Australian Government

Australian Centre for International Agricultural Research

Final report

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Contents

1 Acknowledgments

We acknowledge the traditional owners of the lands upon which we live and work, specifically the Dayak Peoples of Central Kalimantan and the Wurrundjeri Peoples of Naarm Melbourne.

This research would not have been possible without the support of the TERN Ozflux central node team and we acknowledge the invaluable support and advice of Peter Isaac, Cacilia Ewens and Ian McHugh.

Finally, we would like to pay a special tribute to the memory of Didie 'Gebeh'. Gebeh, pictured below, was a core member of the BOSF field team for over a decade. His kindness, generosity and good humour were legendary and having Gebeh on your team could make even the most gruelling tropical peatswamp forest field work campaign enjoyable. His lifetime of experience living and working in tropical peatlands enabled him to bring wisdom and a wealth of practical skills to the research team. He is sorely missed and his legacy lives on in his son Hendra, who has recently joined the Chameleon Flux field team.

Figure 1. In memory of Didie 'Gebeh'.

2 Executive summary

This Small Research Activity occurred within the context of the COVID-19 global pandemic. International and domestic restrictions profoundly altered the way we do field-based research and collaborate across countries. Without underplaying the personal and professional challenges of this extraordinary time, in summary this research team embraced the opportunity to empower the Indonesian researchers and technicians and creatively used remote communications technologies to deliver powerful capacity building. We are proud to have engaged in authentic shared learning with the women, men and VIPs of the Mantangai village to explore potential uses of the Chameleon soil water system in tropical peatlands, and to have successfully maintained the eddy covariance flux tower for more than three years between visits from Australian flux experts. This is a truly outstanding outcome and credit to the dedication and ingenuity of the BOSF team. This project thrived during the pandemic and this Final Report documents key outcomes and outputs. However, perhaps the most significant outcomes are the new ways of working together that we developed; a Co-Leadership Team rather than one Project Leader, technical capacity building and troubleshooting using Whatsapp and zoom, social science capacity building that has laid the foundations for five other research projects, the Partnership Health Check series and a deep and enduring trust between team members.

The proposed research was framed around three research questions focussing on water, carbon and people - communities, government and carbon trading. Evapotranspiration and carbon dioxide fluxes were quantified in a regenerating degraded tropical peatswamp forest for the first time and did not vary strongly between months or the wet and dry seasons. Soil water dynamics and methane flux measurements, in progress and planned, will enable the carbon and water dynamics of a regenerating tropical peatland ecosystem to be thoroughly understood and provide key baseline data for Indonesia's FOLU net sink ambition for peatland management. Women, men and VIPs in the local community engaged strongly with the Chameleon soil water system as conduit for environmental data that aligned with their local and traditional knowledge and lived experiences. Over a nine month series of three hands-on focus group discussion workshops, supported by the BOSF team to trial the Chameleons between workshops in chosen locations within their neighbourhoods, community members embraced this tool. They expressed enthusiasm for applying the Chameleon soil water system in their home gardens and village-adjacent farmlands, as well as to monitor fire risk in the peatland. Government stakeholders were interested in both the Chameleon soil water system and the eddy covariance flux tower as sources of environmental data to inform their decision making. While an exploration of the barriers to carbon trading was beyond the scope of this project, action in this space is progressing rapidly and continuing and expanding the carbon flux and soil water measurements will provide important baseline data sets to validate peatland restoration as a carbon sequestration mechanism.

3 Background

Peatlands are increasingly being recognized as critical carbon stores in global climate change mitigation efforts. Peatland restoration has been identified as an effective way to reduce carbon emissions and increase carbon sequestration. Indonesia, containing the majority of the world's tropical peatlands, has the opportunity to lead technical and social innovations in peatland restoration. The current drained state of much of Indonesia's peatland estate renders it susceptible to fire, and the South East Asian Haze is caused by peat soil burning. National and international efforts to restore Indonesia's vast degraded peatland estate continue to accelerate. The Indonesian Government in 2020 announced a second term for the Peatland Restoration Agency (BRG), created by President Jokowi in 2016 in response to the Paris Climate Agreement. The BRG, now including mangroves as the BRGM, leads Indonesia's peatland restoration efforts under the three pillars of Rewetting, Revegetation and Restoration of livelihoods. The three R's of Indonesian peatland restoration correspond with water, carbon and people, the three foci of this project.

This project aimed to empower communities and government to remotely and accurately monitor and evaluate peatland restoration, by integrating environmental data on peatland water and carbon fluxes with local decision-making structures. The interdisciplinary project used a combination of soil and ecological science with social science to ensure maximum benefit for communities and long-term useability.

4 Objectives

The project was framed around three research questions on water, carbon and community and based around three interconnected objectives.

Research Questions

1. Water: rewetting for restoration and fire suppression in degraded peatland
   a) How does evapotranspiration, water level and soil water content vary across space and time and are there predictive relationships between these properties?
   b) Is there a quantifiable relationship between catchment management rewetting activities and water fluxes?

2. Carbon: Tracking emissions profile of a regenerating peat forest site over time
   a) What is the potential sink for carbon and methane emissions from a degraded peat forest?
   b) How do fluxes change with large seasonal variation in soil water content and water table height?
   c) Is there a quantifiable relationship between catchment management rewetting activities and carbon fluxes?

3. Communities, governance and carbon trading
   a) How can environmental data be most usefully presented to support community and government decision making?

   b) What barriers need to be overcome to implement a process whereby local communities can be financially compensated for land stewardship that prevents carbon emissions and builds the peatland carbon sink?

Objective 1: To monitor environmental fluxes

Continue monitoring water, carbon and methane fluxes as a function of climate and hydrological conditions of a degraded peat forest using the Eddy Covariance (EC) flux tower and Chameleon sensor network installed in SLaM/2018/122

Objective 2: To engage local stakeholders

Collaborate with community and local government stakeholders to further socialise this approach, share initial data and explore uses and formats, via a series of workshops. These workshops are building on relationships developed in SLaM 2018/122. RMIT and The University of Melbourne will work closely with BOSF and UPR on participatory processes. Workshops will be held in a range of locations to accommodate stakeholder access. Gender and diversity of presenters and participants will be considered in workshop design and initiations.

Objective 3: To empower local stakeholders to remotely monitor peatland condition

Gather foundational data to co-create user-oriented decision support tools to empower communities and government to remotely monitor peatland condition

5 Methodology

Research Strategy and Partnerships

The research strategy that guided this project centred around collaboration, connectivity and creativity. The high-level plan was to bring together people with the right mix of skills, knowledge and relationships in country, in the heartland of tropical peat fires, and facilitate novel ways of working together to co-create decision support tools that government and communities want to use. The interdisciplinary project brought together biophysical science and social science to identify processes for integration of scientific data and local knowledge through land-based workshops with community stakeholders.

