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Listing, impact assessment and prioritization of introduced land snail and slug species in Indonesia

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ABSTRACT

As the basis for an assessment of the impact of introduced land snail and slug species in Indonesia, we provide a list of these species and specify their distribution in Indonesia, their native range, their habitats and their earliest recorded occurrence in Indonesia. We focus in particular on Java, but also provide data for other parts of Indonesia. Fifteen land snail and slug species occurring in Indonesia are considered introduced. These introduced species are represented in Indonesia by multiple self-sustaining populations in the wild and, thus, are classified as invasive. Using a generic scoring system, we assess the impact of these species with regard to natural environments and to socio-economic issues. Based on this, we suggest a preliminary prioritization for invasive species. We show that *Laevicaulis alte*, *Sarasinula plebeia*, *Bradybaena similaris* and *Lissachatina fulica* have the highest negative impact scores. This is mainly because of their impact on agriculture and their possible importance as intermediate hosts of the rat lungworm (*Angiostrongylus cantonensis*), a parasite causing eosinophilic meningitis in humans. In order to fulfil one of the targets of the Strategic Plan for Biodiversity 2011–2020, we outline possible measures to control priority species. Finally, we discuss the different scoring systems used for assessing the impacts of introduced species.

INTRODUCTION

For centuries, Indonesia and especially Java was the trade hub of Southeast Asia. Java is now the most populous island in the world and, accordingly, most of its area has been strongly modified by humans (Whitten, Soeriaatmadja & Afiff, 1997). Thus, it is not surprising that many species have been introduced into Indonesia and have become established there (Whitten *et al.*, 1997). One of the targets formulated in the Strategic Plan for Biodiversity 2011–2020 adopted in 2010 by the parties of the Convention on Biological Diversity, including Indonesia, is the identification and prioritization of invasive alien species and the control or eradication of priority species by 2020 (www.cbd.int/decision/cop/?id=12268). However, currently not even a list of invasive mollusc species established in Indonesia exists.

The land snail fauna of Indonesia is highly diverse. Probably >2,000 species of land snail and slug species occur there (based on lists in Hausdorf, in press, and unpublished estimates for areas not covered in these lists). Thus, it harbours almost 10% of global terrestrial gastropod species (Rosenberg, 2014). Non-native species are often implicated as the major factor in the extinction of native species (Lowe *et al.*, 2000; Pyšek *et al.*, 2017). In addition, many non-native mollusc species are important as agricultural pests (Kalshoven, 1950; Mead, 1961, 1979; Raut & Ghose, 1984; Raut & Mandal, 1984; Raut & Barker, 2002; Rueda *et al.*, 2002; Mordan *et al.*, 2003; Herbert, 2010; Brodie & Barker, 2011) or as intermediate hosts of parasites that may affect human and livestock health (Kliks & Palumbo, 1992; Prociv, Spratt & Carlisle, 2000; Grewal *et al.*, 2003; Barratt *et al.*, 2016). However, species should not simply be judged by their origin, but should rather be assessed by their impacts (Davis *et al.*, 2011). A compilation of the available data on introduced snails and slug species in Indonesia is necessary for an assessment of their impacts and the development of appropriate control measures.

Here, we present a list of the land snail and slug species introduced into Indonesia, including records from Java and distributional data from other Indonesian islands. We summarize data on the native ranges of introduced species, their habitats and their earliest recorded occurrence in Indonesia, and assess the impacts of these species with regard to the natural environment and to specific socio-economic issues. Based on the latter assessment, we suggest a preliminary prioritization of invasive species, and in order to fulfil the aim of the Strategic Plan for Biodiversity 2011–2020, we discuss possible measures for controlling priority species.

MATERIAL AND METHODS

We list and discuss the land snail and slug species that are considered introduced into Indonesia (i.e. species that are presumed to have been transported by humans from other regions to Indonesia). The status of two species (*Macrochlamys amboinensis* and *Bradybaena similaris*) is uncertain, but we have included them in our list for the reasons discussed below.

This study is based on fieldwork carried out by the first author in Java and Madura between 2013 and 2015 (Nurinsiyah, 2015;

Nurinsiyah *et al*., 2016); the collected land snail material has been stored in the Museum Zoologicum Bogoriense and the Zoological Museum Hamburg. These data are supplemented by distributional data for Java from the literature and museum collections and by published records from other parts of Indonesia (van Benthem Jutting, 1964; Hausdorf, in press and references therein). The collections-based data for Java were obtained from the following institutions: Museum Zoologicum Bogoriense (Cibinong, Indonesia); the Naturalis Biodiversity Center, Leiden [the Netherlands; including the collections of the former Rijksmuseum van Natuurlijke Historie (RMNH) and the Zoological Museum Amsterdam (ZMA)]; the Senckenberg Museum Frankfurt (Germany); and the Zoological Museum Hamburg (Germany). Citizen-science data from internet webpages (i.e. Youtube and iNaturalist.org) formed an additional source of information; we used scientific and local species names as keywords in our web searches. The list includes descriptions of the habitat of each species (based on data from our fieldwork, from museum labels and/or from the literature); data on the first recorded occurrences of individual introduced species in Indonesia (obtained from the literature and museum labels) and references useful for species determination. Taxonomic classification follows Bouchet *et al.* (2017).

For assessing the impact of individual introduced species, we used the generic scoring system proposed by Kumschick *et al.* (2012). This scoring system considers negative as well as positive impacts on the natural environmental and socio-economic factors. Impacts on the natural environment include those relating to herbivory/toxicity, competition, predation, transmission of diseases to wildlife, hybridization and other aspects (i.e. chemical, physical or structural changes in ecosystems). Socio-economic impacts are those on agriculture, on animal production, on forestry, on infrastructure, on human health and on human social life. Impacts were assessed based on literature reviews and personal evaluations; scores between 0 (no impact) and 5 (highest impact) were given for each impact category, following the score definitions of Kumschick *et al.* (2012).

The conceptual framework used by Kumschick *et al.* (2012) for prioritizing invasive alien species for management on the basis of their impact consists of five steps. These are: (1) stakeholder selection and weighting of stakeholder importance; (2) description and scoring of changes caused by invasive species; (3) evaluation of the relative importance of impact categories by stakeholders; (4) calculation of the weighted impact categories and (5) estimation of the final impact scores. The weighting of stakeholder importance and the relative importance of impact categories depends on the concrete aim of the prioritization. The Strategic Plan for Biodiversity 2011–2020 does not specify the aim of the prioritizing invasive species. So far no stakeholder consortium has been established. Thus, we suggest here a preliminary prioritization based on unweighted impact score sums, which could be discussed and modified by stakeholders in due course.

