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Discovery of *Geodorum densiflorum* (Orchidaceae) on the Ogasawara (Bonin) Islands: A Case of Ongoing Colonisation Subsequent to Long-distance Dispersal

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Abstract *Geodorum densiflorum* (Lam.) Schltr. (Orchidaceae) is newly recorded for the Ogasawara Islands, Japan. The species was found on Mukoujima Island, Hahajima Group, where only a single population of 108 individuals occurs. This case probably represents recent long-distance dispersal. Regular monitoring in the future may allow the process of colonisation of an oceanic island to be documented.

Key words: colonisation, *Geodorum densiflorum*, Japan, long-distance dispersal, new record, Ogasawara Islands, Orchidaceae.

Identification of a *Geodorum* species from the Ogasawara Islands

The Ogasawara (Bonin) Islands are an archipelago of about 30 subtropical islands, situated 1,000 km south of Tokyo (Fig. 1). They are oceanic islands formed around 48 million years ago. Since they have never been connected with a continent, the biota has undergone unique evolutionary processes and about 43% of the plant species are endemic to the islands (Ono *et al.*, 1986).

In 7 December 2009, park rangers of Tokyo Metropolitan Government (the second author together with Kyoko Ohno and Yuko Honma) conducted a vegetation survey on Mukoujima Island, an uninhabited, small island of 1.38 km^2 belonging to the Hahajima Group (Fig. 1). They found about ten orchid plants in a 5×5 m square that did not match any known orchid species recorded from the Ogasawara Islands. Following regular surveys, flowering plants were found on 20 August 2011 (Fig. 2).

The plants are identifiable as *Geodorum densiflorum* (Lam.) Schltr. (Fig. 3) but the taxonomic status of this entity is still not stabilized (e.g., Garay and Sweet, 1974; Seidenfaden, 1983; Clements, 1989; Kores, 1989). The basionym *Limodorum densiflorum* Lam. is based on a pre-Linnean taxon 'Bela Pola' in Hortus Malabaricus (Rheede tot Draakestein, 1692). The Ogasawara plant agrees with the lectotype [tab. 35 associated with the description of 'Bela Pola'; selected in Seidenfaden (1983)] collected from south India. Descriptions and illustrations of *G. densiflorum* from the same area (e.g., Santapau and Kapadia, 1966; Rao, 1998) also coincide with our material. We therefore identified the Ogasawara plant as *G. densiflorum*.

Geodorum densiflorum is widely distributed

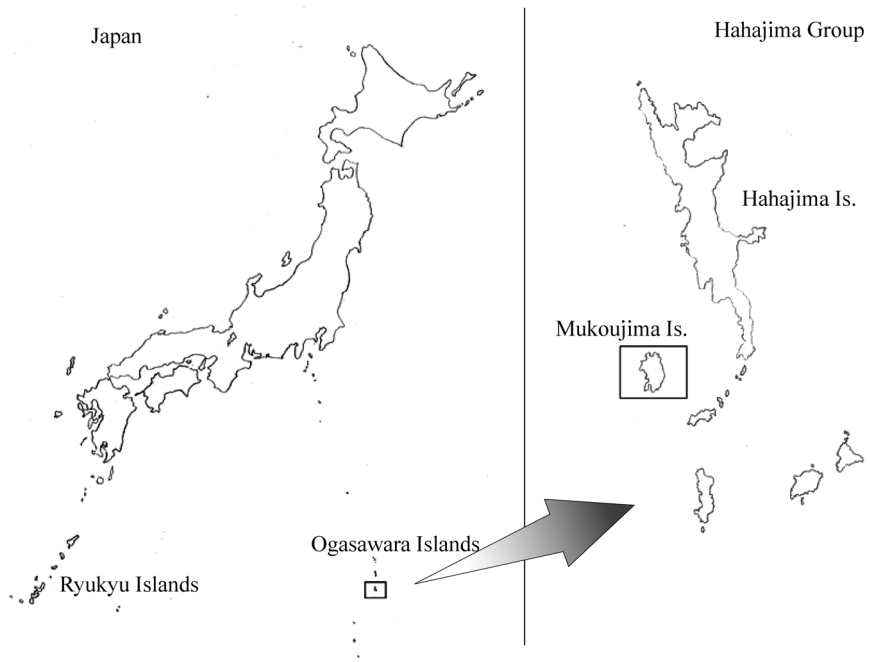

Fig. 1. Location of the Ogasawara Islands. Mukoujima Island belongs to the Hahajima Group.

