Development of forest biodiversity Indicators for a participatory forest biodiversity monitoring system in South Sumatra

A methodological guideline

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The BiCaMSu project team ….

About this document

This methodological guidance is one of the results of the collaborative work between University of Hamburg, Hamburg, Germany; the University of Srivijaya, Palembang, Indonesia; and the GIZ Biodiversity and Climate Change Project (BIOCLIME) within the "Biodiversity and Carbon Monitoring Project in South Sumatra" (BiCaMSu). The BiCaMSu project was funded by the German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) through the GIZ BioClime project.

The aim of the BIOCLIME project is to "preserve biodiversity and the carbon sequestration capacity of the selected forest ecosystems of South Sumatra as a contribution to the implementation of Indonesia's emission reductions target". The project contributes to the implementation of Indonesia's Biodiversity Strategy and Action Plan (IBSAP)[1]. One of the main objectives of the BiCaMSu project is to design a Participatory Forest Biodiversity Monitoring System (PFBMS) at Forest Management Unit (FMU) level in South Sumatra. The PFBMS should assist stakeholders to develop and select highly rewarding/ high-performance criteria and indicators (C&I), and to develop a system to monitor C&I integrating the system into a FMU Forest Management Plan (FMP). The system is a vital component of the FMU FMP within a broader framework of adaptive and responsible forest management. This document provides guidance on how such a system might be put in place.

This report follows the guideline "How to setup a Biodiversity Information System (BIS) for South Sumatra" prepared by the BiCaMSu team .

Chapter 1 of this guideline provides a brief overview of forest and biodiversity status and signifies the importance of biodiversity monitoring. We also outline the initiatives and challenges on biodiversity monitoring with particularly focus on developing indicators. Chapter 2 outlines the importance of selecting the context based approach for biodiversity monitoring. It gives an overview of hierarchical characterization approach of biodiversity monitoring. Chapter further discusses on the detail process of selecting highly rewarding and high performance indicators that are useful for Sumatra Province level and the forest management unit level forest biodiversity monitoring. Chapter 3 presents the results of extensive literature review and the final outcomes of the two – days expert level workshop held in Palembang, Indonesia. Chapter 4 synthesis the workshop outcome with the literatures and discuss on the application of selected indicators on establishing a participatory forest biodiversity monitoring system at forest management unit level.

Criteria and indicators are being promoted internationally as a basis of local stakeholder self-monitoring. As a consequence, indicator development has been one of the most popular research topics in natural resource management and conservation (Noss, 1999). Although the overall sustainability of a nation's forests depends substantially on actions taken at the national scale, in principle, the national-level analysis of indicators may involve the aggregation of data collected at the FMU scale. Therefore, analysis of indicators at the FMU scale is the key to assessing, monitoring and reporting on SFM (ITTO, 2016). Thus, a

[1] http://www.bioclime.org/index.php/en/

monitoring tool, that allows the FMU and local stakeholders to track the progress towards the goal of sustainability, is essential. This guideline provides a conceptual framework to develop rewarding and high-performance indicators and to establish a PFBMS at the FMUL level. Moreover, the selection of forest biodiversity indicators and forest biodiversity monitoring approaches are determined by numerous factors. The PFBMS, as a tool for responsible/ adaptive forest management, should be always flexible and adaptive.

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Acronyms

ATO	African Timber Organization
BiCaMSu	Biodiversity and Carbon Monitoring Project in South Sumatra
BIOCLIME	Biodiversity and Climate Change Project
BMUB	German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
C&I	Criteria and Indicators
CBD	Convention on Biological Diversity
CHM	Clearing House Mechanism of the CBD
CIFOR	Center for International Forestry Research
COP	Conference of the Parties
FAO	Food and Agriculture Organization of United Nations
FMP	Forest Management Plan
FMU	Forest Management Unit
IBSAP	Indonesia's Biodiversity Strategy and Action Plan
ITTO	International Tropical Timber Organization
MCPFE	Ministerial Conference on the Protection of Forests in Europe
NTFP	Non-timber Forest Products
PFBMS	Participatory Forest Biodiversity Monitoring System
SFM	Sustainable Forest Management
UNCED	United Nations Conference on Environment and Development

1. Introduction

Globally around 3.3 million hectare of forest area is lost every year (FAO, 2016). The clearing of land for agriculture, commercial wood extraction, increased mining, infrastructure development and the urban expansion are the major driving factor for such forest deforestation and degradation (FAO, 2016; Geist and Lambin, 2002). Tropics were the only climate domain, which showed an estimated increase in forest loss by 2101 km^2 annually during the period of 2000 to 2012 (Hansen *et al.*, 2013), while the forest rate was decreased globally from 160,000 km^2 per year to 130,000km^2 per year (FAO, 2012). Of all countries globally, Brazil showed the largest decline in annual forest loss with over 40,000 km^2 per year in 2003 to 2004 and less than 20,000 km^2 per year in 2010 to 2011. This reduction in deforestation was offset by increasing forest loss in Indonesia. Indonesia exhibited the largest increase in forest loss (1021 km^2 /year) with over 20,000 km^2 per year in 2011 to 2012, which was double of that occurred between year 2000 to 2003 (less than 10,000 km^2 forest loss per year) (Hansen *et al.*, 2013).

Similar estimates have been observed using remote sensing studies with 0.7 million ha and 0.9 million ha annual change in "forest cover" for the periods 2000–2005 and 2000–2010, respectively (Miettinen *et al.*, 2011; Hansen *et al.*, 2013; Stibig *et al.*, 2014). Annual carbon emissions from gross tropical deforestation are estimated at 2.270 Gt CO_2 from 2001–2013 (Vijay *et al.*, 2016), contributing nearly 10% of the global total of anthropogenic greenhouse gas emissions. Indonesia is the world's second-largest emitter of carbon from gross deforestation, peaking in 2012 at 0.362 Gt CO_2 per year before declining to 0.205 Gt CO_2 per year in 2013.

The rapidly expanding pulp and palm oil production, have led to the most speeded deforestation than any other factors (Zarin *et al.*, 2016). Countries such as Brazil, Indonesia, and Chile have become global players in the world's pulp market by making the most of a strategic advantage—climates conducive to fast growth rates (Abramovitz and Mattoon, 2000). Recently there have been remarkable shift of pulp production from traditional suppliers in the North to new producers in the South. And the shift has raised concern particularly for Southeast Asia. Palm oil was the highest exported commodity for 2011 in Indonesia, accounting for the 18.97 % of the total export and the tragedy is the trend of export is increasing. Indonesia and Malaysia contributed 53% and 34% of the global palm-oil production respectively in 2013 (FAO, 2015; Gaveau *et al.*, 2016). Between 1982 to 2007, in Riau region alone, these two industries replace ca. 2 million hectares of natural forest (Uryu *et al.*, 2008). Between 2000 and 2012, Indonesia alone lost 6 million ha of old-growth and selectively logged natural forests, and surpassed Brazil in the rate of its forest loss in 2012 (Margono *et al.*, 2014; Gaveau *et al.*, 2016).

Plantation expansion and the timber industry have been heavily subsidized by the Indonesian government for years (Zarin *et al.*, 2016). Pulp production has more than quadrupled in the last decade with more than 1.4 million hectares of natural forest been replaced by plantations. The predominant forestry plantation activity in Indonesia is the industrial plantation of acacia species (*Acacia mangium* and *Acacia crassicarpa*) and eucalypts (*Eucalyptus pellita*), primarily for pulpwood plantation with short rotation of 6-7 years (Verchot *et al.*, 2010). The replacement of natural forests either with monoculture palm plantations or with the acacia or eucalypts reduces overall plant diversity and eliminates many animal species that depend on natural forests (Fitzherbert *et al.*, 2008; Vijay *et al.*, 2016). A third of the mangrove cover is gone from Indonesian coasts due to logging and shrimp farming. In addition to the environmental impacts, pulpwood plantations have also had adverse effects on local people. Even plantations programs have displaced indigenous Dayak communities (Abramovitz and Mattoon, 2000).

Archipelagic geography, geographic location and tropical climatic condition of Indonesia have supported the world's second highest level of biodiversity. Its flora and fauna is a mixture of Asian and Australasian species, which is the result of Indonesia's geographic location as meeting point of Asia and the Australian continent. It hosts some of the most bio-diverse ecosystems on earth and unique species such as the critically endangered Sumatran tigers and endangered Sumatran elephants (Uryu *et al.*, 2008).

However, this rapid conversion of forest has resulted in a tremendous effect on the biodiversity contributing to the decline and extinction of biodiversity worldwide. Eisner *et al.* (2016), noted that the areas with the highest rates of increased deforestation are broadly located together with the areas with highest biodiversity threat. The accelerated deforestation together with high biodiversity endemism richness, makes Indonesia the country of the greatest increased threat to biodiversity (Eisner *et al.*, 2016). Coupled with this habitat change, rapid climate change has placed biodiversity under unprecedented pressures. On the one hand, increased deforestation and tree decline have a direct impact on climate change by increasing the overall carbon emission and exacerbating anthropogenic climate change (IPCC, 2007), on the other hand pronounced and rapid climate change has a profound impact on the biodiversity, including change in current distribution of many tree species (Kremer *et al.*, 2014), which may lead to a cycle of tree decline (Sabaté *et al.*, 2002; Bréda *et al.*, 2006).

1.1 Biodiversity monitoring- context, definition and objectives

Following the United Nations Conference on Environment and Development (UNCED) in 1992, forest protection and the sustainable management of forests have received considerable international efforts. In the UNCED the Convention on Biological Diversity (CBD) was signed, as an acknowledgement of biodiversity conservation need. Despite the mounting efforts toward sustainable forest management and biodiversity conservation, the widespread loss of biodiversity continues.

Even the retention or the management of the degraded forests, agro forests, logged forests and the plantation or the secondary forests can ensure the persistence of many flora and fauna species in the managed forests (Chazdon, 2008; Scales and Marsden, 2008). In addition to providing habitat, such ecosystem also contribute significantly to livelihoods of the locals by providing forest products and also support the conservation efforts by providing landscape connectivity to connect forest remnants and buffer reserves (Gardner, 2010). The conventional conservative definition didn't recognize the importance of the other significant values of the forest ecosystem such as its biological diversity, ecological and social values.

Identifying ways to conserve the forest biodiversity in different types of forest use and management and to inform more sustainable management regimes has been major research priority in recent years (Gardner, 2010). If forests loss exceeds plantations, then the focus should be on stopping deforestation. Alternatively, if the management of the plantations can be adapted so that they support a substantial proportion of forest species while maintaining high yields, conservation effort should focus on ways to enhance biodiversity in plantations (Green *et al.*, 2005; Fitzherbert *et al.*, 2008).

The biodiversity conservation is one of the goals of ecologically sustainable forestry, although the concept encompasses much more than biodiversity conservation alone. Biodiversity includes life in its all forms, from the level of gene, to species, to complete ecosystem, including all processes of the ecosystem that maintain these various levels (Noss and Cooperrider, 1994; Hunter, 1996). Given this complexity, it is difficult to judge whether forests/ecosystem are being managed in an ecologically responsible way. Generally we lack understanding about whether the current management plans and processes met the long-term goal of biodiversity conservation.

Biodiversity monitoring is a process of assessment of existing status and change in the condition of biodiversity, as measured against a set of criteria and indicators (ANSAB, 2010). The process determines the status and trends of biological diversity executing repeated measurement under continuous observation. Biodiversity monitoring mostly relies on qualitative and quantitative indicators.

Biodiversity monitoring is an obligatory component in the Convention on Biological Diversity (CBD), which obliges each contracting party, *'as far as possible and as appropriate'*, to *'identify components of biological diversity important for its conservation and sustainable use* ..., to *'monitor, through sampling and other techniques, the components of biological diversity identified'* ..., and to *'identify processes and categories of activities which have or are likely to have significant adverse impacts on the conservation and sustainable* *use of biological diversity, and monitor their effects through sampling and other techniques'* (Art. 7, p.5) (United Nations Convention on Biological Diversity, 1992; Secretariat of the Convention on Biological Diversity, 2005). Indonesia signed the CBD in 1992 and ratified it two years later in 1994.

In order to respond to the information need for conservation purpose and to develop ecologically responsible management strategies that enhance opportunities for conservation, biodiversity monitoring program plays vital role. The general objectives of biodiversity monitoring are to;

- promote sustainable forest/biodiversity management by providing tools, methods and techniques needed to generate monitoring data;
- assess the impacts of forest management activities on biodiversity and health of forest ecosystem; and
- support the development of baseline measurement of biodiversity from which changes to the resource base can be monitored.