The Partners in this project were RMIT University (Dr Samantha Grover, Dr Sarah Treby, Charuni Jayasekara, Steve Zegelin, Gemma Horbury), Borneo Orangutan Survival Foundation (Dr Laura Graham, Thomas Andri, Nafila Izazaya, Sopa Nindya, Hevirona Bani Adam), The University of Melbourne (Dr Andrea Rawluk, Madeleine Sbeghen), Charles Darwin University (Professor Lindsay Hutley), University of Palangka Raya (Dr Zafrullah Daminik, Dr Fengky Adji), The University of Western Australia (Professor Jason Beringer) and CSIRO/Solutech (Dr Richard Stirzaker, Matthew Driver). The project operated with a Co-Leadership team structure, in which Samantha Grover, Laura Graham and Andrea Rawluk met fortnightly to jointly discuss and progress project activities; an extremely successful approach that enabled the project to navigate the challenges of the COVID-19 pandemic.

Gender focus

This project explicitly included a focus on gender, both within the project team and in our work with community stakeholders. The focus group discussion workshop series with community were held separately with three groups; women, men and VIPs. Preliminary analyses have indicated that this strategy was effective in drawing out the different lived experiences of women, men and VIPs and how they relate to fire, water and restoration in their local peatland areas. Access to both the physical landscape and technology differed between groups, with women's movements centred on the village and their access to technology more limited. In-depth analysis of these rich data sets are ongoing (University of Melbourne) and will inform SLAM/2022/104 and SSS/2022/155.

Biophysical science methods

The biophysical science methods employed in this project were developed based on two key technologies: (1) eddy covariance flux measurement; and (2) Chameleon soil water sensors.

Eddy Covariance Flux Measurement

The eddy covariance (EC) method is a micrometeorological technique that measures covariances between turbulent fluctuations of energy and gases between the surface environment and the atmosphere. It is accepted as the most direct and robust method to quantify fluxes such as ecosystem evapotranspiration and carbon dioxide exchange. The EC flux tower installed at the Mawas peatland measures carbon dioxide (CO_2), methane (CH_4), precipitation, evapotranspiration, rainfall, windspeed, and soil water content, as well as many more variables, using a solar powered data logger system. These data undergo rigorous quality control and processing steps, and are statistically analysed, with support from the OzFlux/TERN group in Australia. The humid, tropical conditions at the site create a challenging environment for complex monitoring equipment, and frequent maintenance, repair, and replacement of flux tower components has been essential for the ongoing success of biophysical research activities in this project.

Chameleon soil water system

The Chameleon sensors were developed by CSIRO to monitor soil water content in irrigated rice agricultural systems, and in this project, have been adapted for environmental monitoring of peatland hydrological condition. The original Chameleon sensors had limited lifespans in peatland soils, which are acidic and are near-constantly waterlogged. To adapt the sensors to better meet the project aims, three new casing materials were designed and tested by CSIRO for use in peatland ecosystems. Six new arrays, with one of each Chameleon casing type, have been installed at existing dip well (water table height indicator) transect sites, with three replicates at 200 m, and three replicates at 800 m, from the nearest north-south canal (Fig. 2). This pairing of equipment enables simultaneous measurement of peat moisture and water depth at these sites. The 800 m from canal transect is adjacent to the eddy covariance flux tower (Fig. 2), providing opportunity to link flux and soil hydrology data over both short- and long-term periods of interest.

An additional Chameleon array has been installed for a dissolution test study, next to the ‘soil hydrology monitoring station (see below and Fig. 2). This study enables the explicit testing of the dissolution rate of each Chameleon casing type, through monthly visual analysis, and will inform the long-term use of the Chameleons in waterlogged, acidic peatland environments.

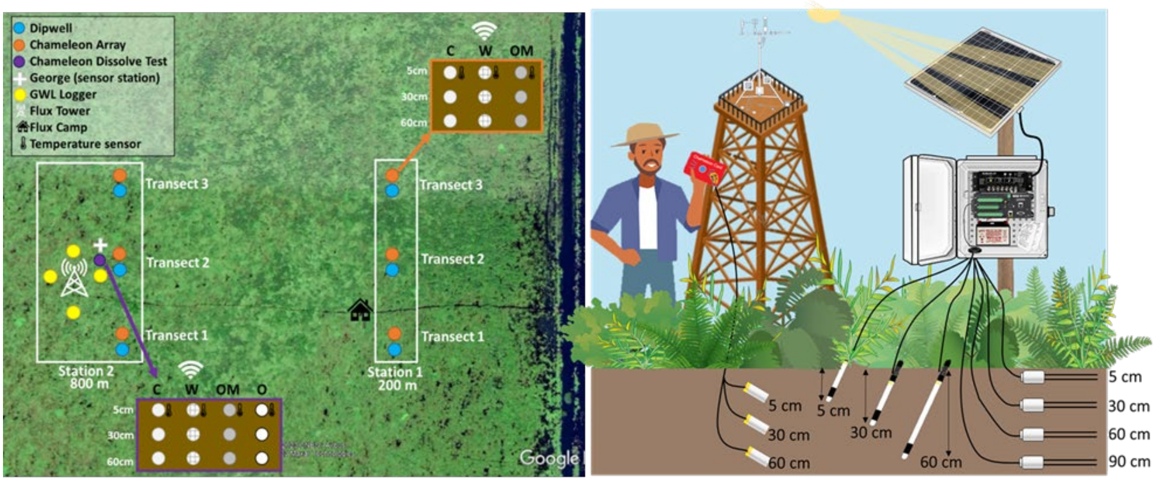

Figure 2. Left: layout of soil, water, and atmospheric monitoring equipment installed at the Mawas peatland; **Right:** Conceptual diagram showing the flux tower, Chameleon sensors and reader, and the soil hydrological monitoring station.

Expansion of soil hydrological monitoring

In 2022, four Trutrack ground water level loggers were installed around the flux tower (Fig. 1). Water table height in peatlands is a fundamental driver of carbon cycling and is closely linked with rates of CO_2 and CH_4 emission and uptake. These loggers will be used to better understand the relationships between peat hydrology and ecosystem global warming/cooling potential, to inform climate-focussed peatland restoration initiatives. A new soil hydrology monitoring system was installed adjacent to the flux tower site in 2023. This station is comprised of four soil moisture and temperature sensors, and three soil tensiometers, which measure soil water potential across the peat soil profile. All seven sensors are connected to a solar-powered datalogger, which collects and stores soil water and temperature data every 30 minutes (Fig. 2).

