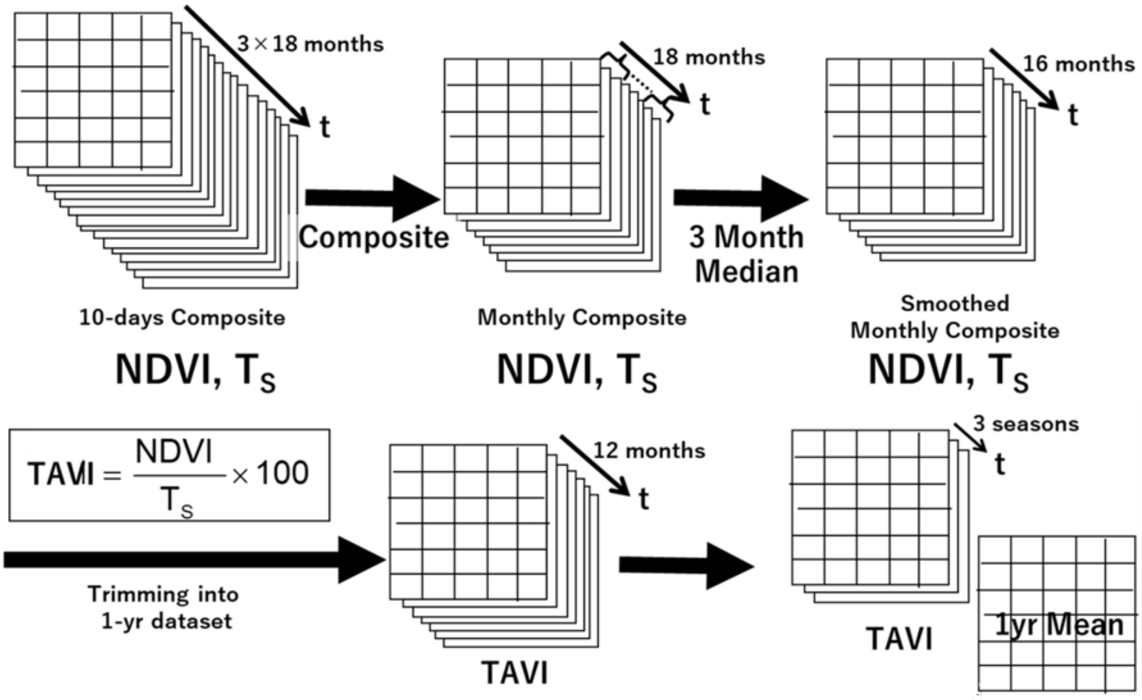


Figure 2-2: Image preprocessing scheme example of deriving one-year mean and seasonal Temperature Adjusted Vegetation Index (TAVI) data from the 10-day composite National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Radiometer (AVHRR) and T_S time-series data.

Step 3. Seasonal period discrimination

- A year of the tropical region can be divided into two seasonal periods, i.e., the wet (rainy) season and the dry season. Each region has its own unique seasonal distribution, e.g., the wet season typically occurs in Central Kalimantan from June to October, with the remaining months constituting the dry season (~ two months) and intermediate months. To reflect vegetative responses resulting from regional and real-time micrometeorology, data corresponding to the region and time of imagery acquisition should be used. Since extraction of vegetation seasonal characteristics is important and the wet season is longer than the dry season, the wet season is divided into two seasonal periods, i.e., the former and latter wet periods (WET1 and WET2, respectively).

Including the dry seasonal period (DRY), three seasonal periods are discriminated (Fig. X. 3).

- Monthly precipitation data and evapotranspiration rate data at the target area and time period are needed to set the ranges of the seasonal periods.

- Identify the month of the year when monthly evapotranspiration exceeds monthly precipitation. Classify these consecutive months as the dry period and the remaining months as the wet period. The wet period should be split in half and the first half of the period classified as WET1 and the second half classified asWET2.

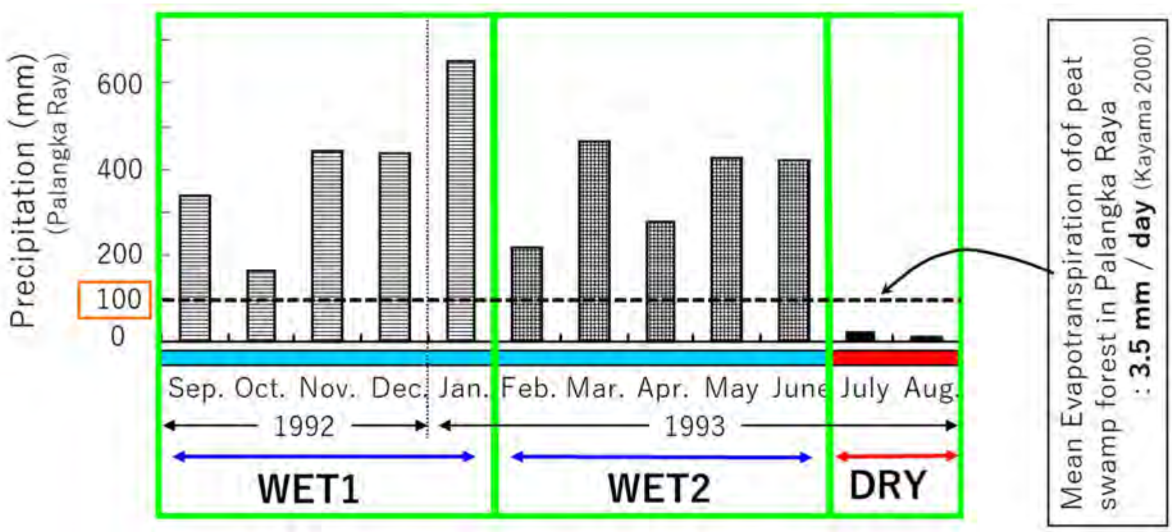


Figure 2-3: Discrimination of three seasonal periods in a target year (September 1992 to August 1993) in a peat swamp forest near Palangka Raya, Central Kalimantan

Step 4. Phenological type classification

- The pixel value of each seasonal vegetation index (e.g., $\overline{TAVI_{WET1}}$, $\overline{TAVI_{WET2}}$, and $\overline{TAVI_{DRY}}$) is to be compared to the corresponding one-year mean vegetation index value (e.g., $\overline{TAVI_{1yr}}$) to assess vegetative activity during different seasonal periods (Fig. X. 4).

- If a value of the seasonal vegetation index exceeds the annual mean value, the vegetation at the corresponding pixel for the seasonal period is considered active, while pixel values below the annual mean value are considered inactive (Table X. 1). All combinations of active and inactive vegetation among the three seasonal periods create six patterns (i.e., in the following order, WET1:WET2:DRY = +:+:–, +:–:–, +:–:+, –:+:+, –:–:+, –:+:–).

- The gradient of vegetation index values between consecutive seasonal periods (i.e., between WET1–WET2 and WET2–DRY) can be analyzed. The total number of possible phenology patterns is 10.

- Each vegetation phenology type can be named, e.g., the ombrophilous type as PHIL and the ombrobobous type as PHOB (Fig. 4, Table X. 1).

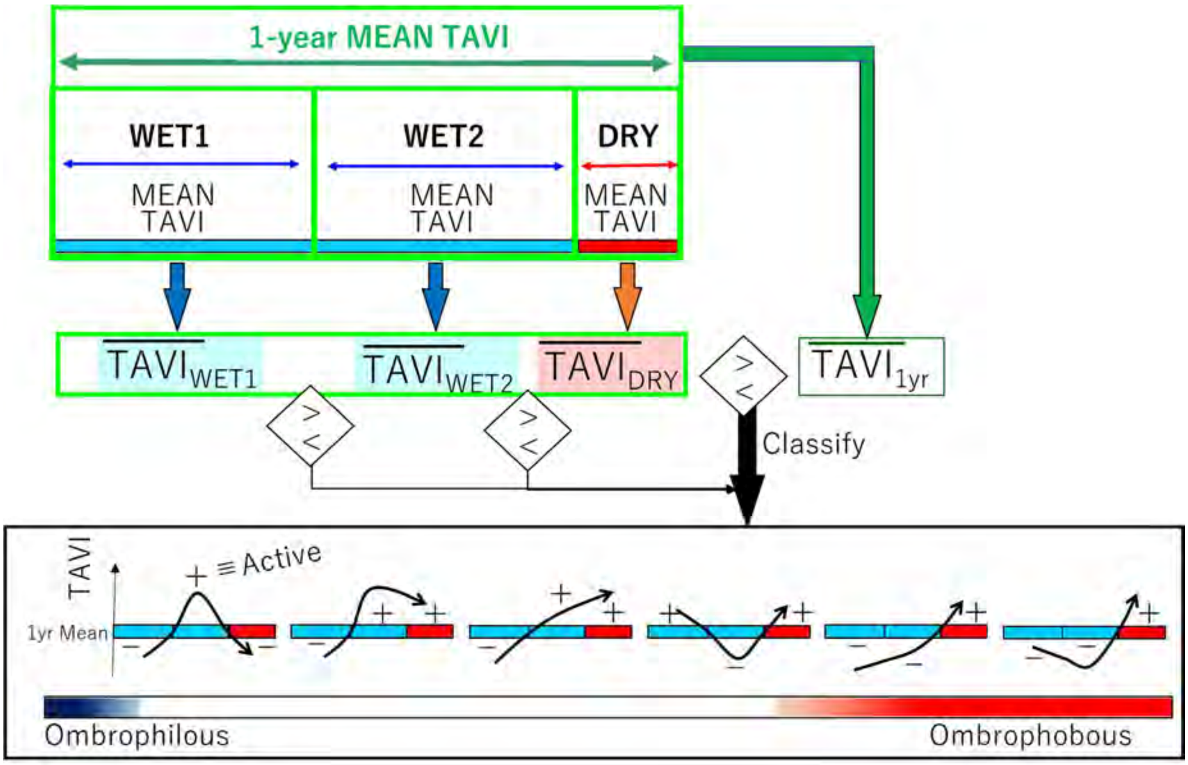


Figure 2-4: Schematic figure on phenology type classification using the Temperature Adjusted Vegetation Index (TAVI) among three seasonal periods in a target year (September 1992 to August 1993) in a peat swamp forest near Palangka Raya, Central Kalimantan.

Figure 2-5: Output map of the phenological schematic figure on discriminating three seasonal periods in a target year (September 1992 to August 1993) in a peat swamp forest near Palangka Raya, Central Kalimantan.

Step 5. Assigning phenological type to peat thickness

As vegetation phenology relates to peat thickness (Fig. X. 1, Table X. 1), the mean thickness value for each phenology type (Table X. 1) can be used to derive an estimated peat thickness map (Fig. X. 6).

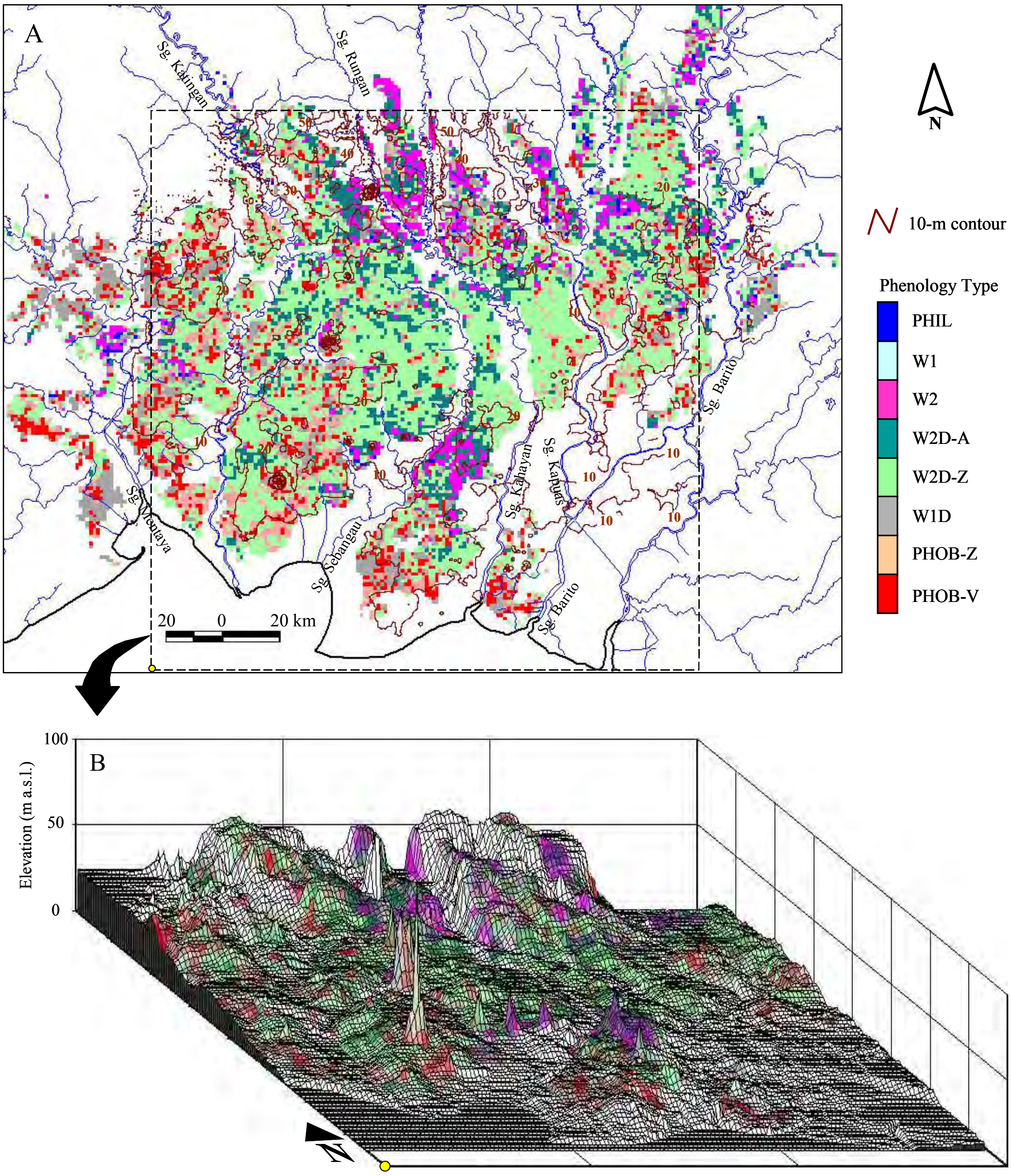


Figure 2-6: Phenology classified map of a peat swamp forest in Central Kalimantan derived using the Temperature Adjusted Vegetation Index derived from National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Radiometer (AVHRR) (September 1992 to August 1993) data. Each phenology type corresponds to a phenological pattern and a specific peat thickness (Table X. 1; cited from Shimada 2001).

REFERENCES

Shimada S. (2001). Distribution of Carbon in Peat Layer and Estimation of Carbon Mass using Satellite Data in a Tropical Peatland, Central Kalimantan, Indonesia, Hokkaido University Ph.D. thesis.

Shimada S., Takada, M., Takahasi, H. (2017) Peat Mapping, In: Tropical Peatland Ecosystems (Osaki & Tsuji Eds.) Chapter 31, Springer Japan.

3.1. Ground Water Table (GWL) Monitoring

Groundwater level measurements
GWL is a key parameter for estimating carbon emissions from peat decomposition and burning. Therefore, it is important that GWL is measured in every type of peatland identified based on distinctive land use and land cover characteristics in the study area (see Sub-section 2.2.1). GWL data are collected through the steps described below.

Step 1. Prepare equipment for field measurements

A minimum list of equipment needed for the field measurement of GWL is provided below, and should be adjusted based on the field condition. This guidebook suggests that GWL be monitored and recorded by using the SESAME system[1], which comes with water level, temperature and precipitation sensors (see Figure 3).

SESAME system
SIM card for mobile network
Laptop computer with a modem
Iron pipe
PVC pipe
Eijkelkamp[2] peat auger
Cleaver
GPS receiver
Compass
Measuring tape

Activate the SIM card. Top up the card (if it is prepaid) before it expires for seamless data transmission.

Obtain a server access license (user ID and

[1] SESAME system SESAME 01-II: http://www.midori-eng.com/english/image/sesame-01-2_pamph.pdf
[2] The Eijkelkamp auger is a peat sampler used for soil profile description and classification. The details about the Eijkelkamp auger are available at https://en.eijkelkamp.com/products/augering-soil-sampling-equipment/peat-sampler.html.

password) for data acquisition[3].

Set up the modem on a laptop computer for data transmission.

Figure 3-1. SESAME system

Test the Internet connection.

Step 2. Select locations for field measurements

Select field measurement locations based on the following conditions:

- The locations must be physically accessible and legally permissible for the installation of the SESAME system and its maintenance.
- GSM/GPRS/Q-CDMA network coverage is available (because the SESAME system transmits data through the mobile network).
  - If the network coverage is not available at the ground surface level, an antenna may be mounted above the vegetation canopy to catch the signal.
- The locations are representative of distinctive peatland types identified by the remote sensing imagery (see Sub-section 2.2.1 on Peatland Type).
  - The SESAME system should be installed at every distinctive type of peatland, as the Carbon Emission Model will be developed per peatland type.
  - The SESAME system should be installed at the CO_2 flux observation sites as well (see Sub-subsection 2.1.2.2).
- The location is safe from potential thefts of instruments.

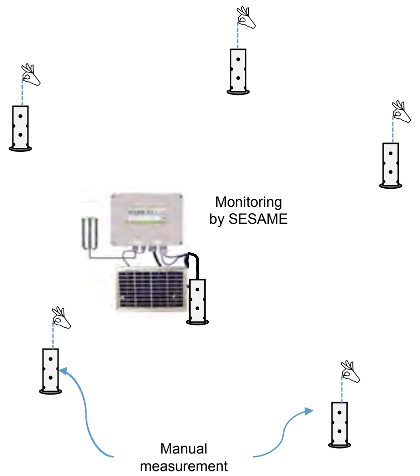
[3] The server is currently maintained by Midori Engineering Laboratory in Japan. Contact Mr. Yukihisa Shigenaga (email: shigenaga@midori-eng.co.jp; Telephone: +81-11-555-5000; URL: http://www.midori-eng.co.jp) for details.

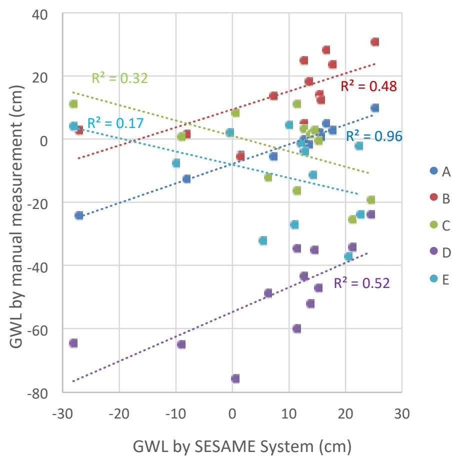
Box 2. How many units of the SESAME system should be installed in the area of interest?

Because GWL is affected by a number of factors including precipitation, vegetation types, land cover, slope of the land, peat depths and water channels (i.e., rivers and canals), there is no single answer to which how many units of the SESAME system are needed in order to represent GWLs over a certain area of peatland. The following method can be adopted to determine the number of SESAME system units to be installed in the study area.

- Install one SESAME system at a sampling location representative of a peatland type based on distinctive land use and land cover characteristics (e.g., drained forest or DF) found in the study area, and measure and record GWL at the location.

- Additionally, set up PVC pipes for manual GWL monitoring randomly in several locations within the same peatland type (DF) in the area. Measure and record GWLs manually at these locations once a month at least for one year. 12 GWL data from each monitoring pipe will be obtained. Then plot GWL data from the SESAME system on the X axis and manual GWL data on the Y axis to obtain their relationships.





- Examine the correlation of each regression line. If the correlation is strong, the data obtained by the SESAME system can be used to represent GWLs at the manual monitoring location. Consider to install another SESAME system at the manual monitoring location which showed a weak correlation.

- Caution needs to be taken for areas in which GWLs tend to change considerably within a short distance and/or short time interval (e.g., areas close to a drainage canal).

Step 3. Install a SESAME system in the selected location

Measure peat depths at the selected location to install the SESAME system.

Install an iron pipe all the way into the mineral soil through the peat layer so that the pipe stays stable (①).

Build a metal platform to hold a rain gauge sensor and the SESAME instrument cabinet. The metal platform must be placed high enough to be free from potential flood damage (②).

Make 0.5 cm diameter holes in a PVC pipe to serve as a water gauge (③).

Install the SESAME instrument cabinet on the iron pipe (④). There is a solar panel on the box. Therefore, the installation must be directed into the sunlight.

Install the rain gauge sensor on the metal platform (⑤).

Install the water logger sensor into the PVC pipe (⑥).

Install an iron pipe all the way into the mineral soil through the peat layer. It must be placed several meters away from the SESAME system (⑦).

Install a ground surface elevation laser sensor into the PVC casing. The laser sensor must be placed high enough to be free from potential flood damages (⑧).

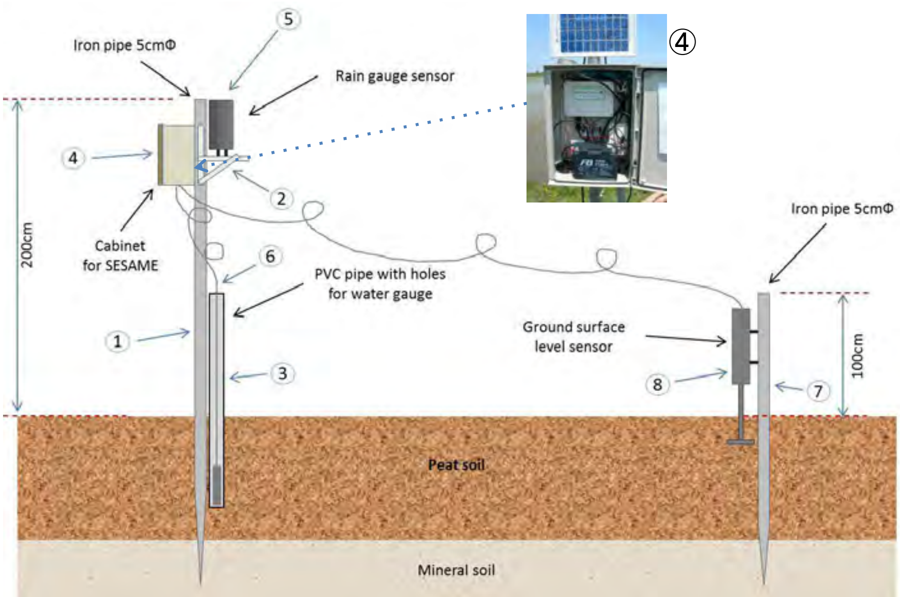


Figure 3-2. Illustration of SESAME system installation

Step 4. Activate the SESAME system and start recording GWL and other microclimate parameters

Check that all components (GWL sensor, rain gauge, temperature sensor and ground surface elevation sensor) are working properly.

Activate the SESAME system and start recording GWL at the interval of 10 minutes and other microclimate parameters (i.e., precipitation and air temperature).

Check that the data from the SESAME system are transmitted to the server without any errors. If there are errors, you must check whether the SESAME system is properly installed in the field.

3.2. Soil Moisture Mapping with a Remote-Sensing Dataset

Step 1. Download an existing peatland map

A peatland map of the study area is needed to delineate peatland from non-peat areas. Indonesia has several peatland maps developed by various institutions and organizations, including the Ministry of Agriculture (MoA) and Wetlands International (WI) (see Figure 2). These are the most frequently cited maps in Indonesia. Peatland maps (in ESRI shape file) from these sources may be obtained by sending a formal letter of request.

Ministry of Agriculture
http://www.pertanian.go.id

Wetlands International
http://indonesia.wetlands.org/Infolahanbasah/PetaSebaranGambut/tabid/2834/language/id-ID/Default.aspx

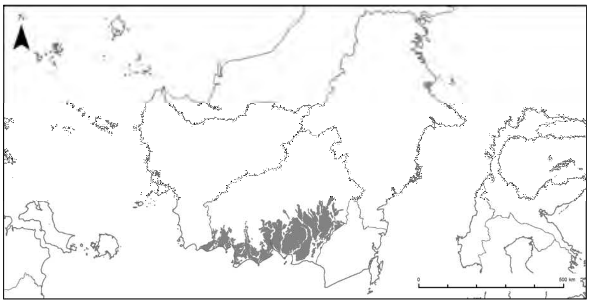


Figure 2. Peatland map of Central Kalimantan by Wahyunto, et al. (2004)

Box 1. An alternative approach: Create a new peatland map

A new peatland map be developed by using a spatial model. There are various methodologies to create a new peatland map, and the following is an example.

- Obtain and pre-process satellite imagery of the study area. In order to reduce data gaps and improve interpretation, it is recommended to use a combination of medium- to high-resolution optical satellite images as well as Synthetic Aperture Radar (SAR) data.
- Obtain BIG (Badan Informasi Geospasial) topography maps at the 1:50,000 scale and SRTM digital elevation model data. These data are used to determine geomorphological features such as peat dome structures and hydrological networks of the study area.
- Obtain NOAA Advanced Very High Resolution Radiometer (AVHRR) data of selected years from the USGS Global Land 1-km AVHRR Project, and evaluate vegetation activities by normalized difference vegetation index (NDVI). In order to estimate accurate peatland distribution in the study area, it is recommended that the NDVI analysis be based on the land cover of the past (e.g., 1990), when peatland was relatively undisturbed and its original condition and distribution could be assessed.
- Conduct ground-truthing to verify peat and non-peat areas in the study area.
- Manually delineate peat boundaries on a GIS platform based on the NDVI values, slope raster data, and morphological and hydrological network information obtained through remote sensing analyses. Peatlands generally occur on gentle slope areas with slope angles of less than or equal to 0.2°, and manual delineation should be conducted in reference to such areas.
- Conduct a geo-statistical analysis to estimate peat thickness distribution within the study area.
- Based on the distribution of peat thickness, filter out areas with peat thickness less than 50 cm (according to the definition of peatland), and develop the final peatland map of the study area.

Step 2. Download soil moisture data

Download soil moisture data from an available source to be used to estimate the spatial distribution of GWLs in the study area.
One source of global soil moisture data available for free of charge is the volumetric soil water layer product of the European Center for Medium-Range Weather Forecast (ECMWF). It is available at http://apps.ecmwf.int/datasets/data/interim-full-daily/.

Before downloading the data, you must select the applicable time-series (i.e., daily), coordinate system (e.g., WGS 84), coordinates, and grid size (e.g., 0.5 degrees). They must match those applied in Step 2 of Sub-section 2.2.1 (Peatland Type).

Step 3. Download NCAR/NCEP soil moisture data

Another source of global soil moisture data that is freely available and can be used to estimate the spatial distribution of GWL in the study area is the volumetric soil water layer product of NCEP (https://rda.ucar.edu/datasets/ds083.2/). After registration, a Gribs2 six-hourly file of soil moisture data can be obtained. These data have a resolution of ~ 0.25° × 0.25° and can be downscaled to 1 km × 1 km by using NOAH land surface models that have been installed in the Weather Research and Forecasting (WRF) software.

Step 4. Download forest cover change data

Download a forest cover change data product from an available source to be used to identify forest and non-forest areas in the study area.

One source of forest cover change data is the Global Forest Change product developed by NASA, available at https://earthenginepartners.appspot.com.

Step 5. Download surface reflectance data

Download a surface reflectance data product from an available source to be used to identify undrained and drained areas in the study area.

One source of surface reflectance data is the MODIS surface reflectance product (MOD09A1), available at http://modis.gsfc.nasa.gov/data/dataprod/mod09.php.
This MODIS surface reflectance product allows you to identify these areas based on plant physiological responses to different degrees of dryness on vegetated land surfaces.

Step 6. Download burned area data

Download a burned area data product from an available source to be used to estimate the spatial distribution of burned areas in the study area.

One of the burned area products available globally is MODIS burned area product (MCD45A1). It is available at http://modis.gsfc.nasa.gov/data/dataprod/mod45.php.

Original imagery data obtained by aerial photography may be used in combination with the MODIS burned area product to improve the accuracy.

Advanced techniques such as LiDAR (Light Detection and Ranging) and PALSAR-2 (Phased Array type L-band Synthetic Aperture Radar) may be used if they are available and applicable. They are high resolution and can determine ground surface levels with an accuracy of several centimeters. However, even if these high-resolution remote sensing techniques are adopted, field measurements must still be conducted for ground-truthing purposes (see Sub-subsection 2.1.2.3 on Burn Scar Measurements).

