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Conservation assessment of *Pinus cernua* (Pinaceae)

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Key words: critically endangered species, Laos, nature conservation, Pinaceae, *Pinus cernua*, plant diversity, plant protection, Vietnam.

Summary. The paper presents results of completed conservation assessment of the strict Laos-Vietnamese endemic, *Pinus cernua*, based on survey of all previous publications and data obtained from extensive fieldworks during September–October 2016, supported by Mohamed bin Zayed Species Conservation Fund, Komarov Botanical Institute of the Russian Academy of Sciences, Russian Foundation for Fundamental Investigations (RFFI) and the Center for Plant Conservation of the Vietnam Union of Science and Technology Associations. Present review verified 23 locations of the species in Pha Luong Mountains situated on the state boundary of Laos (Houaphan province) and Vietnam (Son La province). Among available localities, 6 were found at first, the species extinction was detected in 1 locality. The area of the species distribution (EOO) decreased during last 3–5 years on 25–30 % from about 20 to 15 km^2, with total occupancy area (AOO) becoming less than 3 km^2, therefore species conservation status is assessed as globally critically endangered (CR) following to accepted IUCN Red List Categories and Criteria: B1a, b (i-v), B2a, b (i-v). Report also provides basic data on geography, geomorphology and climate of Pha Luong Mountains, as well as detailed descriptions of *P. cernua* ecology, habitats, vegetation, biology, population structure and taxonomy. All field data and descriptions are based on collected voucher herbaria, which belong to 99 families, 180 genera and 550 species. Among collected plants, 6 species are new for the flora of Laos and Vietnam, 30 species are local threatened endemics needed protection and 12 species are new for science. The main factors of *P. cernua* extinction are formulated and the recommendations for its effective protection are proposed.

Оценка состояния популяций сосны повислой (*Pinus cernua*, Pinaceae)

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Ключевые слова: виды, находящиеся на грани исчезновения, Вьетнам, защита природы, Лаос, охрана растений, разнообразие растений, Pinaceae, *Pinus cernua*.

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Аннотация. В статье представлена оценка состояния узкого лаосско-вьетнамского эндемика – сосны повислой (*Pinus cernua*), основанная как на изучении опубликованной ранее информации, так и на анализе данных, полученных в ходе детальных полевых исследований в сентябре–октябре 2016 г., организованных при поддержке природоохранного фонда Мохаммеда бин Зайеда, Ботанического института им. В. Л. Комарова РАН, Российского фонда фундаментальных исследований (РФФИ) и Центра охраны природы Вьетнамского Союза научно-технических ассоциаций. Выявлено 23 местонахождения вида в горах Фа Луонг, располагающихся на государственной границе Лаоса (провинция Хоуфан) и Вьетнама (провинция Сон Ла), 6 из которых обнаружены впервые. В одном ранее установленном местообитании отмечено полное вымирание вида. Область распространения вида (EOO в определении IUCN Red List Categories and Criteria) сократилась за последние 3–5 лет на 25–30 % с приблизительно 20 до 15 км^2 при общей площади заселения (AOO в определении IUCN), составляющей на настоящий момент менее 3 км^2. На основании этого *P. cernua* определяется как вид, находящийся под угрозой полного вымирания – CR (Critically Endangered): B1a, b (i-v) и B2a, b (i-v), в соответствии с терминологией и критериями, принятыми Международным Союзом охраны природы (IUCN Red List Categories and Criteria). В работе приводятся общие сведения о географии, геоморфологии, климате и растительности гор Фа Луонг, а также детальное описание экологии, мест обитания, биологии, популяционной структуры и таксономии *P. cernua*. Все данные, полученные в ходе полевых работ, подтверждаются гербарными материалами, которые относятся к 99 семействам, 180 родам и 550 видам, среди которых 6 видов – новые для флоры Вьетнама и Лаоса, 30 видов являются узкими эндемиками, заслуживающими специальной охраны, и 12 – новыми для науки. Определены основные факторы современного вымирания сосны повислой и предложены рекомендации по ее эффективной охране.

Introduction

Uplifted landmasses in eastern Indochina form a series of more or less high ridges known today as the Truong Son or Annamese Range. These highlands stretch as a southeastern extension of the Himalayas for more than 1000 km from the mountainous areas of Yunnan across the entire peninsular territory to the seashore of southern Cambodia. During the long and complicated geological history, these mountain chains, running in a longitudinal direction, created a corridor for repeated plant movements from subtropical and temperate Asia to tropical highlands of eastern Indochina. Ancient species migrations and species isolation within many mountain systems resulted in active processes of the species formation in this area (Averyanov et al., 2003). Isolation of representatives of a number of temperate Asian or Holarctic genera led to the creation of numerous endemic and sub-endemic taxa within highest mountain systems of eastern Indochina. Diversity and distribution patterns of pine species (*Pinus* L.) within eastern Indochina is an evident example of such migrations and subsequent isolation within a number of more or less isolated mountain massifs. As a result, eastern Indochina may constitute the region of the world with the highest pine diversity (Hiep, Vidal, 1996; Farjon, 2001; Hiep et al., 2004; Luu, Thomas, 2004; Phan Ke Loc et al., 2013; Averyanov et al., 2015a).