Together with the flux tower, dip wells, and Chameleon arrays, the new water level loggers, and the soil hydrology monitoring system, the project has established a comprehensive system of monitoring equipment to fully understand peat soil-water-atmosphere relationships to inform peatland conservation and restoration.

Social science methods

The social research part of the project utilised and adapted an Action Research methodology. This methodology shifts the dynamics of research away from outside researchers collecting data to serve external objectives and careers, to centring community members as research partners, leaders and knowledge holders. This change in dynamics enables the collection of data and development of research products that directly serve the needs of community members. This Action Research methodology directly engages across multiple worldviews and knowledges, whereas a more traditional design often does not hold space for this diversity. In the social research of Objective 2, a series of focus group discussions were utilised with different demographics of the community (women, men, and community leaders). Each group took part in a series of three focus groups that introduced the chameleons, engaged their learning sensemaking about the technology, and explored the potential application to fire, water and restoration in Mawas. Chameleon sensors were located within the community at key public locations, such as the BOSF office and the village head’s home where community members could interact with the tool. The reflective and iterative nature of the focus group discussions is critical to the Action Research design.

These focus groups were held over the course of a year in 2021-2022, approximately every three months. They enabled reflection from the previous focus group discussions and the presence and engagement with the tool in the village.

6 Achievements against activities and outputs/milestones

Objective 1: To monitor environmental fluxes

no.	activity	outputs/ milestones	completion date	comments
1.1	Set up remote communication between flux tower and cloud-based data storage	Functioning data transfer system	June 2021	A functioning data transfer system has been established. Remote communication is not possible at this time due to constraints within the Indonesian telecommunications system.
1.2	Carbon flux monitoring and analysis	Draft publication on carbon fluxes associated with peatland restoration	Estimated completion February 2024	A draft publication on carbon fluxes is in an advanced stage, led by PhD student Charuni Jayasekara. Rigorous data analysis has been supported by the Ozflux central node team.
1.3	Water flux monitoring and expansion	Expanded and validated soil moisture monitoring system, operating at representative scales in the village and forest landscapes.	Partially completed October 2023	New materials for Chameleon sensors in wet environments have been developed and deployed for testing in the field in the forest landscape. Validation and calibration against direct measures of soil water tension are also underway, with equipment installed in September 2023. Data analysis will take place within SLAM/2022/104.
1.4	Water flux analysis	Draft publication on water fluxes associated with peatland restoration	Estimated completion January 2024	A draft publication on evapotranspiration is in an advanced stage, led by Dr Sarah Treby. Rigorous data analysis has been supported by the Ozflux central node team.
1.5	Equipment maintenance and repair	Radiometer, rain gauge and methane analyser removed from tower and sent for repair	In progress	The radiometer was removed, sent for repair, returned and successfully reinstalled. The rain gauge was fixed on the tower by identification of a programming error. The methane analyser was removed from the tower and is currently with Licor in the USA for repair (November 2023).
1.6	Adapting Chameleons to tropical peat conditions	Research design and method to assess the durability of the new chameleon sensor materials	September 2023, with data analysis ongoing	The research design and method has been developed and implemented in the field. Data analysis will take place within SLAM/2022/104.

Objective 2: To engage local stakeholders

no.	activity	outputs/ milestones	completion date	comments
2.1	Wet season workshop in Mantangai village with local community	Guided by participatory action research, workshops gathered data on the knowledge, practices, and needs of community members in monitoring peatland condition.	March 2022	Workshops (Focus Group Discussion) were completed with community groups in May 2021.
2.2	Dry season field trip and workshop with local community and government	Multiple days of workshops and knowledge sharing were carried out with the community.	August 2022	Workshops (Focus Group Discussion) were completed with community groups. These enabled sharing of research iteratively back with the community groups.
2.3	Wet season workshop with local government	Knowledge sharing workshop was held with village government.	December 2022	
2.4	Social Science data analysis and community engagement	Social science data analysis are being completed. This analysis will be shared with community groups.	December 2023	A research assistant was casually appointed in 2023. The analysis has been delayed due to their availability. Two manuscripts are currently being prepared from the analysis, which will be submitted for publication in 2024.

Objective 3: To empower local stakeholders to remotely monitor peatland condition

no.	activity	outputs/ milestones	completion date	comments
3.1	Co-create the user interface for Peatland Condition Monitoring App	Design brief for user interface	Not completed	While this Objective has become out of scope for this project due to the ongoing testing, validation and calibration of the Chameleon sensor (Objective 1) and the evolution of the workshop structures and ongoing data analysis in Objective 2, this project has provided input to aligned projects funded by ACIAR and (WRI). These proposed activities have been adapted and incorporated into SLAM/2022/104.
3.2	Design the data back end to support the user interface of the Peatland Condition Monitoring App	Design brief for back-end data interface	Not completed	
3.3	Create a prototype with one data stream of the Peatland Condition Monitoring App	Prototype decision support tool Peatland Condition Monitoring App	Not completed	

7 Key results and discussion

The quantum and significance of the results generated by this project have extended well beyond the initial research questions and objectives. As a Small Research Activity, albeit with two Variations extending the total duration to three years, this project has made outstanding progress in validating technologies for monitoring carbon and water fluxes in a restoring tropical peatland and exploring the environmental data needs and aspirations of local communities to support fire management and peatland restoration. Key results pertaining to our three research questions are discussed below, noting that several publications are in progress, within which full details will be publicly available in 2024.

Research Questions

1. Water: rewetting for restoration and fire suppression in degraded peatland
   a) How does evapotranspiration, water level and soil water content vary across space and time and are there predictive relationships between these properties?
   b) Is there a quantifiable relationship between catchment management rewetting activities and water fluxes?

Evapotranspiration (ET) is a key component of peatland hydrological cycling and is often reflective of local environmental conditions. From March to November 2020 ET at the flux tower site ranged from 0.3–7.3 mm d^{-1}, averaged 4.09 ± 0.06 mm d^{-1}, and was consistent between months, despite large fluctuations in monthly precipitation (P). Total ET over the nine-month study period was 1116 mm; approximately 37% of total precipitation. Low ET/P at the site suggests that the volume of water lost through canal drainage is higher at the Mawas peatland than other tropical peat swamp forests (PSFs). Daily ET rates were comparable to previous eddy covariance studies from tropical PSFs and were mostly correlated with the same environmental drivers, i.e. primarily net radiation, and to a lesser extent, vapour pressure deficit (VPD).

Catchment management rewetting activities have begun to be implemented and the relationships, if any, between these restoration infrastructure interventions and water fluxes within the peatland will be explored in the subsequent project.

2. Carbon: Tracking emissions profile of a regenerating peat forest site over time
   a) What is the potential sink for carbon and methane emissions from a degraded peat forest?
   b) How do fluxes change with large seasonal variation in soil water content and water table height?
   c) Is there a quantifiable relationship between catchment management rewetting activities and carbon fluxes?

