Karst and conservation research in Indonesia and its implication to education

E Sulistiyowati1,4, Setiadi2, E Haryono3

1Department of Biology, UIN Sunan Kalijaga, Jl. Marsda Adisucipto No. 1 Yogyakarta, 55281, Indonesia
2Department of Anthropology, Universitas Gadjah Mada, Bulaksumur, Depok Sleman, Yogyakarta, 55281, Indonesia
3Department of Environmental Geography, Universitas Gadjah Mada, Bulaksumur, Depok Sleman, Yogyakarta, 55281, Indonesia
4Graduate School of Environmental Science, Universitas Gajah Mada, Bulaksumur, Depok Sleman, Yogyakarta, 55281, Indonesia

*Corresponding author: eka.sulistiyowati@uin-suka.ac.id

Abstract. Indonesia hosts a vast area of karst landscapes that expand from the island of Sumatra to Papua. Along with the implementation of the World Heritage List and Global Geopark Network, karst environment has become essential topics in Indonesia. By using SCOPUS and Google Scholar database, this paper examined trends of karst research in Indonesia. The result showed that karst related publications have shown to be increasing from 1994 to 2010, and grow more massively after 2010. Also, the publications can be classified into 1) conservation and biodiversity, 2) geophysical studies of karst, 3) environment and resource management, 4) forestry and agriculture, 5) archaeology and prehistoric life, 6) socio-cultural and education aspects. A wide gap occurred in research about conservation strategies at a more comprehensive and integrated scale, such as in a landscape, that takes a multidisciplinary and transdisciplinary approach at achieving sustainability. In terms of environmental education, the use of karst as a natural laboratory remained limited in subjects. Yet, it had excellent potential to be developed as a model for a multidisciplinary and transdisciplinary approach to environmental studies, to achieve the goal of Education of Sustainable Development (ESD).

Keywords: conservation, environment, karst, karst landscape

1. Introduction
Karst is a landscape characterized by spectacular underground water channels, caves, and morphologically unique land with extensive plateau, rugged terrain, deep valley, and carbonate towers [1,2]. It is formed on limestone bedrock and is positively affected by erosion and solutional process [2]. Karst landscape is home for about 20-25 % of earth population [2], many of which depend on its groundwater sources[3–5]. The combinations of the ecological niche, climatic, and edaphic variations shape unique surface and subsurface reliefs. Open conduits allow surface and sub-surface interaction, which in turn creates an isolated environment that leads to biodiversity endemism, including flora [6–8] and fauna diversities [9,10]. Some of the world’s karst has barely been touched and has been functioned as biodiversity reservoirs [11,12].
Although karst area hosts unique and endemic species, it is a very fragile landscape and is prone to habitat-destruction [5]. Loss of biodiversity is often attributed to threats facing the habitat [13], and irreversible habitat degradation [5]. Some literature expressly points out that the degradation of karst in Indonesia is generated by population increase, agricultural intensification, water and natural resources competition [2], deforestation [14], engineered infrastructures [15], roads, mining, and domestic uses [16].

Indonesia hosts a vast karst area, covering 15.4 million hectares from the Island of Sumatra to Papua [17], hence there will be a great potential to study karst biodiversity, primarily related to conservation strategies amid alarming anthropogenic disturbances. However, knowledge about karst and its conservation remains a limited study in Indonesia. This paper aims at reviewing research trends of karst and conservation, putting particular emphasis on prominent Indonesian karsts. While we do not intend to provide an extensive review, we will discuss some gaps in the literature and further potential research, including its implication to environmental education in Indonesia.

2. Methods

We conducted literature research on two databases, SCOPUS and Google Scholar. We used several keywords, such as “conservation”, “biodiversity”, “karst”, “karst landscape”, “deforestation”, “reforestation”, “flora”, “fauna”, and “education”. Although Google Scholar contains grey articles which have not been peer-reviewed, we maintain in using this source because we intend to include research published in the Indonesian Language. In total, we retrieved 554 papers since 1988 to 2020. The type of publication in this research is shown in table 1.

| Types of publications                  | Scopus | Google | Total |
|----------------------------------------|--------|--------|-------|
| Journal                                | 233    | 155    | 392   |
| Proceeding and preprint                | 42     | 59     | 101   |
| Dissertation, thesis, and final paper  | 0      | 23     | 23    |
| Paper and monograph                    | 2      | 12     | 14    |
| Book and book sections                 | 13     | 15     | 28    |
| Total number of articles               | 290    | 264    | 554   |

We omitted literature which does not have valid information regarding author(s), title, year of publication, and publisher(s). Since the topic is mostly interdisciplinary, we deal with a wide range of relevant issues such as conservation, biodiversity, geoscience, agriculture, forestry, and education. We conducted a descriptive analysis of literature from a critical point of view to estimate trends of karst research in Indonesia.