At least 12 native *Pinus* species and varieties were inventoried within this territory during recent explorations, observations and taxonomic studies (Businsky, 2013, 2016; Phan Ke Loc et al., 2013; Averyanov et al., 2015a). Additionally, the highlands of southern Vietnam in limits of Lam Dong, Dac Lac and Khanh Hoa provinces provide a home to *Ducampopinus krempfii* (Lecomte) A. Chev., a unique relictual endemic of Chu Yang Sin and Bi Dup Mountains. This peculiar primitive pine is possibly allies to ancestral complex of all modern pines (Orlova, Averyanov, 2004). Four well defined allopatric varieties of the endemic *Pinus dalatensis* Ferré – *P. dalatensis* var. *dalatensis*, var. *anemophila* (Businsky) Aver., var. *bidoupensis* Businsky and var. *procera* (Businsky) Aver. inhabit isolated mountain areas within southern and central Vietnam and in Laos. A number of isolated massifs of rocky karstic limestone in northern Vietnam and in adjacent regions of China represent the area of distribution of the subendemic *P. henryi* Masters subsp. *averyanovii* Businsky and four calcium-dependent endemic races of *P. wangii* Hu et W. C. Cheng – *P. wangii* var. *wangii*, var. *kwangtungensis* (Tsiang) Silba, var. *varifolia* (Nan Li et Y. C. Zhang) Aver. and var. *eremitana* (Businsky) Aver. Two widespread species, *Pinus kesiya* Gordon and *P. latteri* Mason, occasionally form scattered mixed and coniferous forests throughout Indochina. Meanwhile, many mountainous areas of eastern Indochina, particularly regions along the border with Vietnam remain insufficiently explored because they are often inaccessible for botanists. Such areas certainly contain the potential for the discovery of numerous local endemic plants during future scientific explorations including pine species.

Ancient table-shaped sandstone formations occurring sporadically in northern and central Vietnam and Laos represent particular interest for pine geo-

graphic investigation. These formations resulted in ancient tectonic breaks of sediment sandstone plates and represent faults, which presently have form of more or less continuous table-shaped formations uplifted to 600–1800 m a. s. l. Commonly such formations in eastern Indochina are oriented in more or less longitudinal direction and have cliffy to almost vertical margin at least from one side (commonly on north faced slope). Summits of such formations are often almost flat. However, in some cases uplifted plateaus are dissected by deep rifts or even eroded into a peneplain with numerous rocky mesas in its peripheral zone. Thin sandy, poor, well-drained soils rich in quartzite are favorable for conifers and provide suitable conditions for pine species, which often form here mixed and true monodominant coniferous zonal primary forests. Earlier floristic studies detected such primary indigenous coniferous forests on sandstone with endemic varieties of *Pinus dalatensis* in Quang Binh (Minh Hoa district, voucher herbarium specimens – HAL 11783, year 2008, d-EXSICCATES OF VIETNAMESE FLORA 0121/ HAL 11783) and Quang Nam (Dai Loc district, voucher herbarium specimen – CPC 3575, year 2011) provinces in central Vietnam and Laos (Businsky, 2010). However, highest sandstone formation of mentioned type known as Pha Luong Mountains situated on Laos-Vietnamese border between Houaphan and Son La provinces a long time remains insufficiently investigated. Meanwhile, new endemic pine species – *Pinus cernua* was reported from this area recently as an important co-dominant of indigenous coniferous forests (Averyanov et al., 2014, 2015a). Detailed assessment of this strictly endemic species was undertaken in the present study.

Geographical position and landforms of Pha Luong Mountains

Pha Luong mountain system occupies territory roughly estimated as approximately 40–45 km^2, which extends on 4–5 km from the S to the N (between N20°40′00″ and N20°42′50″) and on about 10 km from the W to the E (between E104°36′30″ and E104°41′40″E). Administratively Pha Luong Mountains in their main territory belong to Son La province, Moc Chau district, Chieng Son commune (municipality) and Van Ho district, Tan Xuan commune of Vietnam. Southern mountain system slopes in smallest part belong to Houaphan province, Xam Neua district (Lao PDR). Eastern part of Pha Luong Mountains is included presently into main and buffer zones of Xuan Nha nature reserve (Vietnam).

On their geomorphology, Pha Luong Mountains represent uplifted well-developed peneplain with many picturesque exposed rocky peaks, deep rifts with vertical cliffs, rocky outcrops and numerous crowded mesas composed with red-brown highly eroded sandstone. Main summit of mountain massif has appearance of uplifted table-shaped plateau with highest point at SW margin elevated to 1869 m a. s. l. (Fig. 1A, B). Sandstone plateau is dissected by numerous rifts on its margin and composed on periphery with eroded mesas, rocky peaks and impressively exposed cliffs (Fig. 1C, D). Tall open vertical cliffs with many lithophytic plant species are very typical landforms in any part of mountains. Almost all mountain body are composed by solid red-brown highly eroded sandstone with many giant roller boulders, caves and overhanging eroded platforms. Few karstic limestone rocks also occasionally are observed in this area, but lime outcrops here are rather rare.

Climate of Pha Luong Mountains

Climate in the area of Pha Luong Mountains is classified in national climatology as “monsoon tropical climate with cold winter and summer rain season” (Nguyen Khanh Van et al., 2000). Mean annual precipitation is about 1560 mm and mean annual temperature is 18.5 °C, with five cold and dry winter months (from November to March). Detailed climate data recorded in nearest meteorology station in Moc Chau town at elevation 958 m a. s. l. – may be found in monograph of Nguyen Khanh Van et al. (2000, page 71, diagram 55). Basic data on mean month temperatures and precipitation recorded in this monograph are presented in Table 1. Absolute temperature maximum recorded here is +35 °C, and absolute minimum –1.5 °C. Cloudy fogs and mists are very common at high elevations in Pha Luong Mountains that provide almost permanent high humidity favorable for rich epiphytic and lithophytic vegetation observed near mountaintop.