RESULTS

List of introduced land snail and slug species in Indonesia

Distributional data for Indonesia (see also Supplementary Material Table S1), with particularly detailed data for Java, are summarized in the maps in Figure 1. The distributional maps for Java are based on a total of 1043 records from our fieldwork (430 records), from museum collections, literature and the internet (Supplementary Material Tables S2, S3). Information about the native ranges of the introduced species and references for their determination can be found in Table 1.

Family VERONICELLIDAE

Laevicaulis alte (Férussac, 1821)

Habitat: Human modified habitats such as agroforests and teak plantations at altitudes ranging from sea level–1000 m.

Date of introduction: van Hasselt (1823) was the first worker to collect veronicellids from Java. He identified several species but, due to his early death descriptions of these species were not published. One of these species, which was from Tjihanjavar in Java (according to Martens, 1867, probably a destroyed village on Mount Gede), was described by Deshayes (1851 in Férussac & Deshayes, 1819–1851) as *Vaginula maculosa*. Vouchers from van Hasselt were examined by Semper (1885 in 1870–1885) and Hoffmann (1925). According to Hoffmann (1925), the vouchers belong to two different species, *L. alte* and *Filicaulis bleekeri* (Keferstein, 1865).

Sarasinula plebeia (Fischer, 1868)

Habitat: Lowland to mid-elevational forests, plantations, grasslands and gardens (Brodie & Barker, 2011).

Date of introduction: Sarasinula plebeia was first recorded in Indonesia from Sumatra in 1926 (van Benthem Jutting, 1959).

Remarks: The distribution in Indonesia is likely to be incomplete known because of possible confusion with veronicellid species that are similar in external morphology.

Family ACHATINIDAE

Lissachatina fulica (Bowdich, 1822)

Habitat: Human-modified habitats with high rainfall and warm climate at altitudes up to 1455 m.

Date of introduction: Lissachatina fulica was probably present in the Riau Archipelago, close to Singapore, by 1903 (Bequaert, 1950). It was introduced to East Kalimantan in 1921 (Mead, 1961) and to Sumatra probably also about the same time (Bequaert. 1950). By 1947 it had been introduced to Sulawesi, the Malaku Islands (Mead, 1961) and New Guinea (van Benthem Jutting, 1964). Kalshoven (1950) reported that a specimen of *L. fulica* was first brought to Bogor in Java from Singapore in 1922, but was apparently not released. According to notes about further introductions compiled by Mead (1961), the species arrived in Java in 1925 in a shipment of grass plants from Sri Lanka, was clandestinely introduced into Sukabumi, a suburb of Jakarta, in 1930–1931 and was brought to Jakarta by plant breeders in 1933 (it may have been introduced to Jakarta from Singapore).

Allopeas clavulinum (Potiez & Michaud, 1838)

Habitat: Shrubs, tea and teak plantations, agroforests, bamboo, secondary and natural forests on volcanic and calcareous soils at altitudes from 0 to 2000 m.

Date of introduction: The earliest record of *A. clavulinum* in Indonesia is a sample from the Tengger Mountains in East Java (ZMA 32506), which was collected by Hans Fruhstorfer, probably during his journey to Java in 1891–1893 (Möllendorff, 1897).

Allopeas gracile (Hutton, 1834)

Habitat: Bamboo, shrubs, agroforests, tea and teak plantations, pine forests, lowland rainforests, secondary and natural forests on volcanic and calcareous soils at altitudes from sea level to 1400 m.

Date of introduction: Based on collections of Heinrich Zollinger, *A. gracile* was first recorded from Java by Mousson (1848) under the synonym *Bulimus apex* Mousson, 1848.