3. Karst and Conservation Research in Indonesia

3.1. General trends of karst research

To study the research trend, firstly, we generated a “world cloud” representation of words in the titles, keywords, and abstracts of our dataset (based on Google Scholar and Scopus searching). We used a word cloud engine (www.wordart.com) and identified the most frequently occurring words in that dataset (figure 1). The total number of words retrieved from titles, keywords, and abstracts were 38182. The word cloud analysis shows that the word “species” is the most occurring in karst-themed papers, about 12%. Other 19 important words include of Area 8%, Cave 7%, Forest, 7%, Conserve 6%, Study 6%, Biodiversity 6%, Use 5%, Region 5%, Soil 5%, Indonesia 4%, Water 4%, Gunungkidul 4%, Diversity 4%, Habitat 4%, Community, Limestone 3%, Ecosystem 3%, Plant 3% and Distribution 3%. The articles using terms such as “education” and “teaching” are rare; hence they could not be illustrated in figure 1.
The number of publications related to karst has shown to be steadily increasing from 1988 to 1990 and has started to grow more massively after 2010. The beginning of worldwide development of karst and conservation research began in the 1990s, coincident with the Rio Conference [18]. It also reflects the political commitment made by parties to ratify the CBD, and thus to reduce biodiversity loss by 2010 [19].

After 2010, research in karst in Indonesia experienced a rapid increase, with topics such as resource and environmental management, tourism (geotourism and ecotourism), landscape architecture, and archaeology. All of these topics reflect challenges of conservation, as it was predicted by [20]. The number of papers reached its peak in 2015-2020, with approximately 325 publications, this can be seen in figure.

Figure 1. a). Wordcloud analysis of titles, keywords, and based on both Scopus and Google Scholar database. This word cloud was created using wordart.com. b). The relative percentage of 20 most frequent words in karst-themed research, based on searches of Scopus and Google Scholar.

Figure 2. The trend on the number of publications from 1988-2019 on karst-themed research based on Scopus and Google Scholar database.

When we developed a more detailed category, we arrived at six topics of karst research. This classification was made by referring to previous review studies on karst, such as the hydrology of karst in Maroko [21], and the research review of karst research in China [22].
Table 2. Wide range of karst-research topics in Indonesia based on Scopus and Google Scholar dataset

| Topics                                           | Subtopics                                                                 | Scopus (n) | Google Scholar (n) |
|--------------------------------------------------|---------------------------------------------------------------------------|------------|--------------------|
| Study of biodiversity and karst environment      | ecosystem, species, genetic, landscape, new species, flora/fauna, endemism, hotspots, microbial diversity, algal diversity, caves and karst water biodiversity, landscape | 150        | 70                 |
| Geophysical studies of karst                     | geology, soils, geomorphology, hydrology, geosite/geopark, landscape science | 54         | 52                 |
| Environment and resource management              | Cave management, water management, alternative energy, mining, governance, ecotourism, geotourism, degradation, sustainability | 42         | 54                 |
| Forestry and Agriculture                         | crop species, food, cocoa industry, climate change, dryland agriculture, intercropping, livelihood, restoration and rehabilitation, forestry, timber production, deforestation and reforestation | 24         | 52                 |
| Archaeology and Prehistoric life                 | ancient biogeography, geoarchaeology, primaeval ecosystem, palaeoenvironment | 7          | 12                 |
| Sociocultural and Education Aspects              | local knowledge and ethnobiology, development, economics                 | 13         | 24                 |
| Total                                            |                                                                           | 290        | 264                |