Table 1

Data on mean month temperatures and precipitation in the area of Pha Luong Mountains

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Temperature	11.8	13.3	16.8	20.2	22.5	23.0	23.1	22.4	21.2	18.9	15.7	12.8
Precipitation	14.8	21.2	34.0	98.7	165.5	220.8	266.3	331.4	257.2	106.4	31.8	11.8

Note: The months are designated by Roman numerals, temperature – in °C, and rainy precipitation in mm)

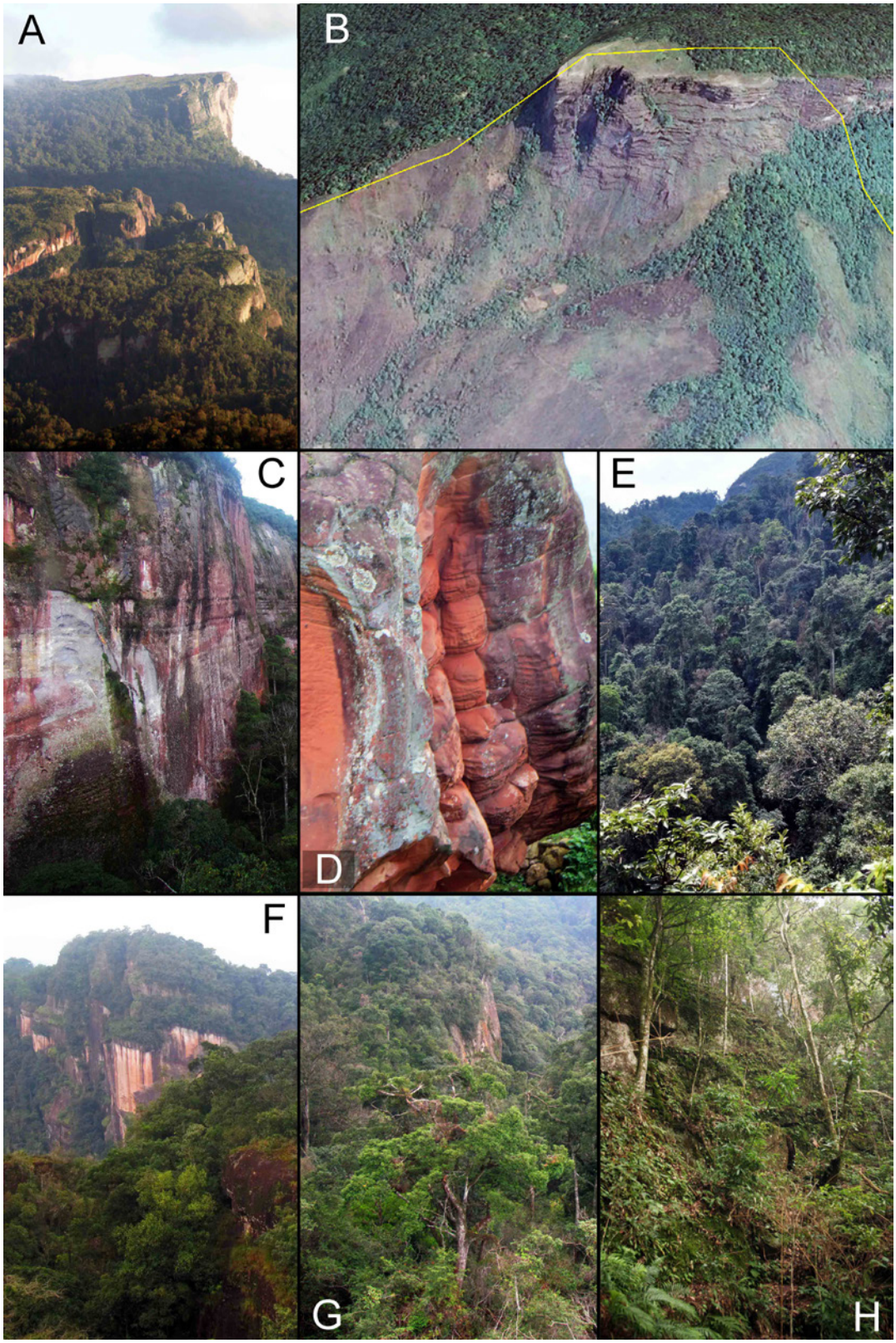


Fig. 1. A – Main summit of Pha Luong Mountains, NNW slope. B – Landscape satellite image of southern slopes of Pha Luong Mountains with vast burned areas in Laos territory where *Pinus cernua* extinct completely (yellow line demarcates border between Laos and Vietnam), photo of 4.04.2015. C, D – Typical sandstone cliffs in central part of Pha Luong Mountains. E – Primary evergreen broad-leaved submontane tropical forest on SEE slope of Pha Luong Mountains at 700–900 m a. s. l. F – Primary evergreen mixed tropical submontane forest with *Pinus cernua* (subpopulation № 18, voucher herbarium collecting number *CPC 8169*. G – Primary evergreen coniferous tropical submontane forest with *Pinus cernua* in central part of Pha Luong Mountains at 1400–1500 m a. s. l. H – Primary evergreen broad-leaved tropical montane cloud forest on upper part of mountain slopes in central part of Pha Luong Mountains at 1500–1600 m a. s. l.