1.2 Initiatives and challenges on developing biodiversity indicators

Biodiversity is too broad concept to measure in it's entirely. In most forests there are thousands of flora and fauna species and countless possible species interactions hence making it impossible to measure them completely. In nature, no two forest system are identical, each one are unique in its components and the processes. Hence in order to measure them, need arises to redefine the biodiversity in terms of measureable attributes relevant to the scale and purpose for which it is to be assessed (Sarkar and Margules, 2002; Williams, 2004; McElhinny *et al.*, 2005). Indicators are usually measurable surrogates that allow isolation of the key aspects of a system from an overwhelming array of signals to describe and monitor biodiversity. Different criteria and the indicators (C&I) can be selected differently for different goal. For instance if goal is species conservation, focus will be on rare and threatened species and often consider the most common species even in the derogatory stage, of little interest. C&I is a powerful tool for monitoring, assessing and reporting on changes in forest conditions and biodiversity.

Though the concept and development of biodiversity indicator is not new, it has gained momentum quite recently. More than two decades before Noss (1990), had developed biodiversity indicator matrix, which can be regarded as an instrument in this change. However, only after the Rio Earth Submit in 1992, rapid international and regional initiatives in C&I processes took place. Subsequently, C&I mechanism emerged as a key mechanism to monitor principles of sustainability in terms of measurable goals (Wijewardana, 2008). The popularity of the C&I is reflected in participation of 150 countries, containing 97.5% of the world's forest area, in one of the nine major ongoing international and regional C&I initiatives and processes (Wijewardana, 2008). These nine major C&I international initiatives includes: i) ITTO process, ii)

The Pan-European Process (1993) (Helsinki process, MCPFP), iii) the ATO Process (the African Timber Organization (ATO) initiative, 2003), iv) the Montreal Process (1995), v) the Amazon Cooperation Treaty (Tarapoto Agreement, 1995); vi) Dry Zone Africa (1995), vii) the Near East Process (1996), viii) the Lepaterique Process for Central America (1999), and ix) the Bhopal–India Process (1999).

However not many of these processes are able to show satisfactory commitment towards sustainable forest management particularly biodiversity conservation, and the situation is particularly poor in case of the tropical countries. Among these, three processes: the Pan-European Process, the Montreal process and ITTO have a track record of following in the concept into practice (Wijewardana, 2008). These processes have made substantial progress in promoting C&I implementation in their combined 85 member countries and reporting on their sustainable forest management achievements. Development of criteria and indicators has proved to be as a powerful information tools that provides holistic picture which recognize all major forest values including wood production.

Despite the large number of studies and the membership of the global initiative, implementation at the forest management unit (FMU) level is rather weak (Raison *et al.*, 2001). There is immense volume of literatures on biodiversity indicators (Ferris and Humphrey, 1999; Poiani *et al.*, 2000; Hagan and Whitman, 2006). There is no single literature that can identify the single coherent framework (Lindenmayer *et al.*, 2000; McElhinny *et al.*, 2005). These literatures have however made clear that there is no single indicator that can provide a satisfactory reflection of biodiversity change (Gardner, 2010). This could be due to the lack of applicable framework, or due to complexity of biodiversity terminology. Many studies about indicators are rather focused on one indicator or indicators concerning individual species and species groups (reviewed in Gao *et al.*, 2015). And when such indicators are designed, question remains whether these indicator sets are sufficient to achieve the goal of developing efficient monitoring of biodiversity and biodiversity conservation as a whole. Most biodiversity monitoring studies are based on species diversity only, while the species diversity is at the best a very rough indicator of biodiversity, as it provides limited indication of the ecosystem and genetic diversity (Spangenberg, 2007). As a result, accounting for the species counting alone can be highly misleading indication of biodiversity.

So far developed criteria and indicators are more focused on implementation and effectiveness monitoring to assess if the forest management practices are against agreed standards and goals of the sustainable forest management or not. Even though management interventions are performed according to agreed standards and the results are achieved as per the goals, they might still impact the biodiversity status in a detrimental way and still may impact dynamics of human’s interactions with nature. Therefore, design of criteria and indicators, also need include accessing mechanism against whether a management practices and plan is successful in achieving the biodiversity goals (Gardner, 2010). For instance sustainable forest management encompasses management interventions like selective logging. Even though logging is performed as per harvesting plan, which is based on the sustainable forest management, due to modified logging will have ecological impacts on the ecosystem. In addition, such impact in different ecological system may result in different ecological dynamics and composition.

Modified forest lacks natural ecological analogue, so their studies will poorly reflects the ecological dynamics and composition of the undisturbed forest (Hobbs *et al.*, 2006; Gardner, 2010). Before and after interventions scenario could depicts the contribution of particular management interventions on biological diversity. However, there is little information available on the baselines (such as baseline data before the human-related impacts) and even if they are available, it would be difficult to differentiate how much of these changes are related to the human related impacts and natural process (Allen *et al.*, 2003). In systems undergoing processes of evolution and co-evolution, equilibrium and unidirectional causality approaches are inadequate concepts to understand stability properties such as resilience and resistance at the ecosystem level (Spangenberg, 2007).

Thus, developing a clear understanding of the links between particular management regime and its impacts and changes in biodiversity/ ecological integrity via measurable changes in major attributes of the ecosystem/forest provides the foundation for reliably assessing and evaluating management performance (Gardner, 2010).

2. Methodology

2.1 A hierarchical characterization approach of biodiversity monitoring

In most forests there are thousands of flora and fauna species and countless possible species interactions. Hence in order to monitor or measure them, need arises to redefine the biodiversity in terms of measureable attributes relevant to the scale and purpose for which it is to be assessed (Sarkar and Margules, 2002; Williams, 2004; McElhinny *et al.*, 2005). These measurable attributes are known as indicators. To be able to evaluate management performance against conservation goals, indicators need to reflect changes taking place at various levels in the ecological hierarchy from gene, to species, to complete ecosystem, including all processes of the ecosystem that maintain these various levels (Noss and Cooperrider, 1994; Hunter, 1996; Lin *et al.*, 2009). A hierarchical characterization approach of biodiversity (Figure 1) includes all three major attributes of the ecosystem i.e. the function, composition and structure at four levels of organization: regional-landscape, community-ecosystem, population-species, and genetic (Noss, 1990).

We use hierarchical characterization approach of biodiversity as a conceptual framework for identifying specific, measurable indicators to monitor change and assess the overall status of biodiversity. On the basis of the attribute it measure, indicators are defined as a structural, functional and compositional indicator.

Structure attributes of the biodiversity involve physical organization or pattern of a system, from habitat complexity as measured within stand communities to the pattern and other elements at the landscape level. The breadth of ecological relationship accounted by the structural attributes may be accounted by three components: heterogeneity, complexity and scale. **Heterogeneity** encompasses the variation due to *relative abundance* of different structural components whether in vertical or horizontal plane. **Complexity** refers to the variation due to *absolute abundance* of individual structural component. S**cale** encompasses the variation due to *size of the area or the volume* used to measure heterogeneity and complexity (Ferris and Humphrey, 1999).

Function involves ecological and evolutionary processes including gene flow, disturbances and nutrient cycling. Many approaches of biodiversity monitoring often ignores ecological processes e.g. natural disturbance, the decomposition of woody debris, the cycling of nutrients, etc.), which are critical for the maintenance of biodiversity (Noss, 1990). However, this ignorance will fail to provide complete definition of biodiversity.

Composition refers to the identity and variety of element in a collection that includes richness and abundance. It is commonly measured by counting number of plant and animal species present in a given area (Ferris and Humphrey, 1999). The compositional indicator approach is the most commonly used measure in biodiversity monitoring.

The structural, functional, and compositional attributes of a stand are often interdependent and interconnected, so that attributes from one group may also be surrogates for attributes from another group (Noss, 1990; Ferris and Humphrey, 1999; Franklin *et al.*, 2002; McElhinny *et al.*, 2005). For example, a structural attribute such as dead wood can also be a good indicator of functional attributes such as decomposition and nutrient cycling processes (McElhinny *et al.*, 2005). Similarly, compositional attributes, such as species composition and abundance can be indicators of structural attributes such as canopy layering (Franklin *et al.*, 2002; Gardner, 2010). Furthermore, measures from one scale can provide information relevant to another scale (Olsen *et al.*, 2007; Lin *et al.*, 2009).

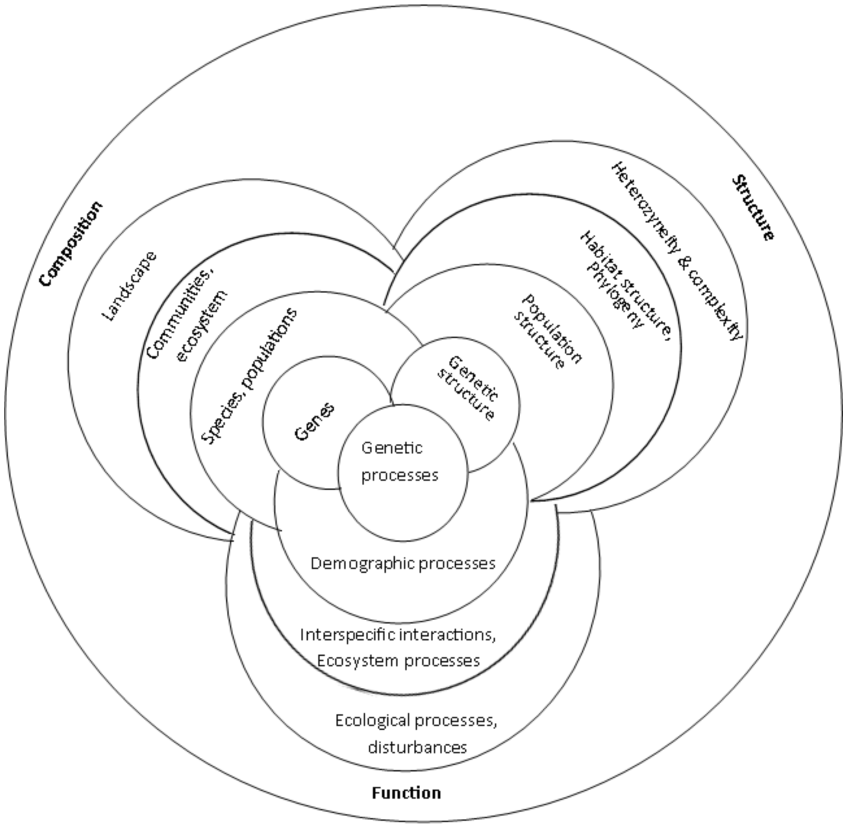


Figure 1: The hierarchical definition of biodiversity. Biodiversity defined as a multidimensional 'metaconcept' encompassing genes, populations, species, habitat and ecosystem.

Source : redrawn from Noss (1990)

2.2 Collection and arrangement of the biodiversity elements related to the forest ecosystem

Indicator selection matrix was built up in order of organizational level namely landscape level, habitat/ ecosystem level, population/ species level and genetic level. Each organizational level was further arranged into the three attributes of biodiversity: composition, structure and function.

Once the matrix was ready, we used ISI Web of Knowledge to review literatures. Combination of different keywords ("Biodiversity monitoring", "Indicator selection", "indicator", "Biodiversity" and "Forests") were used. During the search, we applied restriction to search only peer reviewed literatures and books. Studies, publication and report at the regional and broader scale (e.g. ITTO, CIFOR, CBD) were also included in the study. A study conducted by Prasetyo *et al.* (2014) on biodiversity indicators and parameters for multipurpose monitoring system in South Sumatra supported a valuable reference while preparing the indicator matrix. We considered literatures/ studies that clearly involved with the biodiversity or ecological indicators.

We conducted a quick review of the abstracts of the retrieved 562 articles and screened 52 articles that were relevant to our study. Out of 52 articles, we selected 17 most relevant papers that dealt with biodiversity indicators. Since many studies were based on the one or few attributes (e.g. structural indicators only), and at limited spatial scale (e.g. literatures involved with population level studies only), we considered four criteria to characterize and assign each indicator described in the literature to particular category: purpose of indicator (e.g. habitat quality assessment, ecological status assessment), indicator type, spatial scale, and biodiversity attributes addressed. Each selected indicator was added as an entry to our pool of indicators. Set of keyword used for the literature survey might have influenced our indicator list.