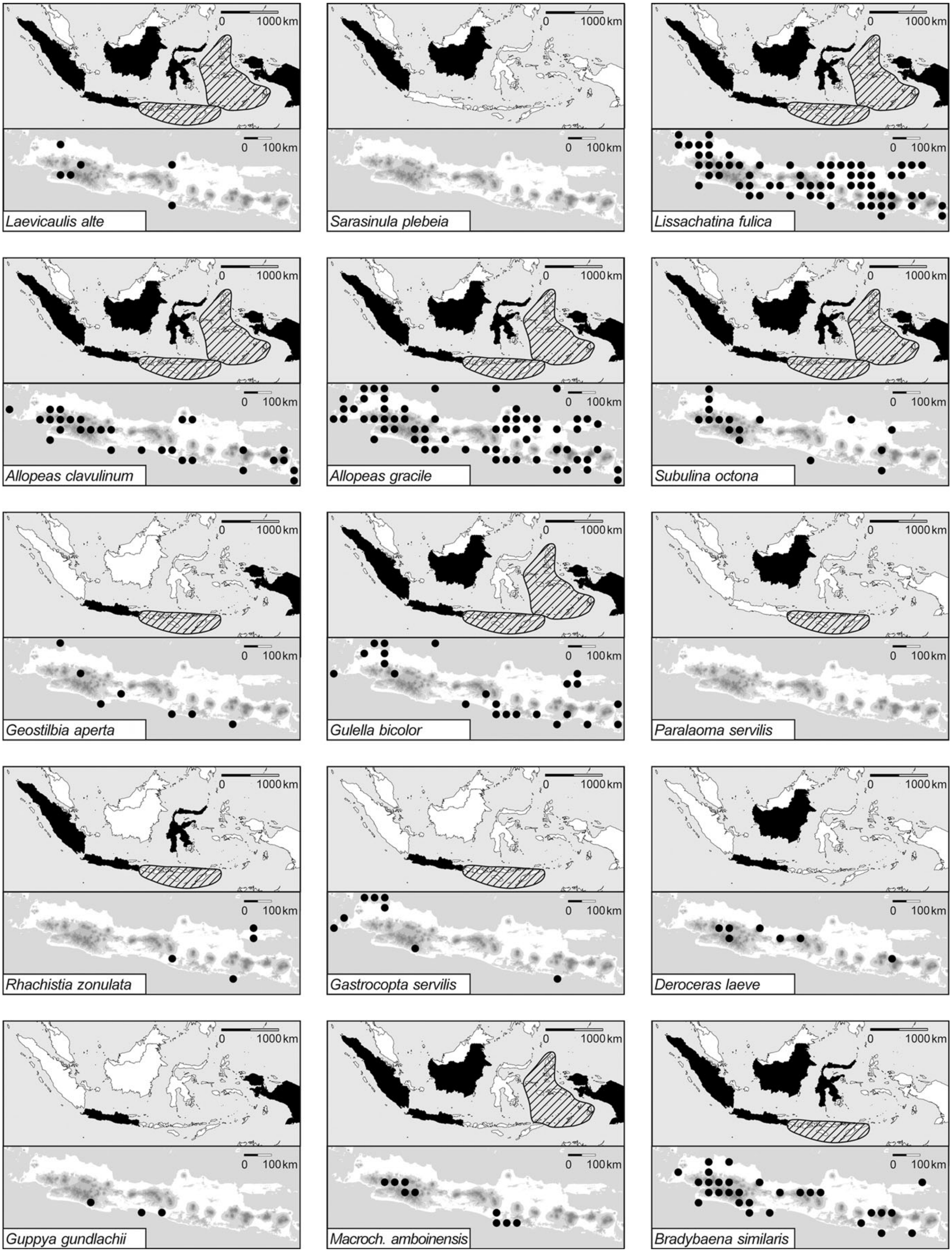

Figure 1. Maps of the distribution of introduced land snail and slug species in Indonesia (upper panel: major islands and island groups; lower panel: Java, 20′ grid). *Macrochlamys amboinensis* has been abbreviated as *Macroch. amboinensis*.

Table 1. Details of the native range and key taxonomic references for introduced land snail and slug species in Indonesia.

	Native range	References for identification
Laevicaulis alte (Férussac, 1821)	Africa (Solem, 1964; Cowie, 1998; Robinson, 1999; Herbert, 2010; Brodie & Barker, 2011)	Gomes & Thomé (2001); van Benthem Jutting (1952)
Sarasinula plebeia (Fischer, 1868)	Neotropics (Solem, 1964; Cowie, 1998; Robinson, 1999)	Gomes & Thomé (2001)
Lissachatina fulica (Bowdich, 1822)	East Africa (Bequaert, 1950)	Bequaert (1950); van Benthem Jutting (1952)
Allopeas clavulinum (Potiez & Michaud, 1838)	Africa (Cowie, 1998; Robinson, 1999; Brodie & Barker, 2011)	van Benthem Jutting (1952)
Allopeas gracile (Hutton, 1834)	Neotropics (Solem, 1964; Robinson, 1999; Brodie & Barker, 2011); Old World (Christensen & Weisler, 2013)	van Benthem Jutting (1952)
Subulina octona (Bruguière, 1789)	Neotropics (Solem, 1964; Cowie, 1998; Robinson, 1999; Brodie & Barker, 2011; but see Bieler & Slapcinsky, 2000)	van Benthem Jutting (1952)
Geostilbia aperta (Swainson, 1840)	West Indian islands (Solem, 1964; Cowie, 1998), Neotropics (Robinson, 1999)	Vermeulen & Whitten (1998)
Gulella bicolor (Hutton, 1834)	India (Naggs, 1989)	van Benthem Jutting (1950)
Paralaoma servilis (Shuttleworth, 1852)	Probably Australasia (Hausdorf, 2002)	Vermeulen & Whitten (1998)
Rhachistia zonulata (Pfeiffer, 1846)	East Africa (Verdcourt, 1961; Solem, 1989)	Dharma (1992), Chan (2010)
Gastrocopta servilis (Gould, 1843)	West Indies (Solem, 1989; Brodie & Barker, 2011), Neotropics (Cowie, 1998; Robinson, 1999)	Solem (1989), van Benthem Jutting (1952, as *Gastrocopta lyonsiana*)
Deroceras laeve (Müller, 1774)	Holarctic (Cowie, 1998; Robinson, 1999; Brodie & Barker, 2011); Palaearctic (Wiktor, 2000)	van Benthem Jutting (1952); Wiktor (2000)
Guppya gundlachii (Pfeiffer, 1840)	Neotropics (Robinson, 1999)	Pilsbry (1946)
Macrochlamys amboinensis (Martens, 1864)	Unknown	Blanford & Godwin-Austen (1908); van Benthem Jutting (1952); Griffiths & Florens (2006)
Bradybaena similaris (Férussac, 1822)	Probably China	van Benthem Jutting (1950)

Subulina octona (Bruguière, 1789)

Habitat: Agroforests, plantations and natural forests on volcanic and calcareous soils at altitudes from sea level to 1600 m.

Date of introduction: The earliest record of *S. octona* in Indonesia is a sample from Sawah Besar (Weltevreden) in Jakarta (ZMA 32447), which was collected by the medical officer Jan Semmelink before 1880.

Geostilbia aperta (Swainson, 1840)

Habitat: Shrubs, guava, teak plantations, agroforests, bamboo and natural forests at altitudes from sea level to 800 m.

Date of introduction: Geostilbia aperta was first recorded in Indonesia from Bali in 1927 and published by Rensch (1932) under the name *Caecilioides* (*Geostilbia*) aff. *moellendorffi* Pilsbry, 1909. Rensch (1935) subsequently collected the species from Timor and changed the determination to *Caecilioides philippinica* (Moellendorff, 1890). In Java it was first recorded from Amsterdam Island (Pulau Untungjawa), which is north of Jakarta, by L. Butot in 1951 (ZMA 387428) and from Bogor in 1952 (Butot, 1952).

Family STREPTAXIDAE

Gulella bicolor (Hutton, 1834)

Habitat: Shrubs, plantations, agroforests, secondary and natural forests at altitudes from sea level to 470 m.

Date of introduction: Gulella bicolor was first recorded from Sumenep on Madura by Heinrich Zollinger, probably in the 1840s (Martens, 1867).

Family PUNCTIDAE

Paralaoma servilis (Shuttleworth, 1852)

Habitat: Primary and secondary forests on volcanic and calcareous soils at altitudes from sea level to 2900 m (Vermeulen & Whitten, 1998).

Date of introduction: In Indonesia *P. servilis* was first recorded from Bali under the synonym *Paralaoma caputspinulae* (Reeve, 1852) by Vermeulen & Whitten (1998), Vermeulen & Whitten (1998) treated *P. javana* Möllendorff, 1897 from Java as a junior synonym of *P. caputspinulae*. However, a re-examination of the holotype of *P. javana* and additional material from Java have revealed that *P. javana* is a distinct species (Nurinsiyah & Hausdorf, in prep.).