3.3. Groundwater level (GWL) analysis

The SESAME system records real-time GWL data at a 10-minute interval (see Sub-subsection 2.1.2.1). The data must be downloaded from the server and analyzed to obtain the lowest monthly average GWL(s) in the study year(s). This value will be used as a key parameter for the Carbon Emission Models explained in Sections 2.3 and 2.4. Obtain at least several lowest monthly average GWL values in the study years (i.e., several continuous years of GWL observation) in order to improve the accuracy of the models.

Step 1. Download raw data from the SESAME server

Access the SESAME server and download raw GWL data for the selected time and location via the procedures described in Annex 2.

You must install the SESAME software on your computer first to be able to access the server. To obtain this software, contact Midori Engineering Laboratory.

Step 2. Organize the raw data into observation data

Make a .csv file (e.g., Excel), and add field names to the spreadsheet.
Organize the downloaded raw data as observation data for each variable (i.e., GWL, precipitation, and ground surface level) via the procedures described in Annex 3.

Repeat this for all downloaded raw data collected at each type of peatland.

Check to see if data are complete.

If there are missing data for a short time period, make an interpolation and fill the data gaps.

If data gaps are caused by mobile network failure, the missing data can also be obtained directly from the SESAME system (data logger). The SESAME system stores data in a memory card for three months.

Step 3. Convert the observation data into daily average values for each parameter

Take the daily average of each observation data recorded at a 10-minute interval.

Add the daily average values for each variable in a new column on the spreadsheet (see Figure 12).

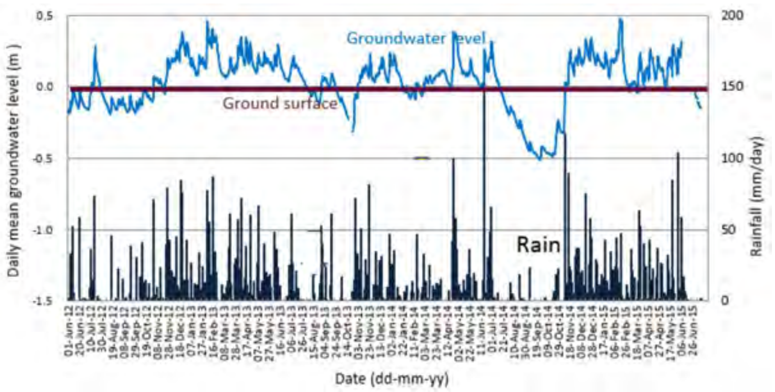


Figure 12. Example for time-series daily average GWLs with other parameters

Step 4. Obtain a linear relationship between daily soil moisture and daily average GWL for each type of peatland

Draw a scatter graph by plotting the observed (measured) daily average GWLs on the Y-axis and the remote-sensing based daily soil moisture data of all grid cells on the X-axis.

Soil moisture data can be obtained in the procedure explained in Step 2 of Sub-section 2.1.1, and daily average GWL values obtained in Step 3 above.

Obtain a linear regression equation between the daily soil moisture and the daily average GWL.

Repeat this for all peatland types (see Figure 13). The equations obtained for the regression lines will be used to simulate daily average GWLs at each peatland type in all other grids throughout the study area.

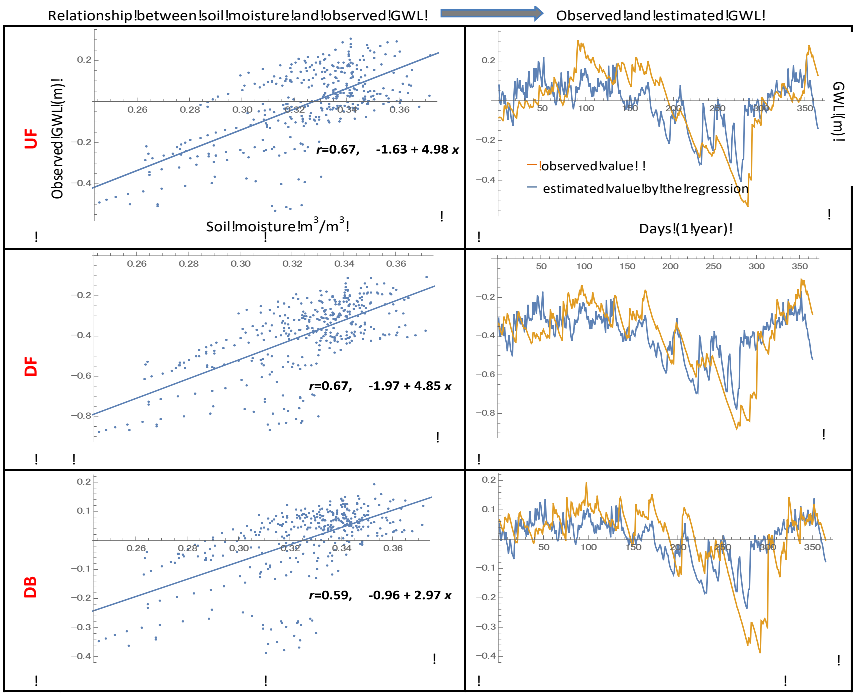


Figure 13. Example of GWL estimations for each peatland type based on the relationship between soil moisture and observed GWL data

Step 5. Estimate daily average GWL values in all other grid cells

Estimate daily average GWL at each peatland type in all other grid cells, using the equations obtained in Step 4 above and daily soil moisture data in each grid.

Step 6. Obtain the estimated monthly average GWL values in all other grid cells

Calculate monthly average GWL at each peatland type in all other grid cells based on the estimated daily average GWL values obtained in Step 5 above.

Step 7. Find the lowest value of the estimated monthly average GWLs for each peatland type in every grid cell

Find the lowest value from the estimated monthly average GWLs of the selected year obtained in Step 6 above.

Repeat this for each peatland type in every grid cell. These values are the **lowest monthly average GWLs in the study year** used as a key parameter for estimating annual average carbon emissions as described in Sections 2.3 (Carbon Emission Model from Peat Decomposition) and 2.4 (Carbon Emission Model from Peat Burning).

3.4. Ground Water Level Mapping

The GWL instrument (such as SESAME) results suggest a strong relationship between GWL and soil moisture in peatlands. This fact can be used to create a GWL map based on the soil moisture map. Required steps are described as follow:

1. Select the area of interest and download soil moisture data from https://rda.ucar.edu/datasets/ds083.2/. The data contain 52 layers of atmospheric moisture and four layers of soil moisture collected every six hours. The data can be downloaded from other sources such as ECMWS but in the Gribs file format. The data typically have a resolution of 0.25° × 0.25°.

2. Downscale the grid resolution into a 1 km × 1 km mesh with a land surface model. The most powerful model is called the Weather Research and Forecasting (WRF) model. The WRF model is a numerical weather prediction and atmospheric simulation system designed for both research and operational applications. WRF is run in the Linux environment so Linux Ubuntu, HDF5, NetCDF, WRF v. 9, and NCL software should be installed. First, initial data from NCEP are processed by the preprocessing procedure using the WPS module. Make the grid by using the geogrid, ungrib, and met grid. Then process the initial data by running WFR. For three days of simulation, the system requires six hours of processing. WRF have four numerical domain D01 (largest area), D01, D02, and D04 (the smallest area). The WRF result of soil moisture map with the D0 domain is depicted in Figure 14.

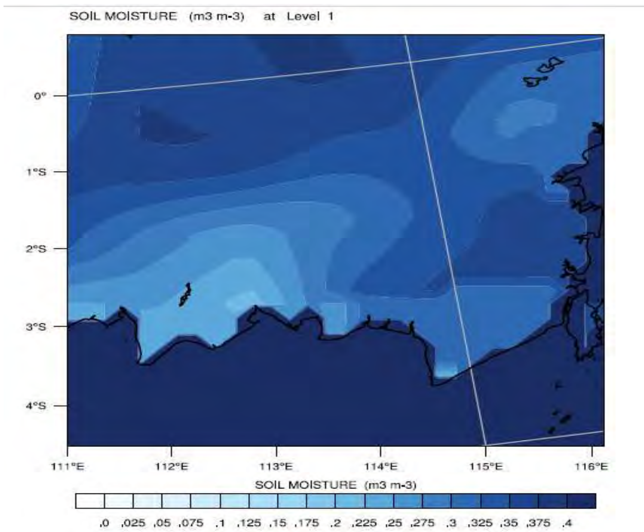


Figure 14: Soil moisture map from WRF output in the D01 domain.

3. Overlay the map with the peatland map to obtain the soil moisture map of the peatland area

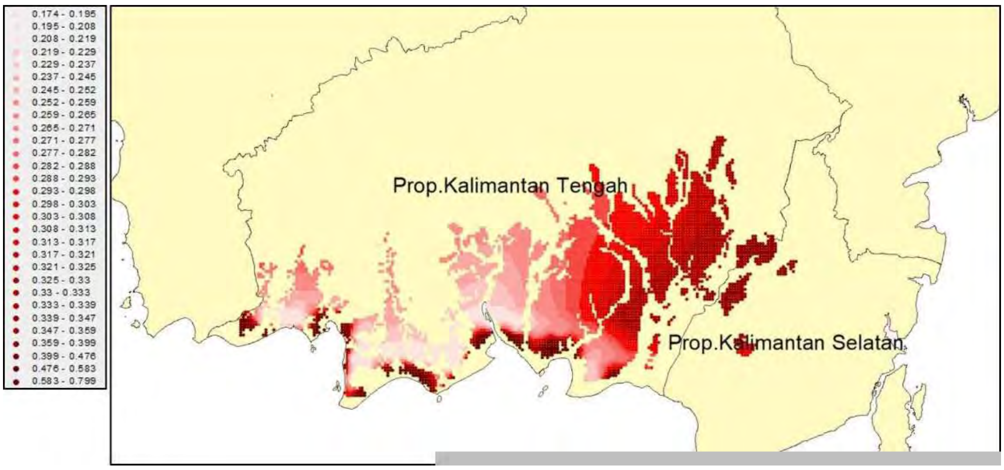


Figure 15: Soil moisture map of peatlands in Central Kalimantan.

4. Apply the empirical formula between soil moisture and GWL (Fig. 13) with three catagories (i.e., UF, DF, and DB) to obtain the GWL map as follows (Fig. 16);l

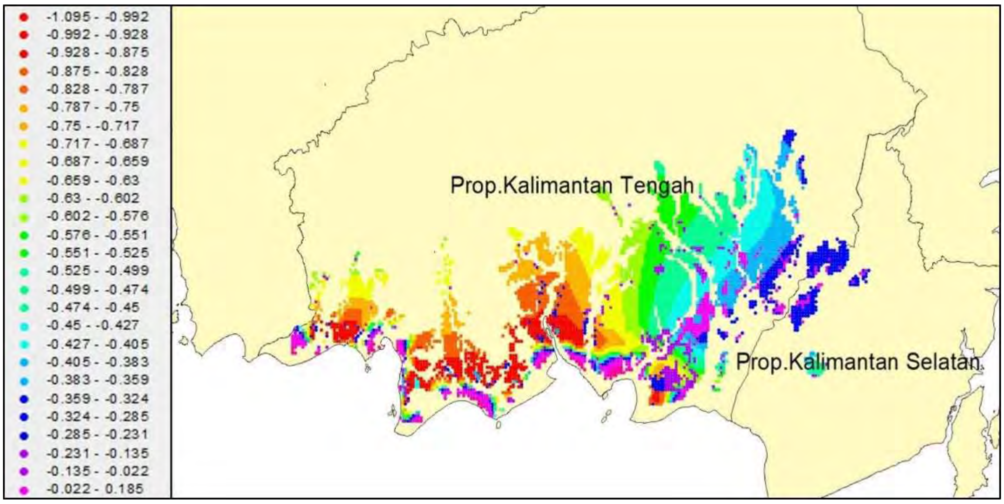


Figure 16: Ground Water Level map of peatlands in Central Kalimantan

4.1.3. Carbon Emission Model from Peat Decomposition

4.1.3.1. Carbon Emission Mapping

Box 1: What is a Carbon Emission Model from Peat Decomposition?

The Carbon Emission Model from Peat Decomposition is based on the assumption that there is a linear relationship between NEE and GWL. Based on this relationship, the model allows the estimation of the annual NEE of the study area using the lowest monthly mean GWL in the study year(s) as a key parameter.

NEE is the difference between the amount of CO_2 that is emitted by ecosystem respiration (RE) and absorbed by photosynthesis (gross primary production). Therefore, the relationship between net ecosystem production (NEP) and NEE is given by:

$$NEE = -NEP$$

$$NEP = GPP - RE$$

RE is found to increase with soil temperature and decrease as GWL (or soil moisture) rises. In forest ecosystems, CO_2 exchange between biomass and atmosphere usually occupies most of the carbon flow. If other carbon sources are negligible, the carbon balance of the forest ecosystem can be determined by NEE as follows:

- NEE > 0: carbon source (emission)
- NEE = 0: carbon neutral
- NEE < 0: carbon sink

Step 1. Obtain a linear relationship between the observed lowest monthly mean GWL in the study year(s) and annual NEE

Use the lowest monthly average GWL value for each peatland type selected from the observed monthly average GWL in the study years as described in Step 7 of sub-section 2.2.2.Use the annual NEE values for each peatland type obtained in sub-section 2.2.3.

Draw a linear regression line between the observed lowest monthly mean GWL in the study year(s) on the *x*-axis and observed annual NEE on the *y*-axis and obtain a relationship for each peatland type (Fig. 14) in the study area. Each regression equation obtained in this step will be used to estimate annual NEE values throughout the study area. The equation can be used to estimate NEE or CO_2 emissions for different years or other locations in the study area based on the estimated spatial distribution of GWL.

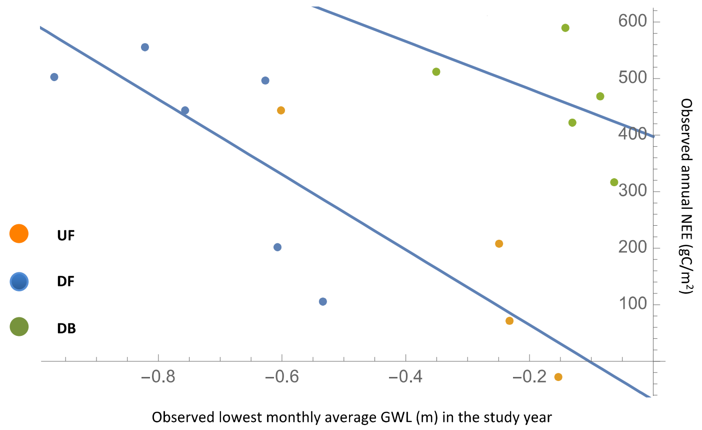


Figure 14: Example of relationships between the lowest monthly mean GWL (m) in the study years and annual NEE (g C m^{-2} $year^{-1}$) observed in Central Kalimantan (Hirano et al., 2012)

Step 2. Estimate annual NEE using the estimated lowest monthly mean GWL in the study year(s) in all other grid cells

Estimate annual NEE for each peatland type in all other grid cells (i.e., areas beyond the observation points) using the equations obtained in Step 1. Use the estimated lowest monthly mean GWL value in the study year obtained in Step 7 of sub-section 2.2.2. Calculate the total NEE from the study area by summing up NEE values from each grid cell using the following equation:

$$T = \sum_{i=1}^{N} A_i \left[\alpha_i X_i + \beta_i Y_i + \gamma_i Z_i + \ldots\ldots \right] \quad \textbf{eq (13)}$$

Where,
T: total NEE,
A_i: peatland area in grid cell i,
α_i: the ratio of peatland type X area in grid cell i,
β_i: the ratio of peatland type Y area in grid cell i,
γ_i: the ratio of peatland type Z area in grid cell i,
X_i: NEE value of peatland type X area in grid cell i,
Y_i: NEE value of peatland type Y area in grid cell i,
Z_i: NEE value of peatland type Z area in grid cell i,
N: the number of grid cells.

Step 3. Generate a map of estimated annual CO_2 emissions

Generate a map of estimated annual CO_2 emissions (positive NEE values) based on the grid file created in Step 2 of sub-section 2.2.1. and the NEE values obtained in Step 2. Fig. 15 shows an example of annual NEE maps for 2012 in Central Kalimantan created on a 0.5° grid file.

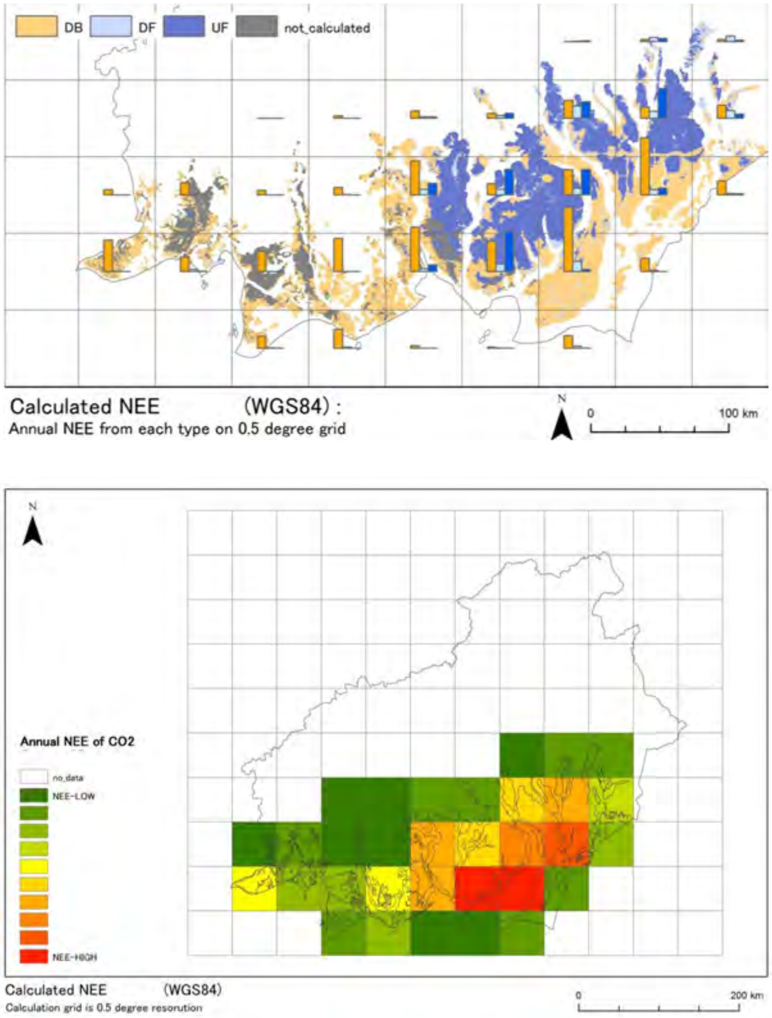


Figure 15: Map of estimated annual NEE values for each peatland type (top) and for total NEE (bottom) in 2012 on grid files for Central Kalimantan

4.1.3.2. Carbon Emission from Time Series Data

Time-series data of GWL can be used to estimate a time series of carbon emission of peat decomposition by applying the Hirano model. We describe the procedure as follows.

Step 1: Obtain time-series data with a daily time interval from the SESAME instrument

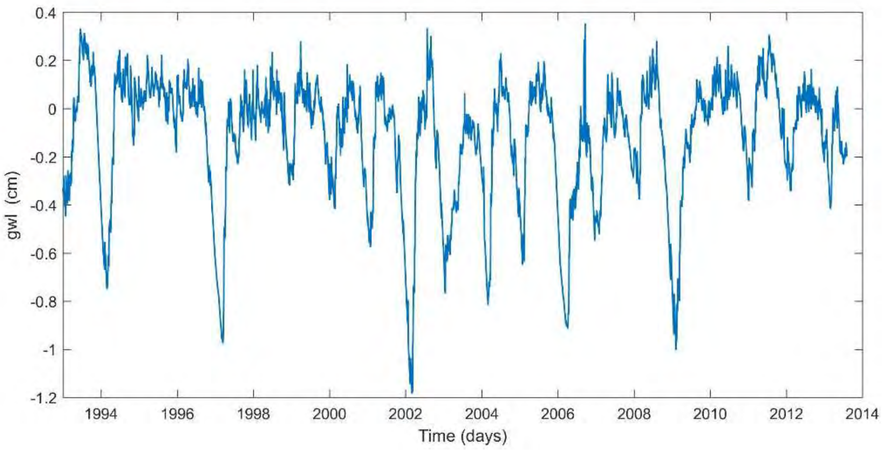


Figure 16: Time series of Ground Water Level in Central Kalimantan

Step 2: Apply the Fast Fourier Transform to obtain the GWL spectrum

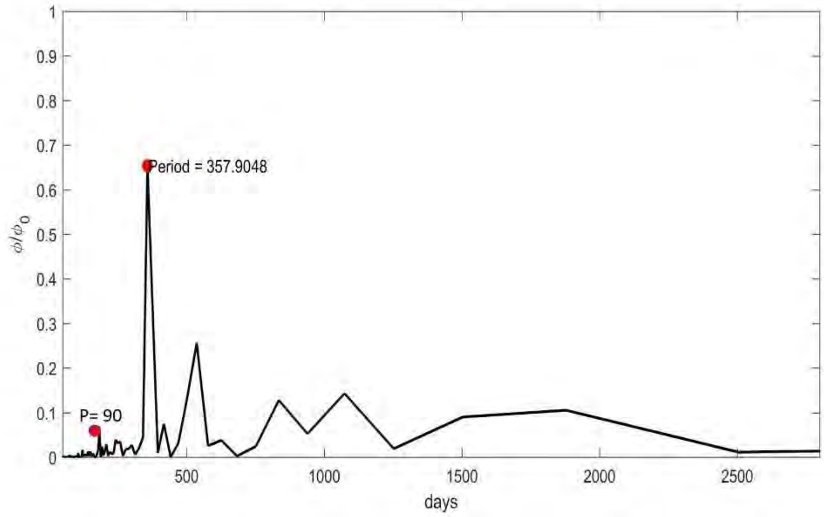


Figure 17: Normalized Ground Water Level power spectrum

Step 3: Due to the significance of the power spectrum over more than 90 days, this should be used as a cut-off frequency in a lowpass filter (Fig. 18)

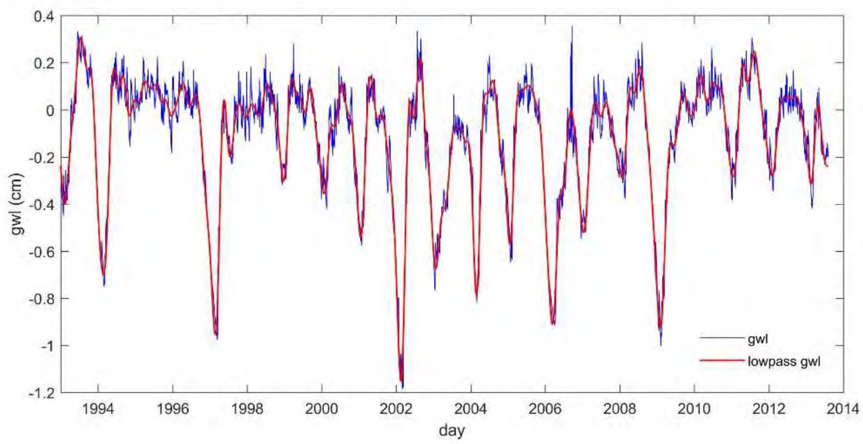


Figure 18: Ground Water Level time series with the lowpass filter with a cutoff period of 90 days

Step 4: Apply the Hirano model to obtain a time series of carbon emission (Fig. 19)

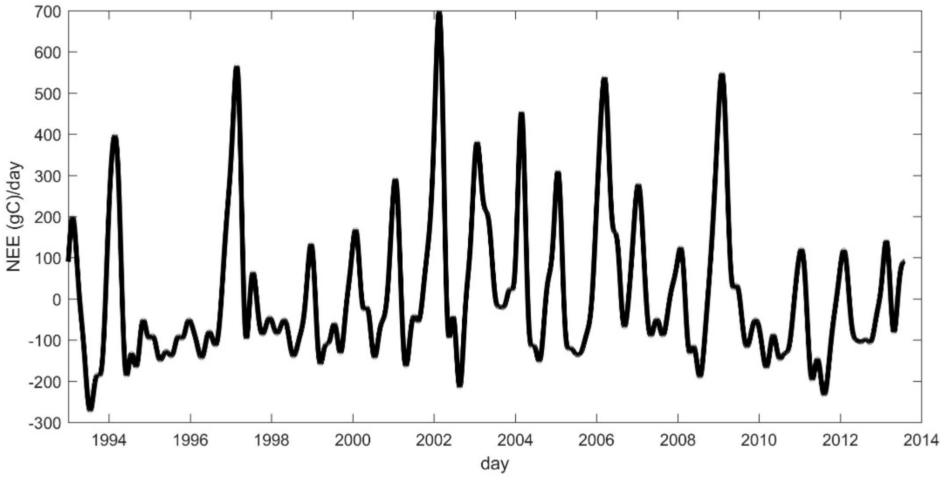


Figure 19: Time series of carbon emission of peat decomposition
A positive value indicates carbon emission and a negative value indicates a carbon sink.

3.5. Ground Water Level Prediction

L

❖ What will you learn in Part III? ❖

➢ How to predict daily groundwater level (GWL) for several days ahead

✓ Key points to understand:

- The GWL Prediction Model uses the Kalman Filter technique introduced by Rudolf E. Kalman.
- The Kalman filter is an algorithm or mathematical calculation which uses time-series values observed over time and returns estimates of uncertain variables in a linear system. It separates time-series noise, and can be used to estimate the past, present and future state of the variables (i.e., GWL).
- The GWL Prediction Model takes a linear model based on the observed GWL values. This means that the future state of the variables (i.e., predicted GWL) has a proportional value to the current average value and statistical noise.
- The model reduces the noise from the observed GWL values. In this model, the slope is assumed constant.
- It is useful to apply the GWL Prediction Model in practice. **40 cm below the ground surface** is the threshold of GWL not only for preventing peatland fires but also for keeping peat carbon stored belowground.

Groundwater level can be used as an ecological indicator for peatland management. Lowering GWL causes various ecological disturbances such as carbon emissions, damages to faunal and floral species, loss of ecosystem services, and devastating peatland fires. Early information about the condition of GWLs will help local authorities, land managers and local communities prevent the occurrence of such disturbances and act upon them in a timely manner. The GWL Prediction Model forecasts GWLs for several days ahead.

Surface peat fires tend to start when the GWL drops to about 20 cm below the ground surface, and expand to the surrounding area when it becomes lower than 40 to 50 cm (Putra et al., 2008). Similarly, it is necessary to maintain the GWL higher than 40 cm below the ground surface in order to make replanting successful and minimize fire risks (Wösten et al., 2006).

Figure 17 shows the framework of the GWL Prediction Model. It only uses observed daily average GWLs obtained in Step 3 of Sub-section 2.2.2 (GWL analysis). Therefore, the data collection and analysis procedures can be seen in the relevant sections above (see 2.1.2.1 on GWL measurements and 2.2.2 on GWL analysis), and will not be repeated in this section.

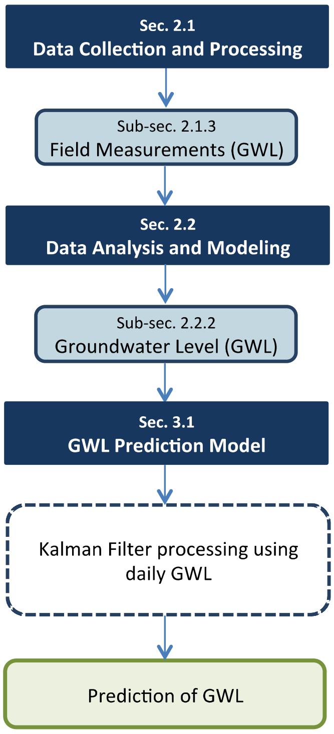


Figure 17. Framework for the GWL prediction

3.5.1. Takahashi Model on Groundwater Level Prediction

Step 1. General understanding of water balance in peatland ecosystem

Term definition and dimension in this section

Groundwater level, GWL, [m]: the height of groundwater table on the basis of ground surface level

Daily mean GWL: Average of hourly GWL from 0 o'clock to 24 o'clock.