This project quantified CO_2 fluxes only, as the CH_4 sensor did not yield reliable results, so the findings with regards to net carbon fluxes can be considered a pilot study. The peatland was a very small net carbon source throughout the measurement period, with a mean daily average Net Ecosystem Exchange (NEE) value of +0.7 gC m^{-2} d^{-1}. The monthly NEE varied between 15 and 35 gC m^{-2} $month^{-1}$, without any significant differences between wet and dry months. The peatland emitted more carbon in the dry season than in the wet season, but the values were not statistically significantly different. The lack of response of CO_2 flux to rainfall and wet and dry seasons could be due to the consistently high soil water content of the peatland. Watertable height loggers were not installed until 2022 due to COVID-19 interruptions, so analysis of the effects, if any, of watertable height will be explored in the next project. The calculated Gross Primary Productivity (GPP) and Ecosystem Respiration (ER) values derived from measured NEE were not affected by the rainfall, but the ER values showed an increase during the 2020 dry season. Furthermore, there was not an increase in the calculated GPP with time, despite substantial observable plant growth. It may be that the CO2 emissions from the peat soil outweigh the CO2 absorption from vegetation at the current stage of restoration of this peatland.

As described above, catchment management rewetting activities begun to be implemented towards the end of this project and thus the relationships, if any, between these restoration infrastructure interventions and carbon fluxes from the peatland will be explored in the subsequent project.

3. Communities, governance and carbon trading

a) How can environmental data be most usefully presented to support community and government decision making?

b) What barriers need to be overcome to implement a process whereby local communities can be financially compensated for land stewardship that prevents carbon emissions and builds the peatland carbon sink?

The Chameleon soil water system proved to be the most engaging environmental data translation tool for community stakeholders, as it was accessible to women, men and VIPs in the community and resonated with their own local and traditional knowledge and lived experience of peatland condition. Government stakeholders were interested in both the Chameleon soil water system and the eddy covariance flux tower as sources of environmental data to support decision making. Over the duration of the project, government interest in carbon flux measurements increased substantially, as the Government of Indonesia introduced and socialised the idea of peatlands acting as a net sink for carbon, termed “FOLU net sink” - Forestry and Other Land Uses net sink.

How best to present environmental data was explored with communities and we found that, due to a lack of internet access, communities preferred that BOSF staff print out Chameleon soil water results and pin them up on the community noticeboard.

How best to present environmental data to support government decision making is ongoing work that will be further explored in the next project.

Due to the COVID-19 pandemic delays, a definitive list of the barriers that need to be overcome to implement a process whereby local communities can be financially compensated for land stewardship that prevents carbon emissions and builds the peatland carbon sink was beyond the scope of the project. This has been discussed with government stakeholders, is an area that BOSF is exploring directly with carbon investors and will be further explored in an SRA aligned with the next project.

The action-based research methodology that was adapted to the Mawas context and use with technology was very successful with the Mawas communities. This adapted social research methodology has in turn been utilised in other projects, such as one funded by the World Resources Institute (WRI) and the ACIAR Mahkota project. It has informed the methodological development of ACIAR SSS/2022/155 Co-designing peatland livelihood options for restored peatlands. The WRI project has a publication in review that engages with this adapted methodology for the development of indicators for a Peat Fire Danger Rating System in Mawas.

The Chameleons were identified by community members from all of the groups as an important tool for knowledge translation. For example, they were meaningful to the lives and activities of women, men, and community leaders. However, interestingly, the groups identified these in different ways, such as for the gardens of women and as a part of a fire danger rating system. The specific ways in which women have engaged with the Chameleon tool is the topic for a paper in preparation. Nafila Izazaya, BOSF early career female researcher, has presented the findings of the focus groups at two international conferences.

The Chameleons were explored as a boundary object for knowledge sharing that is embedded within the social and ecological dynamics of a place. These findings are the central part of a manuscript that is currently being prepared for publication.

Community members were excited to learn and be given agency in the very practical development of their own fire danger rating tool. This tool could function as a science-based indicator that can be linked to a trigger which can support funding release and for communication.

The research was guided by an ethos of decolonisation and removing a traditional helicopter science practice. Instead, the research was geared to research that served communities' needs and perspectives and involved Australian researchers supporting the capacity development of the BOSF team to co-lead the social research design and research decision-making within the project. This intentional focus was further reinforced during the COVID-19 pandemic lockdowns that prevented travel between Australia and Indonesia. Capacity building and training was held on social research design and ethics.

8 Impacts

8.1 Scientific impacts – now and in 5 years

Since 2020, continuing from the previous SRA, the team has been collecting the eddy covariance flux data in the Mawas area and has been monitoring the performance of the flux tower and equipment, by doing regular patrols in the surrounding area - checking the tower condition, daily weather, and all the equipment. The patrol is done once a day in the rainy season and twice a day in dry season, because there is greater possibility of fire occurrence around the peatland in the dry season. As the Flux sensor collects data for 24 hours, the memory card is replaced regularly once a week. The full memory card is then uploaded for the Australian team to review and is also backed up regularly by the Indonesian team. The methane sensor, net radiometer, automatic rain gauge and solar electricity system are also being maintained by conducting daily basis check-up. The quality of the data is also reviewed online by the WhatsApp group. If an unusual output occurs, all team members coordinate to review and solve the problem together.

Figure 3. Daily monitoring in the Flux Tower area; (A) Routine cleaning of Flux Tower equipment: 3D Sonic-Anemometer; (B) Smoke and fire monitoring; (C) Walkway maintenance; (D) Refilling of Accu water.

In addition to the regular maintenance, we also conducted occasional maintenance with a larger group of people involved. In October 2022, all Indonesian and Australian teams from BOSF Mawas, RMIT University, Charles Darwin University, University of Melbourne, and University of Palangka Raya together had a full-week expedition to the Mawas Flux area. On this trip, the team reviewed new tools that would be installed in the field, and installed and repaired flux tower equipment. From this trip the team successfully repaired Flux equipment, got new data and developed a standard operating procedure after installing new tools around the tower. Additionally, some of the dysfunctional or damaged equipment was removed from the top of the tower and sent to their manufacturer for the purpose of repairing, acquiring new ones, and re-calibrating, such as the Radiometer and Open-path CH_4 Analyzer.