Family CERASTIDAE

Rhachistia zonulata (Pfeiffer, 1846)

Habitat: Teak plantations and secondary forests on calcareous soils in lowland areas at altitudes from sea level to 250 m.

Date of introduction: Martens (1867) mentioned that a snail from Tjilankahane (Cilangkahan, Malingping, Banten) resembling *R. zonulata* was figured in a drawing of van Hasselt and this indicates that this species was already present on Java in the early 1820s. However, this record was not confirmed until the species was rediscovered in the same area by B. Dharma and M. Djajasasmita in 1985 (RMNH 246437).

Family GASTROCOPTIDAE

Gastrocopta servilis (Gould, 1843)

Habitat: Teak plantations, agroforests and open areas near the coast at altitudes from sea level to 265 m.

Date of introduction: The first record of *G. servilis* in Indonesia was from Pulau Damar Besar (Edam Island) north of Jakarta by K. Dammerman in 1919 (ZMA 375646). In 1921 K. Dammerman recorded it also from Jakarta (ZMA 375647).

Family AGRIOLIMACIDAE

Deroceras laeve (Müller, 1774)

Habitat: Human-modified habitats at altitudes from 1000 to 1700 m.

Date of introduction: Deroceras laeve was first recorded in Java in Gunung Tangkubanperahu by Jacobson in 1937 (Hoffmann, 1941).

Remarks: The identification of *Deroceras* specimens should be verified by anatomical study. It is possible that additional *Deroceras* species have been introduced to Java.

Family EUCONULIDAE

Guppya gundlachii (Pfeiffer, 1840)

Habitat: Plantations, bamboo forests and limestone rocks at altitudes from 150 to 750 m.

Date of introduction. Guppya gundlachii was first found in New Guinea and adjacent islands in 1952 (van Benthem Jutting, 1964). The first record of *G. gundlachii* from Java is from material collected in 2013. However, it is widely distributed in Java and this indicates that it has probably been present there for some time.

Remarks. While Robinson (1999) reported interceptions of this species by the United States Department of Agriculture in shipments from Thailand, it has not yet been found in the wild in Thailand (Hemmen & Hemmen, 2001).

Family ARIOPHANTIDAE

Macrochlamys amboinensis (Martens, 1864)

Habitat: Shrubs, agroforests, teak plantations, natural forests and on the limestone rocks at altitudes from 20 to 3000 m (in Java).

Remarks: Macrochlamys amboinensis was originally described from Ambon, an island in the Maluku Archipelago, and is similar to *Macrochlamys indica* (Godwin-Austen, 1883). The latter species is thought to be native to eastern India, Nepal and Bangladesh (Raheem *et al.*, 2014). It was also recorded from the Andaman Islands (Ramakrishna, Mitra & Dey, 2010), Sri Lanka (Blanford & Godwin-Austen, 1908; Ramakrishna *et al.*, 2010; Raheem *et al.*, 2014) and the Indo-Australian Archipelago, namely Peninsular Malaysia (Maassen, 2001), Sabah and adjacent islands (Phung, Yu & Liew, 2017), where it is considered exotic. Furthermore, the species has certainly been introduced to Madagascar, Mauritius, Rodrigues and Réunion (Griffiths & Florens, 2006). Van Benthem Jutting (1952) gave 12–13 mm as the shell diameter of *M. amboinensis*, but Martens (1867) specified that the shell diameter of the largest specimen from the Maluku Archipelago was 15 mm. In contrast, Griffiths & Florens (2006) indicated that the shell diameter of *M. indica* varies between 15 and 24 mm in the Mascarene Islands. The measurements of Indian specimens given by Godwin-Austen (1883 and 1910 in 1882–1914) and Blanford and Godwin-Austen (1908) are within that range. The material studied by us from Java includes specimens in the size range given by Griffiths & Florens (2006) as well as specimens with a shell diameter >24 mm. This material agrees with the descriptions of *M. indica* by Godwin-Austen (1883 and 1910 in 1882–1914) and Blanford and Godwin-Austen (1908). It has to be checked anatomically or genetically whether the material from Java and India is conspecific with *M. amboinensis* from Ambon, but until such work is carried out we follow van Benthem Jutting (1952), who considered the specimens she examined from both Ambon and Java to be *M. amboinensis*. It is unclear which areas belong to the native range of *M. amboinensis*. In Java, this species has been found in forest on hills and mountains, but also in human modified habitats and van Benthem Jutting (1952) did not consider it to be introduced.

Family CAMAENIDAE

Bradybaena similaris (Férussac, 1822)

Habitat: Shrubs, agroforests and plantations (guava, teak, kina and bamboo) at altitudes from sea level to 1800 m.

Date of introduction: Bradybaena similaris was first recorded from Timor by Férussac (1821 in 1821–1822) and was collected in Java by H. Kuhl and J. C. von Hasselt, when they began their exploration of the island in 1820–1823 (RMNH 309197).

Remarks: As noted by van Benthem Jutting (1950), the native range of *B. similaris* is difficult to ascertain. Solem (1964) supposed that *B. similaris* is native to Southeast Asia and Indonesia. There is no doubt that the native range is in East Asia, but its southern limit is disputable. The highest morphological variability of *B. similaris* is found in China, where several 'subspecies' have been distinguished (Chen & Zhang, 2004); note that some of these forms have partly overlapping ranges and so cannot be classified as geographical subspecies. The highest species richness of *Bradybaena* is also found in China (Chen & Zhang, 2004). With regard to the species represented in the phylogeny of Hirano, Kameda & Chiba (2014), *B. similaris* is most closely related to *B. pellucida* Kuroda & Habe, 1953, a species endemic to Japan. There are also species in mainland Southeast Asia that have been classified in *Bradybaena* (see e.g. Schileyko, 2011). However, *B. tourannensis* (Souleyet, 1842), the only species from Southeast Asia that has been anatomically examined, has been shown to belong to *Acusta* (Nordsieck, 2002). Due to the high morphological variability of *B. similaris* in China and the fact that its closest related species are probably from Japan or China, we consider an origin of *B. similaris* in China most likely. This hypothesis has to be investigated by analyses of the genetic variability of populations of *B. similaris* from Eastern Asia. It is difficult to determine when *B. similaris* colonized Southeast Asia and Indonesia. Given the rapid spread of the species even across continents, we consider it likely that Southeast Asia and Indonesia were colonized only in historical time, perhaps even in the last few centuries. Genetic investigations may provide insights on this.