Daily change of GWL, dGWL: Difference of GWL between at 0 o'clock and 24 o'clock.

Daily total rainfall, [mm day^{-1}]: Total amount of rainfall from 0 o'clock to 24 o'clock.

For GWL prediction, a general and correct understanding of water balance in peatland ecosystem is necessary. The peatland ecosystem is generally consisted from three basic layers, vegetation, peat and mineral soil layers (Fig. 3.5.2-1). The permeability of the mineral soil layer is generally low, so then the surface groundwater is held in peat layer. The peat layer is divided into the saturated and the unsaturated layers, below and above the groundwater table.

The main water resource to the peatland is rainfall in tropical area. Some part of rainfall is intercepted by vegetation and evaporated to the atmosphere directly. The most of rainfall reaches to the peat layer and increases the volume of unsaturated layer and the moisture of unsaturated layer.

The water in the peat layer uses for evapotranspiration, evaporation from ground surface and transpiration through vegetation, and horizontal outflow of groundwater through peat layer, actually the difference of in- and outflow of groundwater from the upper section and to the lower section. The amount of water loss through the mineral soil layer is not so large because of the low permeability of the mineral soil layer.

In the case of a tropical peat swamp forest in the Sebangau River catchment, the 51% of rainfall was used for evapotranspiration and the remains was used for outflow and change of ground water level (Kayama, M. et al., 2000).

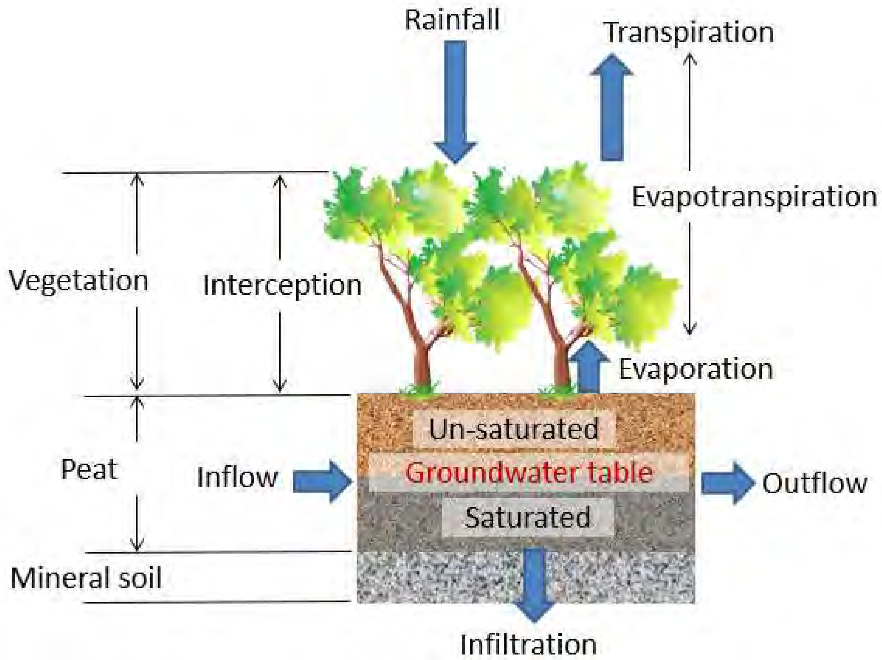


Fig. 3.5.2-1. Water balance of peatland ecosystem

Step 2. Water balance model for prediction of GWL in peatland ecosystem

Water balance in a peat layer is shown in Eq. 3.5.2-1 with several hypothesis as follows, The interception of rainfall by vegetation is zero, the change of water content in the unsaturated peat layer is zero, the infiltration through the mineral soil layer is zero, and the runoff is a difference of inflow and outflow in saturated layer of peat.

$$\mathrm{d}W = \mathrm{d}W_{rain} - \mathrm{d}W_{loss} \qquad \text{Eq. 3.5.2-1}$$

Where $\mathrm{d}W$: Daily change of GWL,

$\mathrm{d}W_{rain}$: Daily change of GWL by daily rainfall,

$\mathrm{d}W_{loss}$: Daily loss of GWL by horizontal runoff and evapotranspiration

In the case of the tropical peat swamp forest, the evapotranspiration has no big difference through a year with 3-4 mm day^{-1} (Takahashi, H., 1999). So then, daily changes of GWL by horizontal runoff and evapotranspiration are combined to daily change of GWL as $\mathrm{d}W_{loss}$.

Daily horizontal runoff in a peatland, which was estimated from the change of GWL during night, was shown as a function of GWL (Takahashi, H. et al, 2000). The $\mathrm{d}W_{loss}$ is also shown as a function of GWL as follows in this section.

$$\mathrm{d}W_{loss} = f_1(W) \qquad \text{Eq. 3.5.2-2}$$

where W: Distance of GWL from the ground surface.

The daily change of GWL, dW_{rain} by daily rainfall is calculated by following equation which is drown from Eq. 3.5.2-1.

$$dW_{rain} = dW + dW_{loss} \qquad \text{Eq. 3.5.2-1'}$$

The value of dW_{rain} has a linear relation with the amount of the daily rainfall (Umeda, Y. and Inoue T., 1985, Takahashi H. and Yonetani Y., 1997). But the relationship between the daily amount of rainfall, R, and the daily change of GWL, dW_{rain} is shown in following equation,

$$dW_{rain} = f_2(R) \qquad \text{Eq.3.5.2-3}$$

where R: daily amount of rainfall.

The $f_2(R)$ is decided by data of field observation in the site in this section.

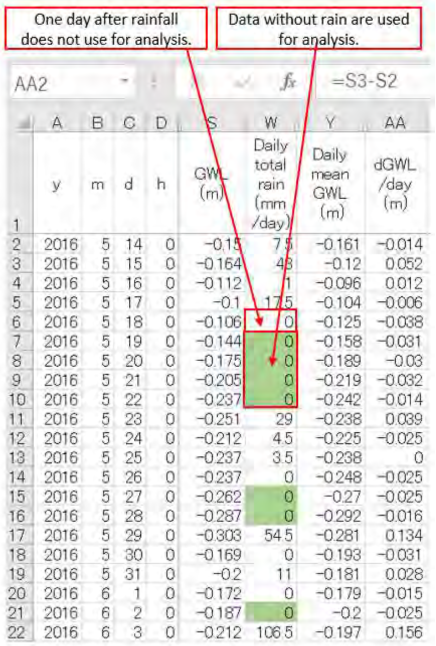
Step 3. Procedure for GWL prediction

Definition of daily GWL is the height of groundwater table on the basis of ground surface level at 0 o'clock of the day, and the definition of daily rainfall is the accumulated rainfall from 0 o'clock to 24 o'clock of the day.

Determination process of Eq. 3.5.2-2 and Eq. 3.5.2-3, which are the key equations for GWL prediction, is described using the data measured in the peatland of Central Kalimantan.

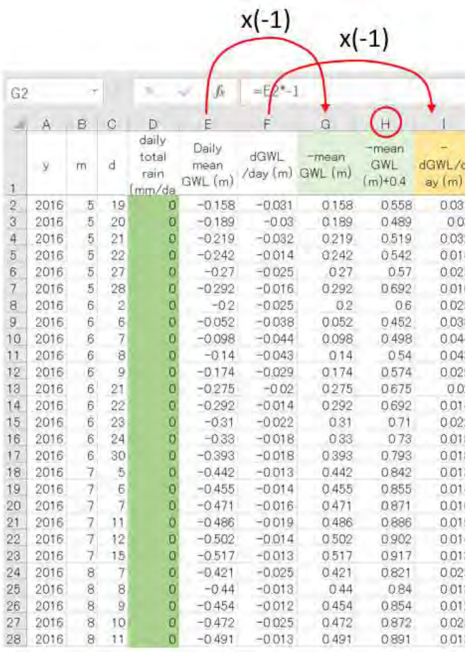
Procedure-1. Determine $f_1(W)$ in Eq. 3.5.2-2

Data-1: Daily GWL [m] at 0 o'clock ----------- Column S in Fig. 3.5.2-2.
Data-2: Daily total rainfall [mm day^{-1}] ----------- Column W in Fig. 3.5.2-2.
Data-3: Daily mean GWL [m] ----------- Column Y in Fig. 3.5.2-2.
Data-3: Daily change of GWL [m] ----------- Column AA in Fig. 3.5.2-2.



	A	B	C	D	S	W	Y	AA
1	y	m	d	h	GWL (m)	Daily total rain (mm /day)	Daily mean GWL (m)	dGWL /day (m)
2	2016	5	14	0	−0.15	7.5	−0.161	−0.014
3	2016	5	15	0	−0.164	43	−0.12	0.052
4	2016	5	16	0	−0.112	1	−0.096	0.012
5	2016	5	17	0	−0.1	17.5	−0.104	−0.006
6	2016	5	18	0	−0.106	0	−0.125	−0.038
7	2016	5	19	0	−0.144	0	−0.158	−0.031
8	2016	5	20	0	−0.175	0	−0.189	−0.03
9	2016	5	21	0	−0.205	0	−0.219	−0.032
10	2016	5	22	0	−0.237	0	−0.242	−0.014
11	2016	5	23	0	−0.251	29	−0.238	0.039
12	2016	5	24	0	−0.212	4.5	−0.225	−0.025
13	2016	5	25	0	−0.237	3.5	−0.238	0
14	2016	5	26	0	−0.237	0	−0.248	−0.025
15	2016	5	27	0	−0.262	0	−0.27	−0.025
16	2016	5	28	0	−0.287	0	−0.292	−0.016
17	2016	5	29	0	−0.303	54.5	−0.281	0.134
18	2016	5	30	0	−0.169	0	−0.193	−0.031
19	2016	5	31	0	−0.2	11	−0.181	0.028
20	2016	6	1	0	−0.172	0	−0.179	−0.015
21	2016	6	2	0	−0.187	0	−0.2	−0.025
22	2016	6	3	0	−0.212	106.5	−0.197	0.156

Fig. 3.5.2-2. Sheet-1: Daily total rainfall [mm day^{-1}] and Daily change of GWL [m]



	A	B	C	D	E	F	G	H	I
1	y	m	d	daily total rain (mm/da	Daily mean GWL (m)	dGWL /day (m)	−mean GWL (m)	−mean GWL (m)+0.4	−dGWL/day (m)
2	2016	5	19	0	−0.158	−0.031	0.158	0.558	0.03
3	2016	5	20	0	−0.189	−0.03	0.189	0.489	0.0
4	2016	5	21	0	−0.219	−0.032	0.219	0.519	0.03
5	2016	5	22	0	−0.242	−0.014	0.242	0.542	0.01
6	2016	5	27	0	−0.27	−0.025	0.27	0.57	0.02
7	2016	5	28	0	−0.292	−0.016	0.292	0.692	0.01
8	2016	6	2	0	−0.2	−0.025	0.2	0.6	0.02
9	2016	6	6	0	−0.052	−0.038	0.052	0.452	0.03
10	2016	6	7	0	−0.098	−0.044	0.098	0.498	0.04
11	2016	6	8	0	−0.14	−0.043	0.14	0.54	0.04
12	2016	6	9	0	−0.174	−0.029	0.174	0.574	0.02
13	2016	6	21	0	−0.275	−0.02	0.275	0.675	0.0
14	2016	6	22	0	−0.292	−0.014	0.292	0.692	0.01
15	2016	6	23	0	−0.31	−0.022	0.31	0.71	0.02
16	2016	6	24	0	−0.33	−0.018	0.33	0.73	0.01
17	2016	6	30	0	−0.393	−0.018	0.393	0.793	0.01
18	2016	7	5	0	−0.442	−0.013	0.442	0.842	0.01
19	2016	7	6	0	−0.455	−0.014	0.455	0.855	0.01
20	2016	7	7	0	−0.471	−0.016	0.471	0.871	0.01
21	2016	7	11	0	−0.486	−0.019	0.486	0.886	0.01
22	2016	7	12	0	−0.502	−0.014	0.502	0.902	0.01
23	2016	7	15	0	−0.517	−0.013	0.517	0.917	0.01
24	2016	8	7	0	−0.421	−0.025	0.421	0.821	0.02
25	2016	8	8	0	−0.44	−0.013	0.44	0.84	0.01
26	2016	8	9	0	−0.454	−0.012	0.454	0.854	0.01
27	2016	8	10	0	−0.472	−0.025	0.472	0.872	0.02
28	2016	8	11	0	−0.491	−0.013	0.491	0.891	0.01

Fig. 3.5.2-3. Sheet-2: Selected Daily total rainfall [mm day^{-1}] and Daily change of GWL [m]

#1. Prepare Data-1 (Daily GWL [m] at 0 o'clock). Data-2 (Daily total rainfall [mm day^{-1}]) and in Sheet-1.

#2. Calculate Data-3 (Daily change of GWL [m]) which is the difference of Daily GWL and it of next day in Sheet-1.
#3. Select the day without rainfall excepting next day of rainfall in Sheet-1. The green color column are selected days.
#4. Selected days are listed in Sheet-2.
#5. Signs of Daily mean GWL and Daily change of GWL in columns E and F are changed from minus to plus and enter columns G and I for easy search of functional relationship together. The values of the columns G and I mean the distance of the groundwater table from the ground surface and the amount of daily loss of groundwater level.
#6. Add an experimental factor α =0.4 in this case, to column G and enter column H.
#7. Determine the suitable function for Eq. 3.5.2-4 using the approximate curve system of the Excel. The logarithmic function is the most suitable one for relationship between GWL and the daily loss of GWL in this case. But if the experimental factor α is not used in the equation, the loss of GWL will approach to the infinity as GWL approach to ground surface as shown in Fig. 3.5.1-4a. The experimental factor α = 0.2 is used in this analysis, Fig. 3.5.2-4a.
Finally, Eq. 3.5.2-2 is decided as next equation.

$$dW_{loss} = -0.028\ln(W - 0.2) + 0.012 \qquad \text{Eq. 3.5.2-4}$$

where dW_{loss}: Daily loss of GWL by horizontal runoff and evapotranspiration
W: Distance of GWL from the ground surface.

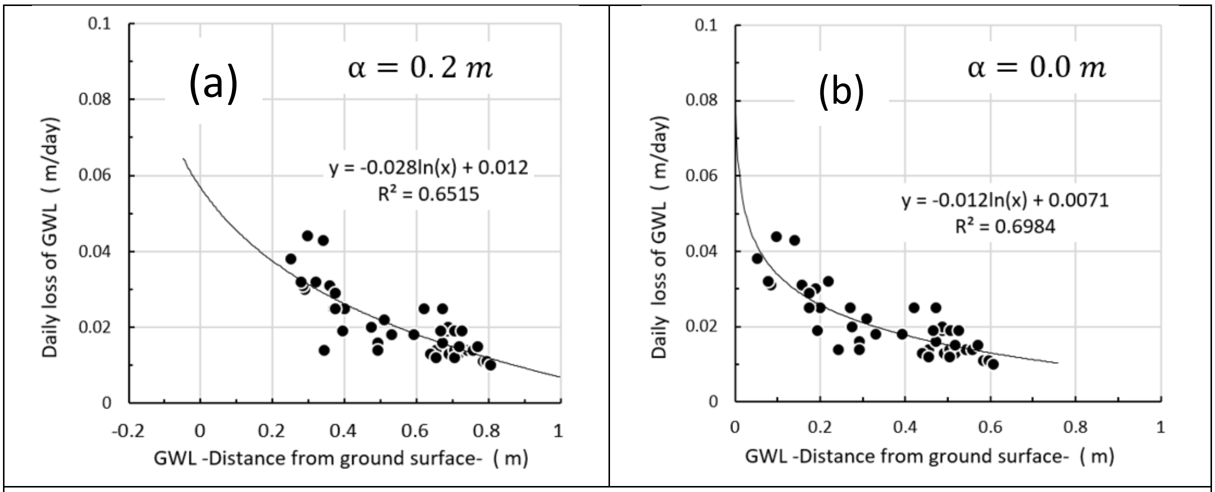


Fig. 3.5.2-4. Relationship between GWL and the daily loss of GWL with (a) and without (b) the experimental factor α = 0.2.

Procedure-2. Determine $f_2(R)$ in Eq. 3.5.2-3

Data-1: Daily GWL [m] at 0 o'clock ----------- Column S in Fig. 3.5.2-5.
Data-2: Daily total rainfall [mm day^{-1}] ----------- Column W in Fig. 3.5.2-5.
Data-3: Daily mean GWL [m] ----------- Column Y in Fig. 3.5.2-5.
Data-3: Daily change of GWL [m] ----------- Column AA in Fig. 3.5.2-5.

#1. Calculate the daily loss of GWL using Eq. 3.5.2-4 and enter the result in the column AB in the Sheet-1 (Fig. 3.5.2-5).
#2. Calculate the real change of GWL by rainfall by adding the daily loss of GWL(Column AB) to the observed change of GWL(Column AA) and enter the results to Column AC).
#3. Select the day when rain fell more than 2.0 mm day-1 and list up the amount of rainfall and the real change of GWL (Column AC in Sheet-1) by rainfall on the Sheet-3 (Fig. 3.5.2-6).

#4. Determine the suitable function for Eq. 3.5.2-5 using the approximate curve system of the Excel. The quadric function is the most suitable one for relationship between the daily total rainfall and the raise of GWL by rainfall in this case with the determination index 0.828 (Fig. 3.5.2-6a). The liner function is not suitable one with the smaller determination index 0.7787 (Fig. 3.5.2-6b).

Finally, Eq. 3.5.2-3 is decided as next equation.

$$dW_{rain} = -12.335R^2 + 2.970R + 0.0062 \qquad \text{Eq. 3.5.2-4}$$

where dW_{rain} : Daily change of GWL by daily rainfall

R: Daily total amount of rainfall

AC2 | =AA2+AB2

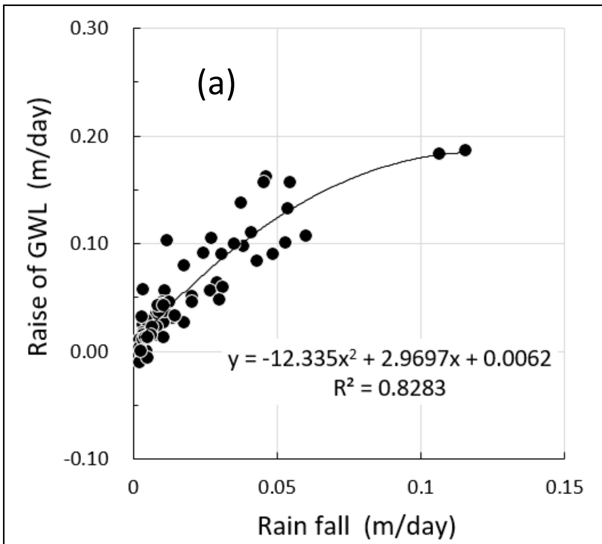
	A	B	C	S	W	Y	AA	AB	AC
1	y	m	d	GWL at 0 o'clock (m)	Daily total rain (mm /day)	Daily mean GWL (m)	dGWL (m/day)	loss GWL (m/day)	dGWL by rain (m/day)
2	2016	5	14	−0.15	7.5	−0.161	−0.014	0.0174	0.0034
3	2016	5	15	−0.164	43	−0.12	0.052	0.0195	0.0715
4	2016	5	16	−0.112	1	−0.096	0.012	0.0208	0.0328
5	2016	5	17	−0.1	17.5	−0.104	−0.006	0.0204	0.0144
6	2016	5	18	−0.106	0	−0.125	−0.038	0.0192	−0.0188
7	2016	5	19	−0.144	0	−0.158	−0.031	0.0175	−0.0135
8	2016	5	20	−0.175	0	−0.189	−0.03	0.016	−0.014
9	2016	5	21	−0.205	0	−0.219	−0.032	0.0146	−0.0174
10	2016	5	22	−0.237	0	−0.242	−0.014	0.0136	−0.0004
11	2016	5	23	−0.251	29	−0.238	0.039	0.0138	0.0528
12	2016	5	24	−0.212	4.5	−0.225	−0.025	0.0144	−0.0106
13	2016	5	25	−0.237	3.5	−0.238	0	0.0138	0.0138
14	2016	5	26	−0.237	0	−0.248	−0.025	0.0133	−0.0117
15	2016	5	27	−0.262	0	−0.27	−0.025	0.0124	−0.0126
16	2016	5	28	−0.287	0	−0.292	−0.016	0.0115	−0.0045
17	2016	5	29	−0.303	54.5	−0.281	0.134	0.012	0.146
18	2016	5	30	−0.169	0	−0.193	−0.031	0.0158	−0.0152
19	2016	5	31	−0.2	11	−0.181	0.028	0.0164	0.0444
20	2016	6	1	−0.172	0	−0.179	−0.015	0.0165	0.0015
21	2016	6	2	−0.187	0	−0.2	−0.025	0.0155	−0.0095
22	2016	6	3	−0.212	106.5	−0.197	0.156	0.0156	0.1716
23	2016	6	4	−0.056	41	−0.008	0.069	0.0263	0.0953
24	2016	6	5	0.013	0	−0.005	−0.05	0.0265	−0.0235
25	2016	6	6	−0.037	0	−0.052	−0.038	0.0234	−0.0146
26	2016	6	7	−0.075	0	−0.098	−0.044	0.0207	−0.0233
27	2016	6	8	−0.119	0	−0.14	−0.043	0.0185	−0.0245
28	2016	6	9	−0.162	0	−0.174	−0.029	0.0167	−0.0123
29	2016	6	10	−0.191	26.5	−0.195	0.029	0.0157	0.0447

Fig. 3.5.2-5. Sheet-1: Daily GWL [m] at 0 o'clock etc.

F2 | =E2/1000

	A	B	C	E	F	H	I
1	y	m	d	total rainfall mm/day	total rainfall m/day	dGWL by rain (m/day)	
2	2016	5	14	7.5	0.0075	0.0034	
3	2016	5	15	43	0.043	0.0715	
4	2016	5	17	17.5	0.0175	0.0144	
5	2016	5	23	29	0.029	0.0528	
6	2016	5	24	4.5	0.0045	−0.0106	
7	2016	5	25	3.5	0.0035	0.0138	
8	2016	5	29	54.5	0.0545	0.146	
9	2016	5	31	11	0.011	0.0444	
10	2016	6	3	106.5	0.1065	0.1716	
11	2016	6	4	41	0.041	0.0953	
12	2016	6	10	26.5	0.0265	0.0447	
13	2016	6	11	2	0.002	−0.0216	
14	2016	6	13	20.5	0.0205	0.0395	
15	2016	6	17	3.5	0.0035	0.0067	
16	2016	6	18	13.5	0.0135	0.0203	
17	2016	6	19	3.5	0.0035	0.0037	
18	2016	6	26	2.5	0.0025	0.0001	
19	2016	6	28	8.5	0.0085	0.022	
20	2016	7	1	2	0.002	1E−04	
21	2016	7	3	9	0.009	0.0274	
22	2016	7	8	2	0.002	−0.0074	
23	2016	7	9	10	0.01	0.0353	
24	2016	7	13	6	0.006	0.0182	
25	2016	7	17	10.5	0.0105	0.0161	
26	2016	7	18	27	0.027	0.0947	

Fig. 3.5.2-6. Sheet-3: Selected days for analysis of $f_2(R)$



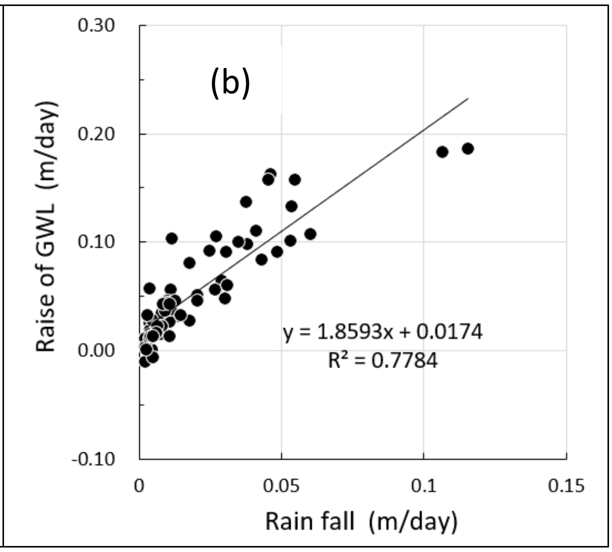


Fig. 3.5.2-7. Regression formulas for $\boldsymbol{f_2(R)}$, the quadric (a) and linear (b) functions

Procedure-3. Estimate daily change of GWL by using the determined equations of dW_{loss} and dW_{rain}:

Data-2: Daily total rainfall [mm day^{-1}] ----------- Column W in Fig. 3.5.2-8.
Data-3: Daily mean GWL [m] ----------- Column Y in Fig. 3.5.2-8.
Data-4: Daily total rainfall [mm day^{-1}] for test with no rain from 7th Sept. to 31st Oct., 2016. ------------- Column Y in Fig. 3.5.2-9.

#1. Select the first day for GWL estimation. The 3rd Sept., 2016 is selected in this estimation.
#2. Copy the measured daily mean GWL on 3rd Sept., 2016 in Column Y to Column AE.
#3. Calculate GWL of next day by using the equation, which is combined $\boldsymbol{f_1(W)}$ and $\boldsymbol{f_2(R)}$.
#4. Compare the estimated GWL with the measured one (Fig.3.5.2-10).
#5. Estimate the GWL using the rainfall data in which it was no rainfall from 7th Sept. to 31st Oct., 2016 (Fig. 3.5.2-11).

AE115 | =AE114-(-0.022*LN(-1*AE114+0.2)+0.0071)+(-12.335*(W115/1000)^2+2.9697*(W115/1000)+0.0062)

	A	B	C	W	Y	AE
1	y	m	d	Daily total rain (mm /day)	Daily mean GWL (m)	EST GWL (m)
113	2016	9	2	46	-0.49	
114	2016	9	3	0	-0.418	-0.4180
115	2016	9	4	10	-0.421	-0.4010
116	2016	9	5	0	-0.411	-0.4131
117	2016	9	6	1	-0.43	-0.4218
118	2016	9	7	0	-0.445	-0.4332
119	2016	9	8	0	-0.466	-0.4441
120	2016	9	9	0.5	-0.479	-0.4532
121	2016	9	10	0	-0.491	-0.4635
122	2016	9	11	0	-0.505	-0.4734
123	2016	9	12	0	-0.518	-0.4830
124	2016	9	13	1.5	-0.532	-0.4879
125	2016	9	14	0	-0.54	-0.4970
126	2016	9	15	12.5	-0.538	-0.4707
127	2016	9	16	0	-0.513	-0.4803
128	2016	9	17	45.5	-0.49	-0.3801
129	2016	9	18	5	-0.384	-0.3785
130	2016	9	19	20.5	-0.373	-0.3357

Estimated GWL using GWL one day before and daily rainfall.

Fig. 3.5.2-8. Sheet-1: Estimation of daily GWL using measured daily rainfall data.

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	F	W	Y	Z	AF	AL
1	Date Time	Daily total rain (mm /day)	Daily total rain (mm /day)	Daily mean GWL (m)	EST GWL (m)	EST GWL (m) no rain
113	2016/9/2 0:00	46	46	-0.49		
114	2016/9/3 0:00	0	0	-0.418	-0.4180	-0.4180
115	2016/9/4 0:00	10	10	-0.421	-0.4010	-0.4010
116	2016/9/5 0:00	0	0	-0.411	-0.4131	-0.4131
117	2016/9/6 0:00	1	1	-0.43	-0.4218	-0.4218
118	2016/9/7 0:00	0	0	-0.445	-0.4332	-0.4332
119	2016/9/8 0:00	0	0	-0.466	-0.4441	-0.4441
120	2016/9/9 0:00	0.5	0	-0.479	-0.4532	-0.4547
121	2016/9/10 0:00	0	0	-0.491	-0.4635	-0.4649
122	2016/9/11 0:00	0	0	-0.505	-0.4734	-0.4748
123	2016/9/12 0:00	0	0	-0.518	-0.4830	-0.4844
124	2016/9/13 0:00	1.5	0	-0.532	-0.4879	-0.4936
125	2016/9/14 0:00	0	0	-0.54	-0.4970	-0.5026
126	2016/9/15 0:00	12.5	0	-0.538	-0.4707	-0.5112
127	2016/9/16 0:00	0	0	-0.513	-0.4803	-0.5196
128	2016/9/17 0:00	45.5	0	-0.49	-0.3801	-0.5278
129	2016/9/18 0:00	5	0	-0.384	-0.3785	-0.5356
130	2016/9/19 0:00	20.5	0	-0.373	-0.3357	-0.5433
131	2016/9/20 0:00	14.5	0	-0.354	-0.3099	-0.5507
132	2016/9/21 0:00	38	0	-0.281	-0.2306	-0.5579
133	2016/9/22 0:00	8	0	-0.279	-0.2270	-0.5649
134	2016/9/23 0:00	3.5	0	-0.282	-0.2364	-0.5717
135	2016/9/24 0:00	6.5	0	-0.281	-0.2368	-0.5783
136	2016/9/25 0:00	0	0	-0.303	-0.2559	-0.5847
137	2016/9/26 0:00	8	0	-0.318	-0.2511	-0.5910

Fig. 3.5.2-9. Sheet-1: Estimation of daily GWL using rainfall data with no rain from 7th Sept. to 31st Oct., 2016.