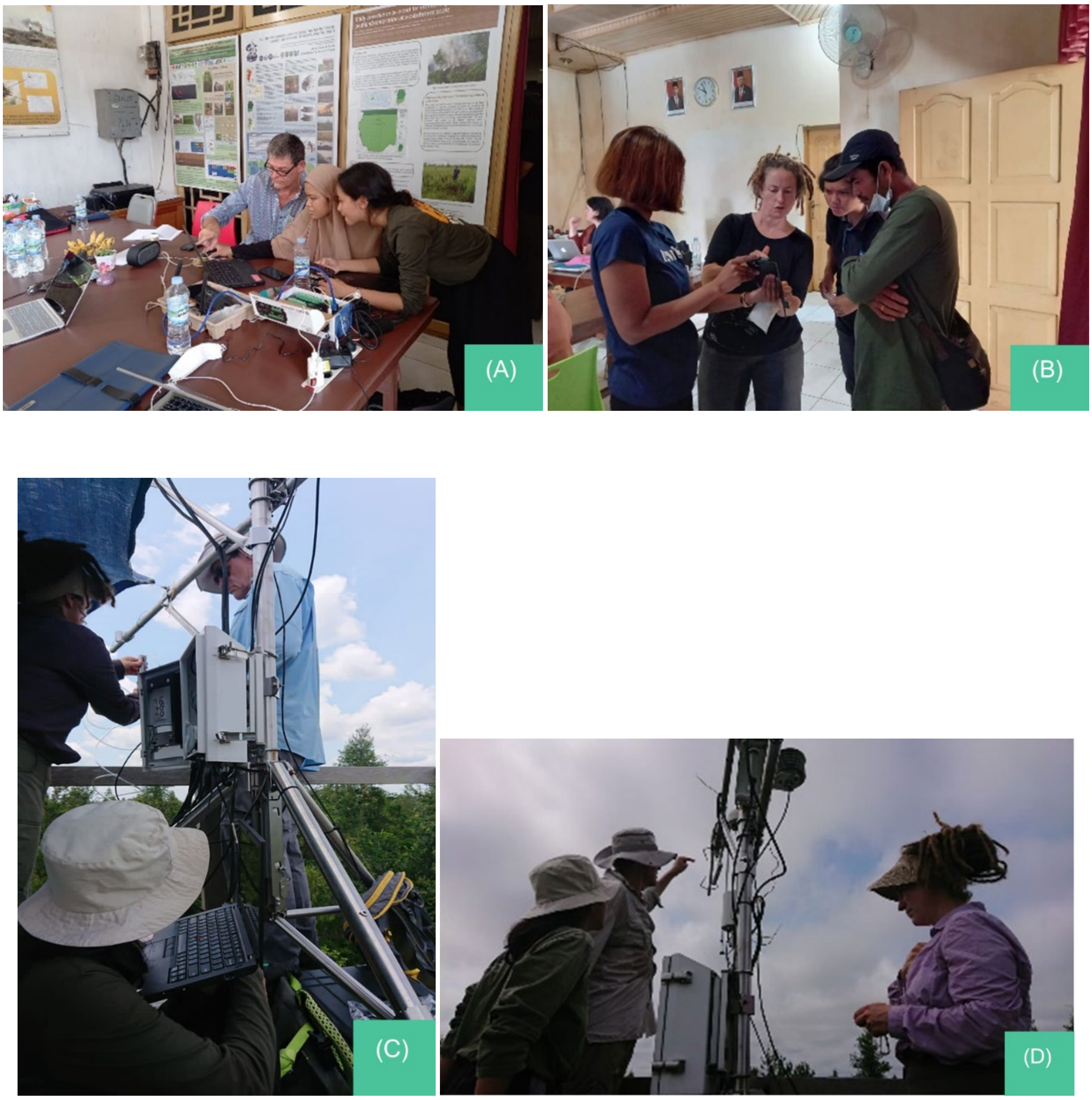

Figure 4. Equipment maintenance activities: **(A)** Checking and installing programs for the new data logger; **(B)** Discussion and preparation of maintenance requirements for Flux equipment; **(C)** and **(D)** Calibration of CO_2 and H_2O Open-path Gas Analyzer signal strengths.

Another Flux maintenance trip was conducted by smaller group also done in January 2023 and March 2023. In January, the team from BOSF Mawas and RMIT University, changed the CO_2 scrubber bottles, cleaned the windows and added wicks to the EC150 CO_2 and H_2O analyser. This improved the signal strength from 0.93 to 0.95 for CO_2 and from 0.90 to

0.92 for H_2O. There was also a discussion on the format for a logbook for routine maintenance tasks and a follow up discussion on elevating the Flux tower height to accommodate the increased canopy height, since the tower was installed in 2019. Then, in March 2023, the BOSF team began raising the height of the Flux Tower from 8 meters to 11 meters. Before increasing the tower's height, the BOSF team removed the Flux equipment from the top of the tower. Subsequently, in April 2023, the team from BOSF Mawas and RMIT University reinstalled the Flux equipment at the new height of 11 meters. In August 2023, the BOSF team repaired the automatic ground water logger that had been installed last October 2022, and corresponding with the Australian team online to solve an initial problem with data storage.

Figure 5. Equipment maintenance and reinstallation activities: **(A)** Checking the strength of CO_2 and H_2O signals and replacing CO_2 scrubber bottles; **(B)** Raising the height of the Flux Tower; **(C)** Reinstallation of Flux equipment; **(D)** Repairing the automatic ground water logger.

Action Research was conducted with the local community surrounding the Mawas peat dome, facilitated by the BOSF team. The local community actively monitored the peatland with the Chameleon tools and reflected on it with their traditional experience and practice, by participating in three consecutive focus group discussions. The themes of these discussions were fire, water, and restoration. This study shows how society perceives the chameleon tools as a method of detecting the condition of peat moisture, which they consider the most important factor to indicate the potential peat fire risk in their area, hence they reflected and thought about the possible locations to use the Chameleon as a tool to assist with restoring the peatland.

The study also yielded many insights to improve the Chameleon equipment, in order to be more suitable for use in peatland areas. One such reason to optimise the equipment is that peatland is known for its acidic and mostly water-logged soil, hence it can make the initial sensor that was installed in the peat prone to dissolve faster, compared to its original use in dryland mineral soil. The sensor is now being tested with several new casing materials to compare durability within peat soil. All the studies are ongoing, with data analysis in progress and plans for a scientific publication.

Figure 6. Focus Group Discussion (FGD) activities: **(A)** and **(B)** Discussion session during FGD; **(C)** FGDs participants; **(D)** Local villager uploading Chameleon data.

We also have produced another interesting output by exploring the peatland restoration by collaborating between art and science. Gemma Horbury is a researcher and practitioner who works across music, sound, video and environmental installations. During the group visit to do equipment maintenance in October 2022, she joined the trip and was exploring the ambience of Mawas tropical peatland into sound packaged in audio-visual form that reflected the Flux equipment, activities, and environment. This Science Art Collaboration is detailed in the 2022 Annual Report.