Additional species

In addition to the species listed above, Whitten *et al.* (1997) reported that *Achatina achatina* (Linnaeus, 1758) (synonym *A. variegata* Lamarck, 1801) has been introduced to Java for rearing as a food source. There is no information about the time or the place of this introduction. We could not find any evidence that the species is still present in Java or that there were ever any populations in the wild. Thus, we do not include this species in our list.

According to the Global Invasive Species Database (http://www.iucngisd.org/gisd/species.php?sc = 92), there are records of *Euglandina rosea* (Férussac, 1821) from Indonesia, but no localities or other details are specified. We could not find vouchers of the species from Indonesia or references specifying where and when this species has been found in Indonesia and whether it had become established. Thus, this species was also not included in our list.

Our results show that there has been a steady increase in the number of species introduced to Indonesia from the early 1820s, when the zoological exploration of Indonesia began (Fig. 2).

Assessment of the impacts of introduced land snail and slug species

The assessment of the impacts of introduced land snail and slug species in Indonesia using the generic scoring system of Kumschick *et al.* (2012) is summarized in Supplementary Material Table S4.

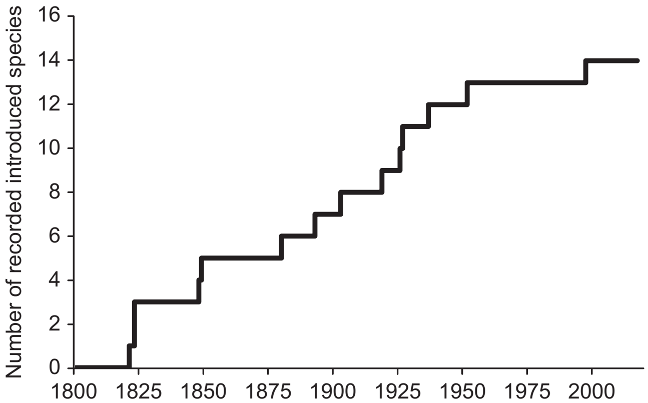

Figure 2. Cumulative number of recorded introductions of land snail and slug species in Indonesia (*Macrochlamys amboinensis* not included).

Herbivory/toxicity: The larger snail and slug species, *Laevicaulis alte, Sarasinula plebeia, Lissachatina fulica, Deroceras laeve, Macrochlamys amboinensis* and *Bradybaena similaris*, may eat the green parts and fruits of a wide variety of plants, including native species (Kalshoven, 1950; Mead, 1961, 1979; Raut & Ghose, 1984; Raut & Mandal, 1984; Raut & Barker, 2002; Rueda *et al.*, 2002; Mordan *et al.*, 2003; Herbert, 2010). However, they generally prefer decomposing plant material to green plant matter (Raut & Ghose, 1984). Even *L. fulica*, which is listed among the 100 worst invasive species on Earth (Lowe *et al.*, 2000), is predominantly detritivorous in natural habitats (O'Loughlin & Green, 2017). No lasting regional or global decline of populations of native plants, much less their extinction by invasive snail species has been documented. Thus, we assign *L. alte, S. plebeia, L. fulica, D. laeve, M. amboinensis* and *B. similaris* a score of –2. The small achatinids *Allopeas clavulinum, A. gracile* and *Subulina octona* are detritivores, but may occasionally also feed on parts of fresh plant (Kalshoven, 1950; Raut & Ghose, 1984; Mordan *et al.*, 2003; Mujiono, 2010). Thus, we assigned them a score of –1. The small sized detritivores *Geostilbia aperta, Paralaoma servilis, Gastrocopta servilis* and *Guppya gundlachii*, the arboreal *Rhachistia zonulata* and the carnivore *Gulella bicolor* have no known negative impact with regard to herbivory. Overall, none of the introduced species has positive effects with regard to herbivory or is known to be toxic.

Competition: Cowie (2001) speculated that the decline of some native litter-dwelling snail species in Samoa has been caused by competition with invasive achatinid species (notably *Allopeas gracile, Subulina octona* and *Paropeas achatinaceum*; see also Cowie, 2005). However, there are no clear cases in which competition between invasive and native species of molluscs has been demonstrated in the Pacific islands (Cowie, 2005). A study that examined interactions between the invasive *Lissachatina fulica* and a similar-sized native species in Brazil also could not find evidence for competition (Miranda, Fontenelle & Pecora, 2015). There is also no evidence for a causal relationship between the population increase of any of the invasive snail species in Indonesia and a population decrease or extinction of native species.

Invasive land snail and slug species occur preferentially in habitats that have been strongly modified by humans and are especially abundant in deforested habitats (Nurinsiyah *et al.*, 2016). While the composition of the snail communities in such habitats is very different from those in natural habitats (Nurinsiyah *et al.*, 2016), the changes in community composition are not primarily caused by invasive species. Rather, invasive species become established and populations of native forest-dwelling species decline or become extinct because of habitat modification by humans (e.g. by selective logging, agroforestry, etc.). Only a few studies have examined the dispersal of invasive snail species into natural habitats in the tropics and their effect on the composition of native snail communities. Lake & O'Dowd (1991) and Nurinsiyah *et al.* (2016) have shown that the abundance of *L. fulica* declines rapidly from disturbed habitats at the forest margin towards the interior of the natural forest. One reason for the limited invasion of natural habitats by introduced snail species is predation by native species. On Christmas Island red crabs *Gecarcoidea natalis* decimated populations of *L. fulica* in rainforest (but not in disturbed habitats, Lake & O'Dowd, 1991), until red crabs were themselves locally extirpated by invasive yellow crazy ants *Anoplolepis gracilipes* (O'Loughlin & Green, 2015, 2017).

We cannot exclude the possibility that invasive detritivorous or herbivorous land mollusc species compete with native species. However, there is little evidence for competitive exclusion in land snail communities (Barker & Mayhill, 1999; Chiba & Cowie, 2016). Interspecific interference competition might be weak because most land snail species are generalists, but might nevertheless result in the decline or extinction of native species, in the long term, as has been speculated by Cowie (2001, 2005). Thus, we scored the negative impact of invasive detritivorous or herbivorous land snail and slug species as 1. More studies investigating the dispersal of invasive species into natural habitats, and long-term studies monitoring habitat change and changes in the community composition of natural habitats, are necessary to clarify whether the impacts of competitive interactions between invasive and native species is greater than generally thought.