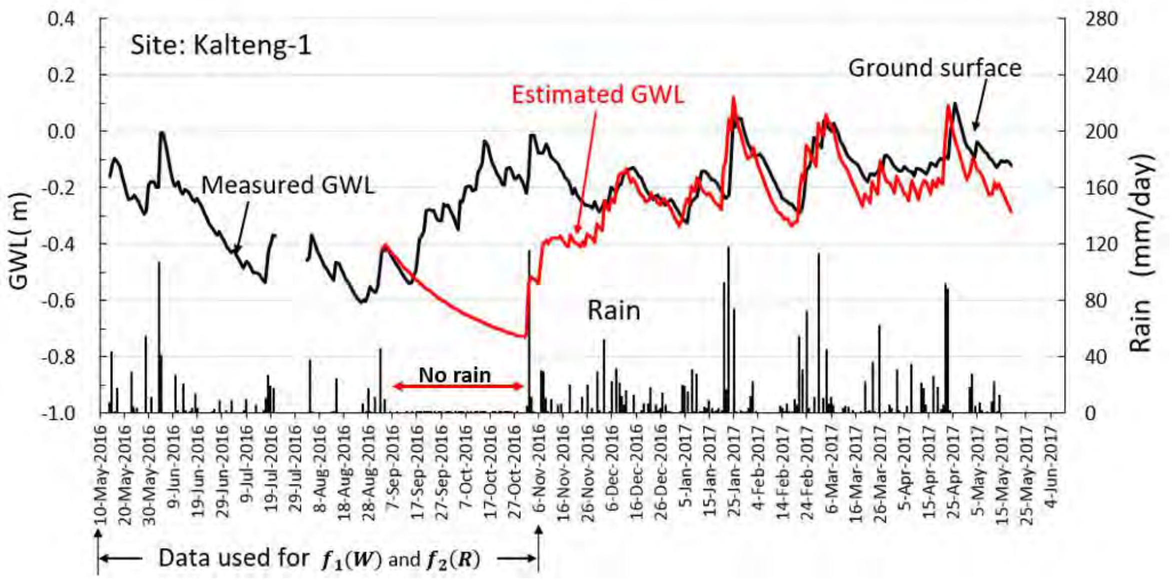


Fig. 3.5.2-11. The estimated GWL using the rainfall data in which it was no rainfall from 7th Sept. to 31st Oct., 2016.

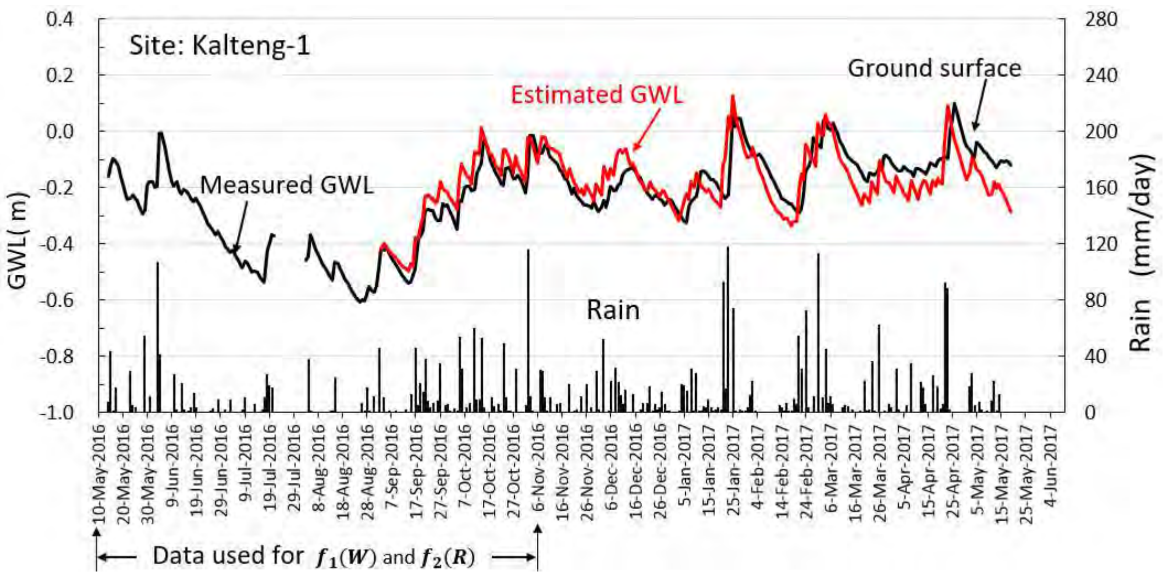


Fig. 3.5.2-10. Measured rainfall and GWL, and the estimated GWL

References

Kayama M., Takahashi H. and Limin H. S., 2000, Water Balance of a Peat Swamp Forest in the Upper Catchment of the Sebangau River, Central Kalimantan, Proceedings of the International Symposium on Tropical Peatlands, Bogor, 299-306.

Takahashi H. and Yonetani Y., 1997, Studies on Microclimate and Hydrology of Peat Swamp Forest in Central Kalimantan, Indonesia. Rieley J.O. and Page S.E. eds, Biodiversity and Sustainability of Tropical Peatlands, Sawara Publishing Ltd., 179-187.

Umeda Y. and Inoue T., 1985, The influence of evapotranspiration on the groundwater table in peatland. Jour. Faculty of Agriculture, Hokkaido University, 62(2), 167-181.

4.1. CO_2 flux measurements

4.1.1. Methodology of CO_2 flux measurements

CO_2 movement or CO_2 flux between the soil and the atmosphere is the primary function of soil respiration. Soil respiration returns substantial amounts of carbon to the atmosphere and is a major component of CO_2 emissions or NEE. Ecosystem disturbances, including climate change, deforestation, peatland drainage, forest and peatland fires, and land conversion, provoke changes in soil respiration and the resulting carbon balance, as the ecosystem loses important soil carbon storage due to such disturbances. Therefore, direct measurements of CO_2 fluxes should be conducted at various sites which include both intact peatland and other peatland areas characterized by varying degrees of ecosystem disturbances (see Sub-section 2.2.1 on Peatland Type). The results of these CO_2 flux measurements are used for the NEE analysis as described in Sub-section 2.2.3.

There are various methods to measure CO_2 fluxes, each with its own advantages and limitations. This guidebook recommends a micrometeorological method using a flux tower. Secondary CO_2 flux data may also be used, if such data are available for the study area.

Box 2. Alternative approaches to flux measurements

If it is not feasible to measure CO_2 fluxes with a flux tower, there are some alternative methods available, as presented below.

Incubation method: This method uses undisturbed sample soil columns stored in containers and incubated over a period of time. CO_2 fluxes are measured using a chamber which is attachable to the top of the container. Undisturbed peat samples from each peatland type should be used to avoid measurement errors. CO_2 fluxes should be measured repeatedly with different GWLs, which can be changed by supplying or draining the groundwater inside the containers. The groundwater used for this method should be drawn from the soil sampling locations.

Closed chamber method: Small chambers are used to directly measure CO_2 fluxes over a small surface area in the closed headspace for a short period of time. Chambers should be set up at each peatland type. The advantage of using this method is that it is relatively low in cost and simple to operate. However, it is easily affected by various environmental conditions in the field, and tends to create errors and biases in gas sampling.

Step 1. Prepare equipment for field measurements

A list of key instruments necessary for measuring CO_2 fluxes using a flux tower is provided below (see Figure 5).

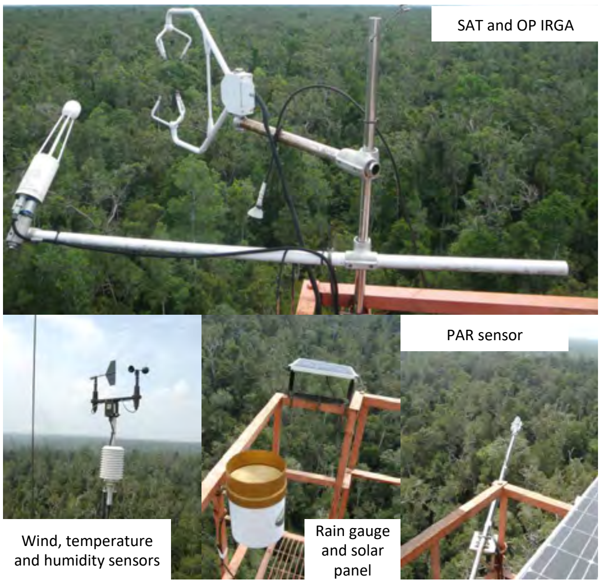


Figure 5. Flux tower instruments

Ultra-Sonic Anemometer-Thermometer (SAT):

Measures the sound speed in air in three-dimensions (especially vertical direction) in order to determine sonic virtual temperature and wind velocity in three-dimensions.

Must be settled exactly horizontally (or perpendicularly to the incline of the slope); otherwise, systematic errors will be included in the vertical wind velocity.

Open-Path CO_2 Infra-Red Gas Analyzer (OP IRGA):

Measures the attenuation of infrared radiation absorbed by CO_2 molecules intervening in the open path of the radiation in order to determine CO_2 concentration.

Recommended to be settled with 10–15 degrees slant from the vertical position in order to minimize the influences of wind distortion and raindrops sticking on the lens located at the end of the open path.

The surface of the lens should be kept clean. Ideally it should be gently wiped every ten days to every month. Application of water repellent on the surface of the lens is recommended.

Most of the commercially available OP IRGAs can simultaneously measure water vapor density. CO_2 and H_2O are individually determined using the infrared radiations with different wavelengths. Based on the same eddy covariance theory, H_2O flux (i.e., evapotranspiration) from the ecosystem into the atmosphere above can be determined.

Data logger:

Stores CO_2 flux data.

The specifications required:

Performance high enough to capture signals from several instruments at least ten times per second (>10 Hz)

Memory capacity high enough to temporarily store the huge amount of eddy covariance data for several days

Connections between the data logger and each sensor without noise and delay of signals

Power source:

Supplies power to run the equipment.

Recommended to use a stable commercial power supply with sufficient capacitance.

Recommended to use solar cells with rechargeable batteries.

In this system, the power generated by the solar cells is used both to drive the instruments and to charge the batteries during the daytime. In the nighttime, the power charged to the batteries is then consumed to drive the instruments.

The number of solar cells and batteries should be determined based on the power required by each instrument. It should also be taken into account that the power generation will be decreased on cloudy days and in the rainy season.

If the flux observation tower is covered by dense canopy, a solar cell panel should be placed on top of the tower. Make sure that the panel does not disturb the flow of the wind.

GPS receiver

Other microclimate measurement instruments:

Microclimate measurements are needed not only to record general weather conditions at the observation tower, but also to detect and correct invalid values in CO_2 fluxes.

Key microclimate parameters controlling rates of CO_2 fluxes should be recorded (temperatures, precipitation and GWL should be recorded with the SESAME system as described in Sub-subsection 2.1.2.1):

Photosynthetically active radiation (PAR) as the main variable, since it strongly affects CO_2 uptake rate during photosynthesis.

Air and soil temperatures

Precipitation

GWL

Step 2. Select locations for field measurements

Select CO_2 flux observation locations which satisfy the following conditions:

General wind direction in the area is known.

Land surface condition in the upwind area should be generally uniform and representative of the distinctive peatland types (see Sub-section 2.2.1 on Peatland Types).

Ideally, the length of the surface area from the observation tower toward the upwind direction, also known as the fetch length, should be 100 times greater than the height of the observation tower.

Permission for building of an observation tower must be available.

There must be accessible paths for the construction of the observation tower and its maintenance.

The location is safe from potential thefts of instruments.

Step 3. Build an observation tower at the selected location

Build CO_2 flux observation towers at the locations selected in Step 2.

The tower must be taller than the surrounding vegetation.

Ideally, the height of the tower is one and a half times to twice of the height of the canopy.

For a long-term observation, the growth of vegetation should be taken into account.

The tower must be strong enough to withstand the weight of instruments and strong wind. A weak tower swaying in the wind makes the observations erroneous.

A lightning rod should be mounted on top of the tower to protect the instruments in the event of lighting strike. Working around the tower during a thunderstorm is strictly prohibited.

Step 4. Install and activate the instruments, and start recording CO_2 fluxes and other microclimate parameters

Install SAT and OP IRGA in the upwind direction from the flux tower to avoid wind distortion effects.

If the prevailing wind direction changes seasonally, the direction of SAT and OP IRGA should be also adjusted toward the upwind direction.

The distance between SAT and OP IRGA should be between 15 and 30 cm.

If <15 cm, the airflow will be disturbed.

If >30 cm, the synchronicity of both sensors will be reduced.

Activate the data logger, and start recording time-series data.

Obtain the data from the data logger every 2 – 3 months.

4.1.2. Net ecosystem exchange (NEE) analysis

The Carbon Emission Model from Peat Decomposition, described in Section 2.3, uses the eddy covariance (EC) technique to estimate NEE. Raw EC data recorded at 10 Hz (see Sub-section 2.1.2.2 CO_2 flux measurements) are used to calculate physical parameters such as three-dimensional wind velocity, air and soil temperatures and CO_2 fluxes at the interval of 30 minutes to one hour. In this calculation process, many kinds of data correction, quality control and gap filling must be conducted.

Box 3. What is Eddy Covariance?

Eddy Covariance (EC) is a method for evaluating vertical transport of energy, water vapor and gases in the near-ground atmosphere. Near the ground surface, wind blows as a turbulent flow, meaning there are many "eddies" with wide ranges in size and duration. These eddies exchange the energy and gases between the upper and the lower atmospheric layers. According to the turbulent flow theory, these vertical fluxes can be given as a function of covariance of vertical wind velocity and gas concentration. Therefore, this method is called "eddy covariance".

Step 1. Conduct quality control on raw data

Check the raw data obtained in Sub-subsection 2.1.2.2 (CO_2 flux measurements), and make corrections if necessary.

Step 2. Calculate NEE values for the selected time interval

Organize the sequential raw data into a specific time interval (also known as averaging time). Averaging time is usually 30 minutes or 1 hour.

Calculate NEE values for each type of peatland by using the following equation.

$$NEE = \overline{w'c'} \quad (1)$$

Where:
W = vertical wind velocity (m/s)
C = CO_2 concentration (mg/m^3)
$'$ = fluctuating component
$\overline{}$ = mean value

Step 3. Conduct quality control on calculated NEE values

Check the calculated NEE values, and remove all erroneous data.

Certain climatic conditions, such as heavy rain and irregular wind direction, may cause errors in NEE calculation.

If necessary, correct the erroneous NEE values with some parameters obtained in the same time interval.

Step 4. Fill data gaps in calculated NEE values

Find data gaps, and estimate missing NEE values using several techniques such as regression, lookup table, or mean daily variation.

Step 5. Calculate annual NEE values

Calculate annual NEE for each type of peatland by accumulating all values of the observation year as expressed in the following equation.

$$Annual\ NEE = \sum_{Year}(NEE\ value\ at\ each\ time\ int\square rval) \quad (2)$$

4.1.3. Carbon Emission Model from Peat Decomposition

❖ What is a Carbon Emission Model from Peat Decomposition? ❖

The Carbon Emission Model from Peat Decomposition is based on the assumption that there is a linear relationship between NEE and GWL. Based on this relationship, this model allows you to estimate an annual NEE of the study area by using the lowest monthly average GWL(s) in the study year(s) as a key parameter.

NEE means the difference between CO_2 amount which is 1) emitted by ecosystem respiration (RE) and 2) absorbed by photosynthesis (gross primary production; GPP). Therefore, the relationship between net ecosystem production (NEP) and NEE is given by:

$$NEE = -NEP$$

$$NEP = GPP - RE$$

RE is found to increase with soil temperature, and decrease as GWL (or soil moisture) rises. In forest ecosystems, CO_2 exchange between biomass and the atmosphere usually occupies most of the carbon flow. If other carbon sources are negligible, the carbon balance of forest ecosystems can be determined by NEE as follows:

- NEE > 0: carbon source (emission)
- NEE = 0: carbon neutral
- NEE < 0: carbon sink

Step 1. Obtain a linear relationship between the observed lowest monthly average GWL(s) in the study year(s) and annual NEE

Use the lowest monthly average GWL value for each peatland type selected from the observed monthly average GWLs in the study years as described in Step 7 of Sub-section 2.2.2.

Use the annual NEE values for each peatland type obtained in Sub-section 2.2.3.

Draw a linear regression line between the observed lowest monthly average GWL(s) in the study year(s) on the *x* axis and observed annual NEE on the *y* axis, and obtain a relationship for each peatland type (see Figure 14) identified for the study area. Each regression equation obtained in this step will be used to estimate annual NEE values throughout the study area.

You can use the equation to estimate NEE (or CO_2 emissions) for different years, or other areas throughout the study area based on the estimated spatial distribution of GWL.

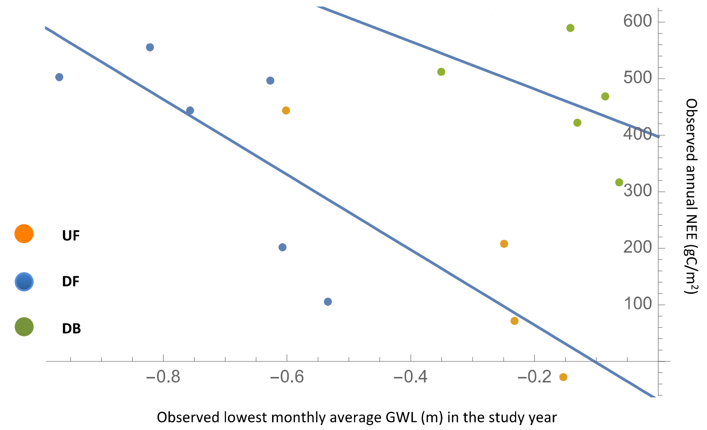


Figure 14. Example of relationships between the lowest monthly average GWLs (m) in the study years and annual NEE (gC/m²/year) observed in Central Kalimantan (Hirano et al., 2012)

Step 2. Estimate annual NEE using the estimated lowest monthly average GWL(s) in the study year(s) in all other grid cells

Estimate annual NEE for each peatland type in all other grid cells (areas beyond the observation points), using the equations obtained in Step 1 above. Use the estimated lowest monthly average GWL value in the study year obtained in Step 7 of Sub-section 2.2.2 (Groundwater level analysis).

Calculate the total NEE from the study area by summing up NEE values from each grid cell by using the following equation.

$$T = \sum_{i=1}^{N} A_i \left[\alpha_i X_i + \beta_i Y_i + \gamma_i Z_i + ... \right] \tag{13}$$

Where:
T = total NEE
A_i = peatland area in grid cell i
α_i = the ratio of peatland type X area in grid cell i
β_i = the ratio of peatland type Y area in grid cell i
γ_i = the ratio of peatland type Z area in grid cell i
X_i = NEE value of peatland type X area in grid cell i
Y_i = NEE value of peatland type Y area in grid cell i
Z_i = NEE value of peatland type Z area in grid cell i
N = the number of grid cells

Step 3. Generate a map of estimated annual CO_2 emissions

Generate a map of estimated annual CO_2 emissions (positive NEE values) based on the grid file created in Step 2 of Sub-section 2.2.1 (Peatland Type) and the NEE values obtained in

Step 2 above. Figure 15 shows an example of annual NEE maps of 2012 for Central Kalimantan created on a 0.5-degree grid file.

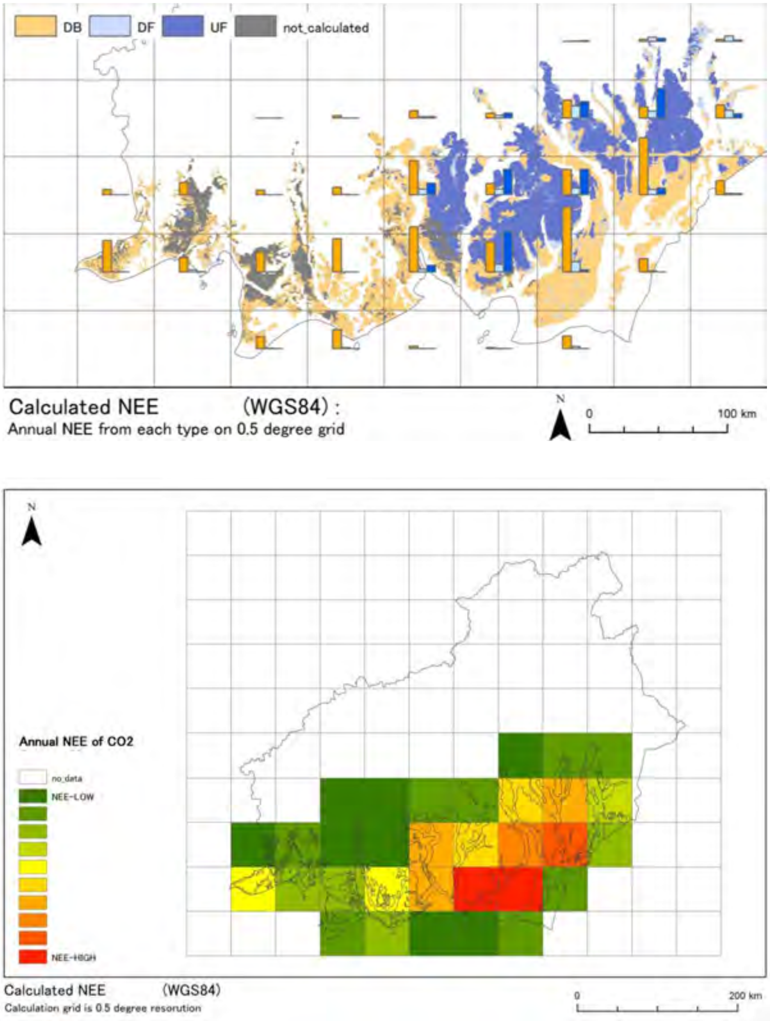


Figure 15. Map of estimated annual NEE values for each peatland type (top) and for total NEE (bottom) of 2012 on grid files for Central Kalimantan

5.1. GWL Prediction Model

Figure 18 is a graphical representation of the model described through the following steps. Detailed procedures of this model are provided in Annex 4.

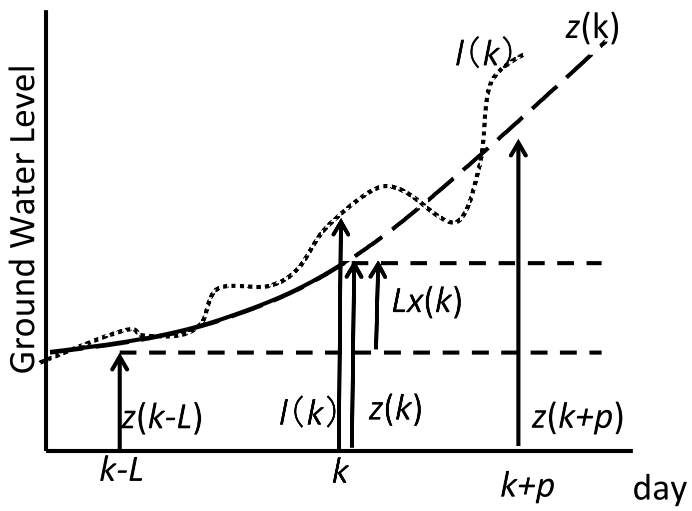


Figure 18. Illustration of the GWL prediction model based on the Kalman Filter technique

N = the number of daily average GWL observation data
k = current date - N
p = the number of days ahead for the prediction of GWL
$z(k)$ = moving average of the observed GWL data at day k
$l(k)$ = observed GWL from the SESAME system data at day k
$(2N+1)$ = range of moving average
$x(k)$ = a changing rate in GWL value per day (state variable)
L = time step width of the slope between the past and present data

Step 1. Select the daily average GWL observation data

Select the daily average GWL observation data which is to be used as an initial value for the calculation of predicted GWL values. The data may be selected arbitrarily, but must be larger than $(2N+1)$.

Determine the value of parameters as follows.

N = the number of daily average GWL observation data
p = the number of days ahead for the prediction of GWL

Step 2. Calculate a moving average of the daily average GWL observation data

Calculate a moving average of the GWL observation data value based on the N value determined in Step 1.

$$z(k) = \sum_{i=-N}^{N} l(k+i) \,/\, (2N+1) \qquad (14)$$

Where:
$z(k)$ = moving average
$l(k)$ = observed GWL from the SESAME system

Step 3. Calculate a state variable

Calculate a state variable as defined below.

$$x(k) = [z(k) - z(k - L)] / L \quad (15)$$

Where:
$x(k)$ = the rate of change (slope) in GWL value per day (state variable)
L = time step width of the slope between the past and present data

Step 4. Apply the Kalman Filter

Apply the Kalman Filter as expressed in the following equations. The equation (16) is based on the assumption that the slope changing rate is constant.

$$x(k+1) = x(k) + w(k) \quad (16)$$

$$y(k) = Lx(k) + v(k) \quad (17)$$

Where:
$w(k), v(k)$ = white Gaussian noise
$y(k)$ = observed data at day k (observed state variable)

Calculate the observed state variable, using the following expression.

$$y(k) = l(k) - z(k - L) = Lx(k) + v(k) \quad (18)$$

Calculate $w(k)$ and $v(k)$, using the following expression.

$$w(k) = x(k) - x(k-1) \ (k = N + L + 2, \ldots, q - N) \quad (19)$$
$$v(k) = l(k) - z(k) \ (k = N + L, \ldots, q - N) \quad (20)$$

Run the Kalman Filter, using the following iteration.

$$\begin{aligned} x(k|k) &= x(k|k-1) + K(k)\,[y(k) - Lx(k|k-1)] \\ x(k+1|k) &= x(k|k) \\ C(k|k) &= C(k|k-1) - LK(k)\,C(k|k-1) \\ C(k+1|k) &= C(k|k) + W(k) \\ K(k) &= LC(k|k-1) / [L^2C(k|k-1)+V(k)] \end{aligned} \quad (21)$$

Where:
$C(k|k)$ = Variance of $x(k|k)$
$C(k+1|k)$ =Variance of $x(k+1|k)$
$W(k)$ = Variance of $w(k)$
$V(k)$ = Variance of $v(k)$

Step 5. Make a prediction of the GWL for p days ahead

Use the following model (equation) to estimate predicted values of the GWL.

$$z(k+p|k) = z(k) + px(k|k) \quad (22)$$

This equation can also be expressed as:

Forecasted GWL at day $p+k$ = *moving average* + day $p \times$ (*forecasted value at day- k*)

The predicted daily GWL values may be applied to the surrounding areas of SESAME GWL observation points, if there are no environmental factors affecting the GWL in those areas. In other words:

Peatland depth is even.
There are no drainage canals or rivers nearby the SESAME observation point.
Peatland type is uniform.

Figure 19 shows an example of GWL prediction for 3 days ahead.