2.3 Indicator selection for Sumatra Province and Forest Management Units

A two-day workshop was organized among thirty experts (Table 1) (experts here means *decision makers, academics and researcher and professionals working in the field of forest and biodiversity management, and who have knowledge of some component of biodiversity in different temporal and spatial scales*) to select final set of indicators that are relevant to the Sumatra province and Forest Management Units (FMUs) level in particular. In the first stage, each of the experts was provided with the 10 stickers so that they can rank indicators based on their personal importance preference. More than one sticker was allowed to be assigned in each indicator based on the weightage given to them.

In the stage second, thirty experts were grouped into three groups on the basis of the organizations/institutes they were representing. Group I included thirteen experts representing Forest Management Units (FMUs), forestry concessions and other professionals in implementing level; group II included twelve experts representing government agencies (decision makers); and group III composed of five experts representing academia and research agencies. Each group was provided with the document with initial set of indicators and parameters created through the literature review (described above, see Table 2). Experts were asked to select/prioritize indicators that are useful and relevant to the province level and also to the forest management unit level.

Participants of the workshop decided that the C&I developed at genetic level (See Table 2) should be excluded in the C&I selection process. The major reasons for the exclusion were the lack of prior experience of and substantially limited knowledge on the functional importance of the indicators among the field level forest management practitioners – the majority of the participants in the workshop.

Table 1: List of the experts participated for the assessment.

SN	Name	Institution
Experts representing forest management units (FMUs) and forestry concessions and other professionals in implementing level (Facilitator- Arum Setiawan, Note- Ina Aprillia)		
1	Khairil Kasdi	KPHP Benakat Bukit Cogong (Production FMU)
2	Ramlan P. Lababa	
3	Mega Selutami	KPHL Banyuasin (Protection FMU)
4	Fitri Rahmi	
5	Udi Setiawan	
6	Wan Kamil	KPHP Meranti (Production FMU)
7	Yoga Travolindra	
8	Amsyahrudin	KPHP Lalan MM (Production FMU)
9	Ika Dana Pratiwi	
10	Amrin Fauzi P. Lubis	PT. GAL (Forestry concession - carbon license)
11	Arifin H.P	PT. BMH (Forestry concession -forest plantation)
12	Ari Rosadi	PT. SBA WI (Forestry concession - forest plantation)
13	Catur Yuono Prasetyo	
Experts representing government agencies (decision makers) (Facilitator- Hendi Sumantri, Note- Rio Firman Saputra)		
1	Asep Sunarya	BBTN Kerinci Seblat (National Park)
2	Nurhadi	Balai PPI-KHL (Climate Change and Fire Prevention Agency)
3	Ridwan Pambudi	
4	Joharis Satria	BTN Berbak & Sembilang (National Park)
5	Agnes Indra	BKSDA Sumsel (Natural Resource Conservation Agency)
6	Octavia Susilowati	
7	Pandji Tjahjanto	Dinas Kehutanan Sumsel (Forestry Agency of S. Sumatra)
8	Hendrizal	
9	Muallimah Gustini	Bappeda Sumsel (Planning and Developing Agency of S. Sumatra)
10	Hartati Yusuf	
11	Apri Nuryanti	
12	Selvi	
Experts representing academia and research agencies (Facilitator- Indra Yustian, Note- Rahmat Pratama)		
1	Delfy Lensari	University of Muhammadiyah, Palembang (UMP)
2	Jun Harbi	
3	Adi Kunarso	Forestry Research Agency of Palembang (BP2LHK)
4	Purwanto	
5	Fandi Susanto	Sriwijaya University (FMIPA UNSRI)

2.4 Selection of highly rewarding and high performance indicators

Once the indicators relevant to the province and the forest management unit level were selected, highly rewarding indicators were selected using different filters (Figure 2). Indicator selection processes to be effective as an assessment tool, Gardner (2010), suggested to proceed with four principle selection criteria, namely: (i) the ‘responsiveness’ of candidate indicators to management actions; (ii) the ease with which they can be measured; (iii) their relevance to changes in the forest condition and biodiversity and/or individual target species; and (iv) the generality with which they can be applied across similar management systems in other landscapes and regions. The process takes into account all these principles and used them as the filters at different stages of the selection process (Figure 2). Figure 2 shows the hierarchical approach of indicator selection, which ensures highly productive and rewarding final set of indicators. Figure 2 further illustrates that the Indicators need to be designed and selected in such a way that the required technical expertise, field expertise or laboratory expertise are available and the project is economically feasible (cost efficient), technically attainable, and ecologically meaningful.

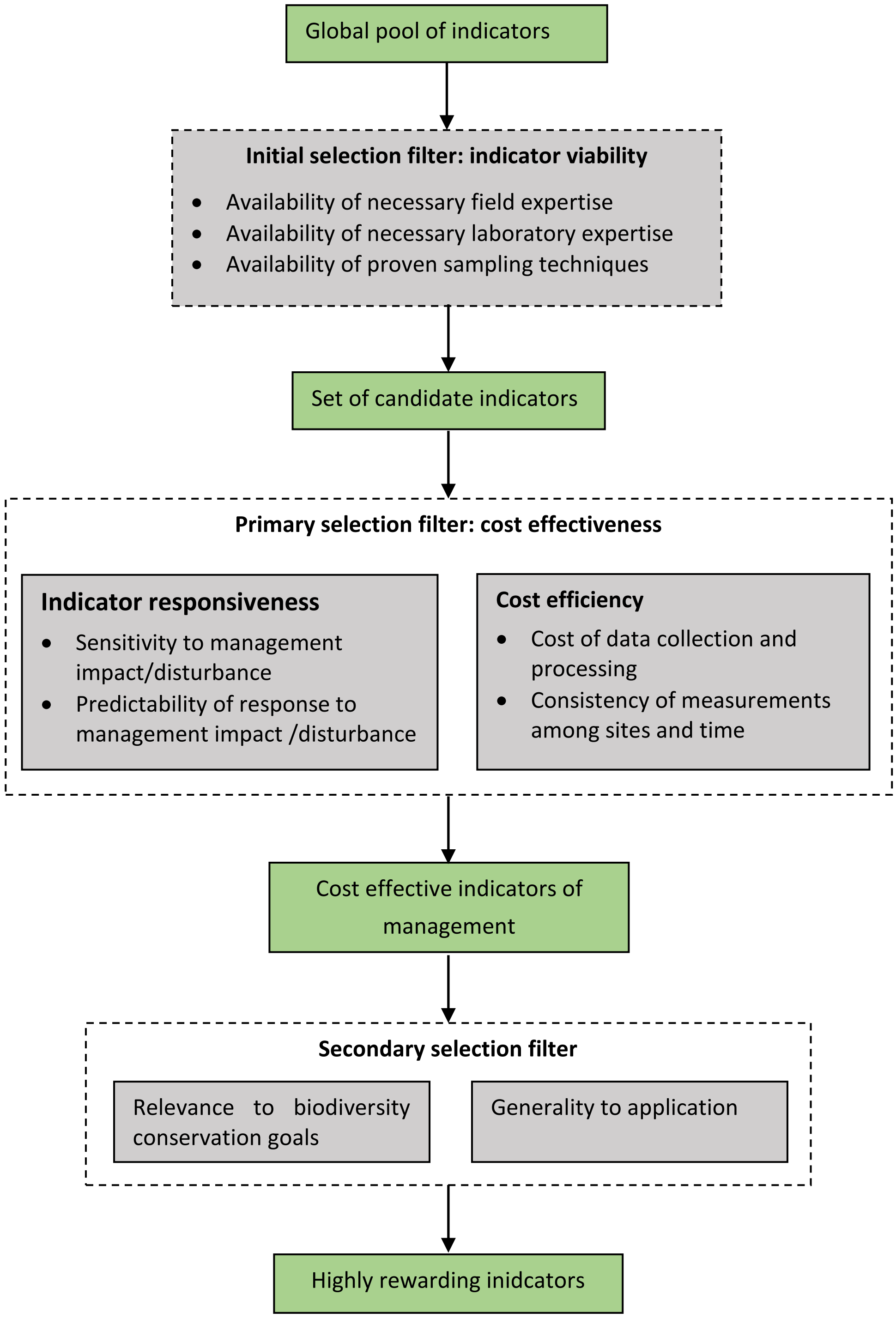


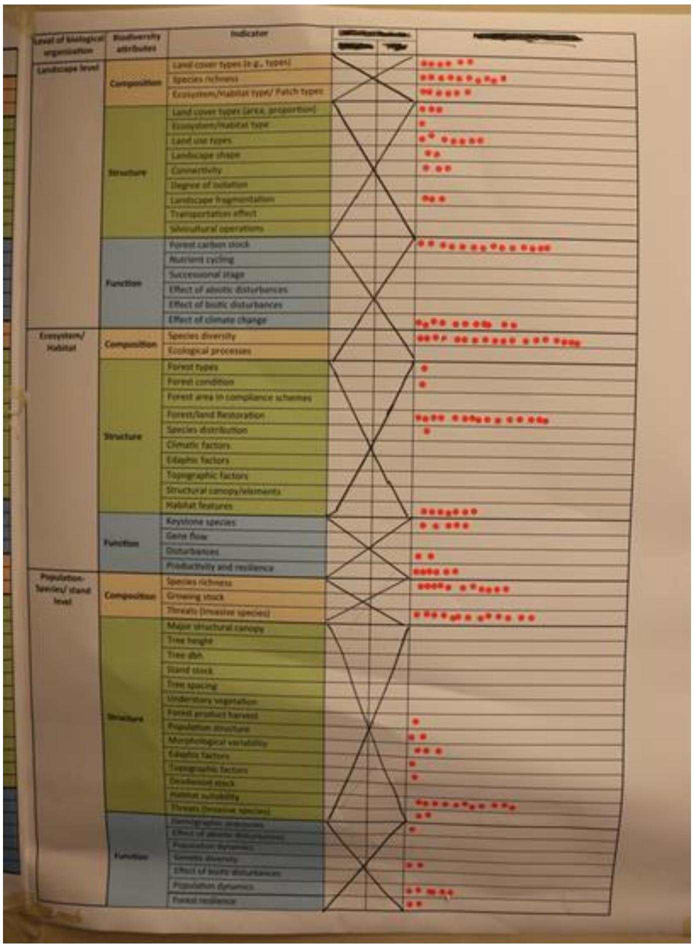
Figure 2: A general framework for selecting highly rewarding indicators for the biodiversity monitoring.

Source: Figure adapted from Gardner, 2010

Ranking of forest biodiversity indicators by experts

Experts are ranking forest biodiversity indicators

Outcome of the ranking exercise



Selection of indicators relevant to province and FMU level forest biodiversity monitoring system, and selection of highly rewarding/ high-performance indicators for FMU level forest biodiversity monitoring

Panel of experts representing academia (universities) and research agencies

Panel of experts representing government agencies (decision makers)

Panel of experts representing forest management units (FMUs), forestry concessions and other forestry professionals at implementing level

Group presentation and discussion: Selection of indicators relevant to province and FMU level forest biodiversity monitoring system, and selection of highly rewarding/ high-performance indicators for FMU level forest biodiversity monitoring

3. Results

3.1 Initial set of Indicators ('Global pool' or 'Laundry list')

Altogether 62 indicators and 162 parameters/ variables were generated from the study. Compilation of biodiversity indicators and their respective inventory and monitoring tools are presented in Table 2. Indicators are organized into four hierarchical levels (Landscape, habitat, stand and genetic) as mentioned above. Each level includes all three ecosystem attributes (structural, functional, and compositional attributes). As with most of the categorization process, there is an overlap between the indicators at different level.

Landscape level

Landscape refers to a mosaic of heterogeneous land forms, vegetation types, and land uses (Urban *et al.*, 1987). Spatial scale of a landscape may vary in size, for instance from 10^2 to 10^7 km^2. Landscape features such as patch size, heterogeneity, perimeter-area ratio, and connectivity can be major controllers of species composition and abundance, and of population viability for sensitive species (Noss, 1990).

Ecosystem/ habitat level

The ecosystem level is relatively homogenous as compared to the landscape level. Indicator attributes for the ecosystem includes composition indicators such as species richness and diversity, variables related to ecological processes such as nutrient cycles, natural and human disturbances etc. Key physical attributes of the habitat that are important for maintenance of the biodiversity, are described using structural indicators such as rock bed types, abundance of water and other resources. Other major habitat level indicators include major structural canopy and vegetation strata.