throughout tropical Asia and Australasia. The range encompasses Sri Lanka, India, Himalayas, Indochina, south China, Taiwan, and the Ryukyu Islands to Southeast Asia, north Australia, Melanesia, and Micronesia (Barretto *et al.*, 2011). We observed material collected from the Ryukyu Islands and Indonesia and found it to be identical to the Ogasawara plants in both vegetative and reproductive morphological characters. The central callus of the lip is variable in shape, but variation exists even within a single individual (Fig. 4). We further consulted illustrations of this entity in floras of other regions [e.g., Pearce and Cribb, 2002 (Bhutan); Barretto *et al.*, 2011 (China); Su, 2000 (Taiwan); Smith, 1908 (Java, as *G. purpureum* R. Br.); O'Byrne, 1994 (New Guinea); Hallé, 1977 (New Caledonia, as *G. pictum* (R. Br.) Lindl.); Dockrill, 1992 (Australia); Raulerson and Rinehart, 1992 (Mariana Islands)] and confirmed the conspecificity across the distribution range.

Characteristics of the Ogasawara population

The Ogasawara population of *Geodorum densiflorum* was investigated on 20 August and 28 November 2011. The plants constitute a single population in the northern part of Mukoujima Island. In total, 108 individuals were found growing along a stream 150 m in length and ranging in elevation from 70 to 95 m a.s.l. Seven plants flowered in August. Both vegetative and floral dimensions vary greatly (number of leaves: 1–4, length of the uppermost leaf: 3–31 cm, width of the uppermost leaf: 5–70 mm, length of inflorescence: 12.5–35 cm, number of flowers: 10–17, length of bract: 8.5–14 mm, length of pedicellate ovary: 7.5–11 mm, length of dorsal sepal: 11–12.5 mm, length of lateral sepal: 11–12.5 mm, length of petal: 11.5–12.5 mm, length of lip: 10.5–13 mm).

The plants inhabit rather open, dry to mesic sites along the stream. We recorded vegetation in association with *Geodorum densiflorum* at three points (Table 1). Methods for recording vegeta-

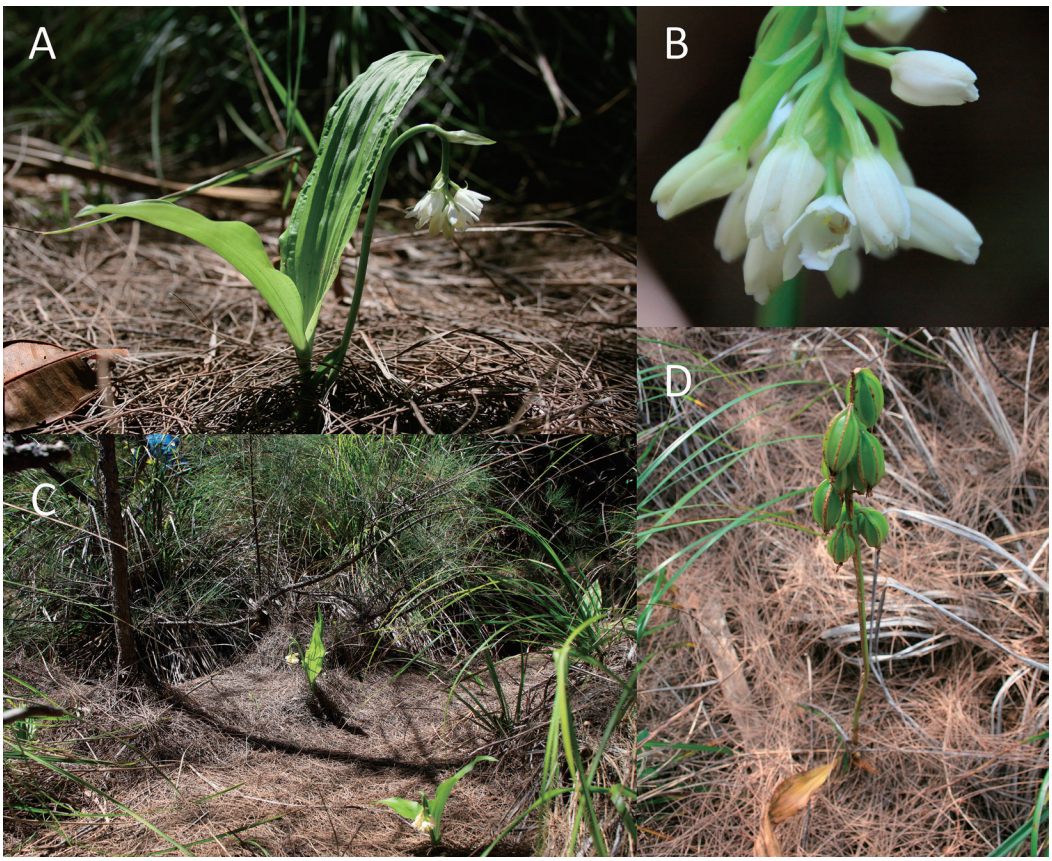

Fig. 2. *Geodorum densiflorum* (Lam.) Schltr. from the habitat of Mukoujima Island, Ogasawara Islands, Japan. A. Flowering plant; B. Inflorescence; C. Habitat; D. Fruiting plant. Photographs taken on 9 September 2011 (A), 20 August 2011 (B, C) or 17 February 2011 (D).

tion composition followed Shimizu (1994). Point A was a dry, open hill dominated by *Casuarina equisetifolia* L. in the tree layer and by *Gahnia tristis* Nees in the herbaceous layer. Point B was scrub in which *Planchonella obovata* (R. Br.) Pierre, *Casuarina equisetifolia*, and *Rhaphiolepis indica* (L.) Lindl. ex Ker var. *umbellata* (Thunb.) H. Ohashi were predominant. Point C was scrub bordered by the stream and at this site most *Geodorum* plants had been damaged by a flood. This site was dominated by *Leucaena leucocephala* (Lam.) de Wit, *Livistona boninensis* (Becc.) Nakai, and *Pandanus boninensis* Warb. in the tree layer and by *Oplismenus compositus* (L.) P. Beauv. in the herbaceous layer. These sites represent typical secondary vegetation of the Ogasawara Islands (Shimizu, 1994). *Casuarina equisetifolia* and *L. leucocephala* are invasive alien species that alter the original vegetation.

Mizutani *et al.* (2003) surveyed twelve habitats of *Geodorum densiflorum* on the Ryukyu Islands. In that study, the species was found to favour open sites, such as roadsides, edges of secondary forests, and grasslands. These secondary habitat types had developed artifically usually as a result of deforestation or road construction. The ecological characteristcs of the Ryukyu populations are in line with those of the Ogasawara population. It is clear that *G. densiflorum* is a pioneer species that colonises disturbed places.

Fig. 5 shows the size distribution of the population as determined by the length of the upper-

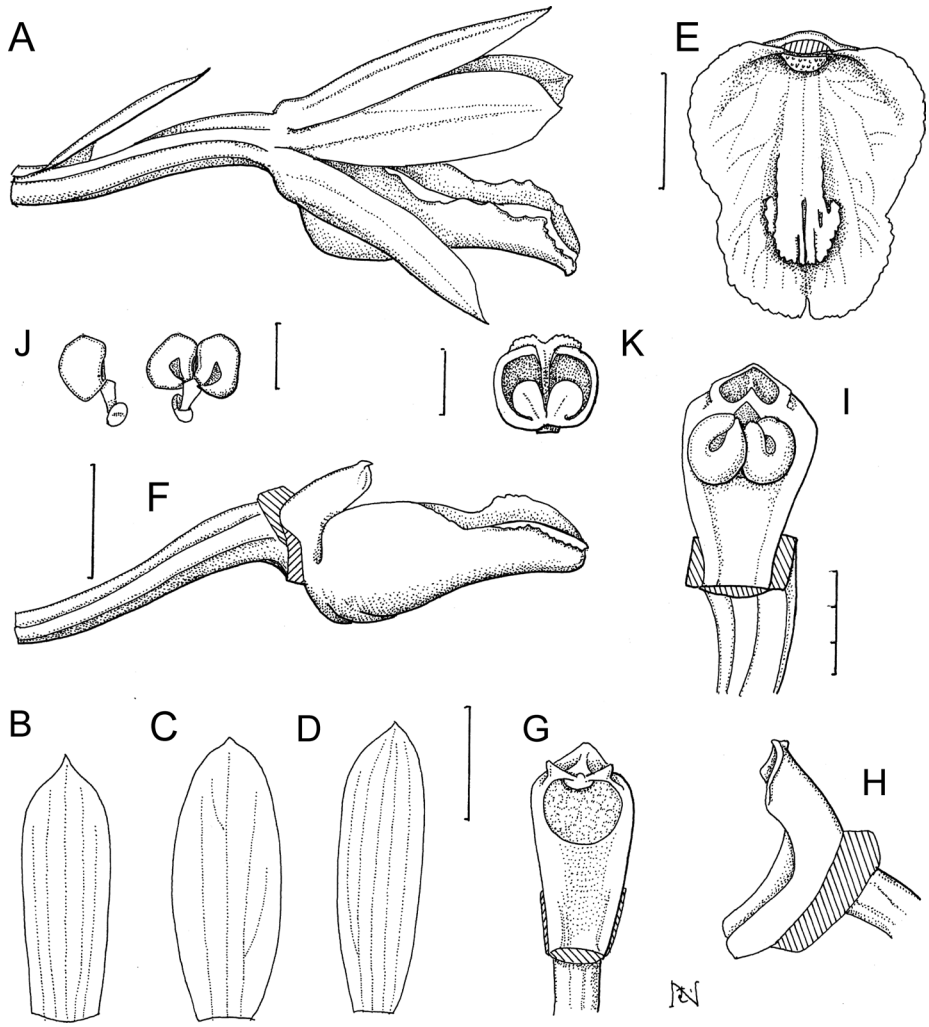

Fig. 3. *Geodorum densiflorum* (Lam.) Schltr. A. Flower, side view; B. Dorsal sepal; C. Petal; D. Lateral sepal; E. Lip; F. Lip and column, side view; G. Column, from below; H. Column, side view. Operculum and pollinarium detached; I. Column, after auto-pollination. Pollinia deposited on the stigma; J. Pollinarium; K. Operculum. Drawn from *Dairo Kawaguchi 1*, Japan, Ogasawara Islands, Mukoujima Island, 20 August 2011 (TNS) by Mutsuko Nakajima. Scale bar = 5 mm (A–F), 3 mm (G–I) or 1 mm (J, K).

most leaf. Since this species does not form clonal colonies (T. Yukawa, unpublished observation), most individuals of smaller size classes represent seedlings. Mizutani *et al.* (2003) estimated that four years or more are needed to reach the reproductive stage in this species. Our data indicates that *Geodorum densiflorum* can shift to the reproductive stage when the uppermost leaf attains 10 cm or more in length. It is thus reasonable to assume that seedling recruitment occurred relatively recently in this population.

Dispersal and colonisation of the Ogasawara population

The Flora of the Ogasawara Islands has been well investigated and documented (e.g., Tuyama, 1970; Kobayashi and Ono, 1987; Toyoda, 2003). It is unlikely that previous surveys overlooked such a conspicuous plant in this small island

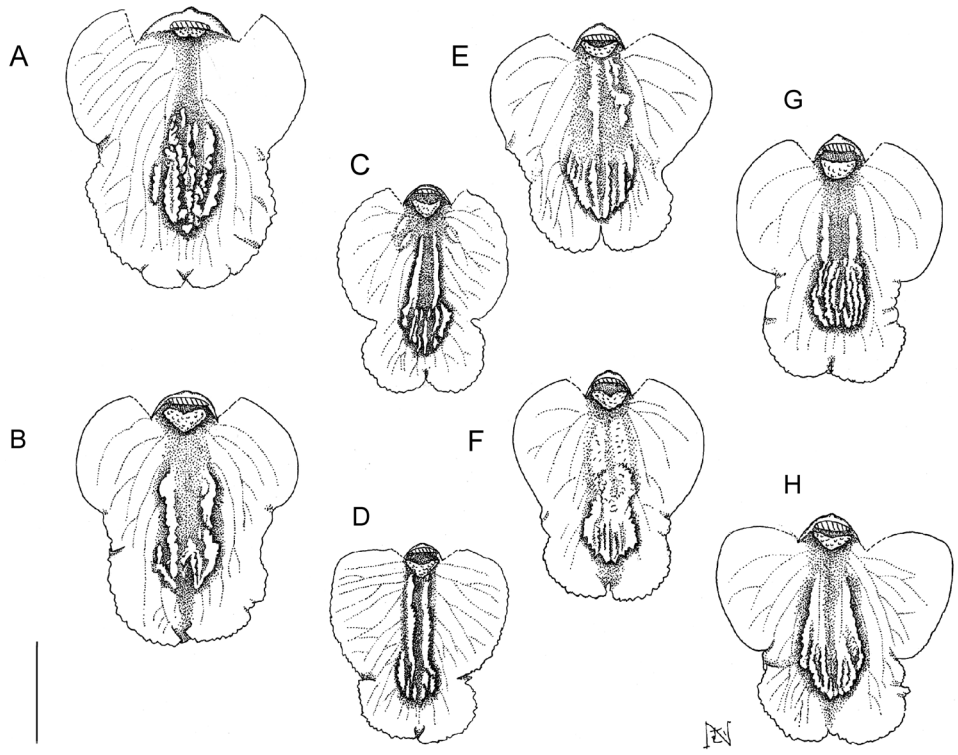

Fig. 4. Variation in lip morphology of *Geodorum densiflorum* (Lam.) Schltr. from plants of different localities. Two flowers in a single inflorescence were illustrated. A and B. *Daisuke Ishikawa 1010*, Japan, Ryukyu Islands, Ishigakijima Island, flowering in cultivation 10 November 2011, Tsukuba Botanical Garden (TNS); C and D. *Dairo Kawaguchi 2*, Japan, Ogasawara Islands, Mukoujima Island, 20 August 2011 (TNS); E and F. *Dairo Kawaguchi 1*, Japan, Ogasawara Islands, Mukoujima Island, 20 August 2011 (TNS); G and H. *Ayub Parnata s. n.*, Indonesia, flowering in cultivation 12 October 2009, Tsukuba Botanical Garden (TNS). Drawn by Mutsuko Nakajima. Scale bar = 5 mm.

group. It is also improbable that the plants were introduced artificially because *Geodorum densiflorum* does not have any economical or ornamental merits and Mukoujima Island has remained uninhabited. Besides, only a single population of this species has been found on Mukoujima Island. Consequently, the Ogasawara population of *G. densiflorum* is probably derived from recent migration by long-distance dispersal.

The colonising nature of *Geodorum densiflorum* has been well documented by its distribution on oceanic islands such as Micronesia (Yap and Guam) and Melanesia (Solomon Islands, Vanuatu, Fiji, Samoa, Tonga, and Niue). Furthermore, this species was recorded at early successional stages of the vegetation on the island of Krakatau in the middle of Sunda Strait, about 40 km from Sumatra and Java, after the volcanic eruption in 1883. The eruption completely sterilised three of the islands in the Krakatau group and floristic surveys of these islands have been conducted since. *G. densiflorum* was recorded as one of 21 pioneer orchid species in 1929, 46 years after the eruption (Partomihardjo, 2003).

A high rate of fruit set also characterises *Geodorum densiflorum*. Mizutani *et al.* (2003) observed that 58.3% of flowering individuals set fruits. We recorded that two of the three flowering plants of the Ogasawara population bore capsules in 2011 (Fig. 2D). The operculum of this species detaches easily and auto-pollination occurs frequently due to limited development of

Table 1. Vegetation associated with the *Geodorum densiflorum* population on Mukoujima Island, Ogasawara Islands.

Point	A	B	C
Tree coverage (%)	20	70	70
Herbaceous coverage (%)	40	15	20
Relative abundance of tree species (%)			
Leucaena leucocephala (Lam.) de Wit	0	1	26
Trema orientalis (L.) Blume	0	1	3
Livistona boninensis (Becc.) Nakai	0	1	12
Neisosperma nakaianum (Koidz.) Fosberg et Sachet	0	0	6
Hibiscus glaber (Matsum. ex Hatt.) Matsum. ex Nakai	0	3	7
Melicope grisea (Planch.) T. G. Hartley	0	1	9
Drypetes integerrima (Koidz.) Hosok.	0	0	2
Cinnamomum pseudopedunculatum Hayata	0	2	6
Planchonella obovata (R. Br.) Pierre	7	35	10
Pandanus boninensis Warb.	11	8	12
Syzygium cleyerifolium (Yatabe) Makino	13	8	4
Melia azedarach L.	0	1	1
Rhaphiolepis indica (L.) Lindl. ex Ker var. *umbellata* (Thunb.) H. Ohashi	5	14	1
Celtis boninensis Koidz.	0	0	1
Casuarina equisetifolia L.	58	19	0
Wikstroemia pseudoretusa Koidz.	5	3	0
Ligustrum micranthum Zucc.	1	2	0
Myrsine maximowiczii (Koidz.) E.Walker	0	1	0
Composition of herbaceous species			
Oplismenus compositus (L.) P. Beauv.			○ (dominant)
Euphorbia cyathophora Murray			○
Rivina humilis L.			○
Pteris boninensis H. Ohba			○
Asplenium setoi N. Murak. et Seriz.			○
Trachelospermum asiaticum (Siebold et Zucc.) Nakai		○	○
Carex sp.		○ (dominant)	○
Gahnia tristis Nees	○ (dominant)	○	
Sphenomeris biflora (Kaulf.) Tagawa	○		
Miscanthus boninensis Nakai ex Honda	○		

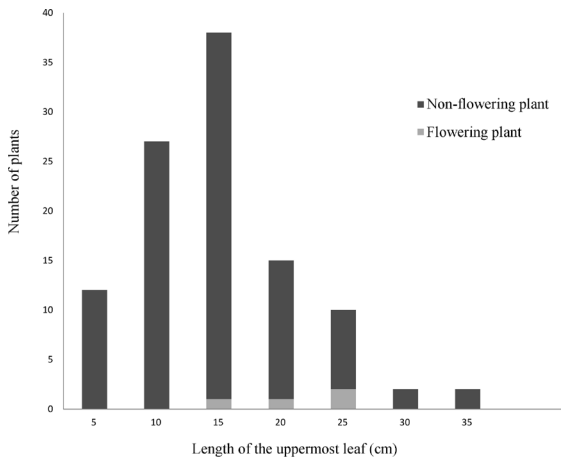

Fig. 5. Size distribution of the population of *Geodorum densiflorum* (Lam.) Schltr. on Mukoujima Island, as determined by the length of the uppermost leaf. Values on the x-axis are the upper size limit for each class. Dark grey bars show the number of the non-flowering plants and light grey bars show the number of the flowering plants.

the rostellum (Fig. 3I). Facultative autogamy facilitates expansion of this species where potential pollinators are absent or few.

The closest extant populations of *Geodorum densiflorum* from the Ogasawara Islands are either those of the Ryukyu Islands or those of Micronesia, both of which are about 1500 km distant from the Ogasawara Islands. Use of molecular markers could elucidate the history of long-distance dispersal of the Ogasawara population.

Our finding probably represents recent long-distance dispersal. Regular monitoring of this population and of the archipelago as a whole in the future may allow the process of colonisation of an oceanic island to be documented.

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