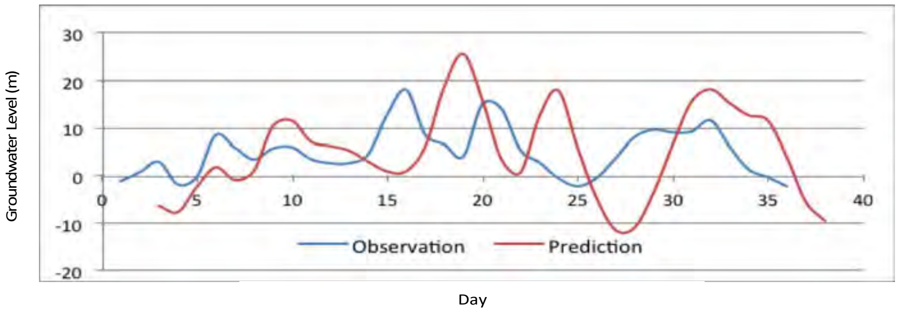


Figure 19. Illustration of GWL prediction for 3 days ahead

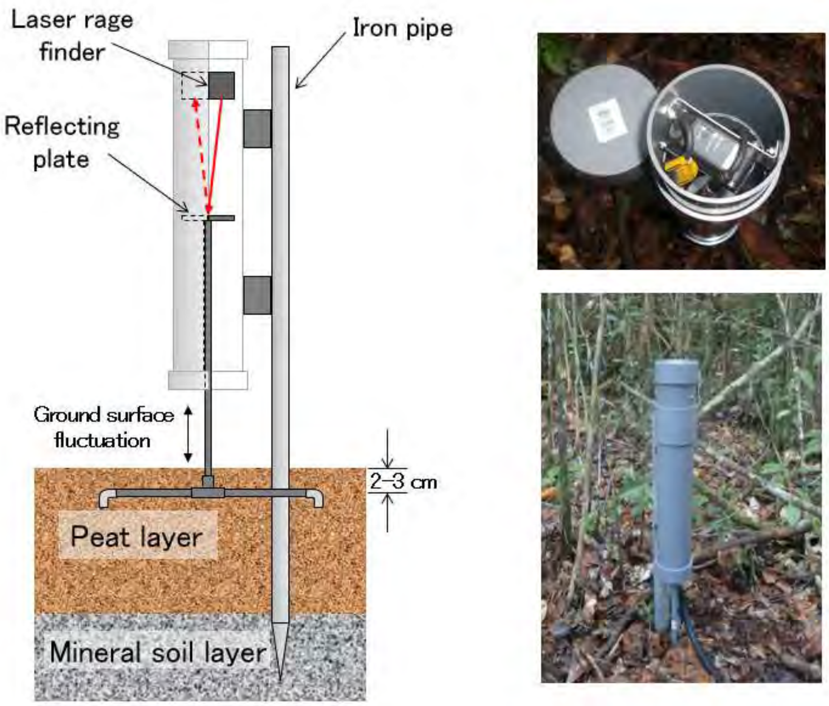
4.2. CO_2 Emission Estimation from Peat Subsidence

The subsidence of ground surface of peatland is mainly caused by biological decomposition, physical decomposition, chemical decomposition, compression by load, shrinkage, loss of matrix by water, and loss of matrix by fire (a type of chemical decomposition).Oxidation is the most important trigger of the subsidence of the peatland surface. Consequently, monitoring the ground surface level is a simple and useful way to assess decomposition and degradation of peatlands.Fluctuation of the ground surface in peatlands is affected by GWL. Monitoring of GWL should be combined with monitoring of ground surface level.

4.2.1. Instruments

Daily fluctuation of the ground surface is affected by changes in GWL. The amount of the fluctuation is usually smaller than a few millimeters. A laser distance sensor is the most suitable sensor for this purpose. The potentiometer is also suitable but the resolution is less than that of the laser distance sensor. The structure of the laser sensor and the layout of the sensor in the field are shown in Fig. 4.2.1. The laser sensor is fixed to the iron pipe which is fixed to the mineral soil layer below the peat layer. The movement of the ground surface transfers to the reflection plate through the plastic pipe which is connected to the plastic frame buried in the peat surface layer. Monitoring GWL should be done within 5 m of the ground surface level monitoring. The method of GWL monitoring is described in section 3.1. The control system of the laser distance sensor is incorporated in the same control box as GWL monitoring. Data of the ground surface level and GWL are sent simultaneously and in real time to the user through the SESAME system.

Figure 4.2.1: Schematic diagram of the laser distance meter and layout of the instrument in



the field (left), the inside of the sensor (right-top), and the full view of the sensor in the field (right-bottom)

4.2.2. Relationship between Ground Surface Level and GWL fluctuations

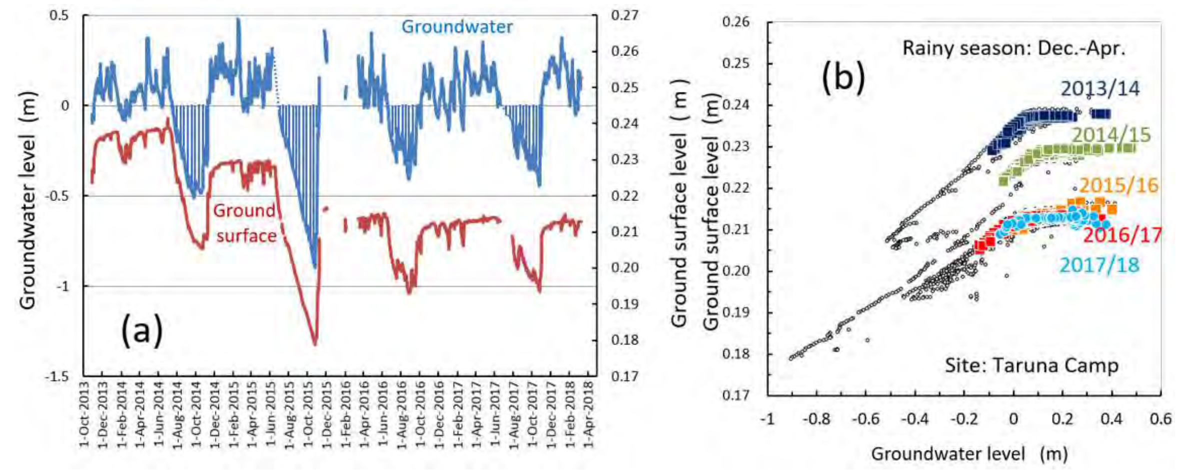
Results for ground surface level and GWL in a peatland in Central Kalimantan are shown in Fig. 4.2.2. The ground surface level changed following the change in GWL during the dry season from June to September (Fig. 4.2.2a). The change in ground water level was small despite the large change in GWL during the wet season from December to April. This means that the ground surface level during the rainy season indicates the standard level for this site.

The relationship between ground surface level and GWL is shown in Fig. 4.2.2b. There is little increase in ground surface level against the rise in GWL when GWL > 0.1 m. In addition, ground surface levels during the rainy season decrease year-by-year. The largest decrease was observed during the rainy season of 2015/16 and a small decrease was observed during the rainy season of 2014/2015. Conversely, decreases were small in 2016/17 and 2017/18. Differences in decreases of ground surface levels can be explained by the length and intensity of the dry season.

4.2.3. . Intensity of Drought Effects on Subsidence of GWL and Carbon Loss

The intensity of drought during a dry season can be represented by accumulated low

Figure 4.2.2: Four-year records of ground surface level and GWL in a peatland in Central



Kalimantan (a) and the relationship between ground surface level and GWL (b).

GWL below the reference water level throughout the dry season.

$$GWL_{day} = \sum_{i=1}^{n}(|G_i - G_0|) \qquad \textbf{eq (4.2.1)}$$

Where,

GWL_{day}: accumulated low GWL (m/day),

G_i: daily mean GWL in the dry season (m),

G_0: reference GWL (m) with $G_i < G_0$.

GWL_{day} in Fig. 4.2.3. was calculated from June 1 to October 31 with the reference GWL (G_i = 0). The average ground surface level during the wet season was obtained from the ground surface level when GWL > 0.2 m from December to April in the following year. The amount of ground surface subsidence is the difference between the ground surface level during the wet season and of the level in the previous wet season.

The volumetric carbon density of young ombrogeneous peat is ~ 50 kg m^{-3} (Shimada, 2001, 2016). The annual amount of subsidence of GSL in peatland (0.01 m) corresponds to ~ 500 g C m^{-2} yr^{-1}. This amount of carbon loss from the surface peat layer is close to the annual sum of NEE in drained and burned former forests (Hirano et al., 2012). The amount of NEE in tropical PSF shows a linear relationship with the lowest monthly GWL (Hirano et al., 2016)

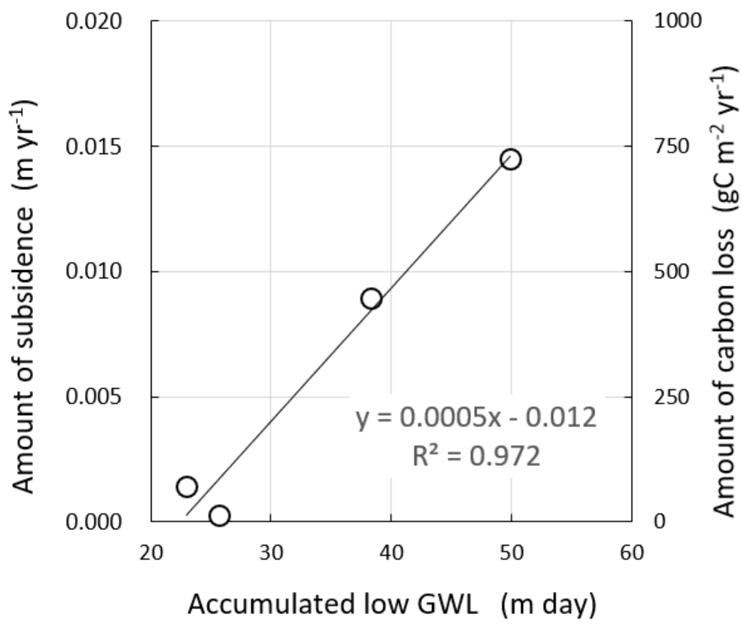


Figure 4.2.3: Relationships between accumulated low GWL (GWL_{day}), ground surface subsidence per year, and estimated carbon loss due to peat subsidence

References

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Shimada S., Takahashi H., Haraguchi A. and Kaneko M., 2001, The carbon content characteristics of tropical peats in Central Kalimantan, Indonesia: Estimating their spatial variability in density, Geochemistry, 53: 249–267.

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4.3. Methane Flux Estimation

CH_4 is the second most important greenhouse emission gas after CO_2. Tropical peatlands have a potential to be a large CH_4 source to the atmosphere because of high temperature, high GWL, and rich soil carbon which are all favorable to CH_4 production in peat. However, field studies using manual chamber systems have so far reported that soil CH_4 efflux in tropical peatlands is small (< 0.5 g C m^{-2} yr^{-1}) compared to that in temperate and boreal peatlands (Melling et al., 2005; Jauhiainen et al., 2008; Hirano et al., 2009). In contrast, CH_4 efflux measured by the eddy covariance technique with an open-path CH_4 analyzer (LI7700, Licor) above a protected tropical peat swamp forest in Sarawak was considerable (Wong et al., 2018). Annual CH_4

emission from the entire peat forest ecosystem was ~ 8 g C m^{-2} yr^{-1}. The large discrepancy between soil efflux and ecosystem-scale efflux is attributable to CH_4 emissions from tree stems (Pangala et al., 2013) and termites nesting aboveground (Martius et al., 1993). Obviously, the soil chamber method cannot measure aboveground CH_4 emissions and consequently underestimates CH_4 emissions. The eddy covariance technique that can measure ecosystem-scale flux is therefore preferable.

Figure 4.4: An eddy covariance system installed above a peat swamp forest. The front white system is an open-path CH_4 analyzer (LI7700)

References

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Melling, L., Hatano, R., Goh, K.J., 2005. Methane fluxes from three ecosystems in tropical peatland of Sarawak, Malaysia. Soil Biology and Biochemistry, 37, 1445–1453.

Pangala, S.R., Moore, S., Hornibrook, E.R., Gauci, V., 2013. Trees are major conduits for methane egress from tropical forested wetlands. New Phytologist, 197, 524–531.

Wong, G.X., Hirano, R., Hirano, T., Kiew, F., Aeries, E.B., Musin, K.K., Waili, J.W., Lo, K.L., Melling, L., Micrometeorological measurement of methane flux above a tropical peat swamp forest. Agricultural and Forest Meteorology, accepted.

4.4. CO_2 Emission from Burn scar measurements

4.4.1. Methodology of Burn scar measurements

The area and depth of burn scar in the study area are needed when estimating carbon emissions from peat burning, as the volume of burn scar is given by the burned peat area and burned peat depth (see Section 2.4). The area of burn scar can be detected with remote sensing data (e.g., MODIS burned area product) and/or original images taken by aerial photography (see Sub-section 2.1.1 on Remote Sensing Data Set). Burned peat depths in selected sampling plots can be measured through the steps described below (see Figure 6).

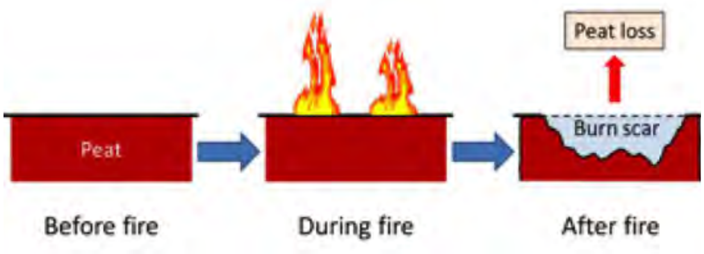


Figure 6. Illustration of burn scar measurement

Step 1. Make a burn scar map

Make a burn scar map of the study area just after a fire event, using the data prepared in the procedures described in Sub-section 2.1.1 (Remote Sensing Data Set).

Determine the burned area by a geometric analysis on the map on GIS.

Step 2. Prepare equipment for field survey

A minimum list of equipment necessary for burn scar field survey is provided below. This list should be adjusted based on the field condition.

- Eijkelkamp peat auger
- Aluminum cups and plastic bags
- Measuring tape and a rope
- Compass
- Measuring pole
- Theodolite
- GPS receiver

Step 3. Select sampling plots for field survey based on the burn scar map

Select sampling plots for field survey. The selected locations must represent the general condition of the burned area as shown in Figure 7.

- The total area of plots should cover at least 15% – 20% of the total burned area.
- If the number of plots is large, the locations can be randomly determined.

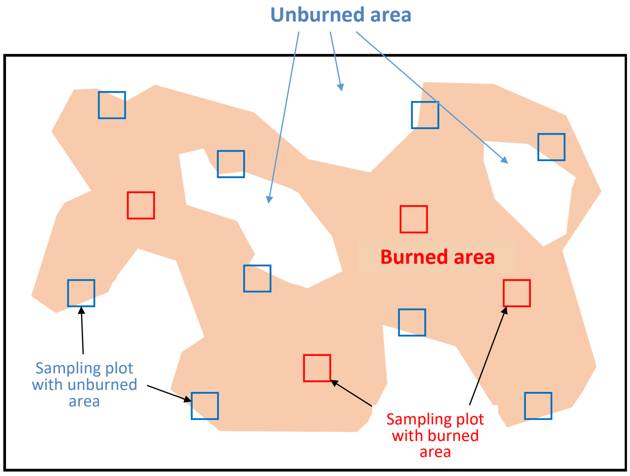


Figure 7. An example of burn scar sampling design

Step 4. Measure and record burned peat depths at the selected plots

Measure burned peat depths at several places in the sampling plots, and record them on a datasheet.

Once the rainy season begins, the burn scar gradually starts to fill in from the ingression of peat from the surrounding unburned area. Therefore, the survey should be conducted as soon as fires are out.

A measurement basis which indicates the level of ground surface before peat burning must be determined. The following objects can be used as the basis (also see Figure 8).

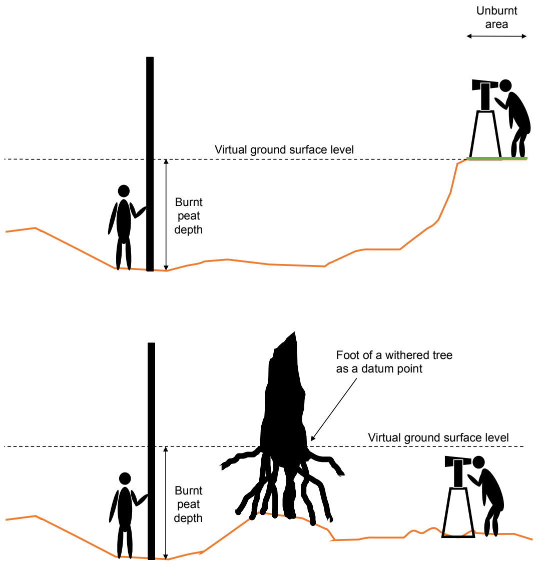


Figure 8. Illustration of burned peat depth measurements using an iron rod and a small unburned area (top) and a withered tree stand (bottom)

A small area which remains unburned: This is the most reliable basis, provided that the study area is generally flat and the ground surface level before burning can be assumed to be almost the same as the level in the surrounding area. If the plot contains an unburned area, its level can be used as the virtual ground surface level in the burned area before peat burning. If the size of each plot is large and the distribution of burned area is patchy, it is recommended to set up sampling plots at locations where plots can contain both burned and unburned areas.

An iron rod penetrated to the mineral soil underlying the peat layer: If the plot does not contain an unburned area, an iron rod may be used as the measurement basis. However, the iron rod must be installed before peat burning occurs (i.e., the beginning of the dry season). After the installation of an iron rod, scratch a line on the rod at the ground surface level. After the peat burning, measure the distance between from the scratched line and the burn scar surface (the new ground surface). This is the depth of burned peat layer.

Withered tree stand: If the plot does not contain an unburned area, a tree trunk may be used as the measurement basis. The level of withered tree foot suggests the ground surface level before peat burning. If the area suffers from peat fires repeatedly, however, this level may suggest the ground surface level from several years ago and may not reflect the peat depth burned by the latest fire.

Step 5. Collect peat samples in an unburned area near burn scar survey plots

Determine peat-boring points at an unburned area surrounding the burned peat depth plots measured in Step 4 above. The selected unburned area should be representative of land surface conditions of the burned area. It is recommended that at least 5 boring holes be made for each plot.

Collect peat samples in 50 cm segments with an auger (see Figure 9). Take 5 cm (50 cm^3) from each sample and place it into an aluminum cup before sealing it into a plastic bag. The number of samples to be collected at each boring point depends on the peat depth there.

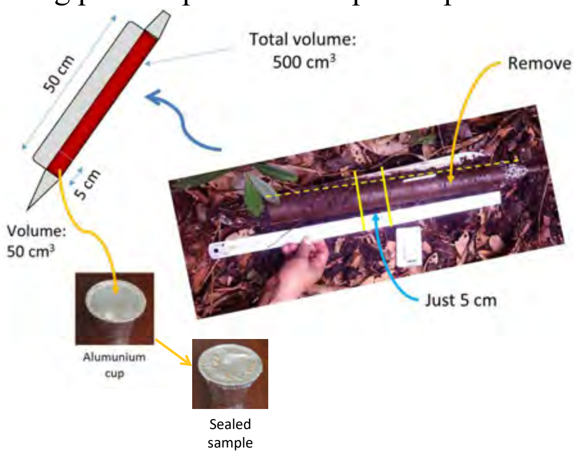


Figure 9. Procedure of peat sampling

Step 6 (Optional). Use advanced techniques for burned peat depth measurements

Select which advanced techniques to use (see Sub-section 2.1.1 on Remote Sensing Data Set).

Measure burned peat depths using the selected advanced techniques, and record data on the datasheet.

Verify the recorded data through ground-truthing.

Advanced techniques such as LiDAR and PALSAR-2 can replace the field measurement of burned peat depths. However, the analysis results should always be ground-truthed.

Data Analysis

❖ What data do you need to analyze? ❖

You will need to analyze raw data collected in field measurements in order to obtain linear relationships between GWL and remote sensing based soil moisture data (Figure 13), between GWL and NEE (Figure 14), and between GWL and carbon emissions from peat burning (Figure 16). These regression models are used to estimate carbon emissions from peat decomposition and burning, as explained at the end of the Part II of this guidebook. Therefore, the following data must be analyzed and each parameter must be calculated.

- ✓ Peatland types classified on a grid file covering the entire study area
- ✓ Lowest monthly average GWL(s) in the study year(s)
- ✓ Annual NEE in the study year
- ✓ The mass of carbon loss (or carbon emission) due to peat burning

Peatland type analysis

Peatland in the study area may consist of a variety of land use and land cover types with different degrees of ecosystem disturbances. The Carbon Emission Model from Peat Decomposition estimates the amount of CO_2 emissions from each type of peatland found in the study area. If land use and land cover characteristics were different, GWLs would be different as well; hence, the amount of CO_2 emissions from peat decomposition would vary, because the NEE is affected by the GWL. Therefore, it is important to classify the study area into different peatland types which represent distinctive characteristics of land use and land cover. Each peatland type must be clearly defined first. Detailed classification procedures are provided in Annex 1.

Step 1. Classify the study area into distinctive peatland types

Classify the study area into distinctive types of peatland by using remote sensing data set as described in Sub-section 2.1.1.

Peatland types may include:

Undrained (intact) forest (UF)
Drained (degraded) forest (DF)
Drained and burned land or non-forest area (DB)
Cropland
Oil palm plantation
Acacia plantation

Define forest and non-forest areas in the study area (if both areas exist).

Canopy loss areas may be classified as a drained and burned land (DB).

Define drained and undrained forest areas in the study area (if both areas exist).

Drained and undrained forest areas can be identified based on the relative dry tendency of dense forest surface. Lower dry classes can be classified as undrained forest (UF), and higher dry classes as drained forest (DF).

Step 2. Create a grid file, and extract pixel values of each peatland type into the grids

The classified study area must be prepared on a grid file, because the amount of CO_2 emissions from each peatland type will be calculated per grid cell.

Create a grid file on WGS 84 on GIS. NEE values are calculated based on a grid file on WGS 84. Therefore, it is necessary to cover the entire area of interest and to fit each grid to the pixel placement of ECMWF soil moisture data (the same grid size) described in Sub-section 2.1.1. Figure 10 shows an example of a grid file on 0.5-degree for Central Kalimantan. It shows the boundary of Central Kalimantan (blue line), new grids (black line) and ECMWF soil moisture data (gray scale).

Extract the pixel number of each peatland type from Step 1 above into every grid cell.

Calculate the area of each peatland type in each grid cell as illustrated in Figure 11. This will be used for NEE calculation in Section 2.3.

Upload the spreadsheet as an attribute table of the grid file on GIS.

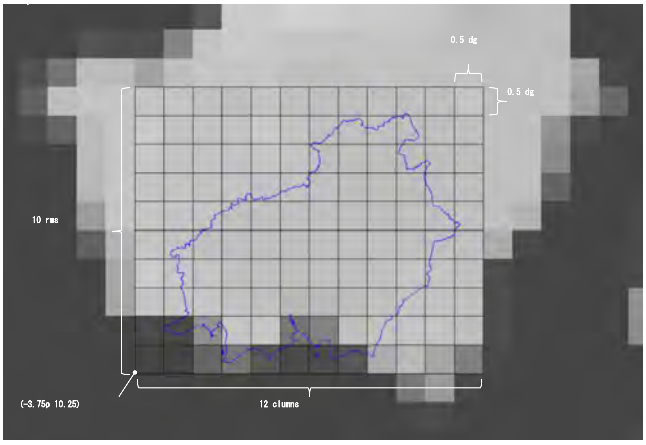


Figure 10. A grid file for Central Kalimantan

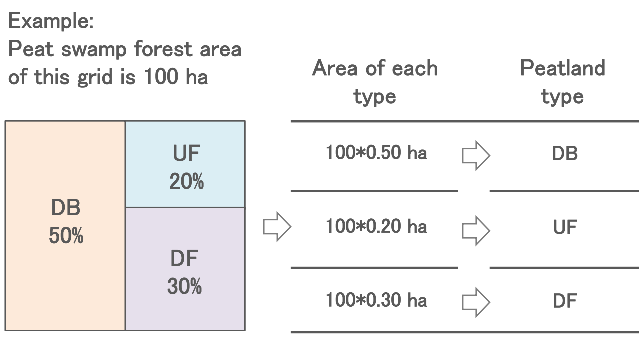


Figure 11. Example for the calculation of areas based on peatland types in a grid cell

4.4.2. Burn scar analysis

Step 1. Calculate the mean and standard deviation of burned peat depths

Calculate the mean and standard deviation of burned peat depths collected inside each plot as described in Step 5 of Sub-subsection 2.1.2.3.

Step 2. Take the average of burned peat depths among all sampling plots

Take the average of burned peat depths among all sampling plots with a standard error as given by:

$$\bar{d} = \frac{\sum_{i=1}^{N} d_i}{N}, \quad \Delta\bar{d} = \frac{\sqrt{\sum(\Delta d_i)^2}}{N} \tag{3}$$

Where:
N = the number of sampling plots
$\bar{d}$ = average burned peat depth among all sampling plots
= the standard error of average burned peat depth
d_i = average burned peat depth in Plot i
Δd_i = standard deviation of burned peat depth in Plot i

Step 3. Calculate burn scar volume

Calculate the volume of burn scar as given by:

$$\textit{Burn scar volume } (m^3) = \textit{Burn scar area } (m^2) \times \textit{Average burn peat depth } (m) \tag{4}$$

If the burn scar area contains an error ($A \pm \Delta A$), burn scar volume V and its standard error ΔV is given as follows. If there is no error, ΔA is assumed to be zero.

$$V = A \times \bar{d}, \quad \Delta V = \sqrt{(A \times \Delta\bar{d})^2 + (\bar{d} \times \Delta A)^2} \tag{5}$$

Step 4. Calculate bulk density of peat samples

Dry peat samples collected in Step 6 of Sub-subsection 2.1.2.3 (Burn scar measurements) in an oven at 105°C for 24 hours or longer until the constant weight is achieved.

Measure the dry weight of peat (W_p) and the weight of aluminum cup (W_c).

Determine the volume of peat samples (V). It is 50 cm^3, if samples are collected according to Step 6 of Sub-subsection 2.1.2.3 (Burn scar measurements).

Calculate the bulk density of peat samples as expressed in the following equation.

$$BD = \frac{(Wp + Wc) - Wc}{V} \tag{6}$$

Step 5. Calculate carbon content of peat samples

The following procedures are based on the loss on ignition (LOI) method. Carbon content can also be calculated by using an elemental analyzer.

Take a tablespoon of peat sample oven-dried as in Step 4 above, grind it, and measure the weight (M_p).

Measure the weight of a small, heat-resistant porcelain cup (M_c).

Place the peat sample into the porcelain cup, and measure the weight ($M_p + M_c$).
Burn the peat sample in a muffle furnace at a temperature >900 °C for 5 to 6 hours.

Cool the burned peat sample (ash) to room temperature in a desiccator, and measure the weight of the ash (M_a) with the porcelain cup.

Calculate the ash content (C_a) of the peat sample as:

$$Ca = \frac{(Ma + Mc) - Mc}{Mp + Mc - Mc} \times 100 \tag{7}$$

Calculate the content of organic matter in the peat sample (Co, %) as:

$$Co = 100 - Ca \tag{8}$$

Calculate the carbon content of peat samples (C, %), using the following equation.

$$C = Co \times 0.58 \tag{9}$$

Step 6. Calculate total peat carbon loss (emissions) from peat burning

Calculate the total amount of peat carbon loss due to peat burning by:

$$\text{Peat carbon loss (kgC)} = \text{Burn scar volume } (m^3) \times \text{Bulk density } (kg/m^3) \times \text{Carbon content (\% of dry weight peat)} \tag{10}$$

If the bulk density and carbon content contain errors ($BD \pm \Delta BD$ and $C\% \pm \Delta C\%$, respectively), calculate carbon content ($C \pm \Delta C$, kgC/m^3) first as follows. If there are no errors, ΔBD and/or $\Delta C\%$ are assumed to be zero.

$$C = BD \times C_{\%}, \quad \Delta C = \sqrt{(BD \times C_{\%})^2 + (\Delta BD \times C_{\%})^2} \tag{11}$$

Where:
C = carbon content
BD = bulk density

After this, calculate the total peat carbon loss ($F_b \pm \Delta F_b$) given as follows. The value, F_b, will be used as the amount of carbon emissions in Section 2.4 (Carbon Emission Model from Peat Burning).

$$F_b = V \times C, \quad \Delta F_b = \sqrt{(V \times \Delta C)^2 + (C \times \Delta V)^2} \tag{12}$$

Where:

F_b = carbon loss (emission)

4.4.3. Carbon Emission Model by Burn scar analysis

❖ What is a Carbon Emission Model from Peat Burning? ❖

Similar to the Carbon Emission Model from Peat Decomposition explained in Section **Error! Reference source not found.**, this model is based on the assumption that there is a linear relationship between the mass of carbon loss from peat burning and GWL. Based on this relationship, the Carbon Emission Model from Peat Burning allows you to estimate the amount of annual carbon emissions by using the lowest monthly average GWL(s) in the study year(s) as a parameter.