8.2 Capacity impacts – now and in 5 years

Mawas peat dome is one of the first areas in Indonesia to have an Eddy covariance flux tower installed to monitor the restoration of a degraded tropical peatland as restoration infrastructure is implemented within the catchment. Even though this project began amid the surge of the global pandemic, and with many challenges to implementing the research with the massive and complex eddy covariance flux and chameleon equipment across two countries, the Indonesian and Australian team have successfully co-ordinated solid teamwork for four years. This new collaboration increases the competence for both sides in hard and soft skills.

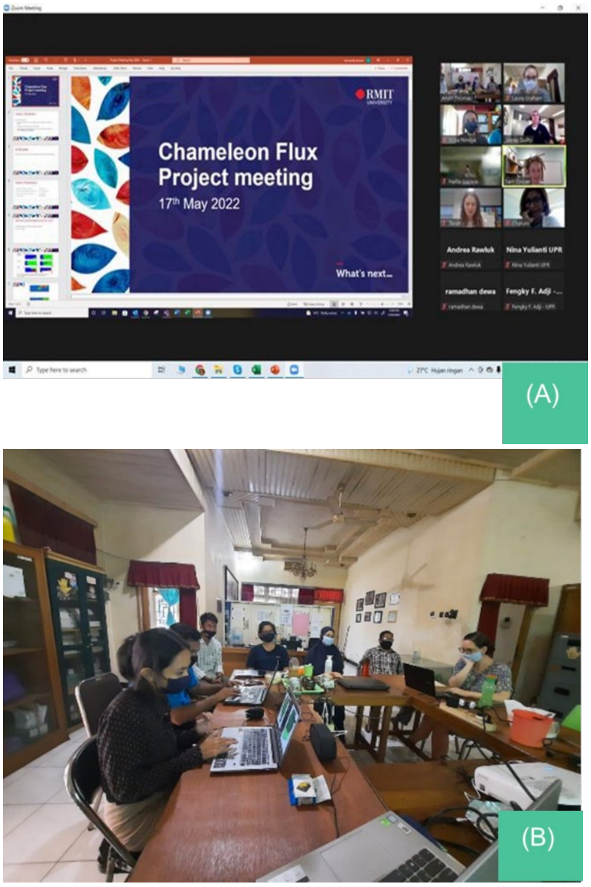

Figure 7. Online coordination between the Indonesian team and the Australian team: **(A)** Coordination meeting opening led by Samantha Grover; **(B)** The Indonesian team during the meeting.

The transfer of knowledge from the Australian team has advanced the Indonesian team's ability to operate the equipment. Hence, the Indonesian team has been actively involved in the daily operational activities of the Flux equipment and gradually more involved in the technical operation. There was one international technical Flux workshop in Australia this year, the participants came from Australia, Africa and Indonesia. Sopa Nindia, as Indonesia's representative joined the workshop virtually to learn more about Eddy Covariance, such as operating the software and how to interpret the data (i.e., CH_4, CO_2 flux, solar radiation, and precipitation data). Furthermore, the opportunity to use the eddy covariance equipment assisted the local community with a more scientific point of view, that joined the team to monitor their peatland in addition to using their local knowledge.

Figure 8. Participants of the Flux technical workshop.

It's not just the Indonesia team that gained more knowledge on this project. Many of the Australian team members had the opportunity to visit Indonesia for the first time, particularly Central Kalimantan, some of whom had never experienced tropical peatland. This project provided a great opportunity for the Australian team to learn more about the ecology of Central Kalimantan peatland. Moreover, by the abundance of local wisdom that was shared by local Dayak staff, many insights were received which gave them a more comprehensive and intuitive familiarity on learnings from the tropical peatland.

The interdisciplinary nature of this project has allowed the team who had already established bio-physical ecological research in this area to also start to learn more about the social-ecological aspects. Since the Action Research began in 2021, the team has become more capable handling the social aspects associated with conducting research. Not only with regards to research, but also on how to coordinate with the local government and collaboration with the local community more deeply.

The data workshop conducted in Palangka Raya from July 31st to August 1st, 2023, marked a pivotal step in the collaborative efforts between the Indonesian and Australian teams involved in the Chameleon Flux Project. This workshop saw the active participation of teams from Palangka Raya alongside various field teams responsible for processing crucial field data. Its primary objective was to enhance the structured distribution of roles and streamline the processes of data input, collection, and verification. The overarching goal was to optimize these procedures to better align with the project's objectives.

Figure 9. Data management workshop; (A) and (B) Team discussion sessions related to data processing.

Due to numerous collaborations between Indonesian and Australian teams, the Partnership Health Check brought together team members from the BOSF field team in Mantangai, the University of Palangkaraya, the BOSF team in Palagkaraya, and Charles Darwin University, RMIT University and the University of Melbourne. The multi-cultural team had strengths in three different languages: Dayak Ngaju, Bahasa Indonesia, and English. As such, we conducted the Partnership Health Check workshop in three languages, working in small groups and then reporting back to the whole group. This activity was held in October 2022 at the Fovere Hotel in Kapuas. The primary objective was to evaluate and strength the relationships of the partnership and create a space where the teams could exchange ideas and recommendations for upcoming project activities.

Figure 10. Partnership Health Check; **(A)** Discussion session; **(B)** Indonesian and Australian teams.

8.3 Community impacts – now and in 5 years

The project has involved the communities surrounding Mantangai and provided various positive impacts. As we employ many local community members in this project, the research activities increase their knowledge of local restoration efforts. Moreover, it increases their awareness of protecting the peatland by widening the restoration perspective with the scientific aspect. Nowadays, the global restoration research community emphasises how important the role and continuous active involvement of local communities is in restoration efforts. We embrace the local knowledge and simultaneously continue to link the local community with global perspective.

Figure 11. Research involving the local communities; **(A)** Socialization and training on the usage of Chameleon within the Mantangai community; **(B)** Focus Group Discussion with the theme of 'Restoration'.

8.3.1 Economic impacts

By hiring the local staff, the research activities also provides alternative livelihood opportunities. Current local livelihood activities are dominated by mining, fishing, and accessing the forest for non-timber and timber products, some of which can lead to more peatland degradation. Involving the community in peat research activities provides more opportunities for the local community to choose a sustainable livelihood option.

Indonesia has officially introduced a carbon trading mechanism, which is in preparation to be fully operational in 2025. This announcement creates opportunities but also challenges for communities of the Mawas peat dome, as a large terrestrial carbon stock area, in which many stakeholders have interests. This project has contributed to creating the scientific basis in this area to prepare for future carbon market activity.