Population species/ stand level

Population/ stand level is the most focused level for the biodiversity monitoring. It targets all populations of a species across its range, a metapopulation (population of a species connected by dispersal), or single or disjunct population. Thus species richness is a major compositional indicator. Stand level structural indicators can be broken down into measurements that relate to the major structural canopy, understorey and herbaceous vegetation strata as well as measurements to describe stocks of standing and fallen dead wood stocks. Functional indicators at the stand level include different biotic and abiotic processes, which are similar to that of habitat level.

Table 2: Biodiversity indicators and associated parameters/ variables for inventorying, monitoring, and assessing forest biodiversity. The indicators and variables are presented at four levels of organization, and each level includes compositional, structural and functional components of an ecosystem. The Table presents whether the indicators are applicable to assess forest degradation. Each variable is provided with the methods/ techniques to measure it.

Level of Biological organization	Biodiversity attributes (Ecosystem attributes)	Indicator	Parameters/ Variables	Biodiversity indicators of forest degradation	Monitoring methods/ techniques
Landscape	*Composition*	Land cover types	Types of different land cover (forest, agriculture, wetland etc.)		Terrestrial/ Remote sensing (RS)
			Diversity or evenness of cover types across the landscape		Terrestrial/ RS
			Dominance of individual cover types		Terrestrial/ RS
		Species richness	Collective patterns of species distributions (richness, endemism)	√	Terrestrial
		Ecosystem/ Habitat type	Identification of different Habitat types & their distribution	√	Terrestrial/ RS
	Structure	Land cover types	Area of each land cover type	√	Terrestrial/ RS
			Proportion of land cover types	√	Terrestrial/ RS
			Spatial distribution of land cover types		Terrestrial/ RS
		Ecosystem/ Habitat type	Area of each habitat/ecosystem types	√	Terrestrial/ RS
			Proportion of habitat/ecosystem types	√	Terrestrial/ RS
			Spatial distribution of habitat/ecosystem types (Homogeneity vs heterogeneity)		Terrestrial/ RS
		Land use types	Area of land use types	√	Terrestrial/ RS
			Proportion of land use types	√	Terrestrial/ RS
			Distribution of land use types		Terrestrial/ RS
		Landscape shape	Edge of forest area	√	Terrestrial/ RS
			Mean shape index	√	Terrestrial/ RS
		Connectivity	Connectivity/ habitat linkages (e.g., number of trees left uncut during rotation)	√	Terrestrial/ RS
			Spatial linkage (e.g., Forest corridors between PAs)	√	Terrestrial/ RS
		Degree of isolation	Area of patches (measure of patch geometry that describes the length of edge between land cover types)	√	Terrestrial/ RS
			Proportion of patches	√	Terrestrial/ RS
			Patch size frequency distribution	√	Terrestrial/ RS
			Perimeter-area ratio	√	Terrestrial
			Distance between different land use types	√	Terrestrial/ RS
			Porosity/gap	√	Terrestrial/ RS
		Landscape fragmentation	Fragmentation index	√	RS
		Transportation effect	Road density, river density	√	RS
			Forest distance from road	√	RS
		Silvicultural operations	Area of small clearings (<25 ha)	√	Terrestrial/ RS
			Area of log landings	√	Terrestrial/ RS
			Density of log landings, skid trials, log decks	√	RS
			Density of drainage in Peat Swamp Forest	√	RS
			Area of forest undergoing selective logging	√	Terrestrial/ RS
	Function	Forest carbon stock	Carbon content (five carbon pools)	√	Terrestrial
		Nutrient cycling	Nutrient cycling rates	√	Terrestrial
		Successional stage	Land use trends	√	Historical data/ Background information (BI)/ interview
			Patch persistence & turnover rates	√	Historical data/ BI/ interview
			Focal ecosystem	√	Historical data/ BI/ interview
		Effect of abiotic disturbances	Areal extent, frequency or return interval, predictability, intensity, severity & seasonality of fire	√	Historical data/ BI/ interview/ terrestrial/ RS
			Areal extent, frequency or return interval, predictability, intensity, severity & seasonality of flood	√	Historical data/ BI/ interview/ terrestrial/ RS
			Areal extent, frequency or return interval, predictability, intensity, severity & seasonality of salinity	√	Historical data/ BI/ interview

			Areal extent, frequency or return interval, predictability, intensity, severity & seasonality of hydrological processes (e.g., erosion drought, storms)	√	Historical data/ BI/ interview/ terrestrial/ RS
		Effect of biotic disturbances	Damaged by pest pathogens	√	Terrestrial / BI / lab
			Damaged by grazing	√	Terrestrial / BI
			Area of forest affected by human interventions (e.g. Controlled burning)	√	Terrestrial / BI
		Effect of climate change	Effect of climate change (frequency & severity of climate-change- related impacts, e. g., climate-change induced droughts, forest fires)	√	Historical data/ BI/ interview/ terrestrial/ RS
Ecosystem / Habitat	***Composition***	Species diversity	Identification of different species		Terrestrial
			Relative abundance/frequency/ richness/ evenness & diversity of species	√	Terrestrial
			Proportions of endemic & exotic species	√	Terrestrial
			Proportions of endangered (critically endangered, endangered) vulnerable, near threatened, & least concerned species	√	Terrestrial
			Identification of focal species (e.g., area-limited, dispersal limited, resource-limited, process-limited, Keystone species)		Terrestrial
			Identification of target species of particular conservation & management concern		Terrestrial
			Proportion of focal species to non-native invasive species	√	Terrestrial
			Dominance-diversity curves		Terrestrial
			Similarity coefficients (Measure of co-occurrence & association)		Terrestrial
			C3:C4 plant species ratios		Terrestrial
		Ecological processes	Presence of species that indicate unaltered ecological processes		Terrestrial
	Structure	Forest types	Extent (e.g., area) of forest types (e. g., protected forest, production forest, conservation/special use forest etc.)	√	Terrestrial/ RS
			Proportion (area) of different forest types	√	Terrestrial/ RS
		Forest condition	Area & proportion of managed natural forest	√	Terrestrial/ RS
			Area & proportion of degraded natural forest	√	Terrestrial/ RS
			Area of secondary forest (successional forest)	√	Terrestrial/ RS
			Degraded forest land presently unstocked	√	Terrestrial/ RS
		Forest area in compliance schemes	Area & proportion of certified forests	√	Terrestrial/ RS
		Forest/land Restoration	Area of degraded forests restored	√	Terrestrial/ RS
			Area of degraded forest land restored	√	Terrestrial/ RS
		Species distribution	Plant community diversity (age size, age size classes, growth form of trees)	√	Terrestrial/ BI
			Proportion of focal species to non-native invasive species	√	Terrestrial/ BI
		Climatic factors	Climatic variables (precipitation, humidity, temperature)	√	Terrestrial/ RS
		Edaphic factors	Substrate & soil variables/soil types	√	Terrestrial/ RS
		Topographic factors	Altitude, slope & aspect		Terrestrial/ RS/ BI
		Structural Canopy/ elements	Vegetation biomass & physiognomy	√	Terrestrial
			Foliage density & layering (arrangement of foliage in different strata)/variation in overstorey & understorey structure & floristics)	√	Terrestrial
			Horizontal patchiness		Terrestrial
			Canopy openness/gap proportions (forest canopy cover, forest canopy gaps, tree fall gaps)	√	Terrestrial
			Snags, dead & down woods		Terrestrial

			Proportion of tree crowns with broken & dead tops		Terrestrial
		Habitat features	Rock bed type		RS
			Abundance, density, & distribution of key physical features (e.g., cliffs, outcrops, sinks)		RS
			Resource availability (e.g., water, pond, mud-bath, mast)		RS
	Function	Keystone species	Ecologically pivotal species	√	Terrestrial
		Gene flow	Migration		Terrestrial / lab work
			Dispersal		Terrestrial / lab work
			Colonization & local extinction rates		Terrestrial / lab work
		Disturbances	Herbivory, parasitism, & predation rates	√	Terrestrial/ BI
			Patch dynamics (fine-scale disturbance processes)	√	
			Forest fire- areal extent, frequency or return interval, predictability, intensity, severity & seasonality	√	Historical data/ BI interview/ terrestrial/ RS
			Human intrusion rates & intensities (e.g., forest encroachment, slash-&-burn)	√	Historical data/ BI interview/ terrestrial/ RS
			Extraction rate (frequency) of harvested volume, felling cycle	√	Archives/BI/interview
		Productivity & resilience	Biomass & resource productivity	√	Terrestrial
			Rate of forest growth (Increment rate)	√	Terrestrial/ lab work
			Decomposition rate	√	Terrestrial/ lab work
			Nutrient cycling rates	√	Terrestrial/ lab work
Population / species/ stand	***Composition***	Species richness	Absolute abundance & distribution/species diversity of target (key) & focal species	√	Terrestrial
			Relative abundance (species richness, diversity, relative abundance of keystone species, flagship, vulnerable, umbrellas, ecological indicators)	√	Terrestrial
		Growing stock	Biomass (stand basal area, stand volume)	√	Terrestrial
			Stem density		Terrestrial
		Threats (Invasive species)	List of invasive species observed in forests	√	Terrestrial/ interview
	Structure	Major structural canopy	Forest canopy cover	√	Terrestrial/ RS
			Forest canopy gap size classes, average gap size	√	Terrestrial/ RS
			Proportion of tree crowns with broken & dead tops		Terrestrial/ RS
		Tree height	Tree height		Terrestrial/ RS
			Standard deviation of height		Terrestrial/ RS
			Height class richness		Terrestrial/ RS
			Horizontal variation in height		Terrestrial/ RS
		Tree dbh	Tree dbh		Terrestrial
			Standard deviation of dbh		Terrestrial
			Horizontal variation in dbh		Terrestrial
			Diameter distribution	√	Terrestrial
			Number of large trees	√	Terrestrial
		Stand stock	Growing stock	√	Terrestrial
			Forest biomass/carbon density (Above ground biomass/carbon density, changes in biomass/carbon density)	√	Terrestrial
			Basal area/volume	√	Terrestrial
		Tree spacing	Tree spacing (number of trees per hector, percentage of trees in clusters)	√	Terrestrial/ RS
		Understory vegetation	Herbaceous cover	√	Terrestrial
			Shrubs cover, & its variation	√	Terrestrial
			Understorey richness	√	Terrestrial
			Shrub height		Terrestrial
			Total understorey cover	√	Terrestrial
		Forest product harvest	Annual allowable harvest (AAH) of wood & non wood product		Terrestrial/BI

			Actual annual harvest of wood & non wood product	√	Archives/terrestrial/ BI
			Number of species harvested	√	Archives/BI
		Population structure	Population structure (sex ratio, age ratio)		Terrestrial
		Morphological variability	Within-individual morphological variability		Terrestrial
		Edaphic factors	Substrate & soil variables/soil types	√	Terrestrial / lab work
		Topographic factors	Altitude, slope & aspect, cliff, outcrops		Terrestrial/ RS
		Deadwood stock	Deadwood (volume & basal area by decay classes/ diameter class)		Terrestrial/ RS
			Volume of coarse woody debris		Terrestrial/ RS
			Litter biomass or cover	√	Terrestrial/ RS
		Habitat suitability	Range/ habitat (proportion of area with different habitat, for e.g., suitable habitat area for target species)	√	Terrestrial
		Threats (Invasive species)	Area & proportion of invasive species	√	Terrestrial
	Function	Demographic processes	Recruitment , survivorship, mortality and turnover rate		Terrestrial
		Effect of abiotic disturbances	Areal extent, frequency or return interval, predictability, intensity, severity & seasonality of fire	√	Historical data/ BI interview/ terrestrial/ RS
			Areal extent, frequency or return interval, predictability, intensity, severity & seasonality of flood	√	Historical data/ BI interview/ terrestrial/ RS
			Areal extent, frequency or return interval, predictability, intensity, severity & seasonality of salinity	√	Historical data/ BI interview/ terrestrial
			Areal extent, frequency or return interval, predictability, intensity, severity & seasonality of erosion & other hydrological processes (e.g., drought) etc.	√	Historical data/ BI interview/ terrestrial/ RS
		Population dynamics	Metapopulation dynamics		Terrestrial
		Genetic diversity	Population genetics (see in genetic section)		Terrestrial
		Effect of biotic disturbances	Damaged by pest & pathogens	√	Terrestrial / lab work
			Damaged by grazing	√	Terrestrial
			Area of forest affected by human interventions (e.g. Controlled burning, forest encroachment, slash-&-burn)	√	Terrestrial/ RS
		Population dynamics	Life history		Historical data/ BI
			Gene flow vectors & mechanism		Terrestrial/ DNA analysis
			Extinction rate of the key species	√	Terrestrial
			Phenology		Terrestrial
			Growth rate (of individuals)	√	Terrestrial
		Forest resilience	Acclimation		Terrestrial
			Adaptation		Terrestrial
			Biomass & resource productivity (recovery after disturbance)	√	Terrestrial
			Rate of forest growth (Increment rate)	√	Terrestrial
Genetic	***Composition***	Genetic diversity	Allelic diversity	√	Lab work/ DNA analysis
			Presence of particular rare alleles, deleterious recessives, or karyotypic variants	√	Lab work/ DNA analysis
	Structure	Viable population size	Census and effective population size	√	Lab work/ DNA analysis
		Genetic diversity	Heterozygosity	√	Lab work/ DNA analysis
			Chromosomal or phenotypic polymorphism		Lab work/ DNA analysis
			Generation overlap		Lab work/ DNA analysis