Main types of vegetation in Pha Luong Mountains

Evergreen tropical submontane broad-leaved, mixed and coniferous forests are main aboriginal zonal kinds of primary vegetation in Pha Luong Mountains. Presently, on largest part of the territory, they are replaced by different kinds of secondary plant communities, pastures and agricultural fields. Primary broad-leaved more or less degraded forests still survives here on steep slopes at elevation from 600–700 to 1700–1800 m a. s. l. Mixed and coniferous primary forests grow in Pha Luong Mountains at 800–1550 m a. s. l. Specific zonal plant formations, like wind-formed broad-leaved cloud forests and ericaceous scrub are observed on highest mountain tops elevated to 1700–1869 m. Secondary azonal bamboo and herbaceous, grassland-like plant communities occupy highland rocky outcrops in places cleaned by forest fires. Main kinds of plant communities in studied area are following:

Zonal (elevational) plant communities:

1. Evergreen broad-leaved tropical submontane forest
2. Evergreen mixed tropical submontane forest
3. Evergreen coniferous tropical submontane forest
4. Evergreen broad-leaved tropical cloud montane forest
5. Evergreen ericaceous montane scrub

Azonal plant communities

6. Bamboo montane thickets
7. Sphagnum-herbaceous montane grassland

Structure and composition of main aboriginal plant communities in Pha Luong Mountains

1. Evergreen broad-leaved tropical submontane forest (Fig. 1E; Averyanov et al., 2016b, Appendix 1, 1).

This kind of the forest spreads in Pha Luong area at elevations of (500)600–1750(1800) m on slopes of any exposition inclined commonly to 0–40(50)°. The parental soil material in all area is solid red-brown sandstone. The leaf litter usually 0–5 cm thick with projective coverage to 100 %. Soils rather thin and poor, well drained, with brown humus-containing horizon about (20)30–40(50) cm. Forest structure includes commonly 5 strata with rich non strata vegetation.

The first forest stratum includes trees 15–30(35) m tall, (30)40–110(120) cm DBH forming projective coverage 30–60(70) %. Main dominants of first forest stratum are *Castanopsis* spp., *Cinnamomum* spp., *Diplopanax vietnamensis*, *Lithocarpus* spp., *Parakmeria robusta*, *Quercus* spp., *Sloanea* sp. with more or less usual associates, such as *Eberhardtia* sp., *Gordonia* sp., *Liquidambar formosana*, *Litsea* spp., *Schima wallichii*, *Styrax* sp.

The second stratum includes trees 5–15 m tall, (7)10–30(40) cm DBH forming projective coverage 30–70(80) %. No any certain dominant trees are observed in this stratum, but more or less common species here are *Acer* sp., *Aglaia* spp., *Antidesma* sp., *Camellia* sp., *Citrus* sp., *Diospyros* sp., *Ficus gibbosa*, *Livistona chinensis*, *Magnolia foveolata*, *M. megaphylla*, *Magnolia* spp., *Manglietia dandyi, Michelia balansae, Michelia* spp., *Ormosia* sp., *Symplocos* sp. and *Wikstroemia* sp.

Third (shrub) stratum consists of treelets and shrubs 2–5 m tall forming projective coverage 10–40(50) %. Dominant species here are *Blastus* spp., *Ixora* sp., *Lasianthus* sp., *Licuala* sp., and *Psychotria* spp. with regular associates, such as *Alphonsea boniana*, *A. gaudichaudiana*, *Ardisia* spp., *Chloranthus* sp., *Clausena* sp., *Croton* sp., *Dichroa febrifuga*, *Medinilla* sp., *Oxyspora* spp., *Pinanga* sp., *Polygala* sp., *Rhapis* sp., *Sarcandra glabra, Schefflera* sp., *Silvianthus tonkinensis,* and *Staphyllea* sp.

The fourth (herbaceous) stratum includes herbaceous and semi-herbaceous plants from 3 cm to 2 m tall. This stratum forms projective coverage (0)5–20(35) %. Most common herbaceous species here are *Alpinia* sp., *Aspidistra nutans, A. subrotata, Aspidistra* sp., *Begonia delavayi, B. handelii, B. hemsleyana, B. howii, B. tetragona, Begonia* sp., *Colysis* sp., *Diplazium donianum, Diplazium* sp., *Elatostema* spp., *Leptochylus* sp., *Microlepia* sp., *Mycetia* spp., *Ophiopogon* spp., *Ophiorrhiza* spp., *Peliosanthes griffithii, Peliosanthes* spp., *Pellionia* spp., *Phyllagathis cavaleriei*, *Polystichum* sp., *Pteris* sp., *Selaginella* sp., *Sonerila* spp., and *Spatholirion puluongense*. More or less usual associates in this stratum are *Anoectochilus annamensis, A. roxburghii, Apostasia wallichii, Aspidistra bifolia, Calanthe alleizettii, C. clavata, C. densiflora, C. puberula, C. sylvatica, Calanthe* sp., *Clerodendron* spp., *Cymbidium ensifolium, C. kanran, C. lancifolium, Disporum* sp., *Geodorum* sp., *Gomphostemma* sp., *Goodyera foliosa, Habenaria medioflexa, Habenaria* sp., *Impatiens* sp., *Kaempferia rotunda, Lindsaea orbiculata, Liparis nervosa, Nervilia aragoana, Ophiopogon alatus, O. intermedius, O. tonkinensis, Peliosanthes kenhilloides, Phyllagathis* sp., *Rhomboda petelotii, Streptolirion volubile, Tainia latifolia, Zeuxine*

nervosa, Zingiber cochleariforme, Z. guangxiense, and *Z. recurvatum*.