Step 1. Obtain a linear relationship between the amount of annual carbon emission from peat burning and observed lowest monthly average GWL(s) in the study year(s)

Draw a linear regression line between the lowest monthly average GWL(s) in the study year(s) observed at a location representative of the characteristic of the burned area on the *x* axis, and observed annual carbon emission from peat burning obtained in Step 6 of Sub-section 2.2.4 on the *y* axis (see Figure 16).

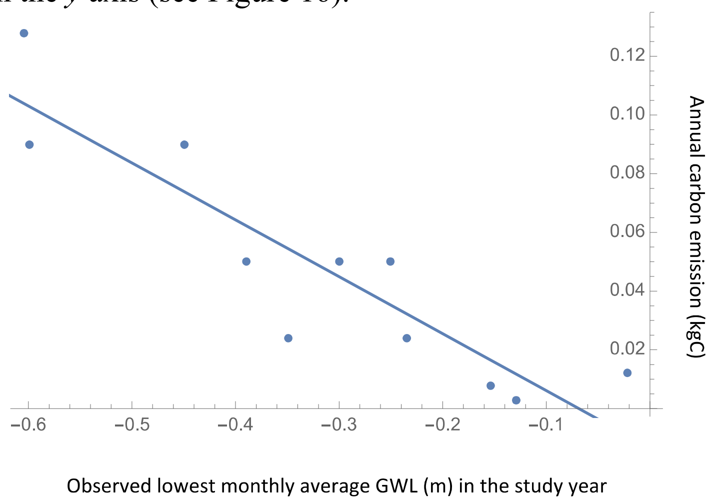


Figure 16. Example of a linear relationship between the lowest monthly average GWL(s) in the study year(s) and annual carbon emission from peat burning observed in the ex-Mega Rice area in Central Kalimantan (Putra et al., 2009)

Step 2. Estimate annual carbon emission from peat burning

Estimate annual carbon emissions from peat burning for other areas of interest. The equation obtained in Step 1 above can only be applied to other areas which indicate similar characteristics of the observed burned area.

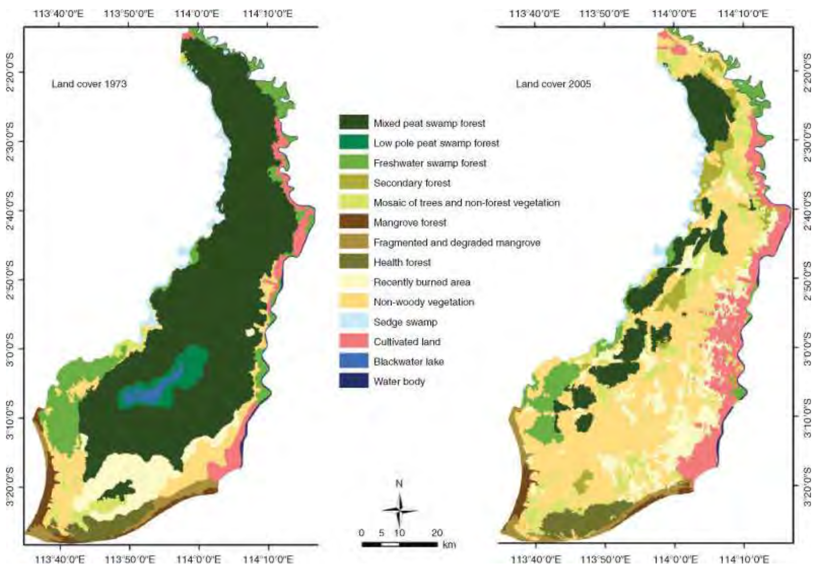
You can use the equation to estimate the amount of carbon emissions from peat burning for different years, or in other areas beyond sampling locations as long as those areas show similar characteristics to the burned area.

4.5. Estimation of Carbon Emission by Remote Sensing Analysis of Burn Scars

Forest fires in tropical peatlands cause deforestation and reduction of carbon density. The detection of burn scars is an important index for the carbon emission estimation. In this section, several remote sensing technologies used to detect burn scars in previous researches are reviewed.

4.5.1. Burn Scar Estimation

In Central Kalimantan, Indonesia, extensive forest fires have been occurring repeatedly in the peatlands after the rapid environmental change caused by the Mega Rice Project.
Prior studies revealed a rising trend in the rate of deforestation and identified fire as the principal factor influencing the subsequent vegetation succession. Agata et al. have analyzed a time series of satellite images of the peatlands of Central Kalimantan for the period 1973–2005. They identified a step change in fire regime, with increased burned areas and fire frequency following the peatland drainage; i.e., while peat swamp forest was the most extensive land-cover class and fires were of relatively limited extent and rarely repeated during the 23-year pre-Mega Rice Project period (1973–1996), in the 9-year post-Mega Rice Project period (1997–2005) there was a 72% fire-related loss in area of the peat swamp forest, mostly converted to non-woody vegetation rather than cultivated land and dominated by ferns or mosaics of trees . Fire is an important factor for land-cover dynamics and forest loss in the peatlands. Hence, there are high expectations on fire burn scar estimation by remote sensing technologies.



Land-cover change detected.(Agata et al.)

- Hoscilo Agata, Page Susan E., Tansey Kevin J., Rieley John O. (2011) Effect of repeated fires on land-cover change on peatland in southern Central Kalimantan, Indonesia, from 1973 to 2005. *International Journal of Wildland Fire* **20**, 578-588

4.5.2. Applicability of Synthetic Aperture Radar Analysis

Synthetic aperture radar (SAR) satellites can cover great areas and they are nearly independent of clouds. Using SAR data, the peat surface variations depending on vegetation, microtopography, and irrigation can be detected by wide-area analysis, including hydrological units.

To properly conserve and manage peat soil, it is necessary to comprehensively and precisely understand its behavior in each area. In principle, the decomposition situation of peat soil can be estimated as the amount of ground surface displacement by SAR differential interferometry (DInSAR) analysis. However, due to the characteristics of the microwaves used for this technique, intensity of interference and data accuracy are affected by the planting and topography of the peatland.

By performing DinSAR analysis with different frequencies by satellites and comparing the results, the amount and type of changes in peatland can be detected according to the respective frequency characteristics. The frequency determines where, what, and how much of the change can be detected in the peatland and the validation of the effectiveness of DInSAR analysis in peatland management. SAR data taken at different times allows the detection of the movement of peat soil surface and occurrence event detection reveals the influence of artificial land alteration and events as fire on the peat soil.

Step 1: Selection of SAR Data

This section focuses on the effectiveness of DInSAR analysis as soil decomposition index by organizing the detected peatland changes according to their frequency characteristics.

The L-band ALOS-2 satellite has been launched by JAXA as a successor to ALOS. ALOS-2 has higher resolution, wider observable area, and better data transfer capacity than ALOS. It will greatly contribute to the efficient management of land and conservation of the environment. TerraSAR-X is a X-band SAR providing consistent and high repetitive coverage thanks to time- and weather-independent acquisitions. It can detect subtle changes in the forest canopy due to high resolution and radiometric stability.

To select the suitable sensor for the research target, it is necessary to understand the characteristics of each sensor. That is, the shorter the wavelength of the microwave used for the interference SAR, the better the resolution of the ground change detection. However, in this case the analysis would be influenced by minute changes, such as vegetation on the ground surface, and is difficult to obtain interference. On the other hand, when the wavelength is longer, the resolution of the surface change detection gets worse but a wide range interference can be obtained.

SARs with different frequencies.

		TerraSAR-X	Sentinel-1	PALSAR-2
Frequency (ν)		9.65GHz (X-Band)	5.405GHz (C-Band)	1,257.5MHz (L-Band)
wavelength (λ)		3.1cm	5.6cm	22.9cm
Polarized wave	Single polarization	HH VV HV VH	VV HH	HH HV VH VV
	Dual polarized wave	HH+VV HH+HV VV+VH	HH+HV VV+VH	HH+HV VV+VH
Maximum resolution		0.25 m	5 m	3 m
Observation period		11days	12days	14days
Operation period		2007～	2014～	2014～

Step2: Burn Scar Estimation by PALSAR-2

This section describes the method of DInSAR analysis by using the actual application of PALSAR-2 sensor.

1) Data Mode Selection

To choose the mode of the data, their specifications, such as frequency, band width, spatial resolution, incidence angle, swath width, and polarization and noise levels (See Table), must be clarified according to the targeted research interest.

PALSAR-2 sensor observation mode and specification

<table>
<tr><th rowspan="2">Mode</th><th rowspan="2">Spot light</th><th colspan="5">Fine-beam</th><th colspan="3">Wide-beam</th></tr>
<tr><th>3m (SM1)</th><th colspan="2">6m (SM2)</th><th colspan="2">10m (SM3)</th><th colspan="2">ScanSAR (WD1)</th><th>Scan SAR (WD2)</th></tr>
<tr><td>Freq. (MHz)</td><td colspan="2">1,257.5</td><td colspan="7">1,236.5/1,257.5/1,278.5</td></tr>
<tr><td>Band width (MHz)</td><td colspan="2">84</td><td colspan="2">42</td><td colspan="2">28</td><td>14</td><td>28</td><td>14</td></tr>
<tr><td>Spatial resolution (m)</td><td>3*1 Rg*Az</td><td>3</td><td colspan="2">6</td><td colspan="2">10</td><td colspan="2">100 (3 looks)</td><td>40</td></tr>
<tr><td>Incidence angle (deg.)</td><td colspan="3">8-70</td><td>20-40</td><td>8-70</td><td>23.7</td><td colspan="3">8-70</td></tr>
<tr><td>Swath width (km)</td><td>25</td><td>50</td><td>50</td><td>40</td><td>70</td><td>30</td><td colspan="2">350 (5 scans)</td><td>490 (7 scans)</td></tr>
<tr><td>Polari-zation(*1)</td><td>SP</td><td>SP
DP</td><td>SP
DP
CP</td><td>FP</td><td>SP
DP
CP</td><td>FP</td><td colspan="2">Sp
DP</td><td>SP
DP</td></tr>
<tr><td>Noise level (dB)</td><td>-24</td><td>-24</td><td>-28</td><td>-25</td><td>-26</td><td>-23</td><td>-26</td><td>-23</td><td>-26</td></tr>
</table>

*SP: HH or VV.
DP: HH+HV or VV+VH.
FP: HH+HV+VH+VV.
CP: Compact polarization (Circular or 45 degree linear polarization).

Step3: Master-Slave Data Pair Images

After clarifying the research interest in terms of multi-temporal analysis, interval of data, data pair acquisition for the multi-temporal analysis, and targeted site, the master and slave data pairs of the DinSAR analysis must be ensured.

As described above, a necessary condition for securing a high interference degree in DinSAR analysis is the selection of an interference pair having a short interorbital distance. In addition, it is important to consider the specifications of the sensors and the time intervals of the interference pairs. However, to objectively evaluate the coherence from the observation parameters, the critical baseline length *Bc*, which described by the following and often applied equation, must be considered.

$$B_c = \frac{\lambda\rho \cdot tan\theta}{2R_{rg}} \quad (1)$$

Where λ is the wavelength of the microwave, ρ is the range distance in the line of sight direction, θ is the incident angle, R_{rg} is the range resolution, and the critical baseline lengths of WD1 and SM3 (Table) are considered as 4,672 m and 9,974 m, respectively. The degree of interference of the DInSAR analysis decreases as the interorbital distance increases with a gradient of approximately 1/critical baseline length. As shown in Table 1, the WD1 and SM3 images by PALSAR-2 have the same wavelength, range length, and incident angle, but WD1 has lower spatial resolution than SM3. Since the critical baseline length of WD1 is shorter, even if all the other observation conditions are the same, its degree of interference inevitably tends to decrease. In the case of SM3, a pair whose interorbital distance is as close to zero as possible and whose time interval is within one year would be preferentially selected.
The figure shows the dependence of the coherence value of the entire image on the time interval. The coherence value rapidly decreases until the time interval reaches about 100 days, and then it gently decreases. Finally, it converges to the smallest value (0.3-0.35) around 200 days.

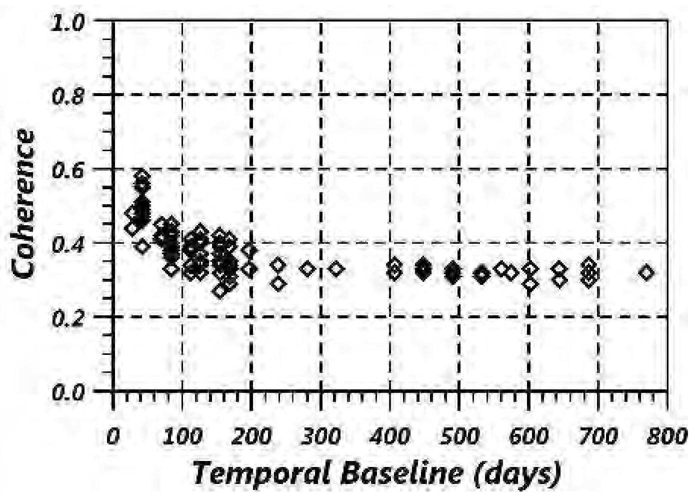


Figure Dependence of coherence value on the time interval of the interference pair.

Step4: Coherence Generation

The interference image is an image obtained by calculating the phase difference between the master image and the slave image and visualizing the change in the distance between the sensor and the ground surface in terms of radian angle. Since the interference image depends on the relative distance change, it indicates how much the ground surface approaches or gets away from the sensor.

In the differential interference analysis, the phase information of the component from which the microwave scatters backward is used. Therefore, the measurement accuracy of the analysis depends on the phase stability of this component. A previous research [11] reports that the phase stability decreases as the interorbital distance of the interference pair increases, and hence it is necessary to position the pairs so that their interorbital distance is as close to zero as possible.

In addition, since the state changes of the water vapor layer and the ionosphere between the sensor and the ground are factors lowering the measurement accuracy of the DInSAR analysis, a process for correcting their influence is necessary.

Since the process of differential interference analysis passes through an image averaging processing called multi-look processing, it is necessary to determine which are the optimal settings that likely cause interference in both the range direction and the azimuth direction.

Rodriguez et al. (1992) describes the relationship between coherence and interference phase by the following equation.

$$\phi = \sqrt{\frac{1}{2N}} \times \sqrt{\frac{1-\gamma^2}{\gamma^2}}$$

Here, φ is the standard deviation of the phase difference obtained by differential interference analysis, N is the number of looks, and γ is the coherence value. In the analysis using the data of WD1, since the number of looks in the range and azimuth directions are fixed to 2 and 8, respectively, the standard deviation of the phase given by a coherence value of 0.3 is 0.56 radians, with a displacement amount of about 1 cm.urthermore, it is good to visually confirm the actual differential interference analysis results in the analysis target range and adopt the combination that obtained sufficient interference.

Step5: Interpretation of Results

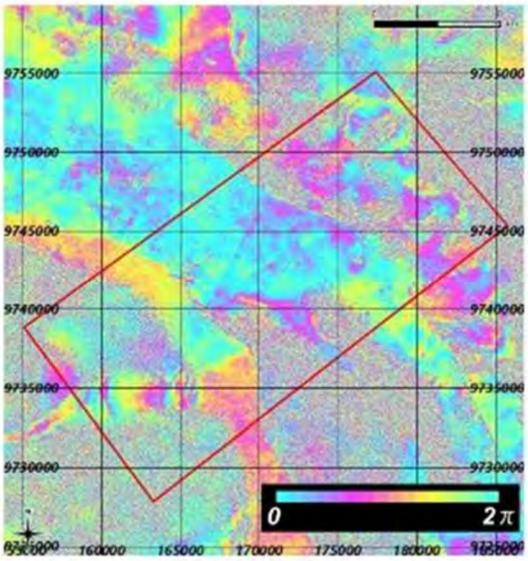
The key to interpret the results is that a change of the color tone from blue to red to yellow to green indicates that the ground surface is displaced away from the sensor, while a change from blue to green to yellow to red corresponds to a ground surface displaced toward the sensor.

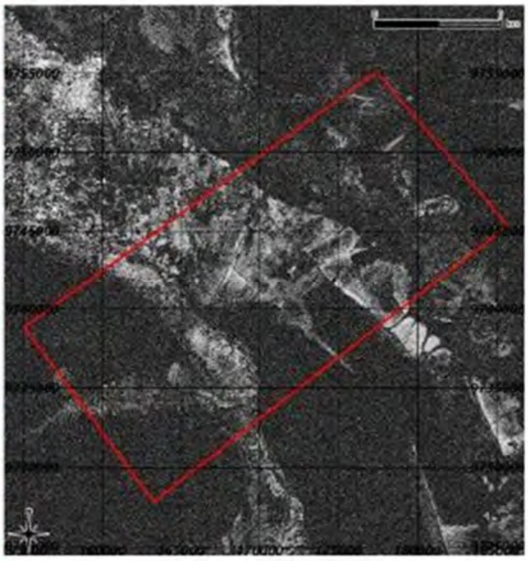
Usually, it is necessary to eliminate the 2π uncertainty by applying the phase unwrapping process. However, in the target area of this work, the phase change in a short period of time is intense and, especially in water systems, many phase discontinuous lines are observed and the phase unwrapping process does not function properly. Therefore, we decided to not apply the phase unwrapping process in this work and to interpret the results with the phase indication as it is.

The coherence image is obtained by indexing the similarity between the master image and the slave image from 0 to 1. Higher coherence values result in a higher correlation (white in the image), and vice versa (black in the image). For example, if the water is submerged or dried due to the difference between the rain precipitation rates of the rainy and the dry season, the coherence decreases.

Coherence decreases even if the surface covering form changes due to forest fires or logging. The coherence value is a synonymous of the degree of interference in the differential interference analysis and is often used for objectively evaluating the measurement accuracy of the ground surface displacement.

Red and blue arrows are shown in each interference images to assist the interpretation of major phase anomalies. A red arrow indicates that the subsidence phenomenon of the earth surface increases toward the tip and a blue arrow means that the tendency of the uplift phenomenon is to increase toward the tip.





In order to proceed with further detailed consideration, it is necessary to analyze fore and aft fires at short time intervals.

V INTEGRATED SENSING SYTEM

Several points should be considered to improve and apply the Water Table Models and Carbon Emission Models presented in this guidebook. To improve these models further, an Integrated Sensing System is necessary for the next program. It is distributed here to develop the concept of a model for an Integrated Sensing System.

5.1. Integrated Sensing System

Peatlands are dynamic ecosystems in relation to groundwater at both vertical and horizontal scales. Thus, each component of interest such as biomass, fire impact, ground subsidence, and landslide must be measured relative to ground movement. In addition to peatlands' significant movement and our index for peatland condition, sensing data lack suitable time-series intervals to monitor dynamic situations. Previously, sensed geospatial information was treated as static data. However, given the dynamics of peatland ecosystem, a new observation system that captures overall spatial dynamics in peatlands is necessary. In this section, we describe the specification of each sensor which can be applied to peatland ground surface measurement (5.1.1.) and illustrate the key concept of an Integrated Sensing System which can monitor the spatial dynamics of peatlands (5.1.2.).

5.1.1. Sensing Systems

In this section, we describe various sensing systems applied to conduct ground surface measurements in peatlands.

(1) Needs for Precise Measurement of Peatland Dynamics

The detection target in peatland ground surface can be summarized as follows (Fig. X).

- Biomass changes
- Fire impacts
- Ground subsidence
- Landslides

The various sensing methods such as the Synthetic Aperture Radar (SAR), Light Detection and Ranging (LiDAR), and camera have been applied to investigate the spatial dynamics of peatlands. To precisely measure field conditions, it is necessary to choose the most suitable sensor.

Annex.01

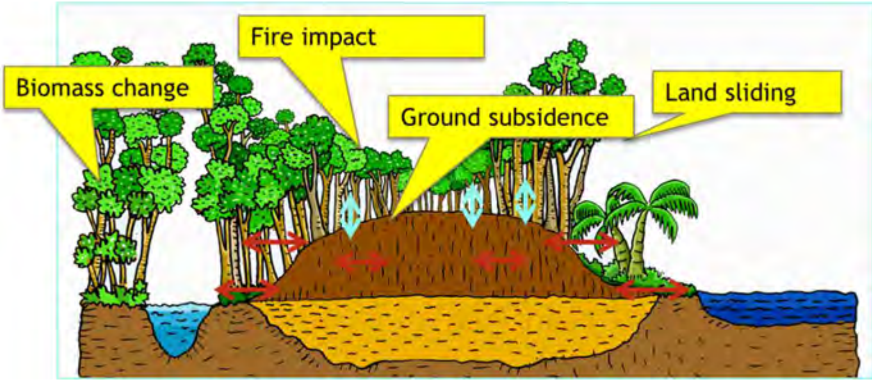


Figure 1:

Figure 2: Derived from https://www.unitedlex.com/news-and-insights/blog/2017/google-tesla-it%E2%80%99s-war-lidar-or-radarF

Table X. Advantages and disadvantages of Light Detection and Ranging (LiDAR), RADAR, and camera sensors

	LiDAR	RADAR	Camera
Advantages	- Possible to detect objects with low reflectivity of radio waves - Distance and direction can be detected with high spatial resolution - Fast detection	- Does not depend on light source and weather conditions - Accurately measures distance to a target object - Fast detection	- Objects can be identified from features
Disadvantages	- Because infrared light is used, the detection performance deteriorates in bad weather conditions	- Low spatial resolution - Difficult to detect objects with low reflectivity of radio waves	- Inspection ability is reduced in bad weather conditions

(2) Hyperspectral sensor
Hyperspectral imaging collects and processes information from across the electromagnetic spectrum. The goal of hyperspectral imaging is to obtain the spectrum for each pixel in the image of a scene with the purpose of finding objects, identifying materials, or detecting processes. Hyperspectral images are suitable for analyzing specific crops by Normalized Vegetation Index (NVI) and in specific climates. The use of hyperspectral remote sensing is increasing for monitoring the development and health of crops.

(3) LiDAR
The LiDAR system can rapidly transmit laser pulses during the day and night. The result is therefore a reflection of both landscape and man-made features. The known speed of light as well as the measured time interval of the laser pulses from transmission to return allows the determination of distances. An aerial survey of a zoning area can be performed either by a fixed-wing airplane, helicopter, or in parts by a drone with LiDAR equipment including an Inertial Navigation System with a GPS. The result is an innovative tool for analyzing the ground and surface. Applications are possible for hydrology, measurements of peat domes, extraction of tree height, estimation of above-ground biomass, the design of infrastructure such as roads, water canals, plantations, etc.

The eye-safe laser in the system has a very narrow beam called a small-footprint LiDAR that can penetrate gaps in vegetation to reach the ground through trees and other elements. This penetration allows for an accurate determination of ground levels in vegetated areas. Due to the instrumentation in the LiDAR system that provides accurate position and altitude information for the laser points as well as an installed camera, very few ground control points are required, which means that accurate surveys are possible for inaccessible areas. These include quarries, wetlands, flood plains, etc. LiDAR data produce a Digital Surface model (DSM) with infrastructure, trees, canopy, and a Digital Terrain Model (DTM) of the topography of the landscape.

Tree height (h) can be obtained as follows:

$$h = DSM - DTM$$

The accuracy of the surface generated is ~ 15 cm in elevation (z), ideal for agricultural planning, peatland research, river catchments surveys, and flood mapping. Eroded areas can be accurately surveyed even through long grass layers.

The main objective was to map changes in the vertical structure of trees and vegetation with the multi-temporal LiDAR technology to identify both sources and sinks of carbon across peat dome-shaped gradients.

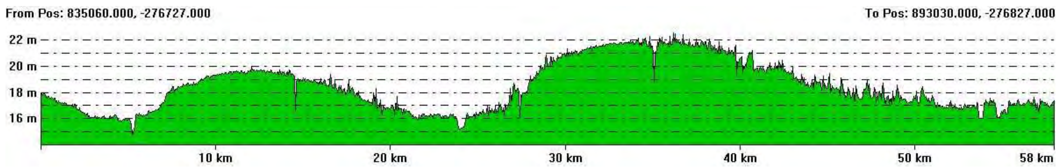


Figure 3: Peat profile with a Digital Terrain Model covering the rivers Sebangau (left), Kahayan (middle), and Kapuas (right)

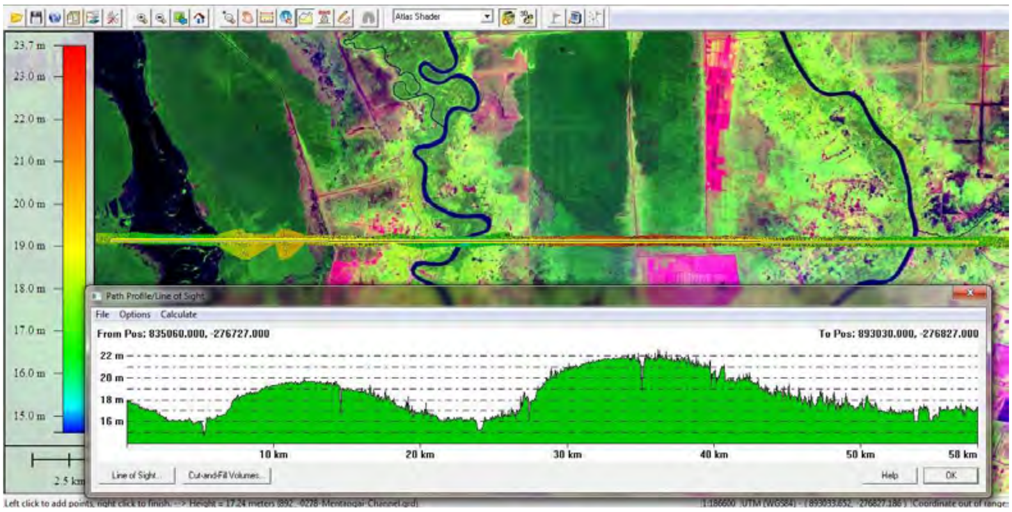


Figure 4: Light Detection and Ranging Digital Terrain Model and peat profile in the Pulang Pisau Province

(4) Radar

To conserve and manage peat soil properly, it is necessary to comprehensively and precisely understand the behavior of peat soil in each area. In principle, the decomposition rate of peat soil can be extracted as the amount of ground surface displacement by SAR differential interferometry analysis (DInSAR). SAR-satellites can cover a greater area and they are nearly independent of clouds. The L-Band ALOS-2 was launched by JAXA as a successor to ALOS. ALOS-2 has higher resolution, wider observable area, and better data transfer capacity than ALOS. ALOS-2 is expected to positively contribute to the efficient management of land and environment conservation. TerraSAR-X is a X-band SAR providing consistent and high repetitive coverage due to time- and weather-independent acquisitions. Subtle changes in the forest canopy are detected with TerraSAR-X due to its high resolution and radiometric stability.

(5) Ortho Photo

Photogrammetry is the process of authoring a digital surface model using multiple photos of the objects based on the principle of triangulation. A high-quality three-dimensional surface model of objects is modeled in a broad-scale application of photogrammetry to photos acquired by drones or unmanned aerial vehicles (UAVs). By taking multiple photos in at least two locations, “lines of sight” (LOS) can be developed from each camera to point to objects. These LOS are mathematically intersected to produce three-dimensional coordinates of points of interest.

Figure 5: Example of the Ortho-Photo method in Palangkaraya-Pahandut Habour on the Kahayan river

5.1.2. Key Concept of an Integrated Sensing System

In this section, we highlight two key concepts in an Integrated Sensing System considering the accuracy and reliability of sensing data.

(1) Sensor fusion technology

In the near future, large amounts of data will become available using drones, UAVs, helicopters, and satellites. To enhance the utility of such data, it is necessary to develop not only individual sensing technologies but also sensor fusion technologies using LiDAR, RADAR, camera, thermal and hyper-spectrum sensors. The combination of such data acquired by different sensor types will be useful for monitoring the rewetting of peatlands and for analyzing peatland deformation.

(2) Ground Control Network

To enable precise field measurements, careful design of a Ground Control Network is necessary. The Ground Control Network determines locations and deformations with improved precision everywhere and anytime on earth to satisfy societal and science requirements (United Nations Global Geospatial Information Management resolution).