3.2. Study of biodiversity and karst environment

The study of karst species still becomes a trend in karst-themed research, especially in Indonesia. The documentation of species and its ecological characters are widely studied by authors such as [23,23,24]. The majority of research within this topic is explored from two points of view; 1) native species characteristics related to endemism, hotspots in the exo-karstic and endo-karstic environment, 2) the biology of human-introduced exotic species such as sandalwood [25] and cacao [26]. This trend shows that the biodiversity of karst remains a big question for researchers. Potentially, new species could also be found. There are 150 articles retrieved from Scopus, and 70 of those from Google Scholar that discuss this topic from the perspectives of biodiversity at various level - genetic, species, ecosystem. Yet, we could only retrieve one article that studies biodiversity at the landscape level. It explored the dynamics of species and the fragmentations that occur in a landscape [24]. The summary of research in the biodiversity of karst in Indonesia can be seen in table 3.

Table 3. Summary of research in the biodiversity of karst in Indonesia.

| Topics                                           | Example of publication | Biodiversity being investigated | Karst region                                      |
|--------------------------------------------------|------------------------|--------------------------------|--------------------------------------------------|
| Topic 1: The investigation of new species        | [27]                   | Cyrtodactylus (Reptilia: Squamata: Gekkonidae) | Tuban and Yogyakarta                            |
|                                                  |                        | Caridina and Parisia (Genus)   | Karst caves in Sulawesi Selatan                   |
|                                                  | [28]                   | Nemacheilus tebo (Teleostei: Nemacheilidae) | Sangkulirang Karst, East Kalimantan, Kalimantan, Indonesia |
|                                                  |                        |                                |                                                  |

4
### Topics

| Topics                                                                 | Example of publication | Biodiversity being investigated            | Karst region                                      |
|----------------------------------------------------------------------|------------------------|-------------------------------------------|--------------------------------------------------|
| Topic 2: Community, habitat, ecosystem structure and distribution    | [30]                   | Begonia                                   | Matarombeo karst, Southeast Sulawesi              |
|                                                                    |                        |                                           | Caves in Gunung Sewu, Yogyakarta                 |
|                                                                    | [23]                   | Arthropods                                | Gombong karst, Central Java                       |
|                                                                    | - [31]                 | Bats (Order: Chiroptera)                  | - Borneo karst                                   |
|                                                                    | - [32]                 |                                           |                                                  |
|                                                                    | [33]                   | Plankton Diversity                        | Masigit-Pawon Cave, West Java                     |
|                                                                    | [34]                   | Teak and mahogany plantation              | Gunung Sewu karst                                |
|                                                                    | [35]; [36]             | Insects                                   | Gunung Sewu karst, Gunung Kidul Regency, Yogyakarta |
|                                                                    | [10]                   | Lampenflora                               | Caves in Gunung Sewu, Yogyakarta                 |
|                                                                    | [37]                   | *Casuarina equisetifolia*                 | Gunung Sewu karst, Gunung Kidul Regency, Yogyakarta and along the southern coast of Yogyakarta |
|                                                                    | [6, 14]                | Structure of Primeval vegetation          | Gunung Sewu karst                                |
| Topic 3: Biological (and genetic) characteristics                   | [38]                   | *Sorghum bicolor*                         | Gunungsewu                                       |
|                                                                    | [25]                   | *Santalum album* (Family: Santalaceae)    | Gunung Sewu, Yogyakarta                          |
| Topic 4: Environmental destruction and biodiversity protection       | [39]                   | *Pongo pygmaeus morio*                    | Sangkulirang Peninsula                           |
|                                                                    | [40]                   | *Pennisetum purpureum* cv. Mott           | Gombong karst, Central Java                      |
|                                                                    | [41]                   | *Anthocephalus macrophyllus*              | Gunung Sewu karst                                |
| Topic 5: Ethnobiology                                               | [42]                   | Medicinal plants                          | Gunung Sewu karst, Gunung Kidul Regency, Yogyakarta |

Table 3 illustrates a wide range of biodiversity research in karst environment in Indonesia, which are classified into five topics: (1) investigation of new species, (2) community, habitat, ecosystem structure and distribution, (3) biological (and genetic) characteristics, (4) environmental destruction and biodiversity protection, (5) ethnobiology. Research on new species still gets much attention, including flora and fauna in *exokarstic* or *endokarstic* environment. It shows that the possibility of finding new species is still prominent. Next, the trend relates to the ecology of plants and animals in karst, including investigations on habitat and community structures and species distributions. And finally, the trend is in topics that incorporate anthropogenic disturbance to karst biodiversity such as restoration of mining area and risk of species extinction due to human influences have a wide gap.