			Heritability		Field trial/ Lab work/ DNA analysis
	Function	Genetic diversity	Inbreeding depression	√	Field trial/ Lab work/ DNA analysis
			Outbreeding rate	√	Field trial/ Lab work/ DNA analysis
			Natural selection	√	Field trial/ Lab work/ DNA analysis
			Rate of genetic drift	√	Field trial/ Lab work/ DNA analysis
			Gene flow	√	Field trial/ Lab work/ DNA analysis
			Mutation rate	√	Field trial/ Lab work/ DNA analysis

Genetic

Genetic indicators provide the information regarding if the species/ population contain sufficient genetic diversity among and within the population to ensure ongoing evolutionary potential or not. Often the management interventions like logging may lead to the deforestation and isolation of the populations which may eventually lead to the increased inbreeding leading to inbreeding depression, which may eventually override local adaptation as well as genetic drift and loss of genetic variation which can curtail evolutionary potential. Due to the cost involved in the genetic level studies, these are usually restricted to the rare species or commercially valuable species.

3.2 Ranking of indicators by the expert

In the beginning of the second session of the workshop, following the introductory session on the CBD, Aichi biodiversity targets, biodiversity indicators and Clearing House Mechanisms (CHM), the experts were provided with the 10 stickers each and requested to rank indicators (Except indicators at genetic level) based on their personal importance preference. More than one sticker were allowed to be assigned in each indicator based on the weightage given to them.

Top fifteen biodiversity indicators preferred by the experts (as indicated by the number of stickers the experts assigned to the indicators) were (in descending order): species diversity, forest and/or forest land restoration, forest carbon stock, invasive species (threats), effect of climate change, species richness, habitat suitability, land use types, habitat features, land cover types, ecosystem/habitat/patch types, productivity and resilience, population dynamics, keystone species and connectivity. Another feature of the expert preference to the selected indicators conveys that the experts provided equal importance for the indicators at all the (three) levels of biological organizations (Landscape level, ecosystem/habitat level and population-species/ stand level) and for all the three ecosystem attributes, i.e., composition, structure and function. Out of fifteen, more or less equal numbers of indicators are associated with the three biological organization levels, and three basic functions of the ecosystem.

Table 3: Ranking of indicators by experts participated in the workshop.

Level of biological organization	Biodiversity (Ecosystem) attributes	Indicator	Ranking of indicator
Landscape level	***Composition***	Land cover types (e.g., types)	6
		Species richness	10
		Ecosystem/Habitat type/ Patch types	6
	Structure	Land cover types (area, proportion)	3
		Ecosystem/Habitat type	1
		Land use types	7
		Landscape shape	2
		Connectivity	3
		Degree of isolation	0
		Landscape fragmentation	3
		Transportation effect	0
		Silvicultural operations	0
	Function	Forest carbon stock	14
		Nutrient cycling	0
		Successional stage	0
		Effect of abiotic disturbances	0
		Effect of biotic disturbances	0
		Effect of climate change	11
Ecosystem/Habitat	***Composition***	Species diversity	18
		Ecological processes	0
	Structure	Forest types	1
		Forest condition	1
		Forest area in compliance schemes	0
		Forest/land Restoration	15
		Species distribution	1
		Climatic factors	0
		Edaphic factors	0
		Topographic factors	0
		Structural canopy/elements	0
		Habitat features	7
	Function	Keystone species	5
		Gene flow	0
		Disturbances	2
		Productivity and resilience	6
Population-Species/ stand level	***Composition***	Species richness	11
		Growing stock	0
		Threats (Invasive species)	13
	Structure	Major structural canopy	0

		Tree height	0
		Tree dbh	0
		Stand stock	0
		Tree spacing	0
		Understory vegetation	0
		Forest product harvest	1
		Population structure	2
		Morphological variability	3
		Edaphic factors	1
		Topographic factors	1
		Deadwood stock	0
		Habitat suitability	11
		Threats (Invasive species)	2
	Function	Demographic processes	1
		Effect of abiotic disturbances	0
		Population dynamics	0
		Genetic diversity	2
		Effect of biotic disturbances	0
		Population dynamics	6
		Forest resilience	2
Genetic*	***Composition***	Genetic diversity (e.g., allelic diversity, presence of particular rare/deleterious recessive alleles)	
	Structure	Viable population size	
		Genetic diversity (e.g., heterozygosity, heritability)	
	Function	Genetic diversity (e.g., inbreeding depression, outbreeding rate, natural selection, gene flow, mutation rate)	

*Genetic level indicators were not discussed.

3.3 Selection of forest biodiversity indicators relevant to Sumatra Province

Fifty six indicators out of 58 were collectively selected by the expert panels (Table 4). Academia and research expert panel selected the highest number of indicators (48 from the list of 58) as relevant indicators for province level (Table 4, Annex 1). Government agencies expert panel selected 33 indicators for province level forest biodiversity monitoring system (FBMS) (Table 4, Annex 2), while FMU and field practitioners' panel choose 31 indicators for province level (Table 4, Annex 3).

For the province level, 18 indicators (32%) received common agreement among the expert panels. Those indicators included: land cover types, ecosystem/habitat/patch types, land cover (area, proportion), landscape fragmentation, transportation effect, forest carbon stock, successional stage, effect of climate change, species diversity, forest condition, forest and/or forest land restoration, keystone species, disturbances, productivity and resilience, species richness, edaphic factors, effect of abiotic factors, effect of abiotic disturbances and population dynamics (Table 4). Additional twenty indicators (35%) were thought relevant for the province level by at least two expert panels. Remaining indicators were selected by one of the expert panels (Figure 3). The result shows that nearly two-third of the total forest biodiversity indicators presented in Table 2 were agreed by at least two expert panels.

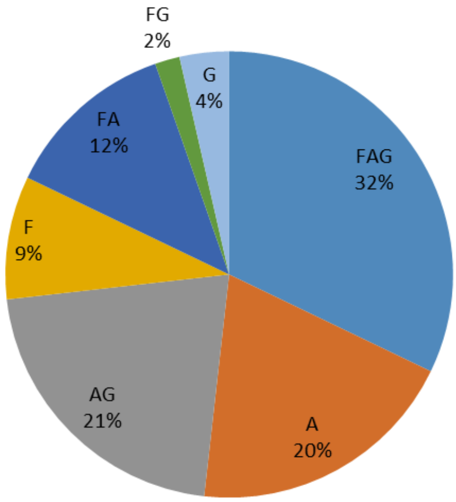


Figure 3: Quantity of indicators (percent of collectively selected indicators) relevant to province (South Sumatra) level forest biodiversity monitoring system selected by different combinations of expert panel. F = Expert panel constituting the representatives from forest management units (FMUs), forestry concessions and other field level forestry professionals; A = Expert panel constituting the representatives from academics (i.e., Universities) and research institutes; and G = Expert panel constituting the representative from government agencies (mostly decision making level).

Table 4: List of indicators applicable to Sumatra province level forest biodiversity monitoring system selected by the expert panels.

(🟢 = selected by the FMU, forestry concession and other field level forestry practitioners, ⚫ = selected by the academicians and researchers, 🔴 = selected by the representatives from government agencies)

Level of biological organization	Biodiversity (Ecosystem) attributes	Indicator	Indicator selected by three expert panels
Landscape level	***Composition***	Land cover types (e.g., types)	🟢 ⚫ 🔴
		Species richness	⚫ 🔴
		Ecosystem/Habitat type/ Patch types	🟢 ⚫ 🔴
	Structure	Land cover types (area, proportion)	🟢 ⚫ 🔴
		Ecosystem/Habitat type	⚫
		Land use types	⚫ 🔴
		Landscape shape	🟢
		Connectivity	🟢 ⚫
		Degree of isolation	⚫ 🔴
		Landscape fragmentation	🟢 ⚫ 🔴
		Transportation effect	🟢 ⚫ 🔴
		Silvicultural operations	⚫
	Function	Forest carbon stock	🟢 ⚫ 🔴
		Nutrient cycling	🟢
		Successional stage	🟢 ⚫ 🔴
		Effect of abiotic disturbances	🟢 ⚫
		Effect of biotic disturbances	⚫
		Effect of climate change	🟢 ⚫ 🔴
Ecosystem/ Habitat	***Composition***	Species diversity	🟢 ⚫ 🔴
		Ecological processes	
	Structure	Forest types	⚫ 🔴
		Forest condition	🟢 ⚫ 🔴
		Forest area in compliance schemes	⚫
		Forest/land Restoration	🟢 ⚫ 🔴
		Species distribution	⚫ 🔴
		Climatic factors	🟢 ⚫
		Edaphic factors	⚫ 🔴
		Topographic factors	⚫ 🔴
		Structural canopy/elements	⚫ 🔴
		Habitat features	🔴
	Function	Keystone species	🟢 ⚫ 🔴
		Gene flow	
		Disturbances	🟢 ⚫ 🔴
		Productivity and resilience	🟢 ⚫ 🔴
Population-Species/ stand level	***Composition***	Species richness	🟢 ⚫ 🔴
		Growing stock	⚫
		Threats (Invasive species)	⚫ 🔴

Level of biological organization	Biodiversity (Ecosystem) attributes	Indicator	Indicator selected by three expert panels
	Structure	Major structural canopy	🟢 ⚫
		Tree height	⚫
		Tree dbh	⚫
		Stand stock	⚫
		Tree spacing	⚫
		Understory vegetation	🟢 ⚫
		Forest product harvest	⚫
		Population structure	🟢 🔴
		Morphological variability	🟢
		Edaphic factors	🟢 ⚫ 🔴
		Topographic factors	🟢 ⚫
		Deadwood stock	⚫
		Habitat suitability	⚫ 🔴
		Threats (Invasive species)	🔴
	Function	Demographic processes	🟢 ⚫
		Effect of abiotic disturbances	🟢 ⚫ 🔴
		Population dynamics	🟢
		Genetic diversity	🟢
		Effect of biotic disturbances	⚫ 🔴
		Population dynamics	🟢 ⚫ 🔴
		Forest resilience	⚫ 🔴
Genetic*	***Composition***	Genetic diversity (e.g., allelic diversity, presence of particular rare/deleterious recessive alleles)	
	Structure	Viable population size	
		Genetic diversity (e.g., heterozygosity, heritability)	
	Function	Genetic diversity (e.g., inbreeding depression, outbreeding rate, gene flow, mutation rate)	

*Genetic level indicators were not discussed.

3.4 Selection of forest biodiversity indicators relevant to forest management units

The expert panel constituting the representatives from FMUs, forestry concessions and other field level forestry professionals selected the highest number of indicators (56 from the list of 58 indicators) relevant to forest management unit level biodiversity monitoring system (Annex 3). Academia and research expert panel selected 48 indicators (Annex 1). The panel constituting the representatives from government agencies (i.e., National Parks, Climate Change and Fire Prevention Agency, Natural Resource Conservation Agency, Forestry Agency of South Sumatra, Planning and Developing Agency of South Sumatra) suggested 33 indicators were relevant from the indicator list (Table 2) to FMU level biodiversity monitoring system (Annex 2).

All of the three panels applied the three-layered filters (Figure 2) to select the highly rewarding forest biodiversity indicators applicable for forest management unit level biodiversity monitoring system (see section below).

3.5 Selection of highly rewarding indicators applicable to FMU level forest biodiversity monitoring system

At the FMU level forest biodiversity monitoring, after applying the initial, primary and secondary filters, collectively, 40 indicators were selected as highly rewarding/ high performance indicators (Table 5). The highly rewarding/high-performance indicators are those which were screened by all of the three sets of filters described in Figure 2.