Predation: There are no reports as yet on the negative impacts of *Gulella bicolor*, the only invasive carnivorous land snail in the list. This is despite the fact that this species has been introduced into many other tropical and subtropical countries. The species only rarely invades natural forests and feeds mainly on other invasive species like *Allopeas gracile*, *Subulina octona* and juveniles of *Lissachatina fulica* (Naggs, 1989). Thus, we scored the negative as well as the positive impact of this species as 1.

Meyer, Hayes and Meyer (2008) reported that *L. fulica* occasionally preyed on invasive veronicellid slugs (*Veronicella cubensis* (Pfeiffer, 1840)) in Hawaii and warned that this usually herbivorous species might represent a greater threat to native species than previously thought. Given that there are no observations of this species preying on native species, much less any evidence for a decline of native species, we scored the negative impact of predation by *L. fulica* as 1. As it is known to prey on invasive species, we scored the positive impact of this species as 1.

Transmission of diseases to wildlife: Many snail species are intermediate hosts for platyhelminth or nematode parasites of vertebrates. Among the invasive land snail and slug species in Indonesia, *Laevicaulis alte*, *Sarasinula plebeia*, *Lissachatina fulica*, *Subulina octona*, *Deroceras laeve* and *Bradybaena similaris* are known as intermediate hosts (Araújo & Bessa, 1993; Grewal *et al.*, 2003). However, most parasites that use molluscs as intermediate hosts accept a broad range of host snail and slug species (Grewal *et al.*, 2003). Thus, it is likely that other invasive species might act as intermediate hosts and transfer parasites to wildlife. There are no surveys on the frequency of parasite transmission to wildlife by invasive snail species and there are no reports of declines of wildlife population caused by parasitic diseases involving invasive mollusc species as intermediate hosts. Given that invasive mollusc species may transmit parasites to invasive final hosts such as rats (Kliks & Palumbo, 1992; Prociv *et al.*, 2000; Barratt *et al.*, 2016), we scored both the negative and positive impacts of disease transmission for all invasive mollusc species as 1.

Hybridization: As far as is currently known, none of the invasive mollusc species have closely related native species in Indonesia. Thus, the impacts of invasive species hybridizing with native species are unlikely.

Impact on ecosystem: No additional impacts on the ecosystem were reported.

Agriculture: The economic impacts of invasive species might best be quantified as costs. However, hardly any estimates of the costs of the damage caused by land snail and slug species in the tropics are available. Andrews (1987) estimated that on average between 15% and 20% of the potential agricultural yield in Central America is lost due to damage from veronicellid slugs (especially *Sarasinula plebeia*); this amounts to $27–45 million per year. Although there is an extensive literature emphasizing the economic importance of *Lissachatina fulica*, not even for this species are comparable figures available. Thus, the assessment of the agricultural impacts of the invasive snail species depends on qualitative data from the literature.

Lissachatina fulica feeds on diverse vegetables, fruits, seedlings (e.g. of tea and rubber trees) and ornamental plants (Kalshoven, 1950; Mead, 1961, 1979; Raut & Ghose, 1984; Raut & Barker, 2002; Mordan *et al.*, 2003). However, in natural habitats it is predominantly detritivorous (O'Loughlin & Green, 2017). It is often classified as the most important agricultural molluscan pest because of its body size and fecundity. However, its impact on agriculture may not be as severe as many reports suggest (Civeyrel & Simberloff, 1996), and it has never been considered a serious pest in Indonesia (Mead, 1979). The veronicellid slugs *Laevicaulis alte* and *Sarasinula plebeia* attack a wide variety of crops (Raut & Mandal, 1984; Rueda *et al.*, 2002; Mordan *et al.*, 2003; Brodie & Barker, 2011). *Bradybaena similaris* feeds on diverse vegetables, legumes, fruits, coffee and ornamental flowers (Kalshoven, 1950; Mordan *et al.*, 2003; Herbert, 2010; Mujiono, 2010; Brodie & Barker, 2011) and may occur at high population densities, thus also causing problems for the clean harvesting of crops (Herbert, 2010). The veronicellid slugs and *B. similaris* are considered serious agricultural pests (Kalshoven, 1950; Rueda *et al.*, 2002; Mordan *et al.*, 2003; Herbert, 2010; Mujiono, 2010; Brodie & Barker, 2011). Due to the absence of quantitative data that allow a more differentiated classification, we gave the negative impact of *L. fulica*, the veronicellid slugs and *B. similaris* on agriculture a score of 3. A better knowledge of the actual damage caused by these species may result in a re-valuation of this score. *Macrochlamys amboinensis* may feed on fresh parts of diverse plants, but clearly prefers decomposing parts of plants (Raut & Ghose, 1984). It is considered a less serious pest and is scored –2. *Deroceras laeve* feeds on diverse vegetables, legumes, maize and ornamental flowers (Herbert, 2010; Brodie & Barker, 2011). It is considered a less serious pest because of its smaller body size and low frequency; it is scored –2. The small achatinid species *Allopeas clavulinum*, *A. gracile* and *Subulina octona* are predominantly detritivorous, but sometimes may damage legumes, tobacco leaves and ornamental plants (Kalshoven, 1950; Raut & Ghose, 1984; Mordan *et al.*, 2003; Mujiono, 2010). More important than the direct damage caused by these snails might be the financial loss in international trade if agricultural or horticultural goods are destroyed at border checks because of snail infestations. We score their negative impact on agriculture 1. *Geostilbia aperta*, *Paralaoma servilis*, *Gastrocopta servilis* and *Guppya gundlachii* are minute and detritivorous species and therefore do not cause agricultural damage and are scored 0. Similarly, the arboreal *Rhachistia zonulata* and the carnivorous *Gulella bicolor* are unlikely to have a negative impact on agriculture. *Gulella bicolor* might even have a positive influence by preying on invasive species like *A. gracile*, *S. octona* and juveniles of *L. fulica* (Naggs, 1989) and, thus, is the only invasive snail species that is given a positive score of 1.