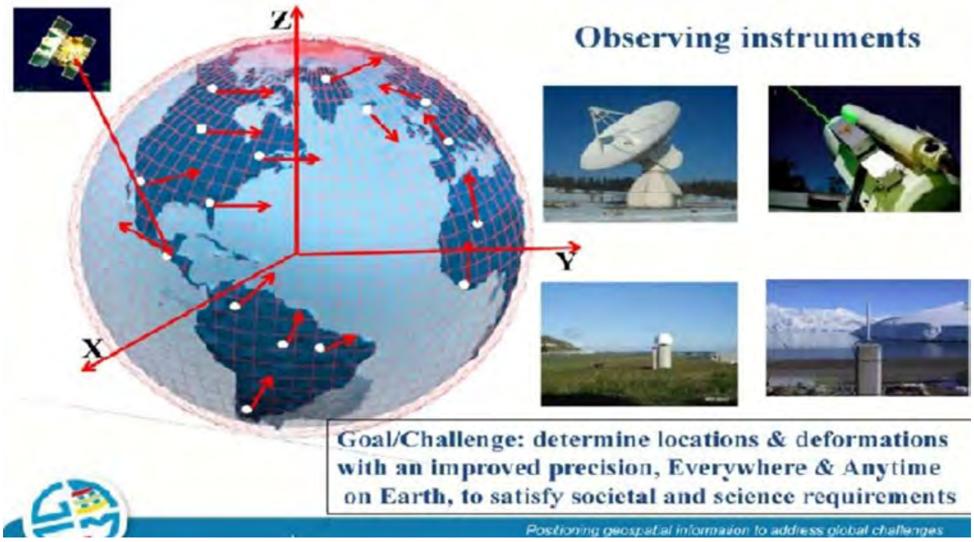


Figure 6:

Implementation of the Geodetic Control Network would contribute to increased application of geospatial data. It will also help observe the spatial dynamics of peatlands. For example, real-time location data would be applied to DInSAR analysis and used to verify the results of the analysis. The points to implement the Geodetic Control Station should be occupied by humans, located in stable ground, and should not be affected by construction activities. The site for setting the Geodetic Control station needs to be selected at a stable point, avoiding swampy or loose-soil areas.

5.2. Mapping Platform

To enable responsible management, it is important to monitor the spatial dynamics of peatlands. Such dynamic information on peatlands should be managed and operated on the integrated mapping platform to contribute to the decision-making process of policy makers. To ensure the high usability of the peatland mapping platform, ensuring the reliability of data will be the crucial for the system operators.

To create a reliable system, data to be uploaded to the system need to pass a screening test to check the accuracy of the contents and attributes of geospatial information. All data should therefore be automatically screened by the system. The mapped secondary data should include accuracy-validation information which is to be used for screening. To ensure the reliability of the material contents, it would be effective to ensure data are public. In addition, timely updating of the system is also important to improve operability. Timely updating would be achieved by the data server which manages data obtained from each SESAME system in Indonesia using a network connection. Improvement of network connection between the server and each SESAME system installed in the field would contribute to real-time updating of metadata by reducing the number of data gaps. Considering the high reliability of the system, the operational cost would be the crucial factor for operationalization. Thus, data processing, collection, evaluation, screening, and updating should be automated in the future.

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ACRONYMS

APHI	The Indonesian Forest Concessionaires Association (Asosiasi Pengusaha Hutan Indonesia)
APRIL	Asia Pacific Resources International Holdings Ltd
BAPPEDA	Regional Development Planning Agency (Badan Perencanaan Pembangunan Daerah)
BAPPENAS	Ministry of National Development (Kementerian Perencanaan Pembangunan Nasional)
BBSDLP	Indonesian Center for Agricultural Land Resources Research and Development (Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian)
BIG	Indonesian Agency of Geospatial Information (Badan Informasi Geospasial)
BPPT	Agency for the Assessment and Application of Technology (Badan Pengkajian dan Penerapan Teknologi)
BRG	Peatland Restoration Agency (Badan Restorasi Gambut)
CEH	Centre for Ecology & Hydrology
CIMTROP	Center for International Cooperation in Sustainable Management of Tropical Peatland
DG	Directorate General
DPR	People's Representative Council (Dewan Perwakilan Rakyat)
DRN	Indonesian National Research Council (Dewan Riset Nasional)
FOERDIA	Forest Research and Development Centre
GAPKI	Indonesian Palm Oil Association (Gabungan Pengusaha Kelapa Sawit Indonesia)
GVL	Geomatic Ventures Limited
GWL	Ground Water Level
HITI	Indonesia Soil Science Society (Himpunan Ilmu Tanah Indonesia)
ICRAF	World Agroforestry Centre
IPB	Bogor Agricultural University (Institut Pertanian Bogor)
IPS	International Peatland Society
ISCC	Indonesia Sustainable Coffee Cooperative
ISRI	Indonesian Soil Research Institute
JICA	Japan International Cooperation Agency
JPS	Japan Peatland Society
KHDTK	Forest Area for the Special Purpose (Kawasan Hutan Dengan Tujuan Khusus)
LAPAN	Indonesian National Institute of Aeronautics and Space (Lembaga Penerbangan dan Antariksa Nasional)
NCEP	National Centers for Environmental Prediction
PASSES	Peatland Assessment in South East Asia by Satellite
SATREPS	Science and Technology Research Partnership for Sustainable Development
SDG	Sustainable Development Goals
WRI	World Resources Institutes

I ACTIVITY LIST

Based on Minutes of Meeting, BRG-JICA Project has done so many activities and attend so many meeting or conference. Those activities summarize as follow:

Table 1 Activity list

No.	Year	Date and Time	Held By	Meeting and Discussion
1.	2017	July 21	LAPAN	Focus Group Discussion on Remote Sensing Applications for Peatland Mapping and Environmental Issue
2.	2017	July 27	University of Nottingham, University of Leicester, Liverpool John Moores University, CEH, GVL, CGI	Workshop for the PASSES Project
3.	2017	July 31	BRG-JICA Project	Meeting with BBSDLP
4.	2017	August 4	BRG-JICA Project	Meeting with Deputy of BRG
5.	2017	August 4	BRG-JICA Project	Trial Demonstration of Real Time Groundwater Level Monitoring Meeting
6.	2017	August 14	BRG-JICA Project	Accelerated Real Time Groundwater Level Monitoring Meeting
7.	2017	August 24	BPPT	SATREPS Meeting: Hydrological Unit Management Based on SDGs Criteria in Tropical Coastal Peatland in Riau Province, Indonesia
8.	2017	August 25	BBSDLP	Seminar of Technology for Oil Palm Utilization in Peatland and National Organic Carbon Map
9.	2017	September 4	BRG-JICA Project	Kick-off Meeting BRG-JICA Project
10.	2017	September 6	BRG	Donor Coordination Meeting
11.	2017	September 20	BRG-JICA Project	Meeting with Head of BRG
12.	2017	September 22	BRG	Launching Joint Action of Central Kalimantan Peatland Restoration

13.	2017	September 23	Palangka Raya University	General Lecture on Gold Peatland
14.	2017	September 25	BRG-JICA Project	Meeting with CIMTROP
15.	2017	September 26	BRG-JICA Project	Field Survey at Palangka Raya
16.	2017	September 27	BRG-JICA Project	Meeting with CIMTROP
17.	2017	September 29	BRG-JICA Project	Meeting with Norwegian Embassy
18.	2017	October 2	IJ-REDD JICA	Field Survey at Ketapang
19.	2017	October 3	IJ-REDD JICA	Meeting at Ketapang
20.	2017	October 4	BRG-JICA Project	Demonstration of Ground Water Level Monitoring
21.	2017	October 31	BRG-JICA Project	SESAME and Modeling Workshop
22.	2017	November 1-5	IPS, BRG, JPS, JICA, UNDP	1st Tropical Peatland Roundtable
23.	2017	November 8-17	UNFCCC	COP 23
24.	2017	November 17	BRG	Sitroom Meeting
25.	2017	November 22	BRG-JICA Project	Meeting with ICRAF
26.	2017	November 27	BRG-JICA Project	Meeting with BBSDLP
27.	2017	November 27	BRG-JICA Project	Meeting with Head of BRG
28.	2018	January 15	BRG-JICA Project	Meeting on MRV Integration
29.	2018	January 18-27	BRG-JICA Project	Joint Survey with Kyoto University
30	2018	January 23	BRG-JICA Project	Meeting with Head of BRG
31	2018	January 23	BRG-JICA Project	Meeting with DG Plantation, Ministry of Agriculture
32	2018	January 26	BRG	Development Partner Coordination Meeting
33	2018	January 29	BRG-JICA Project	Meeting with ICRAF
34	2018	January 29	BRG-JICA Project	Meeting with ISCC
35	2018	January 31	BRG-JICA Project	Meeting with Deputy BRG
36	2018	February 1	BRG-JICA Project	Demonstration of Integrated Monitoring System
37	2018	February 2	BRG-JICA Project	Meeting with Head of BRG
38	2018	February 5	BRG-JICA Project	Meeting with Indonesia Special Envoy on Climate Change
39	2018	February 6	BRG-JICA Project	Meeting with Director of Peat Damage Control, Ministry of Environment and Forestry
40	2018	February 9	BRG-JICA Project	Meeting with Deputy of BRG
41	2018	February 9	BRG-JICA Project	Meeting with FOERDIA
42	2018	February 22	RIHN, Kyoto University, BRG-JICA Project	Joint Symposium on Tropical Peatland Restoration
43	2018	March 19	BRG-JICA Project	Meeting with PT SMART
44	2018	March 20	BRG-JICA Project	Meeting with FOERDIA

45	2018	March 22	BRG-JICA Project	Meeting with Head of BRG & Indonesia Special Envoy on Climate Change
46	2018	March 26	BRG-JICA Project	Meeting with GAPKI
47	2018	March 28	BRG-JICA Project	Meeting with APHI
48	2018	March 31 – April 8	University of Science, Ho Chi Minh National University	Inspection in Peatland and Wetland in Mekong Delta of Southern Vietnam
49	2018	April 14-19	IPS	IPS Executive Board Meeting at Vilnius, Lithuania

Annex.02

1. Focus Group Discussion on Remote Sensing Applications for Peatland Mapping and Environmental Issue

Date	:	21st July 2017
Time	:	10.00 – end
Place	:	LAPAN Office, East Jakarta, Indonesia
Held By	:	LAPAN
Aim	:	to increase the role of data and remote sensing technology in peatland in Indonesia
Participants	:	Dr. Rokhis Khomarudin (LAPAN); Syarif Budhiman, M.Sc. (LAPAN); Ir. Ita Carolita, M.Si (LAPAN); Dr. Haris Gunawan (BRG); Dr. Mitsuru Osaki (Hokkaido University); Dr. Stephen Hagen (Applied Geosolutions); Dr Mathew Warren (USFS); Dr. Aritta Suwarno (Wageningen University); Dr. Agus Kristiyanto (BPPT); Wetadewi (JICA-BRG Project)
Key Points	:	- Satellite data can be used to monitor agriculture, forest, water quality, and land use change - Peatland mapping is really crucial for peatland management, both course scale and very detail map for different purposes - Requirements of peatland mapping and monitoring: accurate surface topography data across wide areas, accurate peat depth for model development and evaluation - Collaboration between LAPAN and BRG, BIG, JAXA are important to provide a better resolution data
Subject of Discussion	:	Remote Sensing for Forest and Peatland Mapping, #01 Automated Detection and Classification of Logging Features with LiDAR, #02 Development of Remote Sensing Application for Peatland Monitoring, #03 Hydrological Restoration to Solve Basic Problems of Tropical Peatland, #04 ERI Data Interpretation: 2D Depth Assessment of Peat-swamp Landscape, #05
Photos	:	 

2. Workshop for the PASSES Project

Date	:	27th July 2017
Time	:	10.00 – 15.30
Place	:	Pullman Hotel, Jakarta, Indonesia
Held By	:	University of Nottingham, University of Leicester, Liverpool John Moores University, CEH, GVL, CGI

Aim	:	to develop and demonstrate cost effective, robust and operational monitoring capabilities for the remote assessment of peatland condition at regional and national scales
Participants	:	Prof. Susan Page (University of Laicester); Dr. Andrew Sowter (GVL); Andrew Groom BSc (Hons), MSc (CGI); Dr. Haris Gunawan (BRG); Dr. Mitsuru Osaki (Hokkaido University); Muhammad Haidar (BIG); Yudi Setiawan Ph.D, M.Sc (IPB); Dr. Surya Tarigan, MSc, M.Kom (IPB); Surahman Putra (WRI); Almo Pradana (WRI); Taufan M. Chrisna (APRIL); Vivik (BIG); Wetadewi (JICA-BRG Project)
Key Points	:	-The passes monitoring concept is focused around a transformative new satellite capability for the routine monitoring of peatland condition -The idea of the project will be done in 2 years followed with 3 phases: 1) a proof concept; 2) a ramp up phase which is scale up the monitoring of wide areas; 3) an operations phase that demonstrate how the system worked operationally -The monitoring solution is focusing on three things: 1) trying to identify where the priorities areas are; 2) provide the implementation of the success area; 3) vegetation is to help characterizing the peatland (indication of peat health). Peat depth is not included -In the next discussion will input detail instructions
Photos	:	 

3. Meeting with BBSDLP

Date	:	31st July 2017
Time	:	08.00 – 10.00
Place	:	BBSDLP Office, Bogor, Indonesia
Held By	:	BRG-JICA Project
Aim	:	to discuss about the next upcoming project with BRG and concept of oil palm cultivation under high water level in peatland
Participants	:	Dr. Mitsuru Osaki (Hokkaido University); Dr. Hideyuki Kubo (IJ-REDD+); Prof. Dedi Nursyamsi (BBSDLP); Prof. Dr. Fahmuddin Agus (BBSDLP); Dr. Yiyi Sulaeman, M.Sc. (BBSDLP); Dr. I. Wayan (BBSDLP); Dr. Woro Estiningtyas (BBSDLP); Dr. Budi Kartiwa (BBSDLP); Dr. Ir. Kusumo Nugroho, MSc., Dipl. AS. (BBSDLP); Dr. Maswar (BBSDLP); Dr. Husnain, M.Sc. (BBSDLP); Wetadewi (JICA-BRG Project)
Key Points	:	-Key factors of oil palm cultivation under high water level: oxygen, nutrients, water -Supply nutrients from the surface by combining conventional fertilizer, natural compost, biochar. -Will conduct further discussion with soil experts

Photos	:	 

4. Meeting with Deputy of BRG

Date	:	4th August 2017
Time	:	10.00 – 11.00
Place	:	BRG Office (Graha Mandiri Building 21st Floor), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	to briefly introduce the main idea of JICA's project
Participants	:	Dr. Mitsuru Osaki (Hokkaido University); Dr. Alue Dohong (BRG); Dr. Eli Nur Nirmala Sari (BRG); Wetadewi (JICA-BRG Project)
Key Points	:	- Decided to cooperate to make some action to support peatland restoration. - Need to convince oil palm companies to increase the groundwater table. - It is better if JICA do a pilot research and cooperate with two oil palm companies that want to manage their own water management system.

5. Trial Demonstration of Real Time Groundwater Level Monitoring Meeting

Date	:	4th August 2017
Time	:	15.30 – end
Place	:	BRG Office (Graha Mandiri Building 21st Floor), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To demonstrate the development of real time groundwater level monitoring
Participants	:	Dr. Haris Gunawan (BRG); Abdul Karim Mukharomah, S.E., M.E. (BRG); Dr. Mitsuru Osaki (Hokkaido University); Dr. Hideyuki Kubo (IJ-REDD+); Dr. Albertus Sulaiman (BPPT); Awaluddin, S.Pi., M.Sc. (BPPT); Prabu Kresna, S.T. (BPPT); Wetadewi (JICA-BRG Project)
Key Points	:	- SESAME tools that belongs to BRG are 23 (18 on peatland; 3 on non-peatland area; 2 will be installed soon) - All the real time data stored in BPPT's server. This data is not a public domain. It is belong to BRG. It depends on BRG authority - Next step will integrate with hotspot data from LAPAN, weather animation from NCEP, temperature and moisture data to predict groundwater level for the next three days - Will be develop android-based system

Photos	:	 

6. Accelerated Real Time Groundwater Level Monitoring Meeting

Date	:	14th August 2017
Time	:	10.30 – 12.00
Place	:	BRG Office (Graha Mandiri Building 21st Floor), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To follow up the development of real time groundwater level monitoring
Participants	:	Dr. Haris Gunawan (BRG); Abdul Karim Mukharomah, S.E., M.E. (BRG); Thomas Rinuwat (BRG); Rizki Aulia (BRG); Dr. Hideyuki Kubo (IJ-REDD+); Dr. Albertus Sulaiman (BPPT); Awaluddin, S.Pi., M.Sc. (BPPT); Prabu Kresna, S.T. (BPPT); Wetadewi (JICA-BRG Project)
Key Points	:	- BRG requested the assistance of BPPT team to build a monitoring system that could be integrated between several tools that already put in the field and satellite data. - It is recommended that during the field visit the President is provided with a satellite-based peatland monitoring system in the form of android.
Photos	:	 

7. SATREPS Meeting: Hydrological Unit Management Based on SDGs Criteria in Tropical Coastal Peatland in Riau Province, Indonesia

Date	:	24th August 2017
Time	:	09.00 – end
Place	:	BPPT Office, Serpong, Indonesia
Held By	:	BPPT
Aim	:	to discuss about the next upcoming SATREPS program "Assessment of Water Resource Management in Peatland"
Participants	:	Dr. Mitsuru Osaki (Hokkaido University); Prof. Koichi Yamamoto (Yamaguchi University); Ir. C. Nugroho S. P., M.Sc. (BRG); Dr. Albertus Sulaiman (BPPT); Dr. Reni Sulistyowati (BPPT); Dr. Fiolenta Marpaung (BPPT); Hiroshi Kobayashi (IJ-REDD+); Kayo Matsui, M.Sc. (Hokkaido University); Dr. Bambang Setiadi (DRN); Dr. Sigit

		Sutikno (Riau University); Dr. Muhammad Yusa (Riau University); Susialita (BPPT); Wetadewi (JICA-BRG Project)
Key Points	:	Decided who will involve in the research, fixing content of proposal and technical administration to submit to DIKTI.
Photos	:	 

8. Seminar of Technology for Oil Palm Utilization in Peatland and National Organic Carbon Map

Date	:	25th August 2017
Time	:	08.30 – end
Place	:	BBSDLP Office, Bogor, Indonesia
Held By	:	BBSDLP
Aim	:	to discuss about the possibility of oil palm to grow in high water table
Participants	:	Dr. Mitsuru Osaki (Hokkaido University); Prof. Dedi Nursyamsi (BBSDLP); Prof. Dr. Fahmuddin Agus (BBSDLP); Dr. Yiyi Sulaeman, M.Sc. (BBSDLP); Dr. Ir. Kusumo Nugroho, MSc., Dipl. AS. (BBSDLP); Dr. Husnain, M.Sc. (BBSDLP); Kayo Matsui, M.Sc. (Hokkaido University); Wetadewi (JICA-BRG Project); staff of BBSDLP
Key Points	:	-Nutrient application from the surface: for small stakeholder use natural compost and chicken manure, for big company use biochar and manure to balance the cost because mineral compost is expensive
Subject of Discussion	:	Breakthrough of Oil Palm Cultivation in High Watertable, #06 Water Table, CO_2 Emissions and Oil Palm Performance on Peatland, #07 Monitoring Water Table in Peatland between Theory and Practice, #08 Cultivation of Oil Palm Plantation in the Peatland, #09
Photos	:	 

9. Kick-off Meeting BRG-JICA Project

Date	:	4th September 2017
Time	:	09.00 – end
Place	:	BRG Office (Graha Mandiri Building 21st Floor), Jakarta, Indonesia
Held By	:	BRG-JICA Project

Aim	:	To share current issues and challenges facing peatland restoration in Indonesia and come up with a short term action plan to address them by March 2018
Participants	:	Dr. Haris Gunawan (BRG); Ir. C. Nugroho S. P., M.Sc. (BRG); Dr. Mitsuru Osaki (Hokkaido University); Dr. Bambang Setiadi (DRN); Prof. Yukihiro Takahashi (Hokkaido University); Dr. Hideyuki Kubo (IJ-REDD); Dr. Albertus Sulaiman (BPPT); Awaluddin, S.Pi., M.Sc. (BPPT); Prabu Kresna Putra, S.T. (BPPT); Dr. Ayako Oide (Hokkaido University); Dr. Kusumo Nugroho (BBSDLP); Kayo Matsui, M.Sc. (Hokkaido University); Wetadewi (JICA-BRG Project)
Key Points	:	- Four agendas of the project: 1) Satellite based model on ground water level monitoring; 2) Peatland restoration actions; 3) Capacity building of Indonesian officials and universities; 4) Knowledge inputs nationally and internationally - Tentative sites (Tebing Tinggi Island & Kahayan-Sebangau River) was proposed as the better demonstration site to establish the field activities and develop models
Subject of Discussion	:	Action Plan for Minutes of Meetings (MoM) between BRG and JICA on the Elaboration of Peatland Restoration, #10 Gold Carbon Mechanism, #11
Photos	:	 

10. Donor Coordination Meeting

Date	:	6th September 2017
Time	:	08.00 – 13.00
Place	:	Jakarta, Indonesia
Held By	:	BRG
Aim	:	- To present an overview of the current state of affairs with respect to peatland restoration (planning and implementation) - To ensure synchronization and coordination among donors and with BRG of external support for peatland restoration - To inventory and update on going , planned and potential donor support to peatland restoration
Participants	:	Dr. Hideyuki Kubo (IJ-REDD)
Subject of Discussion	:	Building the Technical Capacity for Peatland Monitoring and Restoration: JICA's support for peatlands, #12

11. Meeting with Head of BRG

Date	:	20th September 2017
Time	:	12.00 – 13.00

Place	:	BRG Office (Teuku Umar 10), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To discuss about idea and strategy of Tropical Peatland Roundtable and COP 23
Participants	:	Ir. Nazir Foead, M.Sc. (BRG); Dr. Mitsuru Osaki (Hokkaido University); Hitoshi Iriyama (JICA); Dr. Ayako Oide (Hokkaido University); Wetadewi (JICA-BRG Project)
Key Points	:	- BRG has high expectation with ground water level monitoring system (SESAME) - Standardize zoning method in peatland is necessary and need to collaborate with scientist from universities
Subject of Discussion	:	Gold Carbon Mechanism, #11
Photos	:	 

12. Launching Joint Action of Central Kalimantan Peatland Restoration

Date	:	22nd September 2017
Time	:	09.30 – 16.00
Place	:	Palangka Raya, Central Kalimantan, Indonesia
Held By	:	BRG
Aim	:	To demonstrate the rewetting system
Participants	:	Ir. Nazir Foead, M.Sc. (BRG); Dr. Alue Dohong (BRG); Dr. Myrna A. Safitri (BRG); Vegard Kaale (Norway's Ambassador to Indonesia); Ida Suriany (UK Embassy); Ir. Medrilzam, M.Prof.Econ, Ph.D. (Ministry of National Development); H. Hamdani, S.I.P. (DPR Commission IV); Dr. Mitsuru Osaki (Hokkaido University); Dr. Ayako Oide (Hokkaido University); Wetadewi (JICA-BRG Project); Doctoral students of forestry and agriculture faculty of Palangka Raya University; Masyarakat Peduli Api (MPA)
Key Points	:	- Incentives are increasing in Tanjung taruna in the context of restoration and handling of fire prevention - To maintain the development infrastructure, especially the canal blocking, all parties must be involved and help each other - Quick response system needs to be applied not only in local communities (Masyarakat Peduli Api/MPA) but also in the central government.

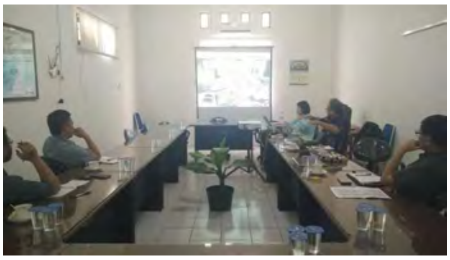
Photos	:	 

13. General Lecture on Gold Peatland

Date	:	23rd September 2017
Time	:	10.00 – 12.00
Place	:	Palangka Raya University, Central Kalimantan, Indonesia
Held By	:	Palangka Raya University
Aim	:	To give general lecture about peatland to doctoral students
Participants	:	Dr. Mitsuru Osaki (Hokkaido University); Prof. Dr. Ir. Salampak, M.S. (Palangka Raya University); Dr. Nina Yulianti (Palangka Raya University); Dr. Ayako Oide (Hokkaido University); Wetadewi (JICA-BRG Project)
Photos	:	 

14. Meeting with CIMTROP

Date	:	25th September 2017
Time	:	09.00 – 12.00
Place	:	CIMTROP, Palangka Raya, Central Kalimantan, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop zoning method in peatland
Participants	:	Dr. Mitsuru Osaki (Hokkaido University); Dr. Ir. Ici Piter Kulu (CIMTROP); Drs. Tampung N. Saman, M.Lib (CIMTROP); Erna Shinta, S.Hut., M.Agr., Ph.D. (CIMTROP); Kitso Kusin, S.P., M.Si. (CIMTROP); Dr. Ayako Oide (Hokkaido University); Wetadewi (JICA-BRG Project)
Key Points	:	- Mr. Kitso selected as a representative of Palangka University to join the survey - Survey selection target: DAM, oil palm cultivation, Sengon plantation, Sago plantation, KHDTK site, several research sites

Photos	:	 

15. Field Survey at Palangka Raya

Date	:	26th September 2017
Time	:	09.00 – 16.00
Place	:	Palangka Raya, Central Kalimantan, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To select several sites for field trip of 1st Tropical Peatland Roundtable
Participants	:	Dr. Mitsuru Osaki (Hokkaido University); Dr. Ir. Ici Piter Kulu (CIMTROP); Drs. Tampung N. Saman, M.Lib (CIMTROP); Erna Shinta, S.Hut., M.Agr., Ph.D. (CIMTROP); Kitso Kusin, S.P., M.Si. (CIMTROP); Dr. Ayako Oide (Hokkaido University); Wetadewi (JICA-BRG Project)
Key Points	:	- Six sites selected for field trip of 1st Tropical Peatland Roundtable: CIMTROP camp (DAM construction site); paludiculture research site at Kalampangan; integrated research site at Kalampangan; canal blocking site at Taruna Jaya; deep well site at Taruna Jaya; KHDTK Tumbang Nusa
Photos	:	 

16. Meeting with CIMTROP

Date	:	27th September 2017
Time	:	08.00 – 14.30
Place	:	CIMTROP, Palangka Raya, Central Kalimantan, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To organize field trip of 1st Tropical Peatland Roundtable
Participants	:	Dr. Mitsuru Osaki (Hokkaido University); Dr. Ir. Ici Piter Kulu (CIMTROP); Drs. Tampung N. Saman, M.Lib (CIMTROP); Erna Shinta, S.Hut., M.Agr., Ph.D. (CIMTROP); Kitso Kusin, S.P., M.Si. (CIMTROP); Dr. Ayako Oide (Hokkaido University); Wetadewi (JICA-BRG Project)
Key Points	:	- CIMTROP agree as a committee to arrange field trip of 1st Tropical Peatland Roundtable

		- CIMTROP will join the survey to develop zoning method and will use line transect method & same location sites as before
Photos	:	

17. Meeting with Norwegian Embassy

Date	:	29th September 2017
Time	:	08.00 – end
Place	:	Norwegian Embassy of Indonesia, Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To propose a new concept of peatland management
Participants	:	Dr. Mitsuru Osaki (Hokkaido University); Dr. Hideyuki Kubo (IJ-REDD); Dr. Ayako Oide (Hokkaido University)
Subject of Discussion	:	Gold Carbon Mechanism, #11

18. Field Survey at Ketapang

Date	:	2nd October 2017
Time	:	11.00 – 14.00
Place	:	Pelang river, Ketapang, West Kalimantan, Indonesia
Held By	:	IJ-REDD JICA
Aim	:	To select site of fire protection project
Participants	:	Dr. Mitsuru Osaki (Hokkaido University); Dr. Hideyuki Kubo (IJ-REDD); Dr. Ayako Oide (Hokkaido University); Dicko Rossanda (IJ-REDD); Wetadewi (JICA-BRG Project)
Key Points	:	- Six sites selected for field trip of 1st Tropical Peatland Roundtable: CIMTROP camp (DAM construction site); paludiculture research site at Kalampangan; integrated research site at Kalampangan; canal blocking site at Taruna Jaya; deep well site at Taruna Jaya; KHDTK Tumbang Nusa
Photos	:	 