Out of the 40 indicators, four indicators were common to all of the expert panels. Land cover types, land use types, forest and forest land restoration, and species richness were the four highly emphasized indicators. Those indicators were also highly preferred during the indicator ranking session (Section 3.2, Table 3). There were 12 indicators common to at least two expert panels. They include species richness, keystone species, landscape fragmentation, effect of climate change, land cover types (area, proportion), forest carbon stock, forest types, forest condition, invasive species, tree height, tree dbh and stand stock. Remaining indicators were selected by at least one of the panels.

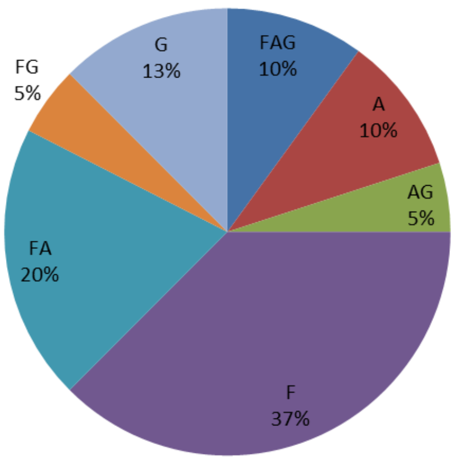


Figure 4: Quantity of highly rewarding/ high performance indicators (percent of collectively selected indicators) applicable to forest management unit level forest biodiversity monitoring system selected by different combinations of expert panels. F = Expert panel constituting the representatives from forest management units (FMUs), forestry concessions and other field level forestry professionals; A = Expert panel constituting the representatives from academics (i.e., Universities) and research institutes; and G = Expert panel constituting the representative from government agencies (mostly decision making level).

The expert panel constituting the representatives from FMUs, forestry concessions and other field level forestry professionals selected the highest number of indicators (29 from the list of 58, i.e., 50% of the total forest biodiversity indicators presented in Table 2) as rewarding/high-performance indicators applicable to FMU level (Table 5, Annex 3). The expert panel suggested that the FMUs' existing financial/ technical capacities are limited and thus external supports are needed, to monitor the selected 10 indicators (out of 29). They included species richness, forest types, forest condition, forest/ forest land restoration, species distribution, climatic factors, edaphic factors, keystone species, growing stock and genetic diversity (Annex 3). Rewarding indicators that the FMUs are able to monitor with the existing financial and technical capabilities are: land cover types, land cover (area, proportion), land use types, forest carbon stock, species diversity, topographic factors, species richness, invasive species, tree height, tree dbh, stand stock, tree spacing, understorey vegetation, forest product harvest, population structure, edaphic factors, topographic factors, and population dynamics.

Table 5: List of highly rewarding/high-performance indicators applicable to forest management units (FMUs) selected by the experts panels.

(● = selected by the FMU, forestry concession and other field level forestry practitioners, ● = selected by the academicians and researchers, ● = selected by the representatives from government agencies)

Level of biological organization	Biodiversity (Ecosystem) attributes	Indicator	Indicator selected by three expert panels
Landscape level	*Composition*	Land cover types (e.g., types)	● ● ●
		Species richness	● ●
		Ecosystem/Habitat type/ Patch types	●
	Structure	Land cover types (area, proportion	● ●
		Ecosystem/Habitat type	●
		Land use types	● ● ●
		Landscape shape	
		Connectivity	
		Degree of isolation	
		Landscape fragmentation	● ●
		Transportation effect	
		Silvicultural operations	
	Function	Forest carbon stock	● ●
		Nutrient cycling	
		Successional stage	
		Effect of abiotic disturbances	●
		Effect of biotic disturbances	
		Effect of climate change	● ●
Ecosystem/ Habitat	*Composition*	Species diversity	●
		Ecological processes	
	Structure	Forest types	● ●
		Forest condition	● ●

Level of biological organization	Biodiversity (Ecosystem) attributes	Indicator	Indicator selected by three expert panels
		Forest area in compliance schemes	⚫
		Forest/land Restoration	🟢 ⚫ 🔴
		Species distribution	🟢
		Climatic factors	🟢
		Edaphic factors	🟢
		Topographic factors	🟢
		Structural canopy/elements	
		Habitat features	🔴
	Function	Keystone species	🟢 🔴
		Gene flow	
		Disturbances	
		Productivity and resilience	
Population-Species/ stand level	***Composition***	Species richness	🟢 ⚫ 🔴
		Growing stock	🟢
		Threats (Invasive species)	🟢 ⚫
	Structure	Major structural canopy	
		Tree height	🟢 ⚫
		Tree dbh	🟢 ⚫
		Stand stock	🟢 ⚫
		Tree spacing	🟢
		Understory vegetation	🟢
		Forest product harvest	🟢
		Population structure	🟢
		Morphological variability	
		Edaphic factors	🟢
		Topographic factors	🟢
		Deadwood stock	
		Habitat suitability	🔴
		Threats (Invasive species)	🟢
	Function	Demographic processes	
		Effect of abiotic disturbances	🔴
		Population dynamics	🟢
		Genetic diversity	🟢
		Effect of biotic disturbances	🔴
		Population dynamics	
		Forest resilience	🔴
Genetic*	***Composition***	Genetic diversity (e.g., allelic diversity, presence of particular rare/deleterious recessive alleles)	
	Structure	Viable population size	
		Genetic diversity (e.g., heterozygosity, heritability)	
	Function	Genetic diversity (e.g., inbreeding depression, outbreeding rate, gene flow, mutation rate)	

*Genetic level indicators were not discussed.

4. Application of the highly rewarding indicators establishing a participatory forest biodiversity monitoring system at FMU level

Conservation and maintenance of forest biological diversity is one of the seven essential elements (components) of SFM[2], and forest biodiversity indicators are quantitative, qualitative or descriptive attributes for assessing and monitoring the element. When measured and monitored periodically, the indicators show changes and trends in the component. A time series of the values of any measurable or clearly descriptive forest biodiversity indicator provides the information on the direction of change, either towards or away from SFM from ecological perspective.

Although the overall sustainability of a nation's forests depends substantially on actions taken at the national scale, in principle, the national-level analysis of indicators may involve the aggregation of data collected at the FMU scale. Therefore, analysis of indicators at the FMU scale is the key to assessing, monitoring and reporting on SFM (ITTO, 2016). Thus, a monitoring tool, that allows the FMU and local stakeholders to track the progress towards the goal of sustainability, is essential.

Conservation and maintenance of forest biological diversity is one of the seven essential elements (components) of SFM[3], and forest biodiversity indicators are quantitative, qualitative or descriptive attributes for assessing and monitoring the element. When measured and monitored periodically, the indicators show changes and trends in the component. A time series of the values of any measurable or clearly descriptive forest biodiversity indicator provides the information on the direction of change, either towards or away from SFM from ecological perspective. The purpose of forest biodiversity monitoring to pilot case study at FMU level is to derive lessons for improving management practices that promotes the biodiversity conservation while maximizing the value of forest products and the services that forests provide. Maintaining biodiversity in the FMUs forest areas is one of the focuses of BIOCLIME's support in South Sumatra.

Forest management unit can be defined as a specified operational forest area with permanently demarcated forest boundaries, managed by a legally established localized body called 'Kesatuan Pengelolaan Hutan or KPH' with a set of explicit economic, social and ecological objectives expressed in a self-contained multi-year and long-term forest management plan (FMP). The forest managing body is also

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[2] Enabling conditins; Extent and conditions of forests; Forest ecosystem and health; Forest production; Biodiversity; Soil and watwer protection; and Economic, social and cultural aspects.

[3] Enabling conditins; Extent and conditions of forests; Forest ecosystem and health; Forest production; Biodiversity; Soil and watwer protection; and Economic, social and cultural aspects.

called FMU, and is responsible for ensuring that SFM is implemented. In Indonesia, based on the dominant forest types/forest functions, the FMU is categorized as: Conservation FMU (KPHK), Protection FMU (KPHL), and Production FMU (KPHP).

Figure 5 below presents a simple-to-use toolkit for a participatory forest biodiversity monitoring, which is divided into six stages (adapted from ANSAB, 2010). The stages are described briefly in the following section.

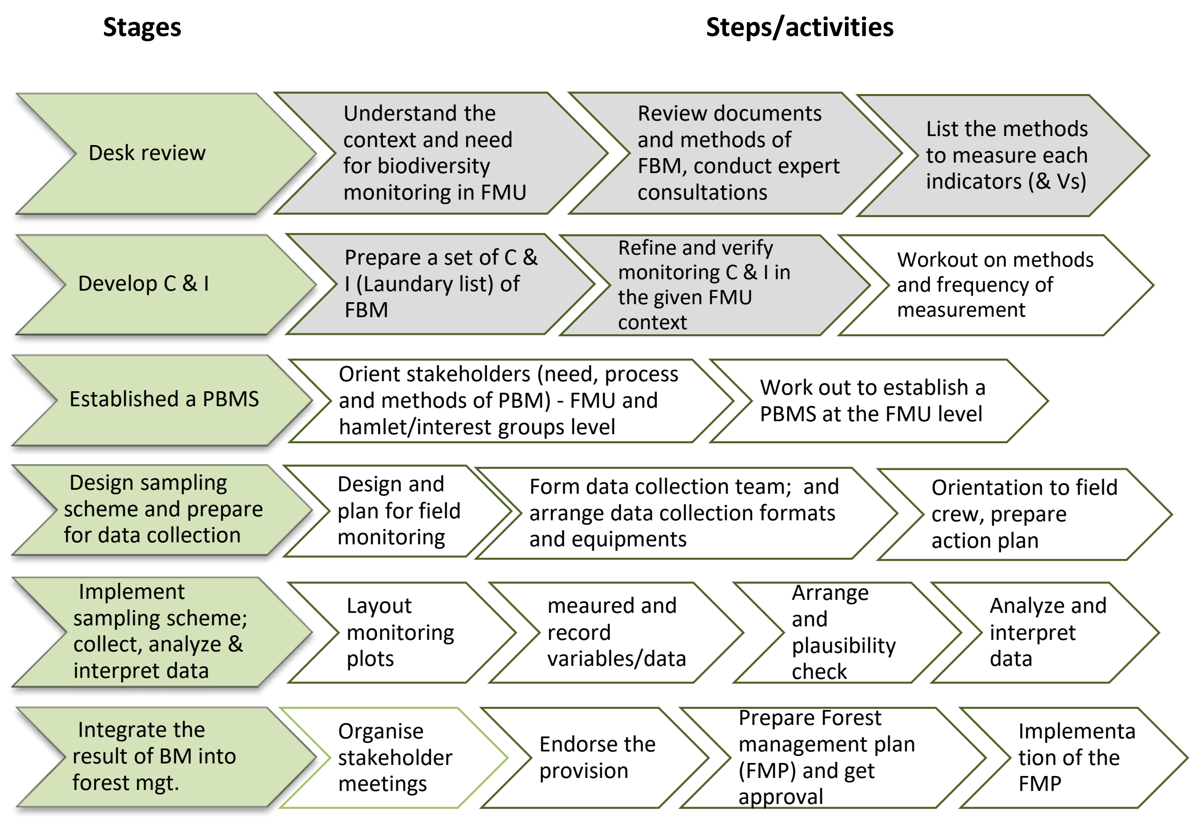

Figure 5: Stages of participatory forest biodiversity monitoring (Adopted from ANSAB, 2010). Steps/activities are accomplished during the BICAMSu project phase are shaded.

Stage 1. Desk review

- Gather basic information about the FMUs where the management is planning to conduct biodiversity monitoring, and understand the context and need for forest biodiversity monitoring in the FMU.

  For forest biodiversity monitoring to be meaningful, clear understanding of the goal and objective (what and why?) of the monitoring is necessary. For instance, in a managed forest (i.e., Production FMU), purpose of monitoring could be to minimize the impact of management interventions on the forest biodiversity and the ecological processes. Monitoring in the protected areas or conservation areas, for example KPHK and KPHL, could be to assess particular sets of species, or particular elements of biodiversity or ecological integrity as a whole. Ecological integrity is defined as the capacity of ecosystem to support and maintain a community of organization that has structural, compositional and functional organization comparable to that of similar yet undisturbed ecosystem. Once the purpose of the monitoring is clear, next step would be the formulations of specific questions to be answered by monitoring. These questions are formulated based on the identified goal and objective. For instance we might want to explore if the management practice are against agreed standards and goal of the sustainable forest management or not? If it is so, they might still have impact on biodiversity. The indicator selected should link the changes in the biodiversity with the management impacts.