Animal production: Poultry and some other types of livestock devour land snails and slugs or are fed snails. *Lissachatina fulica* is gathered in Indonesia in large amounts for duck food (Mead, 1979). According to the business directory of the Indonesian Ministry of Industry (http://kemenperin.go.id/direktori-perusahaan), there are several companies in Java and one in Sumatra trading in the flesh of *L. fulica*. Thus, this species increases animal production both directly and indirectly and is scored +2. The other large-bodied invasive species, which frequently occur in farmland, may contribute to an increase of animal production and are scored +1. On the other hand, these snails are intermediate hosts of diverse parasites (see above) and may thus have a negative impact on animal production by transmitting these parasites (Mujiono, 2010). Thus, we also score these larger snail species –1.

Forestry: It has been speculated that *L. fulica* and veronicellid slugs may prevent rainforest regeneration by destroying newly germinated seedlings of native forest plants (Cowie, 2005). However, a study by O'Loughlin & Green (2017) did not provide evidence that *L. fulica* has a significant impact on seedling recruitment in rainforest. Currently, there is also no evidence that any of the other invasive land snail or slug species has an impact on forestry. Thus, we score the impact of all species on forestry as 0.

Infrastructure: There is a report that *Lissachatina fulica* was so abundant in Saipan, an island of the Mariana Islands in the Pacific Ocean, when the American troops landed there in 1945, that the jeeps lost traction (Kalshoven, 1950; Mead, 1961). However, such impacts of land snails or slugs on the infrastructure are so rare that we scored all species 0.

Human health: A wide variety of terrestrial and freshwater snails act as intermediate hosts of the rat lungworm *Angiostrongylus cantonensis* (Grewal *et al.*, 2003; Barratt *et al.*, 2016), which may cause human angiostrongyliasis, a disease characterized by eosinophilic meningitis (Kliks & Palumbo, 1992; Prociv *et al.*, 2000; Barratt *et al.*, 2016). Of the invasive land mollusc species in Indonesia, *Laevicaulis alte*, *Sarasinula plebeia*, *Lissachatina fulica*, *Subulina octona*, *Deroceras laeve* and *Bradybaena similaris* are known to be intermediate hosts of *A. cantonensis* (Grewal *et al.*, 2003). Given the broad taxonomic range of intermediate hosts, it is likely that other invasive species also act as hosts of *A. cantonensis*. For several reasons, *L. fulica* is more likely than other terrestrial snails to transmit the parasite to humans (Kliks & Palumbo, 1992; Prociv *et al.*, 2000; Barratt *et al.*, 2016). *Lissachatina fulica* is abundant in farmland and disturbed habitats, where rats are also abundant. It is therefore more likely to be infected by the parasite through eating rodent faeces and also more likely to come into contact with humans. Moreover, humans may become infected with the parasite on eating this snail (Kliks & Palumbo, 1992; Barratt *et al.*, 2016). It has been claimed that *L. fulica* was essential in the early dispersion of rat lungworm (Kliks & Palumbo, 1992). However, the establishment of *A. cantonensis* in regions not colonized before by *L. fulica* indicates that the role of this species as dispersal agent of the parasite has been overstated (Prociv *et al.*, 2000).

It has also been claimed that *L. fulica* is a vector of the bacterium *Aeromonas hydrophila*, which causes a wide range of symptoms (Mead & Palcy, 1992; Meyer *et al.*, 2008). However, confirmed reports of the transmissions of *A, hydrophila* by *L. fulica* are lacking. It is also very unlikely that an exotic snail acts as a vector of a bacterium that is almost ubiquitous in waterbodies (Hazen *et al.*, 1978) and is more usually ingested with contaminated water.

We scored the negative impact of the invasive species on human health, based on the likelihood that they transmit the rat lungworm. The minute snail species (*Geostilbia aperta*, *Gulella bicolor*, *Paralaoma servilis*, *Rhachistia zonulata*, *Gastrocopta servilis*, *Guppya gundlachii*), which rarely come into direct contact with humans, and the arboreal *Rhachistia zonulata* were scored 0. The small achatinids, *D. laeve* and *Macrochlamys amboinensis*, were scored –1. The larger pest species *L. alte*, *S. plebeia* and *B. similaris*, which are relatively often in contact with humans during removal from farmland by hand picking, were scored –3. *Lissachatina fulica*, which is also removed by handpicking, is sometimes eaten by humans, and so was scored –4. In terms of positive impacts, *L. fulica* is used for traditional medical purposes (Azliza *et al.*, 2012; also in Indonesia, personal observation) and, thus, was scored +1 with regard to human health.

Human social life: The herbivorous slugs *Laevicaulis alte*, *Sarasinula plebeia* and *Deroceras laeve* (all three of which are abundant in some habitats), and the large snail *Bradybaena similaris*, could be considered a nuisance in recreational or residential areas and were thus given a negative score of 1. There are several reports of *Lissachatina fulica* occurring at population densities so great that they seriously interfere with day-to-day life in human settlements—thus assuming an importance that far outweighs any damage they may otherwise cause to vegetation (Mead, 1961). Thus, this species was given a negative score of 2. *Lissachatina fulica* is not always perceived as repulsive. Many people consider this species to be impressive because of its large size and it is often kept as a pet. This has probably contributed to the global dispersal of this species. Thus, it was also given a positive score of 1.

The scoring revealed that *Laevicaulis alte*, *Sarasinula plebeia* and *Bradybaena similaris* have the highest negative total impacts, with all of these species having unweighted impact-score sums of –10. *Lissachatina fulica* has the next highest total negative impact (unweighted impact score sum = –9); if positive impacts are ignored, *L. fulica* has the highest negative total score (–15).

DISCUSSION

Listing, prioritization and control of introduced land snail and slug species in Indonesia

Our survey revealed that fifteen land-snail and slug species have been introduced to Indonesia over the past two centuries (Fig. 2) and have become established there. Other, as yet unrecorded introductions may have occurred in recent decades; the country lacks regular monitoring of land snails and there are only a handful of in-country workers with the expertise to detect new introductions. Of the 15 introduced snail and slug species, only one (*Lissachatina fulica*) was probably intentionally brought to Indonesia; all the other species were most likely unintentionally introduced. There are fewer introduced land-snail species in other regions of Indonesia than in Java. This may reflect lower human population densities and less intensive trade in these regions. The only introduced species known from other islands, but not yet recorded in Java, are *Sarasinula plebeia* and *Paralaoma servilis*. All the introduced species were recorded from several localities in Indonesia and all were recorded in more than one decade. Thus, they are probably represented in Indonesia by multiple self-sustaining populations in the wild and can be classified as invasive following the definition of Blackburn *et al.* (2011).