Fifth stratum (mosses and lichens) is very thin, not exceeding 3 cm tall. It varies from (0.1)0.5–3 cm and covers ground with projective coverage on 0–80(100) %. Beside the indeterminable mosses (mainly in protonema stage) it includes few species of tiny ferns – *Crepidomanes auriculatum, Mecodium* sp. and *Trichomanes* sp. (Hymenophyllaceae).

Non strata vegetation includes numerous epiphytes and lithophytes.

Dominant epiphytic species: *Asplenium nidus*, *Bulbophyllum ambrosia, B. psychoon, Bulbophyllum* spp., *Callostylis rigida, Ceratostylis himalaica, Coelogyne fimbriata, Davallia* sp., *Dendrobium chrysanthum, D. nobile, D. spatella, D. thyrsiflorum, Dischidia* sp., *Drynaria* sp., *Epigeneium amplum, E. chapaense, Eria pannea, E. siamensis, E. thao, Eria* spp., *Hoya* sp., *Lemmaphyllum microphyllum, Lepisorus* sp., *Liparis viridiflora, Microsorum* sp., *Panisea* spp., *Peperomia* sp., *Pholidota articulata, P. chinensis, Pyrrosia* sp., *Thelasis pygmaea,* and *Thrixspermum centipeda.*

Associated epiphytic species: *Aeschynanthus mendumiae, Aeschynanthus* spp., *Bulbophyllum apodum, B. biesetoides, B. pecten-veneris, B. reptans, Cleisostoma striatum, C. williamsonii, Coelogyne* spp., *Cymbidium lowianum, Cymbidium* spp., *Dendrobium brymerianum, D. eriiflorum, D. falconeri, D. fimbriatum, D. hancockii, D. jenkinsii, Eria apertiflora, E. calcarea, E. rhomboidalis, Huperzia* sp., *Hygrochilus parishii, Liparis longispica, L. pumila, Luisia zollingeri, Luisia* spp., *Lycopodium* sp., *Lysionotus chingii, Oberonia falconeri, Oberonia* spp., *Ornithochilus difformis, Pholidota recurva, Scindapsus* sp., *Smitinandia helferi, Stereochilus brevirachis, Sunipia scariosa, Thrixspermum stelidioides, Trichotosia microphylla, T. pulvinate,* and *Vanda* sp.

Dominant lithophytic species: *Antrophium* sp., *Argostemma* spp., *Asplenium antrophioides, A. rupestre, Asplenium* sp., *Carex* sp., *Chirita* spp., *Didymocarpus* sp., *Eria globulifera, E. siamensis, Hedyotis* spp., *Liparis bootanensis, L. viridiflora, Peperomia* sp., *Rhynchotechum* sp., *Sonerila* spp., *Vittaria hainanensis* and *Vittaria* sp.

Associated lithophytic species: *Aglaomorpha acuminata, Appendicula hexandra, Boea* spp., *Calcareoboea coccinea, Collabium chapaensis, C. chinense, Eria bambusifolia, E. calcarea, E. carinata, E. corneri, E. rhomboidalis, Flickingeria fimbriata, Hedychium yunnanense, Hedychium* sp., *Lilium poilanei, Liparis averyanoviana, L. balansae, L. dendrochiloides, L. superposita, Oreocharis argyrophylla, O. blepharophylla, Oreocharis* sp., *Paraboea* sp., *Streptocarpus* sp., and *Vittaria elongata*.

Among woody and semi-woody vines and scandent shrubs, *Actinidia* sp., *Artobotrys* sp., *Illigera* sp., and *Popovia* sp. were observed. However, all these species are rather uncommon. Rocky habitats along narrow wet shady stream canyons provide home to many ferns including such species as *Angiopteris evecta, Bolbitis* sp., as well as *Tupistra khangii* and *Tupistra* sp. Among specific living forms in forest of this kind achlorophyllous root parasites were observed – *Balanophora laxiflora* and *Balanophora* sp., as well as achlorophyllous mycotrophic plants – *Didymoplexis pallens, Gastrodia khangii* and *Lecanorchis vietnamica*.

The rocky outcrops become dominant in soil cover on very steep cliffy slopes near mountaintops and on summits. In such conditions project coverage of all tree forest strata decrease, but lithophytes become abundant in species diversity and ground coverage.

2. Evergreen mixed tropical submontane forest (Fig. 1F; Averyanov et al., 2016b, Appendix 1, 2).

Mixed forest in Pha Luong Mountains occurs at elevations (800)900–1500(1550) m on slopes of any exposition with inclination commonly 0–70(80)°. In all observed localities, soils of forest habitats are derived from solid red-brown sandstone. Leaf litter here is 0–3 cm thick with projected coverage from 0 to 100 % in small depressions. Soils are thin, poor, well drained, with brown humus-containing horizon (5)10–20(30) cm.

Main co-dominants of first forest stratum are broad-leaved trees like *Acer* sp., *Castanopsis* spp., *Cinnamomum* spp., *Diplopanax vietnamensis*, *Gordonia* sp., *Lithocarpus* spp., *Litsea* spp., *Quercus* spp., and *Schima wallichii*. They reach 15–30(35) m tall and (30)35–45(60) cm DBH with total projective stratum coverage 30–60(70) %. Coniferous component in these forests includes such species as *Amentotaxus argotaenia, A. yunnanensis, Cephalotaxus mannii, Dacrycarpus imbricatus, Fokienia hodginsii*, *Keteleeria evelyniana, Pinus cernua*, *P. latteri,* and *Podocarpus neriifolius.* Most of them are sporadically scattered among broad-leaved trees as more or less rare associates.