8.3.2 Social impacts

Peatland restoration research activities are sometimes being misinterpreted as focussing exclusively on bio-physical parameters, but exposing the community to scientific data by involving them in the research is empowering them to protect their peatland. This project does not make the local community an object of the research, but rather an active partner and agent of change in the restoration activity. The community had great enthusiasm and hope when they were introduced with to equipment, especially the Chameleon, as tools for monitoring their peatland.

Action research has been one of opportunities for the local community to contribute and collaborate on peatland restoration. It’s involved not only the local peatland monitoring frontliners but also local residents whose livelihoods depend on the surrounding peatland. Moreover, it has involved the women’s community group, who are usually barely involved in peatland restoration activities. The women’s involvement has provided new perspectives and inspired follow up with future studies, as women’s role in and knowledge of the peatlands is more appreciated.

8.3.3 Environmental impacts

In addition to monitoring the peatland with eddy covariance, we also recorded the vegetation cover surrounding the flux tower by taking monthly photos of the north, east, south, and west side of flux tower area. The photo compilation shows the increasing height of the tree canopy surrounding the area. This is a good sign of how the peat land is regenerating, with various integrating efforts made by many stakeholders. The immediate implication of this phenomenon was that the height of the flux tower had to be increased, because in order to measure the carbon and water flux, the equipment should sit above the highest point in the tree canopy. We increased the tower from 8 m to 12 m in height. Furthermore, the denser vegetation cover in the peatland is a positive indicator of the restoration progress.

Figure 12. Comparison of tree canopy height around the Flux tower area; **(A)** Tree canopy height in 2020; **(B)** Tree canopy height in 2023.

In the Objective 2 Action Research study, the community gave feedback on how the tools can help the community in monitoring the peatland. The main function of the Chameleon sensor is to measure the soil moisture surrounding the installation. The community felt it helped them monitor the water table surrounding their peatland, especially during the dry season in 2023. The trial was conducted during that year, and one remark on using this new sensor is the community would like ongoing assistance from the team to use the sensors.

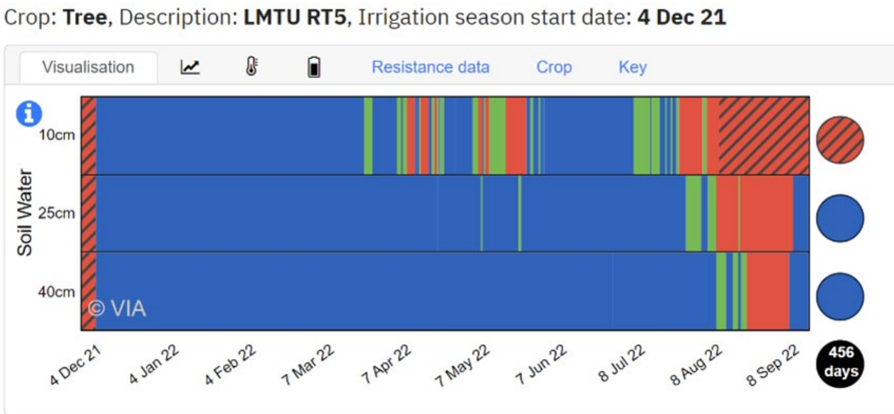

Figure 13. Data Recording of Chameleon in the Mantangai village during the wet season (mostly blue data) and dry season (with some green and then increasing red data).

8.4 Communication and dissemination activities

We are aware that it is important to maintain relationships with various stakeholders that are involved in this project. Hence, since the beginning of the project establishment, we regularly meet with several key stakeholders, such as various Indonesian government agencies, to discuss the project and hence get useful insight on its development. We also disseminated our initial output by participating in several scientific events.

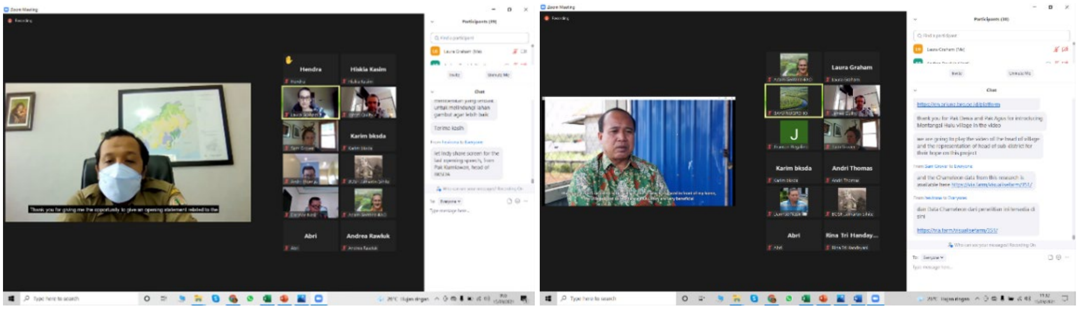

Figure 14. Flux Virtual Field Trip event, the opening speech from Head of BKSDA (left) and the video of Flux Virtual Field Trip when Head of Mantangai Village gave opinion on his impression about Flux tower (right).

On September 2021, we held a virtual event to show progress on establishing the flux tower in Mawas area called ‘Flux Virtual Field Trip (VFT)’. Even amidst the limitations of the pandemic, this event invited wide-ranging Indonesian stakeholders such as Central Kalimantan Natural Resource Conservation Agency (BKSDA Kalimantan Tengah), Provincial and District Environmental Agency (DLH Kalimantan Tengah dan Kapuas), Kapuas Regional Development Agency (BAPPEDA Kapuas), Mantangai Sub-district agency (Kecamatan Mantangai), Sub-district Military Agency (Koramil Mantangai), Head of Mantangai Hulu Village (Kepala Desa Mangtangai Hulu), Kapuas Forest Management Unit (KPHL Kapuas), and BOSF HQ in Bogor. This event was an early opportunity for the team and government institutions to forge and maintain a relationship for further collaboration. This event played a series of short films that were made in April 2021 as a virtual trip to go around the flux site and up the tower to see the development of the research. One discussion session was opened and all the participants showed interest in the progress and many are hoping for the further collaboration with this project.

This project started by building an 8 m tower for the flux equipment and a small camp nearby the tower as a shelter for the team who were conducting the daily monitoring and maintenance. Over the course of the project, we gradually built the infrastructure to ease the access for the daily research and maintenance activities at the site while at the same time doing constructive revision of procedures. In the beginning, the team was only able to access the site by walking through knee-deep mud, and stumbling over logs and roots to the camp site and tower, that were located 350 m and 800 m, respectively, from the nearest canal. After roughly one year walking back and forth to conduct research activities, we built a walkway to access the camp and tower from the nearest canal. It cuts the time to walk between the nearest canal, camp, and tower and makes the research activities far more efficient.