### 3.3. Geophysical studies of karst

In this category, the research about soil, geomorphology, geopark/geosite, and the landscape gets the most attention. We have articles from Scopus and 54 articles from 52 articles from Google Scholar in
this category. Intensive research about karst water has been conducted by authors such as [43,44] and dynamics of karst, its evolutionary processes, and geopark potentials were by [16,45–47]. Geomorphological study of karst remains to be an important topic to understand the overall process of biodiversity conservation in karst. Karst biodiversity cannot be separated with the recent issues about land use and fragmented landscape, in which most geoscientists rely on GIS technology in understanding the pattern of fragmentations and other geophysical features [48–50].

3.4. Environment and resource management
Karst, in general, has been threatened by human-induced factors. Major pressures to karst include species overused, invasive species, pollutants, degradation and habitat fragmentations [51]. Due to this reason, the direction of karst research also addresses some issues, such as management of water [52], cave management as geo-tourism sites and their effects [53], and the use of environmental value for conservation [54]. Sustainability has also been put into perspectives of resource management as studied by [55]. The issues of sustainability and development and karst resource management are also one important indicator of the UNESCO’s Geopark [56,57]. Tackling the issues of sustainability becomes a priority of natural resource management, and is aimed at achieving a balance between ecological integrity and economic benefits. As a result, initiatives such as ecotourism has recently gained popularity [58,59].

3.5. Forestry and agriculture
Indigenous karst inhabitants initially depend on subsistence agriculture to sustain their life. The system has then evolved into a so-called agricultural intensification, especially after the New Order Era in the 1960s, as it was described by [60]. Agriculture has also shaped biodiversity compositions in the landscape, which is reflected in numerous studies in the field of agriculture and agroforestry. We found words in some academic papers, such as teak and mahogany [34], santalum [61], and casuarina [37]. These exotic plants appear several times in our analysis; highlighting the varieties of species which dominate the agricultural and agroforestry landscapes in Indonesian karsts. We noted several agricultural and agroforestry systems in words such as intercropping [62] and silviculture [63].

3.6. Archaeology and prehistoric life
Karst has long been a central settlement zone for prehistoric man, as it has also been reported elsewhere, like in the Caribbean [3], Ethiopia [64], Italy [65] and Kalimantan [66]. Our dataset revealed 12 papers discussed karst in prehistoric time in Indonesia. The research includes interaction between man and its environment, which has been observed by remnants of prehistoric tools [67], reconstruction of the primaeval forest [6], prehistoric remnants in caves of Maros karst [68]. A detailed account of Gunungsewu and prehistoric life was explained by several authors [67,69,70]. The focus of studying prehistoric life in Java, however, has been mostly in Gunungsewu karst, with a little attention was given to other karsts in Java such as Gombong and Tuban.

3.7. Socio-cultural and education aspects
The study of socio-cultural aspects that influence karst biodiversity in Indonesia is mostly put in development perspective, that is karst management for sustainable development. Hence it is common to find articles studying the impacts of land and resource management on socio-economic and cultural values of the people, such as [71]. Few articles discuss local knowledge that shapes people’s resilient and adaptation to the fragile environment, especially facing climate change and alarming environmental problems [72]. It is also important to note that publications related to education aspects of karst are still limited. Mostly, the karst environment is only used as a learning source to teach geography or social sciences [73], and little is used to understand the technical aspects of karst geology, geomorphology, and biology. Although the current trend of Education for Sustainable Development (ESD) requires that schools and education institutions put special attention to environmental issues and sustainability, the facts that it has not been addressed properly in the curriculum is apparent [74,75]. Even when karst has
been gaining status as a Geopark and a member of Global Geopark Network, the teaching of this subject remains limited, especially if it has to include a multidisciplinary nature to achieve sustainability, as required by the ESD.

4. Gap and Challenge for Future Studies of Karst Environment

Our literature research on karst biodiversity and conservation shows that karst and conservation research in Indonesia has gained significant attention from 1990-2020. This trend probably has been influenced by the Global Geopark status and political commitment around biodiversity conservation, such as the Convention on Biological Diversity (CBD) in 1992. Protection of karst area is linked to the conservation status of the karst [76,77]. Karst with an attribute of a geo-site or a geo-heritage has the most attention in the literature. For example, having attributed as a member of the Global Geopark Network by UNESCO in 2015, Karst Gunungsewu in Yogyakarta has been getting much publication in academic journals [78].

We found that the general trend of karst related research has resulted in a wide range of topics and multi-perspectives. From this finding, it can be inferred that most conservation studies in karst put emphasis on biological and ecological characters at a scale of a plot (a habitat or an ecosystem) and thus can be expanded to include conservation strategies at a landscape scale [79]. Also, the issues of sustainable development need to be explored from multidisciplinary and transdisciplinary approaches. In the context of ESD, the teaching of karst is very limited, as it only has been used widely as a learning source for teaching geography. Yet, it could serve as a natural laboratory for teaching a wide range of topics, including biology, biodiversity, even forestry and archaeology. More interestingly, we can use karst environments as a model to understand multidisciplinary and transdisciplinary issues of development.

5. Conclusion

Our finding showed that karst research in Indonesia has gained significant attention from 1990-2020. This attention probably has been influenced by the Global Geopark status and political commitment around biodiversity conservation, such as the Convention on Biological Diversity (CBD) in 1992. We found that the general trend of karst related research has included a wide range of topics and multi-perspectives. We observed that studies at the landscape level are relatively rare. In the future, such a large-scale study will become a trend. Landscape ecology will be needed to understand the complexity of the karst environment. In terms of education, the use of karst as natural laboratories is still limited for subjects. Yet, it can potentially be used to develop a model for multidisciplinary and transdisciplinary teaching, mainly aiming at achieving the goals of ESD.

References

[1] Gillieson D 2005 Karst in Southeast Asia *The Physical Geography of Southeast Asia* ed A Gupta (Oxford University Press) p 21
[2] Ford D and William P 2007 *Karst Hydrogeology and Geomorphology* (West Sussex, England: John Wiley & Sons, Ltd)
[3] Day M 2010 Human interaction with Caribbean Karst Landscapes: Past, present and future *AC* **39** 137–46
[4] Eftimi R and Zojer H 2015 Human impacts on karst aquifers of Albania *Environ Earth Sci* **74** 57–70
[5] Parise M, De Waele J and Gutierrez F 2009 Current perspectives on the environmental impacts and hazards in karst *Environ Geol* **58** 235–7
[6] Faida L R W 2014 Primeval forest in the period of human cultural history on Gunungsewu Karst Indonesia *Procedia Environmental Sciences* **20** 795–802
[7] Luque-Espinar J A, Pardo-Igúzquiza E, Rodríguez-Galiano V F, Chica-Olmo M and de la Vega-Panizo R 2018 Karst and vegetation: Biodiversity and geobotany in the Sierra de las Nieves
8

karst aquifer (Málaga, Spain) *Eurokarst, Besançon* ed C Bertrand, S Denimal, M Steinmann and P Renard (Cham: Springer International Publishing) pp 11–22

[8] Mane A M, Prabakaran N and Manchi S S 2019 Floral diversity, composition, and recruitment on the Karstland of Baratang Island, India *Ecol. Complex.* 37 47–54

[9] Prakarsa T B P and Ahmadin K 2017 Diversitas Arthropoda gua di kawasan Karst Gunung Sewu, studi gua-gua di Kabupaten Wonogiri *Biotropic: The Journal of Tropical Biology* 1 31–6

[10] Kurniawan I D, Rahmadi C, Ardi T E, Nasrullah R, Willyanto M I and Setiabudi A 2018 The impact of lampenflora on cave-dwelling Arthropods in Gunungsewu Karst, Java, Indonesia *J Bio Bio Edu* 10 275–83

[11] Mittermeier R A, Myers N, Thomsen J B, da Fonseca G A B and Olivieri S 1998 Biodiversity hotspots and major tropical wilderness areas: Approaches to setting conservation priorities *Conserv. Biol.* 12 516–20

[12] Clements R, Sodhi N S, Schilthuizen M and Ng P K L 2006 Limestone karsts of Southeast Asia: Imperiled arks of biodiversity *BioScience* 56 733

[13] Coleman J L, Ascher J S, Bickford D, Buchori D, Cabanban A, Chisholm R A, Chong K Y, Christie P, Clements G R, dela Cruz T E E, Dressler W, Edwards D P, Francis C M, Friess D A, Giann X, Gibson L, Huang D, Hughes A C, Jaafar Z, Jain A, Koh L P, Kudavidanage E P, Lee B P Y-H, Lee J, Lee T M, Leggett M, Leimona B, Linkie M, Luskin M, Lynam A, Meijaard E, Nijman V, Olsson A, Page S, Parolin P, Peh K S-H, Posa M R, Prescott G W, Rahman S A, Ramchunder S J, Rao M, Reed J, Richards D R, Slade E M, Steinmetz R, Tan P Y, Taylor D, Todd P A, Vo S T, Webb E L, Ziegler A D and Carrasco L R 2019 Top 100 research questions for biodiversity conservation in Southeast Asia *Biol. Conserv.* 234 211–20

[14] Faida L R W, Sutikno, Fandeli C and Sunarto 2011 Rekonstruksi hutan purba kawasan Karst Gunung Sewu dalam periode sejarah manusia *Jurnal Ilmu Kehutanan* 5 79–90

[15] Milanovic P 2002 The environmental impacts of human activities and engineering constructions in karst regions *Episodes* 25 13–21

[16] Adji T N and Haryono E 2017 *Kawasan karst dan prospek pengembangannya di Indonesia* (INA-Rxiv)

[17] Cahyadi A 2010 *Pengelolaan kawasan karst dan peranannya dalam siklus karbon di Indonesia* (INA-Rxiv)

[18] Convention on Biological Diversity 2006 Convention Text

[19] United Nations Millenium Development Goals

[20] Rand M R W, Adams W M, Bennun L, Butchart S H M, Clements A, Coomes D, Entwistle A, Hodge I, Kapos V, Scharlemann J P W, Sutherland W J and Vira B 2010 Biodiversity conservation: Challenges beyond 2010 *Science* 329 1298–303

[21] Akdim B 2015 Karst landscape and hydrology in Morocco: Research trends and perspectives *Environ Earth Sci* 74 251–65

[22] Liding C, Yang L, Yihe L, Xiaoming F and Bojie F 2008 Pattern analysis in landscape ecology: Progress, challenges and outlook *Acta Ecol. Sin.* 28 5521–31

[23] Kurniawan I D, Soesilohadi R C H, Rahmadi C, Caraka R E and Pardamean B 2018 The difference on Arthropod communities’ structure within show caves and wild caves in Gunungsewu Karst area, Indonesia *Ecol. Environ. Conserv.* 24 72–81

[24] Struebig M J, Christy L, Pio D and Meijaard E 2010 Bats of Borneo: Diversity, distributions and representation in protected areas *Biodivers. Conserv.* 19 449–469

[25] Nurchahyani Y W, Indrioko S, Faridah E and Syahbudin A 2017 The effects of population size on genetic parameters and mating system of sandalwood in Gunung Sewu, Indonesia *IJBiotech* 20 182

[26] Tarmadjia S 2015 The cacao flower visitor insects diversity and their potentialities as pollinators *KLS* 2 540

[27] Riyanto A, Bauer A M and Yudha D S 2014 A new small karst-dwelling species of Cyrtodactylus (Reptilia: Squamata: Gekkonidae) from Java, Indonesia *Zootaxa* 3785 589
[28] Cai Y and Ng P K L 2009 The freshwater shrimps of the genera Caridina and Parisia from karst caves of Sulawesi Selatan, Indonesia, with descriptions of three new species (Crustacea: Decapoda: Caridea: Atyidae) J. Nat. Hist. 43 1093–114
[29] Hadiaty R K and Kottelat M 2009 Nemacheilus Tebo, A New Loach from Sangkulirang Karst, East Kalimantan, Indonesia (Teleostei: Nemacheilidae) Raffles Bull. Zool. 57 119–125
[30] Thomas D C, Bour A and Ardi W H 2018 Begonia of the Matarombeo karst, Southeast Sulawesi, Indonesia, including two new species GBS 70 163–76
[31] Wijayanti F and Maryanto I 2017 Diversity and pattern of nest preference of bat species at bat-dwelling caves in Gombong Karst, Central Java, Indonesia Biodiversitas 18 864–74
[32] Struебig M J, Kingston T, Zubaid A, Le Comber S C, Mohd-Adnan A, Turner A, Kelly J, Bozek M and Rossiter S J 2009 Conservation importance of limestone karst outcrops for Palaeotropical bats in a fragmented landscape Biol. Conserv. 142 2089–96
[33] Lewaru M M, Pratiwi F D and Sunardi 2019 Plankton diversity in karst river, Masigit-Pawon Cave, West Java, Indonesia Omni-Akuatika 15
[34] Udayana C, Andreasen H P and Skarpe C 2020 Understory diversity and composition after planting of teak and mahogany in Yogyakarta, Indonesia J. Sustain. Forest. 39 494–510
[35] Marshall A J, Salas L A, Stephans S, Nardiyono, Engström L, Meijaard E and Stanley S A 2007 Use of limestone karst forests by Bornean orangutans (Pongo pygmaeus morio) in the Sangkulirang Peninsula, East Kalimantan, Indonesia Am. J. Primatol. 69 212–9
[36] Haryono E and Suratman 2010 Significant features of Gunung Sewu Karst as geopark sites International UNESCO Conference on Geopark (INA-Rxiv)
[49] Wang K, Yue Y, Brandt M and Tong X 2019 Karst ecosystem observation and assessment at local and regional scales *Intercarto. InterGIS* Intercarto, InterGIS vol 25 (Lomonosov Moscow State University) pp 43–7

[50] Alexopoulos J D, Dilalos S, Vassilikis E, Michelioudakis D, Mavroulis S and Farangitakis P 2014 A geophysical insight for the occurrence of mediterranean temporary ponds on Mts. Oiti and Kallidromo (Greece) *Near Surf. Geosci. - Eur. Meet. Environ. Eng. Geophys.* (European Association of Geoscientists and Engineers, EAGE)

[51] Millenium Ecosystem Assessment 2015 Current States and Trends Assessment *Millenium Ecosystem Assessment*

[52] Kudella P, Loges I, Mutschler T, Eiche E, Ruppert J and Neumann T 2016 Bypassing and tightening of an underground water retention system in permeable karst: case study of the hydropower plant (HPP) Bribin, Indonesia *Appl. Water Sci.* 6 241–57

[53] Danardono D, Haryono E and Margareta W 2019 The nature of carbon flux in various ecosystem types in the Biduk-Biduk Karst Region, Berau District, East Kalimantan *EDP Sciences* 76 4005

[54] Waluyo H, Sadikin S R, Gustami and Whiting P 2005 An economic valuation of biodiversity in the karst area of Maros, South Sulawesi, Indonesia *Biodiversity* 6 24–6

[55] Sunkar A 2008 *Sustainability in karst resources management: The case Of The Gunung Sewu in Java* Dissertation (New Zealand: The University of Auckland)

[56] Gunung Sewu Geopark 2020 Gunung Sewu Geopark

[57] Martono B 2018 *Penyusunan strategi dan langkah-langkah Gunung Sewu UNESCO Global Geopark* (Jakarta, Indonesia: Kementrian Pariwisata)

[58] Hakim L 2017 Managing biodiversity for a competitive ecotourism industry in tropical developing countries: New opportunities in biological fields *AIP Conf. Proc.* 1908 30008

[59] Marlina E Geotourism as a strategy of geosite empowerment towards the tourism sustainability in Gunungkidul Regency, Indonesia *Int. J. Smart Home* 10 131–50

[60] Nibbering J W 1991 *Hoeing in the hills: Stress and resilience in an upland farming system in Java* Unpublished thesis (Australia: Australian National University)

[61] Ratnaningrum Y W, Faridah E, Indrioko S and Syahbudin A 2016 Flowering and seed production of sandalwood (Santalum album; Santalaceae) along environmental gradients in Gunung Sewu Geopark, Indonesia *Nusantara Biosci.* 8 180–91