Other required information might include: (local) stakeholders' interest on biodiversity monitoring, benefits of the monitoring, extent and condition of forests (for example, forest types and distribution, forest area under each forest type, extent of forests committed to production and protection, FMP, forest area in compliance schemes, change in forested area, forest condition), information related to forest ecosystem health and resilience (for example, threats to forests – drivers and pressures, invasive species, area of degraded forest or forest land, area of degraded forest or forest land restored), information on forest production (e.g., forest inventory, forest growth and yield, actual and allowable of wood and non-wood product harvest, forest product harvesting and tracking system or control mechanism, RIL and silvicultural operations), forest biological diversity (area of protected forest, species diversity, threatened forest-dependent species, procedures for conserving tree species diversity, biodiversity conservation measures), use of forest products and the services provided by the forests (type, pattern), participation of local communities and other stakeholders in forest management, existing forest monitoring system, mechanisms for the equitable sharing of the costs and benefits of forest management, control of illegal logging, availability of professionals and technical personnel to perform and support forest management including biodiversity monitoring, capacity building and workforce for forest management, and dependency of local communities on forest for their livelihoods.

- Prepare a list of experts with whom consultation about biodiversity monitoring would be necessary and useful.
- Review recent biodiversity-related documents/literature (e.g., National Biodiversity Strategies and Action Plans, National Reports, Clearing-House Mechanisms, laws and regulations), other reports, articles and other relevant sources. These provides valuable insights, among others, about the national biodiversity (periodic) targets, criteria and indicators to be monitored, methods and tools

to assess/measure the indicators and verifiers, potential sources of information related to the indicators and verifiers.

- Based on the review, prepare a list and review the specific methods for measuring and assessing each of the C & I.

Stage 2. Develop criteria and indicators for a for biodiversity monitoring system

- Prepare a list or set of Criteria and Indicators for forest biodiversity monitoring system (Please see Section 2.1 and 2.2 of Chapter 2). Selection of forest biodiversity indicators also guided by the forest biodiversity management approach we adopt. To discuss about the forest biodiversity monitoring approaches is out of the scope of this report.[4]
- Selecting rewarding and high performance indicators from the (laundry) list. A stakeholder workshop can be organized to refine the C & I at the local context involving participants from forest management unit (FMU), representatives from interest groups (traditional users, NTFP collectors, entrepreneurs etc.), government agencies, forestry practitioners/ professionals working for I/NGOs, private companies related to forest conservation and management, representatives from CBOs and civil society organizations, civil society and academic and research institutions. Frameworks suggested by Gardner (2010) are very useful to refine the C&I at the FMU context. The frameworks include different selection filter: Indicator viability, indicators responsiveness to the forest management impact, cost effectiveness (e.g., cost of data collection and processing), relevance to biodiversity conservation goals, and generality of application, cross-taxon representation and prior ecological knowledge of a species group. The process of refining indicators to the local context using a participatory approach (through stakeholder workshop) is presented in Section 2.3 and 2.4 of Chapter 2.
- Workout on methods and frequency of measurement and monitoring for the selected indicators and their verifiers (For the examples, see Table 1 and references mentioned in the Table for the methods)

[4] ’Implementation’ monitoring approach for assessment of management activities needs ‘management process’ indicators. ‘Effectiveness monitoring’ approach to assess the performance with respect to forest structure and function requires structural and ecological process indicators. Meanwhile, if the effectiveness monitoring approach is to assess the performance with respect to biodiversity, we need to involve biological indicators (environmental, biodiversity and ecological indicators) and target species. If the FMU management want to improve the understanding of the processes that link changes in forest management practices to changes in biodiversity via intermediate changes in the structure and function of forest (i.e., evaluation of cause-effect relationship), ‘validation’ monitoring approach accompanied with long term research is to be adopted. The approach involves indicators of all types – management process, structural, functional and biological indicators.

Stage 3. Establish a participatory forest biodiversity monitoring system

The participation of local people; FMU-level forestry practitioners, decision-makers, and managers; and other range of relevant stakeholders, for example, prevailing and concerned research and academic institutions; and community based organizations in forest biodiversity monitoring is crucial not only for local legitimacy and ownership of the entire processes but also for the acceptance of the outcomes of the processes.

- Orientation for biodiversity monitoring: Organize orientation sessions for biodiversity monitoring for the FMU personnel who did not participate in the stakeholder workshop described in Stage 2. In the sessions, the FMU ensures the participation of major forest stakeholders including interest groups as described earlier and/or as identified in the FMU Forest Management Plan. The content of the sessions include: defining biodiversity and biodiversity monitoring, objectives and need of and benefits from biodiversity monitoring, activities to achieve the objectives, need for participatory biodiversity monitoring, and obligations and roles of each stakeholder to establish, implement and monitoring the system.
- Organize a workshop to form a system of biodiversity monitoring. Major points/agenda that need to be discussed and decided during the workshop might include:
    - Decide what to monitor: Identify and decide resources and habitats to be monitored under the monitoring program
        - protection/conservation area of high social and economic importance
        - high conservation value forest species
        - focal species, for example, area-limited, dispersal-limited, resource-limited, process-limited species, and keystone species
        - target species of particular conservation such as endemic, threatened, rare and endangered species
        - target species of management concern, e.g., invasive species, pest species that may have significant impacts on local biodiversity
        - species of economic and cultural importance for local people, for example, NTFP species
        - flagship species, e.g., rhino, tiger, orangutan

    - Identify the major drivers and pressures over the forest resources and habitats; and associated biodiversity (threats could be- intentional forest fire, illegal logging, encroachment and slash-and-burn, overgrazing, over harvesting of timber and NTFPs, invasive species, pest and pathogens, natural calamities- forest fire etc.)

- Prioritize the threat using agreed criteria, for example, area coverage, intensity, frequency, urgency and feasibility)
- Decide which forest management practices are to be monitored (if one of the objectives of biodiversity monitoring is to improve the understanding of the processes that link changes in forest management to changes in biodiversity).
- Build a competent monitoring team under the leadership of the FMU
- FMU identifies the methods for the measurement of C&I and verifiers in support of the experts
- Decide the time schedule for the field work
- Discuss and determine the facilities, required equipment and benefits for the team
- Determine how to cover the cost of forest biodiversity monitoring
    - FMU itself?
    - Intended contributions from forestry concessions, private entrepreneurs and other stakeholders?
    - Possible support from other governmental, non-government organizations, conservation NGOs?
- Arrange experts and logistics for data collection and analysis
    - Capacity building of FMU and stakeholders – to prepare local resource persons
    - Seek support from other governmental, non-government organizations, conservation NGOs in the beginning and for short-term?
- Discuss and endorse the outputs and decisions of the workshop by the FMU and/or competent authority

Stage 4. Design a sampling scheme; and develop a plan and prepare for data collection

Forest biodiversity monitoring should not be perceived as blind data gathering. But, in part, it has been so (Noss, 1990). A proper field sampling design to collect representative samples from the targeted population in the field is crucial for a biodiversity monitoring system.

- Select monitoring sites for identified questions and objectives, and design/ choose sampling design (sampling type, e.g., randomized systematic sampling; sampling intensity - high or low intensive)
- Carefully developed data collection scheme – which is crucial for effective and efficient fieldwork.
- Form a data collection team (or an inventory crew), in general, of 5-7 members, specifying role/ responsibilities of each member according to their interest and capacity (expertise). The FMU is recommended to include a villager who is able to identify plant species in the area (i.e., tree/ species identifier) in the team.

- Arrange data collection equipment and formats, stationery items and logistics required by the field crew.
- Provide crew members needed theoretical and practical orientation including sessions:
    - Objectives and forest biodiversity sub-end points of concern (recap)
    - Indicators and verifiers (recap)
    - Specification (measurements) of the verifiers
    - Monitoring methods and techniques
    - Equipment handling (calibration, orientation and use) and using materials
    - Data recording on specified data collection formats
- Develop an action plan for forest biodiversity monitoring, which includes:
    - Activities – design and planning for field work, monitoring the indicators/ verifiers and recording, analysis and interpretation, intervention design, application etc.
    - Time period for each activities
    - Methods and techniques for each activity
    - Responsible person the activities

Stage 5. Implement sampling scheme; and collect, analyze and interpret the data

- Lay out the sampling/ monitoring plots – all treatments and controls should be replicated.
- Measure and record the verifiers (monitoring data) – using prescribed methods/ techniques, time and frequency.
- Analyze trends (increasing, same, and decreasing) comparing with baseline data (i.e., with status of previous measurements/ years) and recommend management actions:
    - Temporal series of measurements (of the verifiers or monitoring data) must be analyzed in a statistically rigorous way
    - Verify how well the selected indicators and verifiers correspond to the biodiversity monitoring objectives and the bio-diversity sub-end points of concern.
    - Synthesize the results into an assessment that is relevant to policy makers including FMU (managers) and concerned stakeholders who develops and implement FMU Forest Management Plan.
- Maintained a database

Stage 6. Integrate the results of forest biodiversity monitoring in the FMU Forest Management Plan (FMU-FMP)

- Organize stakeholder meetings and present the results (assessment report mentioned in stage 5), interpret how the results from the biodiversity monitoring have implications on sustainable management of forests. If the assessment can be translated into positive changes in management practices and directions; in planning assumptions; implemented schemes and regulations; the biodiversity monitoring scheme will have proved itself a powerful tool for conservation and sustainable management of forests (Noss, 1990).

- Stakeholder meetings can be organized at different levels- FMU level, village level
- The meetings suggest:
    - Which forest management practices and directions are essential in the FMU-FMP for responsible forest management while maintaining and enhancing forest biodiversity
    - Which provisions, schemes and regulations (for example, certification) is essential in the FMU-FMP
    - Which enhancing factors (e.g., silvicultural operations, RIL, forest restoration, afforestation, controlled fire, controlled grazing, bush clearing, shrub-land management) are essential in the FMU-FMP.
- Group and sort the suggestions from the above meetings.
- Identify which forest management practices/ provisions are beneficial to SFM and biodiversity conservation, and thus to be retained; which new ones should be adopted and implemented; and which ones implemented in the past be avoided (prepare a list).
- Endorse the list of the forest management practices/ provisions by a stakeholder forum workshop at the FMU level. The FMU level stakeholder forum workshop might endorse after some refinement. If the agreed practices and provisions comprise a significant deviation from previous FMU-FMP and prevailing relevant government guidelines, laws and regulations; the FMU should lead the rigorous debate and for the necessary refinements.
- Get agreement of the management practices/ provisions by the competent authority. Some minor amendments might be inevitable in this approval process.
- The agreed forest management practices/ directions, provisions and enhancing factors should be integrated while writing the FMU-FMP. If there are new concerns, these should be incorporated and addressed.

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6. Annexes

Annex 1: Indicator selected by the experts representing academia (universities) and research agencies.