The Strategic Plan for Biodiversity 2011–2020 aims to control or eradicate priority species by 2020. Our assessment of the impact of introduced land snail and slug species in Indonesia using Kumschick *et al.* (2012) generic scoring system revealed that *Laevicaulis alte*, *Sarasinula plebeia*, *Bradybaena similaris* and *Lissachatina fulica* have the highest negative total scores. This is mainly because these species have an impact on agriculture and because of their potential role in transmitting the rat lungworm to humans (Supplementary Material Table S4). Thus, they can be classified as priority species. *Lissachatina fulica*, *L. alte* and *B. similaris*, however, are so widespread and frequent in Java and Indonesia that their eradication is not feasible in Java, much less in Indonesia as a whole. Nevertheless, steps should be taken to prevent the further spread of these and the other invasive species into islands and regions that have not been infested so far. With regard to 'controlling' populations of invasive species in already infested areas and their further spread, the different impacts of these species have to be considered.

When environmental impacts are considered, the most sustainable measure for controlling invasive land mollusc species is reforestation, with areas immediately around remaining natural forests being an especially high priority in this respect. In closed-canopy forest, the growth of herbs, the food resource of herbivorous invasive species, is reduced. Instead, there is a steady accumulation of leaf litter on the forest floor and this favours native mollusc species, which in contrast to invasive taxa tend to be smaller in size and detritivorous. The abundance of invasive species decreases rapidly from the boundary of the forest towards its interior (see Nurinsiyah *et al.*, 2016, for *L. fulica*). Newly planted forests reduce the abundance of invasive species in the reforested habitat and may thus help to prevent/minimize invasion of surrounding natural forest.

With regard to human health and agriculture, one simple control measure is the regular removal of waste (especially plant matter), which represents a food resource and suitable habitat for both the priority invasive mollusc species and for rats, which are the final host of the rat lungworm. In addition, hand picking and the use of chemical agents (molluscicides) may be necessary in farmland. The increasing demand for *L. fulica* by local food companies will no doubt contribute to the increased market value of collected snails. This may result in a more sustainable control of the species than a state-funded campaign and may reduce the need for chemical pest control. It is important that these control measures remain restricted to anthropogenic environments. Efforts to control *L. fulica* in Brazil through hand picking by untrained personnel has posed a serious threat to many similar-sized native snails belonging to the families Strophocheilidae and Orthalicoidea (Agudo-Padrón, 2012; Miranda *et al.*, 2015).

Alternative assessment systems and objectives

Introduced species can be prioritized for different purposes and the criteria for and outcomes of assessment can differ. Kumschick *et al.* (2012) scoring system, as used here, comprehensively considers the negative and positive impacts of introduced species on the natural environment as well as on socioeconomic issues.

In recent years, other schemes for evaluating the impact of introduced species have been put forward. Hawkins *et al.* (2015), for example, proposed the Environmental Impact Classification for Alien Taxa (EICAT). This classification focusses on ecological impacts on native species and communities, specifically considering whether introduced species cause local extinction, changes to community composition, declines in population densities or reductions in individual fitness. This classification requires more detailed knowledge than Kumschick *et al.* (2012) system. In particular, the question whether a decline of a population of a native species or a change in community composition is caused by an introduced species or is a consequence of a modification of the habitat by humans is difficult to assess without long-term monitoring. There are no documented cases of an introduced land snail or slug species in Indonesia having demonstrably caused local extinction of native species, reductions in density or fitness of such species or changes in community composition. Currently therefore, all the introduced land snail and slug species known from Indonesia can be considered to have impacts of minimal concern according to the EICAT or are data-deficient. This categorization depends on whether an evaluator is convinced that the introduced species really do not have the described effects or whether this cannot yet be assessed. Although concerns have often been expressed that introduced species may cause the extinction of native species, the only firm evidence for this is the case of the carnivorous *Euglandina rosea* (Régnier, Fontaine & Bouchet, 2009). In contrast to the generic scoring system used here, changes induced by introduced species with regard to socioeconomic issues and positive impacts are not considered in the EICAT. Thus, evaluations based on the latter scheme will not be considered relevant by stakeholders interested in agriculture or human health. Whereas the version of the generic scoring system (Kumschick *et al*., 2012) that we used considers both positive and negative impacts of introduced species, the version published by Nentwig *et al*. (2016) scores only negative impacts. For a balanced view, however, positive effects should not be ignored (Kumschick *et al*., 2012). The function of the assessment is the objective compilation of any information about impacts of an introduced species. This assessment should form the basis for the decisions by the stakeholders, who then have to determine which impacts are considered relevant and how they are weighted. A strength of the generic scoring system, as used here, is that it considers all kinds of impacts and allows a flexible interpretation of the compiled knowledge by different groups of stakeholders. The Strategic Plan for Biodiversity 2011–2020 does not specify whether the prioritization of invasive species should be based solely on the impact of such species on the natural environment or whether other issues should also be considered.

The versions of the generic scoring system proposed by Kumschick *et al*. (2012) and Nentwig *et al*. (2016), as well as Hawkins *et al*. (2015) EICAT scheme, aim to assess the impacts of introduced species that are already present in a region. Cowie *et al*. (2009), in contrast, performed an assessment of the negative impacts of land snail and slug species that might become invasive in the USA; their aim was to identify invasive species of priority quarantine importance. Thus, they considered only species that were not present at the time in the USA or were only highly locally present. Three of the high-priority species in our list (*Laevicaulis alte*, *Sarasinula plebeia* and *Lissachatina fulica*) were also highly ranked in Cowie *et al*. (2009) list.

In the context of identifying species with high quarantine significance in Indonesia, the carnivorous *E. rosea* should be given highest priority. The establishment of this species, which caused the extinction of >100 snail species from islands across the Pacific (Régnier *et al*., 2009), might result in a wave of extinctions of land snail species endemic to Indonesia. Thus, preventing this snail from entering Indonesia should have a much higher priority than the control of invasive species that have been established in Indonesia for a long time and have not been linked to the documented extinction of any native species.

SUPPLEMENTARY MATERIAL

Supplementary material is available at *Journal of Molluscan Studies* online.

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