Second stratum of mixed forest has no certain dominants and includes such species as *Acer* sp., *Aglaia* spp., *Eriobotrya* sp., *Livistona chinensis, Photinia cucphuongensis, Schefflera* sp., *Symplocos*

sp., and *Wikstroemia* sp., which are 5–15 m tall and (7)10–20(25) cm DBH. Projective coverage of this stratum is (15)20–45(55) %.

Third (shrub) stratum includes treelets and shrubs 2–5 m tall. It has projective coverage 10–30(40) %. Most common dominants here are *Ixora* sp., *Lasianthus* sp. and *Psychotria* spp. associated with *Ardisia* spp., *Camellia* sp., *Lasianthus* spp., *Licuala* sp., *Oxyspora* sp., *Psychotria* spp., and *Schefflera* sp.

Fourth stratum (herbs) includes herbaceous species 0.03–2 m tall. Projective coverage of this stratum varies from 0 to 30 %. Most common taxa here are *Diplazium* sp., *Elatostema* spp., *Microlepia* sp., *Pellionia* spp., *Polystichum* sp., *Selaginella* sp. As more or less common associated such species as *Alpinia* sp., *Goodyera schlechtendaliana, Ophiorrhiza* spp., *Sonerila* spp., *Tainia latifolia*, *Zingiber cochleariforme, Z. guangxiense, Z. recurvatum* were observed.

Fifth stratum includes indeterminable mixture of juvenile mosses and lichens (0.1)0.5–3 cm tall with coverage 10–80(100) % as well as few tiny ferns – *Trichomanes* sp. (Hymenophyllaceae).

Non strata vegetation includes numerous epiphytes and lithophytes.

Dominant epiphytic species: *Bulbophyllum ambrosia, B. reptans, Callostylis rigida, Ceratostylis himalaica, Coelogyne fimbriata, Davallia* sp., *Dendrobium spatella, D. thyrsiflorum, Dischidia* sp., *Drynaria* sp., *Epigeneium amplum, E. chapaense, Eria pannea, E. siamensis, E. thao, Eria* spp., *Lemmaphyllum microphyllum, Lepisorus* sp., *Microsorum* sp., *Pholidota articulata, P. chinensis, P. recurva, Pyrrosia* sp., and *Thelasis pygmaea*.

Associated epiphytic species: *Aeschynanthus mendumiae, Aeschynanthus* spp., *Bulbophyllum apodum, B. biesetoides, B. pecten-veneris, B. psychoon, Bulbophyllum* spp., *Cleisostoma striatum, C. williamsonii, Coelogyne* spp., *Cymbidium* spp., *Dendrobium brymerianum, D. chrysanthum, D. falconeri, D. fimbriatum, D. hancockii, D. nobile, Eria apertiflora, E. bambusifolia, Hoya* sp., *Huperzia* sp., *Hygrochilus parishii, Liparis longispica, L. pumila, L. viridiflora, Luisia zollingeri, Luisia* spp., *Lycopodium* sp., *Oberonia falconeri, Oberonia* spp., *Ornithochilus difformis, Panisea* spp., *Peperomia* sp., *Smitinandia helferi, Stereochilus brevirachis, Sunipia scariosa, Thrixspermum stelidioides, Trichotosia microphylla, T. pulvinata,* and *Vanda* sp.

Dominant lithophytic species: *Asplenium antrophioides, A. rupestre, Carex* sp., *Eria carinata, E. globulifera, E. siamensis, Flickingeria fimbriata, Liparis averyanoviana, L. bootanensis, L. viridiflora, Pyrrosia* spp., *Vittaria hainanensis,* and *Vittaria* sp.

Associated lithophytic species: *Antrophium* sp., *Appendicula hexandra, Argostemma* spp., *Asplenium* sp., *Boea* spp., *Chirita* spp., *Collabium chapaensis, C. chinense, Cymbidium lowianum, Didymocarpus* sp., *Eria bambusifolia, E. calcarea, E. corneri, Hedychium yunnanense, Hedychium* sp., *Hedyotis* spp., *Lilium poilanei, Liparis balansae, L. dendrochiloides, L. superposita, Oreocharis argyrophylla, O. blepharophylla, Oreocharis* sp., *Paraboea* sp., *Peperomia* sp., *Rhynchotechum* sp., *Sonerila* spp., *Streptocarpus* sp., and *Vittaria elongata.*

Among plants of specific living forms, woody and semi-woody lianas like *Actinidia* sp., *Dioscorea* sp., *Smilax* sp., and *Tetrastigma* sp. should be mentioned. All they in primary intact forest are rather uncommon.

3. Evergreen coniferous tropical submontane forest (Fig. 1G; Averyanov et al., 2016b, Appendix 1, 3).

Fragments of true mono- or oligodominant coniferous forest in Pha Luong Mountains cover very small highly fragmented, mosaic rocky areas at elevations of (800)900–1500(1550) m. Commonly they cover very steep to almost vertical cliffs with inclination of 70–90° and rocky tops of remnant mesas composed exclusively red-brown sandstone (Fig. 1G, 2E-I). Leaf litter here may be 0–3 cm thick with projected coverage 0–100 %. Soil is very thin, well drained, with brown humus-containing horizon (5)10–20(30) cm.