The Flux walkway was installed with permission from the BKSDA Kalteng, hence after finishing the establishment, we invited Nur Kurniawan head of BKSDA Kalteng, Jamartin Sihite as CEO of BOSF, Denny Kurniawan as Program Manager of BOSF Nyaru Menteng to conduct a “Flux Walkway Opening Ceremony”, hosted by Jhanson Regalino, Program Manager and Laura Graham, Environmental Monitoring Project Leader of BOSF Mawas Program. Once the Flux site became more accessible with the walkway, we also hosted some visits from some national and international colleagues to show our research activities and to discuss further opportunities. The walkway also assisted the expansion of the Flux camp site, hence it can facilitate more research activity via its new small field laboratory.

In 2023, we started to do regular meetings with local governmental institutions to disseminate our progress in this research project, along with other environmental activities conducted by BOSF in the Mawas area. This activity is called Stakeholder Engagement Networking (SEN). In this opportunity, we are not only updating stakeholders on the current projects but also exploring with them the potential new research activities. This event is useful to keep the collaboration between regional, national, and international NGO, academic and governmental institutions on track and well-delivered.

Figure 15. World Ecological Restoration Conference by Society for Ecological Restoration: **(A)** BOSF team as part of this project presented the Flux VFT event in SER 2021; **(B)** novel technology with Chameleon sensor with local community in SER 2023; **(C)** The poster featuring the Chameleon Soil Moisture Sensor at SER Conference 2021.

We participated in the World Ecological Restoration Conference by the Society for Ecological Restoration (SER) in 2021 and 2023. The SER event in 2021 was held virtually. We presented the Flux Virtual Field Trip video, showing to SER delegates our efforts in tropical peatland restoration research by implementing novel technologies of eddy covariance and Chameleon sensors. We also joined the poster session to present our ongoing efforts using the Chameleon soil water system in degraded and restored areas and that we planned to continue to use Chameleons with the community in Mantangai Hulu village area. This was when the Action Research approach began to be conducted.

At SER 2023, we participated in a virtual oral presentation session to present the outcome of our Action Research study using the Chameleon Sensor with the community to empower them to interpret the fire risk surrounding their peatland area. The presentation was online and the main theme of the event was to promote the role of traditional communities in the global restoration effort.

We also presented this research at online and in person TERN Ozflux conferences

Samantha Grover, Amanda Sinclair, Steve Zeglin, Lindsay Hutley, Jason Beringer, Laura Graham, Tomas Andri, Ramandan, Zafrullah Daminik, Nina Yulianti, Fengky Adji, Eddy Covariance as a tool for monitoring tropical peatland restoration, oral presentation Ozlfux conference, Brisbane 2019

Samantha Grover, Sarah Treby, Dilani Gunawardhana, Charuni Jayasekara, Steve Zegelin, Peter Isaac, Ewen Silvester, Laura Graham, Nafila Izazaya, Thomas Andri, Lindsay Hutley, Jason Beringer, A tale of two peatlands: EC and ER (Ecosystem Restoration), oral presentation, Ozflux conference 2021 online

Sarah Treby, Samantha Grover, Laura Graham, Linsday Hutley, Jason Beringer, Charuni Jayasekara, Nafila Izazaya, and Sopa Nindya. Evapotranspiration from a Drained Tropical Peat Swamp Forest. Oral presentation, OzFlux Annual Conference, 2022, Cairns.

9 Conclusions and recommendations

9.1 Conclusions

In conclusion, we found that the evapotranspiration water fluxes of the peatland vary little over an annual cycle and that, in these early stages of restoration within the catchment, an impact of the restoration infrastructure on evapotranspiration water fluxes has not been measurable. Further research on soil water fluxes is required to gain a more nuanced understanding at a range of scales of how restoration impacts the water dynamics of peatlands. Similarly, fluxes of carbon dioxide did not show a strong seasonal pattern or relationship with intrinsic or extrinsic drivers. The initial two years of QA/QC'd and processed data suggests that the peatland is a small net carbon source, with soil respiration from the peat outweighing photosynthetic carbon uptake from the strong vegetation recovery that has occurred at the site. This Small Research Activity enables us to conclude that the Chameleon soil water system is a useful tool to support community monitoring of, and decision making about, the Mawas peatland. The Government of Indonesia's ambition for peatlands to contribute to a national FOLU net sink has roused strong interest in the carbon flux data from the eddy covariance system. Despite the challenges of the COVID-19 global pandemic, this Small Research Activity has laid strong foundations in infrastructure, capacity and stakeholder interest to utilise these environmental monitoring tools to support government and communities to sustainably manage restoring peatlands.

9.2 Recommendations

Recommendations from this Small Reseach Activity are:

1. To extend the carbon and water flux monitoring to the adjacent Mawas peatland tropical peatswamp forest, in order to have a point of comparison for monitoring and assessing the success of peatland restoration interventions and to support the Government of Indonesia's ambition for peatlands to contribute to a national FOLU net sink.

2. To implement the suggestions of the Mawas community to apply the Chameleon soil water system to explore soil-plant interactions in their home gardens/village adjacent farmlands and to monitor fire risk in the locations they chose in nearby peatland, as well as expanding this work with the Chameleon soil water system to additional communities

3. To increase the height of the eddy covariance flux system by installing a metal tower and to add a methane sensor suitable to the tropical conditions, in order to enable continued monitoring of the carbon and water fluxes of the recovering vegetation as the Mawas peatland is restored.

10 References

10.1 References cited in report

10.2 List of publications produced by project

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Treby, S., Jayasekara, C., Izazaya Idrus, N., Nindia Ati Ningsih, S., Graham., L. L. B., Hutley, L. B., Beringer., J., Grover., S. *In preparation.* Evapotranspiration from a drained tropical peatland undergoing active restoration. Agricultural and Forest Meteorology

Samantha P. Grover, Nafila Izazaya, Sopa Nindya, Hevirona Bani Adam, Laura Graham, Sarah Treby, Matt Driver, Richard Stirzaker, Tessa Toumbourou, Madeleine Sbeghen, Andrea Rawluk. *In preparation.* Exploring soil moisture sensors for women's involvement in livelihoods and tropical peatland restoration: preliminary reflections from a pilot project. Mires and Peat

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11 Appendixes

11.1 Appendix 1: SOPs

Standard Operating Procedure documents that have been developed in this project are:

1. Indy, Aldina & Sarah: Chameleon & George Installation and Experimental Design v3 (2023)
2. Yunnita, Sarah, Indy & Laura: TruTrack Water Table Height Loggers v2 (2022)
3. Sarah: Draft Flux Tower Equipment Maintenance Schedule v1 (2023)
4. Laura & Sarah: Guidelines & regulations for shipment and visas (Australia-Indonesia) (2023).