Level of biological organization	Biodiversity (Ecosystem) attributes	Indicator	Relevant indicator		Indicator selection applicable to FMU		
			Sumatra province	FMU level	Initial filter[1]	Primary filter[2]	Secondary filter[3]
Landscape level	*Composition*	Land cover types (e.g., types)	●	●	●	●	●
		Species richness	●	●	●		
		Ecosystem/Habitat type/ Patch types	●	●	●	●	●
	Structure	Land cover types (area, proportion)	●	●	●	●	●
		Ecosystem/Habitat type	●	●	●	●	●
		Land use types	●	●	●	●	●
		Landscape shape					
		Connectivity	●	●	●		
		Degree of isolation	●	●	●		
		Landscape fragmentation	●	●	●	●	●
		Transportation effect	●	●	●		
		Silvicultural operations	●	●	●	●	
	Function	Forest carbon stock	●	●	●	●	●
		Nutrient cycling					
		Successional stage	●	●	●		
		Effect of abiotic disturbances	●	●	●	●	●
		Effect of biotic disturbances	●	●	●		
		Effect of climate change	●	●	●	●	●
Ecosystem/ Habitat	*Composition*	Species diversity	●	●	●		
		Ecological processes					
	Structure	Forest types	●	●	●	●	●
		Forest condition	●	●	●	●	●
		Forest area in compliance schemes	●	●	●	●	●
		Forest/land Restoration	●	●	●	●	●
		Species distribution	●	●	●	●	
		Climatic factors	●	●	●	●	
		Edaphic factors	●	●	●		
		Topographic factors	●	●	●		
		Structural canopy/elements	●	●	●		
		Habitat features					
	Function	Keystone species	●	●	●		
		Gene flow					
		Disturbances	●	●	●		
		Productivity and resilience	●	●	●		

Level of biological organization	Biodiversity (Ecosystem) attributes	Indicator	Relevant indicator		Indicator selection applicable to FMU		
			Sumatra province	FMU level	Initial filter[1]	Primary filter[2]	Secondary filter[3]
Population-Species/ stand level	***Composition***	Species richness	●	●	●	●	●
		Growing stock	●	●	●	●	
		Threats (Invasive species)	●	●	●	●	●
	Structure	Major structural canopy	●	●	●		
		Tree height	●	●	●	●	●
		Tree dbh	●	●	●	●	●
		Stand stock	●	●	●	●	●
		Tree spacing	●	●	●		
		Understory vegetation	●	●	●		
		Forest product harvest	●	●	●		
		Population structure					
		Morphological variability					
		Edaphic factors	●	●	●		
		Topographic factors	●	●	●		
		Deadwood stock	●	●	●	●	
		Habitat suitability	●	●	●		
		Threats (Invasive species)					
	Function	Demographic processes	●	●	●	●	
		Effect of abiotic disturbances	●	●	●		
		Population dynamics					
		Genetic diversity					
		Effect of biotic disturbances	●	●			
		Population dynamics	●	●			
		Forest resilience	●	●			
Genetic[4]	***Composition***	Genetic diversity (e.g., allelic diversity, presence of particular rare/deleterious recessive alleles)					
	Structure	Viable population size					
		Genetic diversity (e.g., heterozygosity, heritability)					
	Function	Genetic diversity (e.g., inbreeding depression, outbreeding rate, gene flow, mutation rate)					

[1]Initial selection filter: indicator viability (availability of necessary field expertise, laboratory expertise, and of proven sampling techniques

[2]Primary selection filter: cost-effectiveness (cost-efficiency, indicator responsiveness)

[3]Secondary selection filter: relevance to biodiversity goals, prior knowledge, generality in application

[4]Genetic level indicators were not discussed.

Annex 2: Indicator selected by the experts representing government agencies (decision makers).

Level of biological organization	Biodiversity (Ecosystem) attributes	Indicator	Relevant indicator		Indicator selection applicable to FMU		
			Sumatra province	FMU level	Initial filter[1]	Primary filter[2]	Secondary filter[3]
Landscape level	***Composition***	Land cover types (e.g., types)	●	●	●	●	●
		Species richness	●	●	●	●	●
		Ecosystem/Habitat type/ Patch types	●	●	●	●	
	Structure	Land cover types (area, proportion)	●	●	●	●	
		Ecosystem/Habitat type					
		Land use types	●	●	●	●	●
		Landscape shape					
		Connectivity					
		Degree of isolation	●	●	●	●	
		Landscape fragmentation	●	●	●	●	●
		Transportation effect	●	●	●	●	
		Silvicultural operations					
	Function	Forest carbon stock	●	●	●	●	
		Nutrient cycling					
		Successional stage	●	●	●		
		Effect of abiotic disturbances					
		Effect of biotic disturbances					
		Effect of climate change	●	●	●	●	●
Ecosystem/ Habitat	***Composition***	Species diversity	●	●	●		
		Ecological processes					
	Structure	Forest types	●	●	●		
		Forest condition	●	●	●		
		Forest area in compliance schemes					
		Forest/land Restoration	●	●	●	●	●
		Species distribution	●	●	●		
		Climatic factors					
		Edaphic factors	●	●	●		
		Topographic factors	●	●	●		
		Structural canopy/elements	●	●	●		
		Habitat features	●	●	●	●	●
	Function	Keystone species	●	●	●	●	●
		Gene flow					
		Disturbances	●	●	●		
		Productivity and resilience	●	●	●		
Population-Species/ stand level	***Composition***	Species richness	●	●	●	●	●
		Growing stock					
		Threats (Invasive species)	●	●	●	●	
	Structure	Major structural canopy					

Level of biological organization	Biodiversity (Ecosystem) attributes	Indicator	Relevant indicator		Indicator selection applicable to FMU		
			Sumatra province	FMU level	Initial filter[1]	Primary filter[2]	Secondary filter[3]
		Tree height					
		Tree dbh					
		Stand stock					
		Tree spacing					
		Understory vegetation					
		Forest product harvest					
		Population structure	●	●			
		Morphological variability					
		Edaphic factors	●	●	●		
		Topographic factors					
		Deadwood stock					
		Habitat suitability	●	●	●	●	●
		Threats (Invasive species)	●	●	●	●	
	Function	Demographic processes					
		Effect of abiotic disturbances	●	●	●	●	●
		Population dynamics					
		Genetic diversity					
		Effect of biotic disturbances	●	●	●	●	●
		Population dynamics	●	●			
		Forest resilience	●	●	●	●	●
Genetic[4]	***Composition***	Genetic diversity (e.g., allelic diversity, presence of particular rare/deleterious recessive alleles)					
	Structure	Viable population size					
		Genetic diversity (e.g., heterozygosity, heritability)					
	Function	Genetic diversity (e.g., inbreeding depression, outbreeding rate, gene flow, mutation rate)					

[1]Initial selection filter: indicator viability (availability of necessary field expertise, laboratory expertise, and of proven sampling techniques

[2]Primary selection filter: cost-effectiveness (cost-efficiency, indicator responsiveness)

[3]Secondary selection filter: relevance to biodiversity goals, prior knowledge, generality in application

[4]Genetic level indicators were not discussed.

Annex 3: Indicator selected by the experts representing forest management units (FMUs), forestry concessions and other professionals in implementing level. Red bullets indicate the indicators which needs external support to be assessed by the FMUs.

Level of biological organization	Biodiversity (Ecosystem) attributes	Indicator	Relevant indictor		Indicator selection applicable to FMU		
			Sumatra province	FMU level	Initial filter[1]	Primary filter[2]	Secondary filter[3]
Landscape level	***Composition***	Land cover types (e.g., types)	●	●	●	●	●
		Species richness		●	●[4] (UNSRI)	●	●
		Ecosystem/Habitat type/ Patch types	●	●			
	Structure	Land cover types (area, proportion)	●	●	●	●	●
		Ecosystem/Habitat type		●			
		Land use types		●	●	●	●
		Landscape shape	●	●	●		
		Connectivity	●	●			
		Degree of isolation		●			
		Landscape fragmentation	●	●			
		Transportation effect	●	●			
		Silvicultural operations		●	● (REKI)		
	Function	Forest carbon stock	●	●	●	●	●
		Nutrient cycling	●	●			
		Successional stage	●				
		Effect of abiotic disturbances	●				
		Effect of biotic disturbances		●			
		Effect of climate change	●	●	●		
Ecosystem/ Habitat	***Composition***	Species diversity	●	●	●	●	●
		Ecological processes		●			
	Structure	Forest types		●	● (UMP)	●	●
		Forest condition	●	●	● (UMP)	●	●
		Forest area in compliance schemes		●			
		Forest/land Restoration	●	●	● (REKI, PT. GAL)	●	●
		Species distribution		●	● (UNSRI)	●	●
		Climatic factors	●	●	● (BMKG)	●	●
		Edaphic factors		●	● (UNSRI)	●	●
		Topographic factors		●	●	●	●
		Structural canopy/elements		●	●		
		Habitat features		●			
	Function	Keystone species	●	●	● (BKSDA)	●	●
		Gene flow		●			
		Disturbances	●	●			
		Productivity and resilience	●	●	●		

Level of biological organization	Biodiversity (Ecosystem) attributes	Indicator	Relevant indictor		Indicator selection applicable to FMU		
			Sumatra province	FMU level	Initial filter[1]	Primary filter[2]	Secondary filter[3]
Population-Species/ stand level	***Composition***	Species richness	●	●	●	●	●
		Growing stock		●	● (UMP)	●	●
		Threats (Invasive species)		●	●	●	●
	Structure	Major structural canopy	●	●			
		Tree height		●	●	●	●
		Tree dbh		●	●	●	●
		Stand stock		●	●	●	●
		Tree spacing		●	●	●	●
		Understory vegetation	●	●	●	●	●
		Forest product harvest		●	●	●	●
		Population structure	●	●	●	●	●
		Morphological variability	●	●			
		Edaphic factors	●	●	●	●	●
		Topographic factors	●	●	●	●	●
		Deadwood stock		●	●		
		Habitat suitability		●			
		Threats (Invasive species)		●	●	●	●
	Function	Demographic processes	●	●			
		Effect of abiotic disturbances	●	●			
		Population dynamics	●	●	●	●	●
		Genetic diversity	●	●	● (UNSRI)	●	●
		Effect of biotic disturbances		●			
		Population dynamics	●	●			
		Forest resilience		●			
Genetic[5]	***Composition***	Genetic diversity (e.g., allelic diversity, presence of particular rare/deleterious recessive alleles)					
	Structure	Viable population size					
		Genetic diversity (e.g., heterozygosity, heritability)					
	Function	Genetic diversity (e.g., inbreeding depression, outbreeding rate, gene flow, mutation rate)					

[1]Initial selection filter: indicator viability (availability of necessary field expertise, laboratory expertise, and of proven sampling techniques

[2]Primary selection filter: cost-effectiveness (cost-efficiency, indicator responsiveness)

[3]Secondary selection filter: relevance to biodiversity goals, prior knowledge, generality in application

[4]The expert panel suggested that the FMUs existing financial/ technical capacities are limited and thus external supports are needed, to monitor the selected 10 indicators (out of 29).

[5]Genetic level indicators were not discussed.

(UNSRI = Sriwijaya University, Palembang; REKI =
UMP = University of Muhammadiyah, Palembang; PT. GAL = Forestry concession - carbon license; BMKG =
BKSDA = Natural Resource Conservation Agency)

Annex 4: List of highly rewarding/high-performance indicators applicable to forest management units (FMUs) selected by the experts.

Level of biological organization	Biodiversity (Ecosystem) attributes	Indicator	Rewarding indicators		
			FMU experts	Academic & Researcher	Government agencies
Landscape level	***Composition***	Land cover types (e.g., types)	●	●	●
		Species richness	●		●
		Ecosystem/Habitat type/ Patch types		●	
	Structure	Land cover types (area, proportion)	●	●	
		Ecosystem/Habitat type		●	
		Land use types	●	●	●
		Landscape shape			
		Connectivity			
		Degree of isolation			
		Landscape fragmentation		●	●
		Transportation effect			
		Silvicultural operations			
	Function	Forest carbon stock	●	●	
		Nutrient cycling			
		Successional stage			
		Effect of abiotic disturbances		●	
		Effect of biotic disturbances			
		Effect of climate change		●	●
Ecosystem/ Habitat	***Composition***	Species diversity	●		
		Ecological processes			
	Structure	Forest types	●	●	
		Forest condition	●	●	
		Forest area in compliance schemes		●	
		Forest/land Restoration	●	●	●
		Species distribution	●		
		Climatic factors	●		
		Edaphic factors	●		
		Topographic factors	●		
		Structural canopy/elements			
		Habitat features			●
	Function	Keystone species	●		●
		Gene flow			
		Disturbances			
		Productivity and resilience			
Population-Species/ stand level	***Composition***	Species richness	●	●	●
		Growing stock	●		
		Threats (Invasive species)	●	●	
	Structure	Major structural canopy			

Level of biological organization	Biodiversity (Ecosystem) attributes	Indicator	Rewarding indicators		
			FMU experts	Academic & Researcher	Government agencies
		Tree height	●	●	
		Tree dbh	●	●	
		Stand stock	●	●	
		Tree spacing	●		
		Understory vegetation	●		
		Forest product harvest	●		
		Population structure	●		
		Morphological variability			
		Edaphic factors	●		
		Topographic factors	●		
		Deadwood stock			
		Habitat suitability			●
		Threats (Invasive species)	●		
	Function	Demographic processes			
		Effect of abiotic disturbances			●
		Population dynamics	●		
		Genetic diversity	●		
		Effect of biotic disturbances			●
		Population dynamics			
		Forest resilience			●
Genetic*	***Composition***	Genetic diversity (e.g., allelic diversity, presence of particular rare/deleterious recessive alleles)			
	Structure	Viable population size			
		Genetic diversity (e.g., heterozygosity, heritability)			
	Function	Genetic diversity (e.g., inbreeding depression, outbreeding rate, gene flow, mutation rate)			

* Genetic level indicators were not discussed.