Only two tree species – *Fokienia hodginsii* and *Pinus cernua* – form first stratum of coniferous forests in Pha Luong Mountains. These trees reach 12–20(25) high and (30)35–60(80) cm DBH. Commonly they form rather open forests with projective coverage of first stratum in 15–35(45) %. As more or less common associates here were observed such species as *Acer* sp., *Amentotaxus argotaenia, A. yunnanensis, Camellia* sp., *Castanopsis* spp., *Cephalotaxus mannii, Cinnamomum* spp., *Dacrycarpus imbricatus, Gordonia* sp., *Lithocarpus* spp., *Litsea* spp., *Podocarpus neriifolius, Quercus* spp., *Schefflera* sp., *Schima wallichii,* and *Symplocos* sp. The second pine species – *Pinus latteri* was observed as occasional coniferous forest co-dominant on very limited square at elevation 800–1000 m a. s. l. among degraded secondary vegetation on southern

marginal slopes of Pha Luong Mountains allied to agricultural area (Nguyen Minh Tam et al., 2015; Businsky, 2016).

Second coniferous forest stratum has no certain dominants. Occasional species here, except for few immature conifers, are *Acer* sp., *Aglaia* spp., *Eriobotrya* sp., *Lithocarpus* spp., *Photinia cucphuongensis, Quercus* spp., *Schefflera* sp., *Symplocos* sp. These trees have trunks 5–12 m tall, with (7)10–20(25) cm DBH. Usual projective coverage of this stratum is (15)23–50(60) %.

Third (shrub) stratum in coniferous forest includes treelets and shrubs 2–5 m tall and forms canopy coverage (10)15–40(45) %. It has no certain dominants and occasionally includes such species as *Ardisia* spp., *Camellia* sp., *Eriobotrya* sp., *Gaultheria fragrantissima, Gaultheria* sp., *Ilex* sp., *Leucothoe* sp., *Lyonia ovalifolia, Lyonia* spp., *Oxyspora* sp., *Photinia cucphuongensis, Psychotria* spp., *Rhododendron* spp., *Schefflera* sp.

Fourth forest stratum includes herbaceous species 0.03–2 m tall covering ground on (0)5–15(25) %. Most common species here are *Diplazium* sp., *Elatostema* spp., *Pellionia* spp., *Polystichum* sp., *Selaginella* sp. Sporadically observed species are *Alpinia* sp., *Goodyera schlechtendaliana, Ophiorrhiza* spp., *Sonerila* spp., *Tainia latifolia, Zingiber cochleariforme, Z. guangxiense,* and *Z. recurvatum*.

Stratum of mosses and lichens (fifth forest stratum) of (0.1)0.5–3 cm tall covers ground on (10)30–80(100) %. It mainly includes mixture of indeterminable juvenile Bryophytes and lichens, as well as few tiny ferns, like *Trichomenes* sp. (Hymenophyllaceae) and species of cup lichens (*Cladonia* spp., Cladoniaceae).

Non strata vegetation includes numerous epiphytes and lithophytes.

Dominant epiphytic species: *Bulbophyllum ambrosia, B. reptans, Callostylis rigida, Ceratostylis himalaica, Coelogyne fimbriata, Davallia* sp., *Dendrobium spatella, Dischidia* sp., *Drynaria* sp., *Epigeneium amplum, E. chapaense, Eria pannea, E. siamensis, E. thao, Eria* spp., *Lemmaphyllum microphyllum, Lepisorus* sp., *Microsorum* sp., *Pholidota articulata, P. chinensis, P. recurva, Pyrrosia* sp., and *Thelasis pygmaea.*

Associated epiphytic species: *Aeschynanthus mendumiae, Aeschynanthus* spp., *Bulbophyllum apodum, B. biesetoides, B. pecten-veneris, B. psychoon, Bulbophyllum* spp., *Cleisostoma striatum, C. williamsonii, Coelogyne* spp., *Cymbidium* spp., *Dendrobium brymerianum, D. chrysanthum, D. falconeri, D. fimbriatum, D. hancockii, D. nobile, Eria apertiflora, Hoya* sp., *Huperzia* sp., *Hygrochilus parishii, Liparis pumila, L. viridiflora, Luisia zollingeri, Luisia* spp., *Lycopodium* sp., *Oberonia falconeri, Oberonia* spp., *Ornithochilus difformis, Panisea* spp., *Peperomia* sp., *Stereochilus brevirachis, Sunipia scariosa, Thrixspermum stelidioides, Trichotosia microphylla, T. pulvinata,* and *Vanda* sp.

Dominant lithophytic species: *Asplenium rupestre, Carex* sp., *Eria carinata, E. globulifera, E. siamensis, Flickingeria fimbriata, Liparis averyanoviana, L. viridiflora, Pyrrosia* spp., *Vittaria hainanensis,* and *Vittaria* sp.

Associated lithophytic species: *Antrophium* sp., *Appendicula hexandra, Argostemma* spp., *Asplenium* sp., *Boea* spp., *Chirita* spp., *Cymbidium lowianum, Didymocarpus* sp., *Eria bambusifolia, E. calcarea, E. corneri, Hedychium yunnanense, Hedychium* sp., *Hedyotis* spp., *Lilium poilanei, Liparis superposita, Oreocharis argyrophylla, O. blepharophylla, Oreocharis* sp., *Paraboea* sp., *Peperomia* sp., *Rhynchotechum* sp., *Sonerila* spp., *Streptocarpus* sp., and *Vittaria elongata.*

Woody and semi-woody lianas, like *Actinidia* sp., *Dioscorea* sp., *Smilax* sp., and *Tetrastigma* sp., may be occasionally found in coniferous forests, commonly on open rocky outcrops.