19. Meeting at Ketapang

Date	:	3rd October 2017

Time	:	09.00 – end
Place	:	Regional Development Planning Agency (Bappeda) Office, Ketapang District, West Kalimantan, Indonesia
Held By	:	IJ-REDD JICA
Aim	:	To discuss about plot design preparation of fire protection project
Participants	:	Ir. Sunaji (Bappeda); Gusti Indra Kusuma (Bappeda); Dr. Mitsuru Osaki (Hokkaido University); Dr. Hideyuki Kubo (IJ-REDD); Dr. Ayako Oide (Hokkaido University); Dicko Rossanda (IJ-REDD); Wetadewi (JICA-BRG Project); Razanah (Bappeda); Edi Prayitno (Bappeda); Head of Pelang River Village, Rahmat Rohendi (Head of South Matan Hilir District)
Key Points	:	- This project can begin in the second week of October adjusted to the time schedule that has already been made - Charcoal and compost will be added in the surface of the peat to increase the soil fertility - Sengon and Bamboo are suggested to plant as a barrier around the canal blocking site - This project are expected to be useful not only to prevent forest fire but also to maintain soil moisture during dry season
Photos	:	

20. Demonstration of Ground Water Level Monitoring

Date	:	4th October 2017
Time	:	10.00 – 12.00
Place	:	BRG Office (Graha Mandiri Building 21st Floor), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To demonstrate the development of real time groundwater level monitoring
Participants	:	Dr. Haris Gunawan (BRG); Ir. C. Nugroho S. P., M.Sc. (BRG); Wahyu Utami Tulis Wiyati, S.T. (KLHK); Dr. Mitsuru Osaki (Hokkaido University); Dr. Hideyuki Kubo (IJ-REDD+); Dr. Yudi Anantasena (BPPT); Dr. Albertus Sulaiman (BPPT); Awaluddin, S.Pi., M.Sc. (BPPT); Prabu Kresna, S.T. (BPPT); Dionysius Bryan Sencaki (BPPT); Wetadewi (JICA-BRG Project)
Photos	:	 

21. SESAME and Modeling Workshop

Date	:	31st October 2017
Time	:	10.00 – 12.00
Place	:	BRG Office (Graha Mandiri Building 21st Floor), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To share and discuss about technical issue of the development of real time groundwater level monitoring
Participants	:	Dr. Haris Gunawan (BRG); Dr. Mitsuru Osaki (Hokkaido University); Dr. Takashi Hirano (Hokkaido University); Dr. Hidenori Takahashi (NPO Hokkaido Institute of Hydro Climate); Dr. Yohei Hamada (Midori Engineering Inc.); Dr. Hideyuki Kubo (IJ-REDD+); Dr. Albertus Sulaiman (BPPT); Awaluddin, S.Pi., M.Sc. (BPPT); Fany Melieani, S.Pi. (BPPT); Wetadewi (JICA-BRG Project)

22. 1st Tropical Peatland Roundtable

Date	:	1st - 5th November 2017
Time	:	08.30 – 17.00
Place	:	Menara Peninsula Hotel, Jakarta, Indonesia
Held By	:	IPS, BRG, JPS, JICA, UNDP
Aim	:	To discuss "The Framework on Tropical Peatland Restoration" and propose an action plan called Jakarta Declaration
Participants	:	69 participants (Scientists, Policy Makers, and Academician, Corporates, Donor Agencies, and NGOs representatives) from Indonesia, Japan, Finland, Germany, Netherlands, Vietnam, Singapore, Malaysia, Mexico.
Key Points	:	A principal strategy of Responsible Management of Tropical Peatland was agreed as Jakarta Declaration that includes five pillars of action: - establish a "Tropical Peatland Center" - organize an "International Committee for Technical Consultation" - develop an "Integrated Monitoring System" - conduct a "Model Project" for responsible management - achieve capacity building
Subject of Discussion	:	"Jakarta Declaration" on Responsible Management of Tropical Peatland, #13
Photos	:	 

23. COP 23

Date	:	8-17th November 2017
Time	:	13.00
Place	:	Bonn, Germany
Held By	:	UNFCCC

Aim	:	To discussing how to follow up on the Paris agreement, which was the result of a previous COP summit
Key Points	:	- Demonstrated the results of the groundwater level estimation map being developed by BPPT. Based on this, 1) carbon dioxide release model by microbial decomposition of peat, 2) generation frequency and intensity estimation model of fire, 3) creation of prediction model of rainfall, 4) fire frequency and intensity estimation

24. Sitroom Meeting

Date	:	17th November 2017
Time	:	14.00
Place	:	BRG Office (Teuku Umar 10), Jakarta, Indonesia
Held By	:	BRG
Aim	:	To discuss about the progress of the monitoring system that has been built by BRG
Participants	:	Abdul Karim Mukharomah (BRG); Awaluddin, S.Pi., M.Sc. (BPPT); Ayako Oide (Hokkaido University); Rahmadi Dadi; Surahman Putra (WRI); Almo Pradana (WRI); Herni Ramdlaningrum (UNDP); Hening Parlan (UNDP)
Key Points	:	- BPPT has built the monitoring system from 21 points that supported by JICA - The system already running from November 2016 - WRI also built similar system that focused on what was BRG has planned and implemented

25. Meeting with ICRAF

Date	:	22nd November 2017
Time	:	10.00 – 12.00
Place	:	BRG Office (Graha Mandiri Building 21st Floor), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To collaborate in the context of peatland restoration in Indonesia
Participants	:	Prof. Mitsuru Osaki (Hokkaido University); Hideyuki Kubo, Ph.D (IJ-REDD+); Dr. Ayako Oide (Hokkaido University); Wetadewi (JICA-BRG); Dr. James Roshetko (ICRAF); Dr. Gerhard Manurung (ICRAF); Anisa Budi Erawati (ICRAF); Elok Mulyoutami (ICRAF)
Key Points	:	- The project should focus on sustainable management - The candidate to submit the proposal is to SATREPS - Will conduct a meeting in January to develop a concept
Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14
Photos	:	

26. Meeting with BBSDLP

Date	:	27th November 2017
Time	:	08.00 – 09.30
Place	:	BRG Office (Graha Mandiri Building 21st Floor), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop an innovated oil palm cultivation under high water level in tropical peatland
Participants	:	Prof. Mitsuru Osaki (Hokkaido University); Dr. Ayako Oide (Hokkaido University); Wetadewi (JICA-BRG); Prof. Dedi Nursyamsi (BBSDLP); Prof. Fahmuddin Agus (BBSDLP); Dr. Kusumo Nugroho (BBSDLP); Dr. Yiyi Sulaeman (BBSDLP); Dr. Ai Dariah (BBSDLP); Dr. Budi Kartiwa (BBSDLP); Dr. Poppy R. (BBSDLP); Dr. Wiwik Hartatik (BBSDLP)
Key Points	:	- BBSDLP interest about this concept and the next meeting should invite Directorate General Plantation of Ministry of Agriculture to have a further discussion
Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14
Photos	:	

27. Meeting with Head of BRG

Date	:	27th November 2017
Time	:	09.30 – 11.00
Place	:	BRG Office (Teuku Umar 10), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop an innovated oil palm cultivation under high water level in tropical peatland
Participants	:	Ir. Nazir Foead, M.Sc. (BRG); Dr. Mitsuru Osaki (Hokkaido University); Dr. Ayako Oide (Hokkaido University); Wetadewi (JICA-BRG Project)
Key Points	:	- Need to create a workshop inviting some researcher's companies and company managers and workers to introduce the system - Need to do some appliead research and testing - The Minister of Environment and Forestry suggested to have the Tropical Peatland Center in Bogor. Need to discuss with resource development part of forestry and agriculture.
Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14

28. Meeting on MRV Integartion

Date	:	15th January 2018
Time	:	10.00 – 17.00

Place	:	BRG Office (Graha Mandiri Building 21st Floor), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To discuss about the progress of development MRV system for peatland and to exchange ideas on the significance of MRV system for peatland restoration
Participants	:	Dr. Haris Gunawan (BRG); Dr. Mitsuru Osaki (Hokkaido University); Dr. Albertus Sulaiman (BPPT); Awaluddin, S.Pi., M.Sc. (BPPT); Kayo Matsui (Hokkaido University);
Photos	:	

29. Joint Survey with Kyoto University

Date	:	18-27th January 2018
Time	:	08.00 – 17.00
Place	:	Palangka Raya, Central Kalimantan, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop zoning method of peatland
Participants	:	Dr. Mitsuru Osaki (Hokkaido University); Dr. Shimamura (Ehime University); Dr. Itoh (Kyoto University); Dr. Ayako Oide (Hokkaido University); Kayo Matsui, M.Sc. (Hokkaido University); Dr. Shiodera (Kyoto University); Wahyu (Kyoto University); Drs. Ahmad Muhammad (Riau University); Dr. Nurni Komar (Riau University); Wetadewi (JICA-BRG Project)
Photos	:	 

30. Meeting with Head of BRG

Date	:	23rd January 2018
Time	:	08.30 – 09.45
Place	:	BRG Office (Teuku Umar 10), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop an innovated oil palm cultivation under high water level in tropical peatland
Participants	:	Ir. Nazir Foead, M.Sc. (BRG); Dr. Mitsuru Osaki (Hokkaido University); Dr. Hideyuki Kubo (IJ-REDD); Dr. Ayako Oide (Hokkaido University); Wetadewi (JICA-BRG Project)
Key Points	:	- SIRAT or Sinar Mas willing to participate and pay it by themselves. Need to find area included some part of Sinar Mas concession area and

		some part of community or government's protected forest. They should be in one Hydrologycal Peatland Unit side by side. We will have one research model and several spot to measure the station. This could be anywhere as per BRG mandate - Should invite Indonesian Agency for Agricultural Research and Development Ministry of Agriculture
Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14

31. Meeting with DG Plantation, Ministry of Agriculture

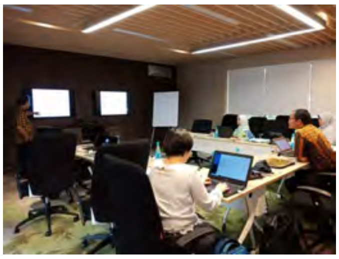
Date	:	23rd January 2018
Time	:	12.30 – 15.30
Place	:	Ministry of Agriculture Office, Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop an innovated oil palm cultivation under high water level in tropical peatland
Participants	:	Prof. Mitsuru Osaki (Hokkaido University); Dr. Hideyuki Kubo (IJ-REDD); Dr. Ayako Oide (Hokkaido University); Wetadewi (JICA-BRG); Ir. Bambang, MM (DG Plantation); Ir. Irmijati R. Nurbahar, M.Sc. (Director of Perennial and Beverage Crops); Drs. Dudi Gunadi, B.Sc., M.Si (Director of Plantation Protection); Prof. Dedi Nursyamsi, M. Agr (Director of BBSDLP); Dr. Ir. Kusumo Nugroho, M.Sc., Dipl. AS. (Soil Scientist/GIS BBSDLP); Maswar (BBSDLP); Yiyi Sulaeman, M.Sc (Deputy for Research Collaboration and Dissemination BBSDLP)
Key Points	:	- Need to conduct futher study to prove this concept - Ministry of Agriculture agree to collaborate with BRG to make demonstration research by using Mr. Osaki technology. The research should compare between GWL 40cm (Regulation number PP 57/2016) with GWL 60-80cm (Permentan 14/2009).
Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14
Photos	:	

32. Development Partner Coordination Meeting

Date	:	26th January 2018
Time	:	09.00 – 15.30
Place	:	Pangeran Hotel Pekanbaru, Riau, Indonesia
Held By	:	BRG
Aim	:	To build coordination with development partners to support restoration in the province

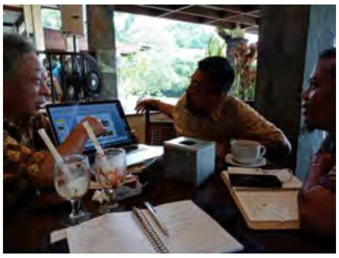
Participants	:	Dr. Budi Wardhana (BRG); Ir. Soesilo Indrarto, M.Si (BRG); Dr. Ir. Suwignya Utama, M.B.A (BRG); Dr. Mitsuru Osaki (Hokkaido University); Wetadewi (JICA-BRG Project); Provincial Restoration Team
Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14
Photos	:	 

33. Meeting with ICRAF

Date	:	29th January 2018
Time	:	10.00 – 12.00
Place	:	ICRAF Office, Bogor, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop a sustainable management project
Participants	:	Prof. Mitsuru Osaki (Hokkaido University); Dr. Ayako Oide (Hokkaido University); Wetadewi (JICA-BRG); Dr. Gerhard Manurung (ICRAF); Anisa Budi Erawati (ICRAF); Elok Mulyoutami (ICRAF)
Key Points	:	- ICRAF wants to develop "Sustainable Improved Paludiculture for Conservation Enhancement and Poverty Reduction in Indonesia" - Prof. Osaki has a new concept to develop "Fieldology on Land Surface Management for Earth Sustainability" - Will try to submit the proposal to Global Innovation Fund
Photos	:	

34. Meeting with ISCC

Date	:	29th January 2018
Time	:	15.30 – 16.30
Place	:	Kebun Raya Bogor, Bogor, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop an innovated coffee plantation in tropical peatland
Participants	:	Prof. Mitsuru Osaki (Hokkaido University); M. Akbar Fitri (ISCC); Muhamad Syarip Lambaga (ISCC); Wetadewi (JICA-BRG)
Key Points	:	- AeroHydro concept needs to be proven by conducting further studies that can be done in other types of land (not only peat) and for other commodities (not just oil palm). Maybe this technology is able to

		increase the productivity of coffee which can also be linked to climate change issues
Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14
Photos	:	

35. Meeting with Deputy BRG

Date	:	31st January 2018
Time	:	15.00 – 16.00
Place	:	BRG Office (Graha Mandiri Building 21st Floor), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To discuss the preparation of Joint Symposium
Participants	:	Dr. Haris Gunawan (BRG); Dr. Mitsuru Osaki (Hokkaido University); Dr. Ayako Oide (Hokkaido University); Kayo Matsui, M.Sc. (Hokkaido University); Wetadewi (JICA-BRG Project); Lutfiah Surayah (RIHN); Festy Putri (BRG)
Key Points	:	- BRG and FORDA already have a discussion to establish Tropical Peatland Center (follow up Jakarta Declaration). FORDA provide a space in Gunung Batu, Bogor for the secretariat office. - RIHN will conduct a symposium on 21st February and JICA-BRG project on 22nd February. The title for both event will be “Responsible Management of Tropical Peatland.” - Need to invite foreign colleagues such as Malaysia, Vietnam, Thailand
Photos	:	

36. Demonstration of Integrated Monitoring System

Date	:	1st February 2018
Time	:	09.30 – 11.00
Place	:	BRG Office (Graha Mandiri Building 21st Floor), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To demonstrate the development of real time groundwater level monitoring
Participants	:	Dr. Haris Gunawan (BRG); Dr. Mitsuru Osaki (Hokkaido University); Dr. Hideyuki Kubo (IJ-REDD+); Nakamura (Embassy of Japan in Indonesia); Suzuki (JICA); Hitoshi Iriyama (JICA); Dr. Albertus Sulaiman (BPPT); Awaluddin, S.Pi., M.Sc. (BPPT); Adam Gerrand

		(FAO); Bambang Arifatmi (FAO); Dr. Osamu Kozan (Kyoto University); Dr. Ayako Oide (Hokkaido University); Kayo Matsui, M.Sc. (Hokkaido University); Kazuo Watanabe (Hokkaido University); Koshiyama (Hokkaido University); Daikobu (Hokkaido University); Wetadewi (JICA-BRG Project)
Key Points	:	- There's a high correlation between soil moisture and water level. Water level prediction is performed with the precision of the grid of 1 km × 1 km. WPS domain configuration. Carbon dioxide emissions can also be predicted using Hirano model (good correlation between CO_2 emissions and water level)
Photos	:	 

37. Meeting with Head of BRG

Date	:	2nd January 2018
Time	:	11.30 – 12.00
Place	:	Pulman Thamrin, Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop an innovated oil palm cultivation under high water level in tropical peatland
Participants	:	Ir. Nazir Foead, M.Sc. (BRG); Dr. Budi Wardhana (BRG); Dr. Mitsuru Osaki (Hokkaido University); Dr. Ayako Oide (Hokkaido University); Kayo Matsui, M.Sc. (Hokkaido University); Wetadewi (JICA-BRG Project)
Key Points	:	- BRG already choose 3 landscape areas for pilot project: 1) KHG Sungai Gaung – Sungai Kampar. In this area there are a lot of types of land use. There's a wildlife sanctuary in the middle part (Jamrud National Park), plantation, HTI, RAPP Sinarmas; 2) 70% of the land licensed to Sinarmas including HTI and palm oil plantation in Ogan Komering Ilir, South Sumatera; 3) Kuburaya, West Kalimantan KHG Sugian Lumpur
Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14

38. Meeting with Indonesia Special Envoy on Climate Change

Date	:	5th February 2018
Time	:	12.00 – 13.00
Place	:	Aromanis Restaurant, Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop an innovated oil palm cultivation under high water level in tropical peatland
Participants	:	Prof. Ir. Rachmat Witoelar; Dr. Mitsuru Osaki (Hokkaido University); Kayo Matsui, M.Sc. (Hokkaido University); Wetadewi (JICA-BRG Project); Lia Zakiyyah; Titi Pandjaitan

Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14
Photos	:	 

39. Meeting with Director of Peat Damage Control, Ministry of Environment and Forestry

Date	:	6^{th} February 2018
Time	:	09.00 – 10.30
Place	:	Ministry of Environment and Forestry Office Kebon Nanas, Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop high water table cultivation and Gold Carbon mechanism
Participants	:	Ir. Wahyu Indraningsih, M.Sc.; Dr. Mitsuru Osaki (Hokkaido University); Dr. Hideyuki Kubo (IJ-REDD); Kayo Matsui, M.Sc. (Hokkaido University); Wetadewi (JICA-BRG Project)
Key Points	:	- Need to have pilot project in several location of private sector and community and need to design the criteria of the area and compare the result - Need to cooperate with Ministry of Agriculture
Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14
Photos	:	 

40. Meeting with Deputy BRG

Date	:	9^{th} February 2018
Time	:	13.30 – 14.30
Place	:	BRG Office (Teuku Umar 17), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop an innovated oil palm cultivation under high water level in tropical peatland
Participants	:	Dr. Budi Wardhana (BRG); Dr. Haris Gunawan (BRG); Dr. Mitsuru Osaki (Hokkaido University); Dr. Hideyuki Kubo (IJ-REDD); Dr. Ayako Oide (Hokkaido University); Kayo Matsui, M.Sc. (Hokkaido University); Wetadewi (JICA-BRG Project); Velanie Adiwijaya (BRG); Edison (BRG)
Key Points	:	- Period of research: Intensive activity in one year and the second year is monitoring

		- The team consists of: BRG (Deputy I and IV); JICA; BPPT; and operator manager
Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14
Photos	:	 

41. Meeting with FOERDIA

Date	:	9th February 2018
Time	:	14.30 – 15.00
Place	:	BRG Office (Graha Mandiri Building 21st Floor), Jakarta, Indonesia
Held By	:	BRG
Aim	:	To develop Tropical Peatland Center
Participants	:	Ir. C. Nugroho S. P., M.Sc. (BRG); Dr. Hesty Lestari Tata (FOERDIA); Dr. Yayuk Siswiyanti (FOERDIA); Dr. Mitsuru Osaki (Hokkaido University); Dr. Hideyuki Kubo (IJ-REDD); Nuri Luthfiana (BRG); Dede Hendry Tryanto (BRG): Nugroho Adi Utomo (BRG)
Key Points	:	- FOERDIA will be the secretary office that has duty to manage activities. BRG will participate during event management. - For networking not only representing state but also institution. International committee needs to consider NGO - Other European countries that concern with peat need to invite as well - Some flyer of dissemination and publication has been prepared - It is better to determine the topic research. The title of the research will be specify by whoever who proceed the research.
Subject of Discussion	:	Global Tropical Peatland Center, #16

42. Joint Symposium on Tropical Peatland Restoration

Date	:	22nd February 2018
Time	:	11.30 – 12.00
Place	:	Manara Peninsula Hotel, Jakarta, Indonesia
Held By	:	RIHN, Kyoto University, BRG-JICA Project
Aim	:	To demonstrate the establishment of an Integrated Monitoring System
Participants	:	60 participants (Scientists, Policy Makers, and Academician, Corporates, Donor Agencies, and NGOs representatives) from Indonesia, Japan, Germany, Russia, Vietnam
Key Points	:	- Suggestions for updating the system: consider better data sets such as soil moisture radar data due to the many aspects that can affect the soil moisture (i.e. porosity) & to pay attention to the positioning of the sensor (how much away from the canal and surface)
Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14 & #15

		Global Tropical Peatland Center, #16 Action Plan on Tropical Peatland Center, #17
Photos	:	 

43. Meeting with PT SMART

Date	:	19th March 2018
Time	:	17.30 – 19.00
Place	:	Chatterbox, Plaza Senayan, Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop an innovated oil palm cultivation under high water level in tropical peatland
Participants	:	Ir. Nazir Foead, M.Sc. (BRG); Dr. Mitsuru Osaki (Hokkaido University); J.P. Caliman (PT SMART); Melanie Camaro (BRG); Wetadewi (JICA-BRG Project)
Key Points	:	- Ministry of Environment and Forestry allow BRG to do the research in the concession area. The result or the report of the research should be submitted by the end of the year to the President - Should make MoU between BRG, Ministry of Agriculture and Ministry of Environment and Forestry for this project - There will be two slots for BRG to present paper on ICOPE at the end of April (25-27 April) at Nusa Dua, Bali. Prof. Osaki will be presenting AeroHydro Culture System (the whole concept for the upcoming project) to engage company to apply this technology to their concession area - PT SMART has done so many research that related to subsidence and water table in Riau, North Sumatera, South Sumatera, Lampung, Jambi, Central Kalimantan
Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14 & #15
Photos	:	

44. Meeting with FOERDIA

Date	:	20th March 2018
Time	:	09.00 – 12.00
Place	:	Forest Research and Development Centre Office, Bogor, Indonesia
Held By	:	BRG-JICA Project

Aim	:	To develop an innovated oil palm cultivation under high water level in tropical peatland and develop Tropical Peatland Center
Participants	:	Ir. C. Nugroho S. P., M.Sc. (BRG); Dr. Ir. Kirsfianti L. Ginoga, M.Sc. (FOERDIA); Dr. Mitsuru Osaki (Hokkaido University); Wetadewi (JICA-BRG Project); Staffs of Deputy IV BRG; Researchers from FOERDIA
Key Points	:	- Main idea of Tropical Peatland Center: -International advisor -Model peatland management -Networking -Capacity building: to educate communities not only by training - The Minister of Environmental and Forestry selected Bogor to be the host of Tropical Peatland Center.
Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14 & #15 Action Plan on Tropical Peatland Center, #17
Photos	:	 

45. Meeting with Head of BRG and Indonesia Special Envoy on Climate Change

Date	:	22nd March 2018
Time	:	10.30 – 11.30
Place	:	Indonesia Special Envoy on Climate Change Office (Teuku Umar 10), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop an innovated oil palm cultivation under high water level in tropical peatland
Participants	:	Ir. Nazir Foead, M.Sc. (BRG); Prof. Ir. Rachmat Witoelar; Dr. Mitsuru Osaki (Hokkaido University); Wetadewi (JICA-BRG Project)
Key Points	:	- The tentative result should be submitted by the end of the year. - From the research it is better to have a rough calculation of the carbon emission. - Need to held a stake holders meeting with the company probably on 21st April 2018
Photos	:	

46. Meeting with GAPKI

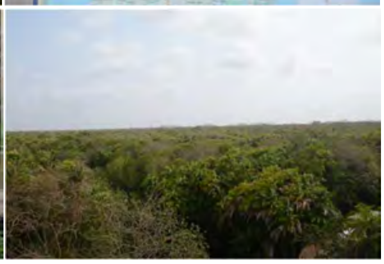
Date	:	26th March 2018
Time	:	10.00 – 11.00
Place	:	BRG Office (Teuku Umar 17), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop an innovated oil palm cultivation under high water level in tropical peatland
Participants	:	Ir. Nazir Foead, M.Sc. (BRG); Dr. Mitsuru Osaki (Hokkaido University); Rapolo Hutabarat (Musimmas); Ermin (Musimmas); Melanie Camaro (BRG); Wetadewi (JICA-BRG Project)
Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14 & #15
Photos	:	

47. Meeting with APHI

Date	:	28th March 2018
Time	:	15.30 – 17.00
Place	:	BRG Office (Teuku Umar 17), Jakarta, Indonesia
Held By	:	BRG-JICA Project
Aim	:	To develop an innovated oil palm cultivation under high water level in tropical peatland
Participants	:	Ir. Nazir Foead, M.Sc. (BRG); Dr. Mitsuru Osaki (Hokkaido University); Melanie Camaro (BRG); Wetadewi (JICA-BRG Project); Colleagues from APHI
Subject of Discussion	:	AeroHydro Culture: Innovated Oil Palm Cultivation under High Water Table in Tropical Peatland, #14 & #15
Photos	:	

48. Inspection in Peatland and Wetland in Mekong Delta of Southern Vietnam

Date	:	31st March - 8th April 2018
Place	:	Uminh Ha Park (Peatland), Vietnam
Held By	:	Ho Chi Minh National University
Aim	:	Southern Vietnam locate Mekong Delta area, covering many ecosystems such 1) Mekong River, 2) Wetland and Swamp/lake, 3) Paddy field, 4) Mangrove (Costal Ecosystem), and 5) Peatland. Mekong Delta Ecosystem is very high food productivity, however Mekong Delta Ecosystem is recently suffering by human impact (intensive land use,

	international and domestic poor water management) and by climate change impact (doughtiness/wetness by climate change, sea water affection on coastal and inland). Thus, as Mekong Delta Ecosystem issues are overlapping with issues in lowland/wetland/peatland in Indonesia, it is very important and useful to understand Mekong Delta Ecosystem Management for Responsible Management of Tropical Peatland in Indonesia.
Participants	: Professor Lê Thuyên Xuân (University of Science, Ho Chi Minh National University
Key Points	: - Peatland Management after big fire in 2002 (completely control of high water table and reforestation) - Soil subsidence monitoring by SET system (subsiding in coastal zone of Mekong Delta by wrong water management) - Biomass production program (Biomass of Mangrove and Nipa palm and Coconuts palm will contribute to protection costal, give economic benefit of products and bio-fuel) - Develop and Propose Asian Program on Costal Ecosystem Management
Subject of Discussion	: Fieldology" for Mekong Delta Sustainability, #18
Photos	:    

49. IPS Executive Board Meeting at Vilnius, Lithuania

Date	: 14-19th April 2018
Place	: Vilnius, Lithuania
Held By	: International Peatland Society
Aim	: Propose and discuss with 2nd Tropical Peatland Table in Indonesia
Participants	: Gerald Schmilewski (President), Guus van Berckel (1st Vice-President), Samu Valpola (2nd Vice President), Moritz Böcking, Donal Clarke, Erki Niitlaan, Jack Rieley, Meng Xianmin, Mitsuru Osaki, Lulie Melling, Susann Warnecke (Communications Manager, IPS)
Key Points	: - Discussing for 2nd Tropical Peatland Table in Indonesia, and agree to organize 2nd Tropical Peatland Table by IPS, JPS, Indonesia Peatland Society, BRG, and MoEF (Ministry of Environment and Forest, Indonesia) on November 2018 at Bogor. Responsible person of IPS are Jack Rieley and Mitsuru Osaki

		- (International) Tropical Peatland Center (tentative) will be establish at FORDA under MoEF (Ministry of Environment and Forest, Indonesia)
Subject of Discussion	:	EB Meeting 96, #19 Short Agenda for 2nd Tropical Peatland Roundtable, #20 Managing Peatlands to Cope with Climate Change: Indonesia's Experience, #21
Photos	: