DIVERSITY AND ECOLOGY OF LAND SNAILS IN GUNUNG HALIMUN SALAK NATIONAL PARK (GHSNP) IN JAVA, INDONESIA

KEANEKARAGAMAN DAN EKOLOGI KEONG DARAT DI TAMAN NASIONAL GUNUNG HALIMUN SALAK (TNGHS) DI JAWA, INDONESIA

Ayu Savitri Nurinsiyah[1,4], Ita Faizah[2], Yogi Prasetio[2], Tedi Setiadi[3], Ristiyanti Marsetiowati Marwoto[1], Bernhard Hausdorf[4]

[1]Research Center for Biology-Indonesian Institute of Science (LIPI), Gedung Widyasatwaloka, Jl. Raya Bogor KM 46, Cibinong, West Java, Indonesia
[2]Balai Taman Nasional Gunung Halimun Salak, Jl. Raya Cipanas, Kec. Kabandungan, Sukabumi 43157, West Java, Indonesia
[3]Pusat Informasi Lingkungan Indonesia, Jl. Tumenggung Wiradireja No. 216, Cimahpar, Bogor, Indonesia
[4]Center of Natural History, Zoological Museum, University of Hamburg, Martin-Luther-King-Platz 3, Hamburg 20146, Germany
E-mail: *ayus002@lipi.go.id, ayu_nurinsiyah@yahoo.com*

(diterima April 2019, direvisi Juni 2019, disetujui Juli 2019)

ABSTRACT

The land snail fauna of the largest tropical montane forest in Java, the Gunung Halimun Salak National Park (GHSNP), was surveyed during the dry season (June-July) in 2015, concentrating on four park's resorts, i.e. Cikaniki, Mt. Botol, Cisarua (Halimun area) and Cidahu (Salak area). In total, 399 specimens representing 43 species were collected. Prior to the surveys, 48 land snail species were known from the GHSNP. Fifteen new records for the GHSNP were discovered so 63 species are now known to inhabit the Park. This number represent 25% of the total land snail fauna of Java. 21 of the species found in GHSNP are endemic to Java. The species richness of the plots in GHSNP was correlated with soil pH and the composition of the land snail communities was correlated with elevation, annual mean temperature, and amount of deadwood.

Keywords: Endemism, tropical mountain forest, Java, Gastropods

ABSTRAK

Telah dilakukan survey keong darat di kawasan hutan pegunungan tropis terbesar di Jawa, Taman Nasional Gunung Halimun Salak (TNGHS) pada musim kering (Juni-Juli 2015) yang terkonsentrasi pada empat resort yaitu Cikaniki, Gunung Botol, Cisarua (kawasan Halimun) dan Cidahu (kawasan Salak). Sebanyak 399 spesimen dari 43 spesies telah dikoleksi. Sebelum survei ini dilakukan, tercatat 48 spesies keong darat diketahui berada di TNGHS. Berdasarkan survei terdapat 15 catatan baru keong darat untuk TNGHS, sehingga total 63 spesies keong darat tercatat di taman nasional ini. Angka ini merepresentasikan 25% dari total spesies keong darat yang ada di Jawa. 21 spesies endemik Jawa ditemukan di TNGHS. Kekayaan spesies pada plot di TNGHS memiliki korelasi terhadap pH tanah, sementara komposisi komunitas keong darat ditemukan berkorelasi terhadap elevasi, rata-rata suhu udara tahunan dan jumlah kayu lapuk (kayu mati).

Kata kunci: endemisitas, hutan pegunungan tropis, Jawa, Gastropoda.

INTRODUCTION

It is virtually impossible or at least ineffective to survey the whole fauna and flora for prioritizing areas for the conservation of biodiversity. Thus, prioritizing areas for conservation requires the use of surrogates for assessing overall patterns of biodiversity. It has been shown that land snails and insects were strong predictors of conservation priorities for vertebrates and snails were also reasonably effective as surrogates for plants, but neither plants nor vertebrates were adequate as surrogates for snails or insects (Moritz *et al*. 2001). Nevertheless, molluscs are one of the animal groups that are often ignored with regard to conservation. Régnier *et al*. (2015) estimated that 7% of the described land snail species on earth are extinct. Conservation areas like national parks are one of the most effective ways to protect both the ecosystem and the species within (Bruner *et al*. 2001; Sodhi *et al*. 2004). The land snail fauna of the Gunung Halimun Salak National Park (GHSNP) in Java is the subject of this study.

Gunung Halimun Salak National Park is one of the oldest conserved forests and the second largest national park in Java. In 1924, Mt. Halimun was first determined a protected forest covering an area of 39,941 ha (Endangered Species Team GHSNPMP-JICA 2005). In 1935, the status changed into natural reserve and in 1992 into national park. In 2003, Mt. Salak was included in the national park so that the park reached a total area of 113,357 ha (Halimun Salak National Park Authority 2016). It is the second largest national park in Indonesia after Ujung Kulon National Park (122,956 ha) (Ministry of Environment and Forestry 2016.

GHSNP is the largest tropical montane forest in Java and is believed to host the highest biodiversity within Java (Kubo & Supriyanto 2010). Various rare and endemic animal and plant species, such as the Javan Hawk Eagle (*Nisaetus bartelsi*), Javan Gibbon (*Hylobates moloch*) amongst others, can be found in this national park. A comprehensive list of animal and plant species that inhabit GHSNP is crucial as baseline data for the national park's management.

The first malacological exploration of Mt. Salak was by JC von Hasselt in the early 1820s (Martens 1867). Boettger (1890) reported 33 species, followed by van Benthem Jutting (1948, 1950, 1952) and Loosjes (1953) who summarized the previous knowledge and listed a total of 35 land snail species. The land snail fauna of the Mt. Halimun region has been investigated by Marwoto (1998), Subasli & Munandar (1999), Heryanto (2001) and Heryanto *et al*. (2003). Heryanto *et al*. (2003) recorded land snails from eight sites in the Halimun area, summarized the previous knowledge about the land snail fauna of that region, and listed 38 species. However, it should be noted that previous records of *Landouria ciliocincta* (Möllendorff, 1897) and *Landouria smimensis* (Mousson, 1848) from GHSNP by van Benthem Jutting (1950) and Heryanto *et al*. (2003) were based on misidentifications. These species are endemic in East Java (Nurinsiyah *et al*. 2019). In total, 48 land snail species (not counting misidentifications) including 13 species endemic to Java, as well as four introduced species were previously recorded from GHSNP. Given the size of the park and lack of concerted sampling efforts, it can be expected that the list is still far from comprehensive. Thus, we conducted a survey in four areas in GHSNP to investigate and provide an update of the land snail species diversity and to assess environment variables that may influence the species composition of the land snail communities.

MATERIALS AND METHODS

Study Area

GHSNP is one of the oldest conserved forests and the second largest national park in Java. The national park is located at 6°32'-6° 55'S and 106°13'-106°46' E. The altitude ranges from 500 to 2200 m a.s.l. Three forest ecosystems are present in GHSNP: lowland rainforest (<1000 m a.s.l.), submontane forest (1000-1500 m a.s.l.) and montane forest (>1500 m a.s.l.) (Kubo and Supriyanto 2010; Halimun

Salak National Park Authority 2016).

The study focused on the area between 106°27' E to 106°42' E and between 06°38' S to 06°45' S, with an altitudinal ranging from 800 to 1800 m a.s.l. (Fig. 1). Four resorts were sampled: Cikaniki, Mt. Botol, Cisarua (Mt. Halimun area) and Cidahu (Mt. Salak area). Cikaniki resort is the main research station in GHSNP. It is located in the center of the Mt. Halimun area on the foot of Mt. Kendeng. Cisarua is located in Mt. Salak area, and closest to human settlement. Mean annual rainfall in Halimun area ranges from 3200 to 6000 mm and annual temperature ranges from 16°C to 30°C (DPJLHK 2016).

Sampling and Determination

Fieldwork was conducted from June to July 2015. We combined timed searches and sieving litter within plots to optimize the inventory as recommended for single visit land snail inventories (Emberton *et al.* 1996; Cameron & Pokryszko 2005; Schilthuizen 2011). We selected 24 random plots of 10m x 10m, eight each in Cikaniki resort and at Mt. Kendeng (1028-1366 m a.s.l.), four in Mt. Botol resort (1649-1741 m a.s.l.), four in Cisarua area (872-941 m a.s.l.), and eight in Cidahu resort (1166-1253 m a.s.l.) (Fig. 1). Three researchers intensively searched and collected both living snail and dead shell inside each plot for one hour. In addition, 5L of soil and leaf litter were sampled at each plot, which was later dried, sieved and sorted. Land snails encountered along the way between plots were also opportunistically collected. Environmental variables including elevation, canopy cover, cover of herbaceous layer, presence of deadwood, presence of stones, amount of leaf litter, and degree of human impact were recorded (Appendix 1). The pH of the uppermost soil layer at each plot was acquired from the SoilGrids250m map (http://www.isric.org/content/soilgrids; Hengl et al. 2017) and annual mean temperature and annual precipitation were obtained

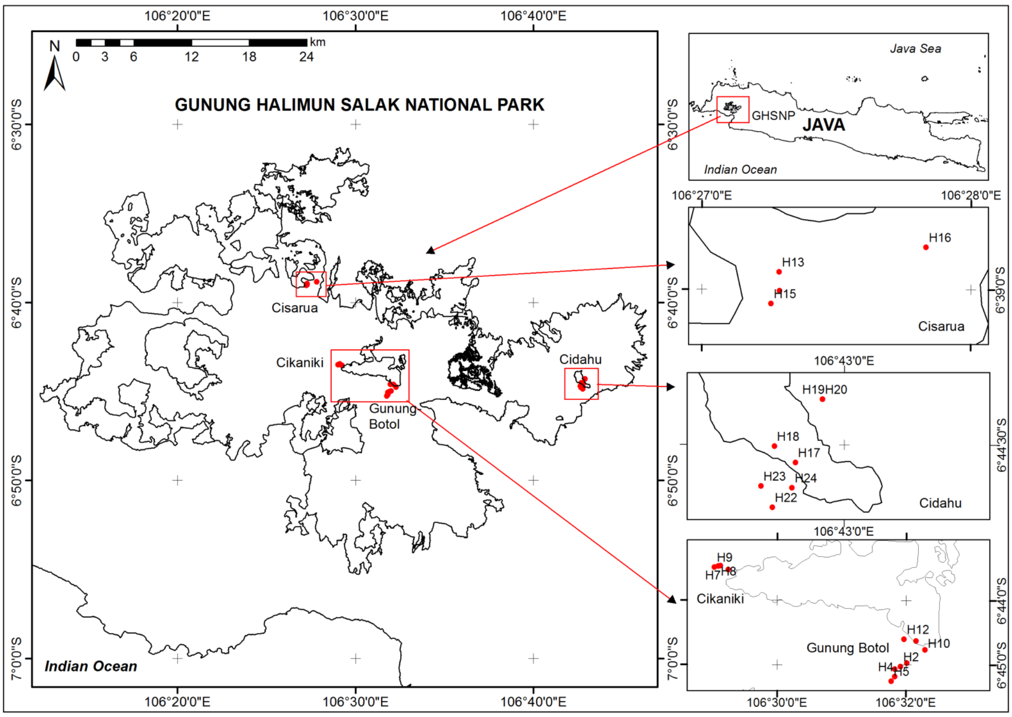

Figure 1. Sampling locations in GHSNP.

from the WorldClim database (http://www.worldclim.org; ca. 1 km2 resolution; Hijmans *et al*. 2005).

All specimens were identified to the lowest taxonomic level based on their shell characters using van Benthem Jutting (1948, 1950, 1952), Loosjes (1953), Vermeulen & Whitten (1998), Nurinsiyah & Hausdorf (2017), and Nurinsiyah *et al*. (2019). Several species for instance species belongs to the genus *Landouria* and *Parmarion* were examined based on shell as well as genitalia characters. Species were classified as introduced following Nurinsiyah & Hausdorf (2019). The specimens are kept in the Museum Zoologicum Bogoriense (Indonesia) and in the Zoological Museum of the University of Hamburg (Germany).

Putative determinants of species richness and community composition.

To assess the completeness of the sampling, we calculated the iChao1 estimator (Chao & Chiu 2016) for species richness based on the species abundance data using SpadeR Online (Chao et al. 2015). We analyzed the relationship between the number of sampled species in the plots and the measured environmental variables using generalized linear models, which were calculated with the function *glm* of the statistical software R (R Core Team 2018). To correct for over-dispersion, we used a quasipoisson error structure. We started with a maximal generalized model including all environmental variables and then excluded variables without significant influence stepwise until only variables with a significant influence remained.

The similarities between land snail communities were explored by a non-metric multidimensional scaling (NMDS) calculated by the R function *metaMDS* using quantitative Kulczýnski distances (Faith *et al*. 1987) based on abundance data. We investigated the influence of environmental variables (Appendix 1) on the composition of communities by fitting them onto the ordination using vegan (Oksanen *et al*. 2013), a package within the R environment (R Core Team 2018). The goodness of fit of the environmental variables was computed with the R function *envfit*. Significance of fit was tested based on 999 permutations.

RESULTS AND DISCUSSION

Results

In total, 399 specimens were collected in 24 plots and along the ways. The samples were assigned to 43 species belonging to 15 families (Table 1, Appendix 2; Fig. 2). The number of specimens per plot varied between 1 and 47 (median 8). Species richness per plot ranged from 1 to 14 (median 5.5). The iChao1 estimate of species richness for the GHSNP based on the samples taken in this study was 59 species with the 95% confidence interval extending from 48 to 93.

The most species-rich family was Ariophantidae (7 species). The most abundant family was Helicarionidae (62 specimens). Panpulmonate species were more abundant (85% of all specimens) than caenogastropod snails (15%). Thirteen species endemic to Java were recorded in the area. Only one introduced species, *Allopeas clavulinum* (Achatinidae), was recorded in all four locations. One minute new species, *Diplommatina halimunensis* (shell height 2.45

-2.8 mm; Fig. 3), was discovered at Mt. Kendeng during this study and described in Nurinsiyah & Hausdorf (2017). It was also recently found on Mt. Salak (Greke 2019).

Among the four sampled areas, the highest number of specimens was collected in Cikaniki (129 specimen), followed by Cidahu (120 specimen), Cisarua (81 specimen) and Mt. Botol (69 specimen). Although the highest number of specimens was found in Cikaniki, the highest number of species was recorded in Cidahu (30 species), followed by Cisarua (22 species), Cikaniki (18 species), and Mt. Botol (15 species) (Fig. 4).

Using generalized linear models we could establish a significant decrease of species richness with decreasing soil pH (ANOVA p = 0.014). The composition of the land snail communities in GHSNP was significantly correlated with elevation, annual mean temperature, and amount of deadwood (Table 2). The non-metrical multidimensional scaling (Fig. 4) showed that all four sampled locations in the Mt. Halimun and Mt. Salak regions have overlapping snail fauna.

Table 1. Land snail species recorded in four areas (see Fig. 1) in the GHSNP in this study as well as records from the literature. *endemic to Java; **introduced in Java.

Family	Species	Cikaniki	Cidahu	Cisarua	Mt. Botol	van Benthem Jutting (1948, 1950, 1952), Loosjes (1953)	Heryanto et al. (2003)
Cyclophoridae	*Cyclophorus rafflesi* (Broderip & Sowerby, 1833)	+	+	+	-	+	+
Cyclophoridae	*Cyclophorus perdix* (Broderip & Sowerby, 1830)	-	+	-	+	+	+
Cyclophoridae	*Cyclotus discoideus* Sowerby, 1843	-	-	-	-	+	+
Cyclophoridae	*Dicharax longituba* (Martens, 1867)	-	-	-	-	+	-
Cyclophoridae	*Ditropopsis fruhstorferi* (Möllendorff, 1897)*	-	-	-	-	+	-
Cyclophoridae	*Japonia ciliocinctum* (Martens, 1865)	-	+	+	-	+	+
Cyclophoridae	*Japonia ciliferum* (Mousson, 1849)	-	+	-	-	+	-
Cyclophoridae	*Japonia grandipilum* Boettger, 1891	-	-	-	-	+	-
Cyclophoridae	*Opisthoporus corniculum* (Mousson, 1849)*	-	-	-	-	+	+
Diplommatinidae	*Diplommatina auriculata* Möllendorff, 1897	-	+	+	-	-	+
Diplommatinidae	*Diplommatina halimunensis* Nurinsiyah & Hausdorf, 2017*	+	-	-	-	-	-
Diplommatinidae	*Diplommatina planicollis* Möllendorff, 1897*	-	-	-	+	-	-
Pupinidae	*Pupina bipalatalis* Boettger, 1890*	-	+	-	-	-	-
Pupinidae	*Pupina junghuni* Martens, 1867*	+	-	-	-	+	+
Pupinidae	*Pupina treubi* Boettger, 1890	-	+	-	-	+	+
Veronicellidae	*Filicaulis bleekerii* (Keferstein, 1865)	-	-	-	-	-	+
Achatinidae	*Allopeas clavulinum* (Potiez & Michaud, 1838)**	+	+	+	+	-	-
Achatinidae	*Allopeas gracile* (Hutton, 1834)**	-	-	-	-	+	-
Achatinidae	*Glessula sumatrana* (Martens, 1864)	-	-	+	-	+	+
Achatinidae	*Paropeas achatinaceum* (Pfeiffer, 1846)	-	-	-	-	-	+
Achatinidae	*Paropeas acutissimum* (Mousson, 1857)	-	+	+	-	+	-

Family	Species	Cikaniki	Cidahu	Cisarua	Mt. Botol	van Benthem Jutting (1948, 1950, 1952), Loosjes (1953)	Heryanto et al. (2003)
Achatinidae	*Subulina octona* (Bruguière, 1792) **	-	-	-	-	+	+
Punctidae	*Paralaoma javana* (Möllendorff, 1897)*	-	-	+	-	-	-
Charopidae	*Philalanka nannophya* Rensch, 1932	-	-	-	+	-	-
Charopidae	*Philalanka thienemani* Rensch, 1932	+	+	-	+	-	-
Charopidae	*Philalanka tjibodasensis* (Leschke, 1914)	+	+	+	-	-	-
Clausiliidae	*Oospira javana* (Pfeiffer, 1841)*	-	-	-	-	+	+
Clausiliidae	*Oospira salacana* (Boettger, 1890)*	-	-	-	+	+	+
Phylomycidae	*Meghimatium striatum* van Hasselt, 1824	+	+	+	-	+	+
Trochomorphidae	*Geotrochus conus* (Philippi, 1841)*	-	-	+	-	+	+
Trochomorphidae	*Trochomorpha appropinquata* (Martens, 1864)	-	+	+	-	+	+
Trochomorphidae	*Trochomorpha concolor* Boettger, 1890*	+	+	+	-	-	-
Trochomorphidae	*Trochomorpha strubelli* Boettger, 1890*	-	-	-	-	+	+
Chronidae	*Kaliella barrakporensis* (Pfeiffer, 1852)	-	+	-	-	-	+
Dyakiidae	*Dyakia clypeus* (Mousson, 1857)	-	-	-	-	-	+
Dyakiidae	*Dyakia rumphii* (von dem Busch, 1842)	+	+	-	+	+	+
Dyakiidae	*Elaphroconcha bataviana* (von dem Busch, 1842)	+	-	+	-	+	+
Dyakiidae	*Elaphroconcha patens* (Martens, 1898)*	-	-	-	-	-	+
Euconulidae	*Coneuplecta microconus* (Mousson, 1865)	+	+	+	+	-	+
Euconulidae	*Coneuplecta sitaliformis* (Möllendorff, 1897)	-	+	+	-	-	-
Euconulidae	*Liardetia convexoconica* (Möllendorff, 1897)	-	+	-	-	-	+
Euconulidae	*Liardetia pisum* (Möllendorff, 1897)*	+	+	+	+	-	-
Euconulidae	*Liardetia scandens* (Cox, 1872)	-	-	-	-	-	+
Helicarionidae	*'Helicarion' albellus* Martens, 1867	+	+	+	+	+	+
Helicarionidae	*'Helicarion' perfragilis* Möllendorff, 1897	-	+	+	+	+	+
Helicarionidae	*'Helicarion' radiatulus* (Möllendorff, 1897)	+	+	-	-	-	+
Ariophantidae	*Hemiplecta humphreysiana* (Lea, 1841)	-	-	+	-	+	+
Ariophantidae	*Macrochlamys amboinensis* (Martens, 1864)**	-	-	-	-	+	-
Ariophantidae	*Microcystina circumlineata* (Möllendorff, 1897)	-	-	-	+	-	-
Ariophantidae	*Microcystina fruhstorferi* (Möllendorff, 1897)*	+	+	-	-	-	-
Ariophantidae	*Microcystina gratilla* van Benthem Jutting, 1950	+	+	+	-	-	-
Ariophantidae	*Microcystina subglobosa* (Möllendorff, 1897)*	-	-	-	+	-	+
Ariophantidae	*Microparmarion* sp.	-	-	-	-	-	+
Ariophantidae	*Parmarion martensi* Simroth, 1893	-	+	-	-	-	-
Ariophantidae	*Parmarion pupillaris* Humbert, 1864	-	+	+	+	+	+
Camaenidae	*Amphidromus alticola* Fulton, 1896*	-	-	-	-	-	+
Camaenidae	*Amphidromus palaceus* (Mousson, 1848)	-	+	+	-	+	-

Family	Species	Cikaniki	Cidahu	Cisarua	Mt. Botol	van Benthem Jutting (1948, 1950, 1952), Loosjes (1953)	Heryanto et al. (2003)
Camaenidae	*Bradybaena similaris* (Fèrussac 1821)**	-	-	-	-	-	+
Camaenidae	*Chloritis crassula* (Philippi, 1844)*	-	-	-	-	+	+
Camaenidae	*Chloritis fruhstorferi* (Möllendorff, 1897)*	-	+	-	-	-	+
Camaenidae	*Landouria rotatoria* (von dem Busch, 1842)*	+	+	+	+	+	+
Camaenidae	*Landouria winteriana* (Pfeiffer, 1841)*	+	+	+	+	+	-
Camaenidae	*Pseudopartula galericulum* (Mousson, 1848)	-	-	-	-	+	-

Figure 2. *Geotrochus conus* (Philippi, 1841) from Cidahu (above left) size ca height (H) 10-13mm and width (W) 15-18mm; *Cyclophorus perdix* (Broderip & Sowerby, 1830) from Cidahu (above right) size ca. H 20-24mm and W 30-35mm; *Pupina junghuni* Martens, 1867 from Cikaniki (below left) size ca. H 11mm and W 7.5-8mm; *Meghimatium striatum* van Hasselt, 1824 from Cidahu (below right) size ca. Length 40mm and W 9mm.

Figure 3. *Diplommatina halimunensis* Nurinsiyah & Hausdorf, 2017 from Mt. Kendeng, scale bar 1mm.

Table 2. Fit of environmental variables on the NMDS based on quantitative Kulczýnski distances among land snail communities. The dataset consists of species abundance data for 24 plots in the GHSNP. Significant results are given in bold.

Environmental variables	Fit on NMDS	
	R^2	P
Elevation	**0.347**	**0.008**
Canopy cover	0.147	0.194
Soil pH	0.001	0.991
Annual mean temperature	**0.247**	**0.050**
Annual precipitation	0.028	0.730
Herbaceous layer	0.050	0.703
Deadwood	**0.230**	**0.021**
Stones	0.045	0.727
Bare rock	0.002	1.000
Leaf litter	0.058	0.288
Human impact	0.040	0.422

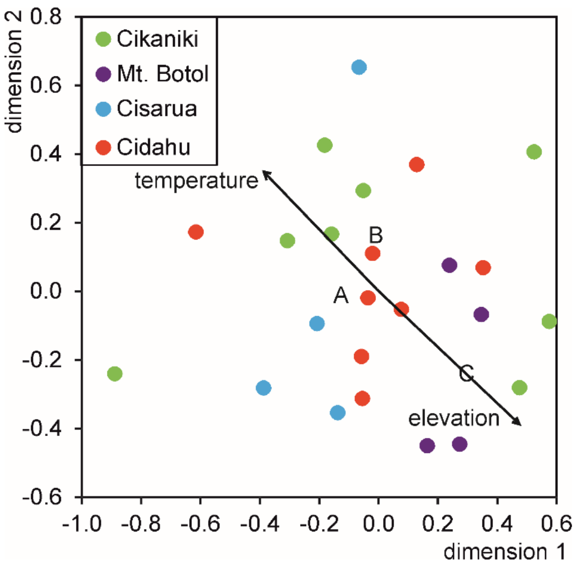

Figure 4. NMDS based on quantitative Kulczýnski distances showing the similarities between the snail communities at the 24 sampling plots in GHSNP and significant fitted environmental variables. Continuous environmental variables (annual mean temperature, elevation) are shown as arrows and letters indicate the centroids of the categories of amount of deadwood (A to C: increasing amount of deadwood).

Discussion

We recorded 43 land snail species in the GHSNP, of which 15 species were new records for the park. Supplemented with literature records (Martens 1867; Boettger 1890; van Benthem Jutting 1948, 1950, 1952; Loosjes 1953; Marwoto 1998; Subasli & Munandar 1999; Heryanto 2001; Heryanto *et al.* 2003), a total of 63 species are now known from GHSNP. Based on our samples, the iChao1 estimate suggested that 48 to 93 occur in the park. However, it should be noted that our samples are all from natural forest. Other habitats in GHSNP like deforested areas or brooksides with potentially different snail communities have not been sampled, so the iChao1 estimate is probably an underestimate. For example, we found only a single introduced species, *Allopeas clavulinum*, and it is known that introduced species are generally restricted to modified habitats and rarely invade primary forest (Tillier 1992; Cowie 1998; Hausdorf 2002; Nurinsiyah *et al.* 2016). Thus, it is not surprising that four additional introduced species were already known from the GHSNP from other surveys (see Heryanto *et al.* 2003).

With 63 recorded species, the land snail fauna of GHSNP is richer than that of two other mountainous areas in Java that have been recently surveyed, Gunung Ciremai National Park in West Java with 48 recorded land snail species (Heryanto 2008) and Gunung Slamet in Central Java with 62 species (Heryanto 2012). The species richness of GHSNP is also higher than that of two recently surveyed limestone areas in Java, Sukolilo with 33 species (Nurinsiyah 2015; Nurinsiyah et al. 2019) and South Malang with 55 species (Nurinsiyah *et al.* 2016), although only 399 specimens were collected in GHSNP in this study, whereas 1123 specimens were collected in Sukolilo and 2919 in South Malang. Although GHSNP does not even cover 1% of total area of Java, it hosts some 25% of the 242 land snail species known from Java (Nurinsiyah 2018). 21 of the species found in GHSNP are endemic to Java, whereas 14 of the species found in Gunung Ciremai, 15 of the species found in Gunung Slamet National Park, six of the species found in Sukolilo and six of the species found in South Malang are endemic to Java. Thus, GHSNP is of critical importance for the conservation of biodiversity in Java and Indonesia.

Three environmental variables i.e. elevation, annual mean temperature, and amount of deadwood influenced the composition of land snail communities in GHSNP. Twenty one out of 43 species were recorded in a short elevation range. Five species were recorded only at sampling points above 1500 m a.s.l. e.g. *Diplommatina planicollis*, *Meghimatium striatum, Microcystina fruhstorferi, Parmarion pulpillaris,* and *Philalanka nannophya*; and six species were recorded only at area below 1000 m a.s.l. e.g. *Cyclophorus rafflesi*, *Glessula sumatrana*, *Landouria winteriana*, *Microcystina circumlineata, Paralaoma javana,* and *Trochomorpha appropinquata*. However, most of these species actually have wider elevation ranges (van Benthem Jutting 1950, 1952; Nurinsiyah & Hausdorf, 2017). The overlap of the land snail communities of the four sampled locations in the Mt. Halimun and Mt. Salak regions in the ordination plot (Fig. 4) showed that the different geographical regions of the GHSNP are not characterized by distinct land snail communities, but that the occurrence of snail species does depend more on the availability of suitable microhabitats.

With regard to the factors that affect the species richness of the land snail communities in GHSNP, the only correlation we found is the decrease of species richness with decreasing soil pH. However, the statistical power for this analysis was low because of the low number of investigated plots, the low abundance of the species, the low species richness of plots and the limited habitat diversity that has been sampled. Many of the species that require a constantly high humidity like the caenogastropods are threatened by local extinction if the canopy cover is reduced so that insolation increases and, thus, temperature increases and humidity decreases at the forest floor (Schilthuizen *et al*. 2005; Nurinsiyah *et al*. 2016). We have not found this effect in the parts of GHSNP surveyed, because we surveyed only natural forest habitats with a more or less intact canopy cover.

GHSNP has suffered from deforestation since decades. The annual deforestation rate was 1.2–2.3% between 1989 and 2003 and from 2003 to 2007 5006 ha of the park were deforested in Bogor district (Kubo & Supriyanto 2010; Carolyn *et al*. 2013). Although the total area of GHSNP is 113,357 ha, only about 60,000 ha remained covered with forest (Kubo & Supriyanto 2010). Future studies of degraded habitats in the GHSNP are needed to investigate the effects of the degradation on the native snail communities. This will also be important for assessing the distribution of introduced species in the GHSNP because an opening of the canopy cover favors introduced snail species with a higher desiccation tolerance (Nurinsiyah *et al.* 2016).

ACKNOWLEDGEMENT

We are grateful to Thomas and Kristina von Rintelen (ZMB), the Halimun-Salak National Park authorities and the Ministry of Environment and Forestry, staffs from Museum Zoologicum Bogoriense for the help during field and laboratory work. We also thank Tan Siong Kiat (NUS) and Barna Páll-Gergely (Hungary) for the reviews and helpful comments. The study is supported by the Indonesian-German Scholarship Program (KEMENDIKTIRISTEK-RI and DAAD), the University of Hamburg, and BMBF (INDOBIOSYS MfN Berlin, 16GW0111K).

REFERENCES

Boettger, O. (1890). Ad. Strubell's Konchylien aus Java I. *Bericht über die Senckenbergische Naturforschende Gesellschaft,* 1890, 137–173, pls. 5–6.

Bruner, A.G., Gullison, R.E., Rice, R.E., & da Fonseca, G.A.B. (2001). Effectiveness of parks in protecting tropical biodiversity. *Science*, 291, 125-128.

Cameron, R.A.D. & Pokryszko, B.M. (2005). Estimating the species richness and composition of land mollusc communities: problems, consequences and practical advice. *Journal of Conchology*, 38, 529–547.

Carolyn, R.D., Baskoro, D.P.T. & Prasetyo, L.B. (2013). Analisis degradasi untuk penyusunan arahan strategi pengendaliannya di Taman Nasional Gunung Halimun-Salak Provinsi Jawa Barat. *Majalah Ilmiah Globe*, 15, 39-47.

Chao, A. & Chiu, C.H. (2016). Nonparametric estimation and comparison of species richness. Wiley *StatsRef: Statistics Reference Online*, 1, 26.

Chao, A., Ma, K.H., Hsieh, T.C. & Chiu, C.H. (2015). Online Program SpadeR (Species-richness Prediction and Diversity Estimation in R). Program and User's Guide. Accessed from http:// chao.stat.nthu.edu.tw/wordpress/ software_download/.

Cowie, R.H. (1998). Patterns of introduction of non-indigenous non-marine snails and slugs in the Hawaiian Islands. *Biodiversity and Conservation*, 7, 349–368.

DPJLHK (Direktorat Pemanfaatan Jasa Lingkungan Hutan Konservasi) (2016). Profil kawasan TN Gunung Halimun Salak. Accessed from http://jasling.net/ profil_kawasan/detail_kawasan.php? id_kawasan=190&cat=1 . [19 February 2016].

Emberton, K.C., Pearce, TA. & Randalana, R. (1996). Quantitatively sampling land-snail species richness in Madagascan rainforests. *Malacologia*, 38, 203–212.

Endangered Species Team GHSNPMP-JICA (2005). Ecological Study Halimun-Salak Corridor Mount Halimun-Salak National Park. Accessed from https:// report.nat.gov.tw/ReportFront/ PageSystem/reportFileDownload/ C10202500/003

Faith, D.P., Minchin, P.R. & Belbin, L. (1987). Compositional dissimilarity as a robust measure of ecological distance. *Vegetatio*, 69, 57–68.

Greke, K. (2019). New species and record of

Diplommatina Benson, 1849 (Gastropoda: Diplommatinidae) from Java, Indonesia. *Nautilus*, 133, 14–21.

Halimun Salak National Park Authority (2016). Accessed from http:// halimunsalak.org/ [19 February 2016].

Hausdorf, B. (2002). Introduced land snails and slugs in Colombia. *Journal of Molluscan Studies,* 68, 127–131.

Hengl, T., Mendes, J.J., Heuvelink, G.B.M., Ruiperez, G.M., Kilibarda, M., Blagotić, A., Shangguan, W., Wright, M.N., Geng, X., Bauer-Marschallinger, B., Guevara, M.A., Vargas, R., MacMillan, R.A., Batjes, N.H., Leenaars, J.G.B., Ribeiro, E., Wheeler, I., Mantel, S. & Kempen, B. (2017). SoilGrids250m: global gridded soil information based on machine learning. *PloS One*, 12, 1-40.

Heryanto. (2001). Snails composition in the southern part of Gvjsung Halimun National Park. *Berita Biologi*, 5(6), 765-771.

Heryanto. (2008). Ekologi keong darat di Taman Nasional Gunung Ciremai. *Jurnal Biologi Indonesia*, 4, 359-370.

Heryanto. (2012). Keanekaragaman keong darat di dua macam habitat makro di Gunung Slamet Jawa Tengah. In: Maryanto, I., Noerdjito, M. & Partomihardjo, T. (Editors.) *Ekologi Gunung Slamet: Geologi, klimatologi, biodiversitas dan dinamika sosial.* Jakarta: LIPI Press.

Heryanto, Ristiyanti, M.M., Munandar, A. & Susilowati, P. (2003). *Keong dari Taman Nasional Gunung Halimun, Sebuah Buku Panduan Lapangan*. Cibinong: Biodiversity Conservation Project-LIP-JICA-PHKA.

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G. & Jarvis, A. (2005). Very high-resolution interpolated climate surfaces for global land areas. *International Journal of Climatology*, 25, 1965–1978.

Kubo, H. & Supriyanto, B. (2010). From fence -and-fine to participatory conservation: mechanism of transformation in conservation governance at the Gunung Halimun-Salak National Park, Indonesia. *Biodiversity Conservation*, 19, 1785-1803.

Loosjes, F.E. (1953). Monograph of the Indo-Australian Clausiliidae (Gastropoda, Pulmonata, Clausiliidae, Phaedusinae). *Beaufortia*, 31, 1–226.

Martens, E. (1867). Die Landschnecken. In: Die Preussische Expedition nach Ost-Asien. Nach amtlichen Quellen. *Zoologischer Theil.* Vol. 2. Berlin: Decker

Marwoto RM (1998) A Preliminary Study of Land Snails in Gunung Halimun National Park. Research and Conservation of Biodiversity in Indonesia Vol. IV. Gunung Halimun: The Last Submontane Tropical Forest in West Java. LIPI-JIKA-PHPA, Bogor, pp.148-154.

Ministry of Environment and Forestry. (2016). Statistik Kementrian Lingkungan Hidup dan Kehutanan Tahun 2015. Jakarta: Pusat Data dan Informasi Kementrian Lingkungan Hidup dan Kehutanan Republik Indonesia.

Moritz, C., Richardson, K.S., Ferrier, S., Monteith, G.B., Stanisic, J., Williams, S.E. & Whiffin, T. (2001).

Biogeographical concordance and efficiency of taxon indicators for establishing conservation priority in a tropical rainforest biota. *Proceedings of the Royal Society of London. Series B: Biological Sciences,* 268(1479), 1875-1881.

Nurinsiyah, A.S. (2015). Land snail fauna of the Sukolilo karst in Java (Indonesia). *American Conchologist*, 43, 30–32.

Nurinsiyah, A.S. (2018). *Land snails of Java: a study on systematics, ecology, and biogeography.* Dissertation. Hamburg: University Hamburg

Nurinsiyah, A.S., Fauzia, H., Hennig, C. & Hausdorf, B. (2016). Native and introduced land snail species as ecological indicators in different land use types in Java. *Ecological Indicators*, 70, 557–565.

Nurinsiyah, A.S. & Hausdorf, B. (2017). Revision of the Diplommatinidae (Gastropoda: Cyclophoroidea) from Java. *Zootaxa*, 4312, 201-245.

Nurinsiyah, A.S. & Hausdorf, B. (2019). Listing, impact assessment and prioritization of introduced land snail and slug species in Indonesia. *Journal of Molluscan Studies*, 85, 92-102.

Nurinsiyah, A.S., Neiber, M.T. & Hausdorf, B. (2019). Revision of the land snail genus Landouria Godwin-Austen, 1918 (Gastropoda, Camaenidae) from Java. *European Journal of Taxonomy*, 526, 1-73.

Oksanen, J., Blanchet, F.G., Kindt, R., Legendre, P., Minchin, P.R., O'Hara, R.B., Simpson, G.L., Solymos, P., Stevens, M.H.H. & Wagner, H. (2013). Package 'vegan': Community Ecology Package. R package version 2.0-6. Accessed from http://CRAN.R-project.org/package=vegan.

Pusat Pendidikan dan Pelatihan Kehutanan. (2016). Modul Pengantar KPH. http://pusdiklathut.org/baktirimbawan/kph/index.html. Accessed from [19 December 2016].

R Core Team. (2018). R: A language and environment for statistical computing, version 3.5.2. R Foundation for Statistical Computing, Vienna, Austria. Accessed from http://CRAN.R-project.org/.

Régnier, C., Achaz, G., Lambert, A., Cowie, R.H., Bouchet, P. & Fontaine, B. (2015). Mass extinction in poorly known taxa. *PNAS,* 112(25), 7761-7766.

Schilthuizen, M. (2011). Community ecology of tropical forest snails: 30 years after Solem. *Contributions to Zoology*, 80, 1–15.

Schilthuizen, M., Liew, T.S., Elahan, B. & Lackman-Ancrenaz, I. (2005). Effect of karst forest degradation on pulmonate and prosobranch land snail communities in Sabah, Malaysian Borneo. *Conservation Biology*, 19, 949-954.

Sodhi, N.S., Koh, L.P., Brook, B.W. & Ng, P.K.L. (2004). Southeast Asian biodiversity: an impending disaster. *Trends in Ecology and Evolution*, 19, 654-660.

Subasli, D.R. & Munandar, A. (1999). *Laporan Perjalanan ke Taman Nasional Gunung Halimun.* Unpublished report. Balitbang Zoologi, Puslitbang Biologi LIPI.

Tillier, S. (1992). Introduced land snails in

New Caledonia: A limited impact in the past, a potential disaster in the future. *Pacific Science*, 46, 396-397.

van Benthem Jutting, W.S.S. (1948). Systematic studies on the non-marine Mollusca of the Indo-Australian archipelago. I. Critical Revision of the Javanese Pulmonate land-shells of the families Hydrocenidae, Helicinidae, Cyclophoridae, Pupinidae and Cochlostomatidae. *Treubia*, 19, 539–604.

van Benthem Jutting, W.S.S. (1950). Systematic studies on the non-marine Mollusca of the Indo-Australian archipelago. II. Critical Revision of the Javanese Pulmonate land-shells of the families Helicarionidae, Pleurodontidae, Fruticicolidae and Streptaxidae. *Treubia*, 20, 381–505.

van Benthem Jutting, W.S.S. (1952). Systematic studies on the non-marine Mollusca of the Indo-Australian archipelago. III. Critical Revision of the Javanese Pulmonate land-shells of the families Ellobiidae to Limacidae, with an Appendix on Helicarionidae. *Treubia*, 21, 291–435.

Vermeulen, J.J. & Whitten, A.J. (1998). *Fauna Malesiana Guide to the Land Snails of Bali*. Leiden: Backhuys Publishers.