[62] Khasanah N M, Perdana A, Rahmanullah A, Manurung G, Roshetko J M and Van Noordwijk M 2015 Intercropping teak (Tectona grandis) and maize (Zea mays): Bioeconomic trade-off analysis of agroforestry management practices in Gunungkidul *Agrofor. Syst.* 89 1019–33

[63] Sadono R, Soeprijadi D and Wirabuana P Y A P 2020 Kesesuaian Lahan untuk Pengembangan Tanaman kayu putih dan implikasinya terhadap teknik silvikultur *J. Pengelolaan Sumberd. Alam Lingkung.* 10 43–51

[64] Sahle Y, Giusti D, Gossa T and Ashkenazy H 2019 Exploring karst landscapes: New prehistoric sites in South-Central Ethiopia *Antiquity* 93 e21

[65] Boschian G and Montagnari-Kokelj E 2000 Prehistoric shepherds and caves in the Trieste Karst (Northeastern Italy) *Geoarchaeology* 15 331–371

[66] Sumantri D I G 2017 Sangkulirang Mangkalihat: The earliest prehistoric rock-art in the world *Proc. of the ICA* vol 1 p 5

[67] Simanjuntak T 2001 Gunungsewu in Prehistoric Times (Yogyakarta, Indonesia: Gadjah Mada University Press)

[68] Duli A, Mulyadi Y and Rosmawati 2019 The mapping out of Maros-Pangkep karst forest as a cultural heritage conservation *IOP Conf. Ser. Earth Environ. Sci.* vol 270 (Institute of Physics Publishing)

[69] Bartstra G-J 1976 *Contributions to the study of the palaeolithic Patjitan culture Java, Indonesia* vol 6 (Groningen: s.n.)
[70] Bartstra G-J 1983 Some remarks upon fossil man from Java, his age, and his tools Bijdragen tot de taal-, land- en volkenkunde 139 421–34
[71] Ruslanjari D 2017 Enhancing capacity of local community towards agricultural drought: Case in Ploso Village, Yogyakarta Jurnal Teknosains 7 40–52
[72] Retnowati A, Anantasari E, Marfai M A and Dittmann A 2014 Environmental ethics in local knowledge responding to climate change: An understanding of seasonal traditional calendar pranotomongso and its phenology in karst area of Gunung Kidul, Yogyakarta, Indonesia Procedia Environmental Sciences 20 785–94
[73] Ganesia P P and Sudarsono A 2018 Pengaruh Museum Karst Indonesia sebagai sumber belajar terhadap prestasi belajar IPS peserta didik kelas VII SMP Negeri 1 Polokarto Social Studies 7
[74] Nomura K 2009 A perspective on education for sustainable development: Historical development of environmental education in Indonesia Int. J. Educ. Dev. 29 621–7
[75] Suprapta, Abbas I and Maddatuang 2019 Perancangan model pembelajaran project base learning (Outdoor) Karst Maros Sem. Nas. Pengabdian Kepada Masyarakat 2018
[76] Debevec V and Kranjc D 2019 The karst biosphere reserve in Slovenia Eco.mont 11 43–9
[77] Lu Z, Yang G, Zhao D D, Wu Y H, Meng Y J and Zhou F 2013 Guild structure of forest breeding bird community in Nonggang Nature Reserve of Guangxi Zool. Res. 36 601–9
[78] Tyas D N, Vidityawati R and Nusantari R 2016 Konservasi dan pemanfaatan berkelanjutan kawasan Karst Gunung Sewu sebagai bagian geopark untuk mempertahankan fungsi ekologis Prosiding Symbion Symposium on Biology Education (UAD) pp 311–24
[79] DeFries R, Rovero F, Wright P, Ahumada J, Andelman S, Brandon K, Dempewolf J, Hansen A, Hewson J and Liu J 2010 From plot to landscape scale: Linking tropical biodiversity measurements across Spatial Scales Front. Ecol. Environ. 8 153–60

Acknowledgements
This paper was written during the doctoral degree study at Universitas Gadjah Mada with generous funding from the Ministry of Religious Affairs, under the MORA Scholarship 5000 Doctor, of whom we deliver many thanks and gratitude.