4. Evergreen broad-leaved tropical montane cloud forest (Fig. 1H; Averyanov et al., 2016b, Appendix 1, 4).

Evergreen broad-leaved tropical montane cloud forest covers mountain tops and main summit of Pha Luong Mountains (Fig. 1H). Its fragments also may be seen on steep humid slopes and upper rocky cliffs of any exposition at elevations (1500)1700–1860 m a. s. l. with inclination up to 90°. They grow on very thin, poor, well drained soils having brown, humus-containing horizon (0)5–10(15) cm derived from solid red-brown sandstone bedrocks. Leaf litter commonly 0–3 cm thick, with projected coverage from 0 to 100 % observed in small local depression. Vertical forest structure is simple and consists of only three strata.

First stratum includes mossy gnarled treelets and shrubs 2–5(8) m tall with (3)5–15(30) cm DBH forming canopy projective coverage (25)50–90(100) %. In chines, depressions or other wind protected places trees of these forests can reach 10–12 m tall, but in windy slopes the canopy stratum neither exceeds 2–3 m tall. Main dominants here are such species as *Camellia* sp., *Castanopsis* spp., *Gordonia* sp., *Ilex*

sp., *Lithocarpus* spp., *Quercus* spp., *Rhododendron* spp., *Schima wallichii* and *Viburnum* sp., with more or less usual associates like *Cinnamomum* spp., *Eriobotrya* sp., *Fokienia hodginsii, Gaultheria fragrantissima*, *Gaultheria* sp., *Leucothoe* sp., *Lithocarpus* spp., *Litsea* spp., *Lyonia ovalifolia, Lyonia* spp., *Photinia cucphuongensis, Podocarpus neriifolius, Psychotria* spp., *Rhododendron* spp., and *Schefflera* sp.

Herbaceous stratum (second forest stratum) includes herbs 0.03–2 m tall with projective coverage (0)5–15(20) %. Main dominants here are *Carex* sp., *Diplasium* sp., *Elatostema* spp., *Pellionia* spp., *Plagiogyria pycnophylla, Polystichum* sp., *Scleria* sp., *Selaginella* sp. As a more or less common associated species were observed *Alpinia* sp., *Calanthe alleizettii, C. puberula, Collabium chinense, Cymbidium ensifolium, C. kanran, C. lancifolium, Goodyera schlechtendaliana, Ophiorrhiza* spp., *Sonerila* spp., *Tainia latifolia, Zeuxine nervosa, Zingiber cochleariforme, Z. guangxiense* and *Z. recurvatum*.

Bryophytes and lichens (0.1)0.5–3 cm tall form third forest stratum covering (10)30–80(100) % of the forest floor. Mainly it includes mixture of juvenile mosses and lichens, as well as few tiny ferns – *Trichomanes* sp. (Hymenophyllaceae), cup lichens (*Cladonia* spp., Cladoniaceae) and haircap mosses (*Polytrichum* spp., Polytrichaceae).

Non strata vegetation includes many epiphytes and locally abundant lithophytes.

Dominant epiphytic species: *Bulbophyllum ambrosia, B. reptans, Ceratostylis himalaica, Coelogyne fimbriata, Davallia* sp., *Epigeneium amplum, E. chapaense, Eria pannea, E. siamensis, Eria* spp., *E. thao, Lepisorus* sp., *Microsorum* sp., *Pholidota articulata, P. chinensis, P. recurva, Pyrrosia* sp., and *Thelasis pygmaea.*

Associated epiphytic species: *Bulbophyllum pecten-veneris, B. psychoon, Bulbophyllum* spp., *Cleisostoma striatum, C. williamsonii, Coelogyne* spp., *Cymbidium* spp., *Dendrobium nobile, Eria apertiflora, Huperzia* sp., *Liparis pumila, L. viridiflora, Luisia zollingeri, Luisia* spp., *Lycopodium* sp., *Oberonia falconeri, Oberonia* spp., *Ornithochilus difformis, Panisea* spp., *Stereochilus brevirachis, Sunipia scariosa, Thrixspermum stelidioides, Trichotosia microphylla, T. pulvinata,* and *Vanda* sp.

Dominant lithophytic species: *Asplenium rupestre, Carex* sp., *Eria carinata, E. globulifera, E. siamensis, Flickingeria fimbriata, Liparis viridiflora,* and *Pyrrosia* spp.

Associated lithophytic species: *Appendicula hexandra, Argostemma* spp., *Asplenium* sp., *Boea* spp., *Chirita* spp., *Cymbidium lowianum, Didymocarpus* sp., *Eria bambusifolia, Hedychium yunnanense, Hedychium* sp., *Hedyotis* spp., *Lilium poilanei, Oreocharis argyrophylla, O. blepharophylla, Oreocharis* sp., *Paraboea* sp., and *Vittaria elongata.*

Woody and semi-woody lianas are rather rare. Among them, *Dioscorea* sp., *Smilax* sp. and *Tetrastigma* sp. were observed.

5. Evergreen ericaceous montane scrub (Fig. 2A; Averyanov et al., 2016b, Appendix 1, 5).

Ericaceous montane scrub covers highest rocky peaks of Pha Luong Mountains. These dense thickets are observed on windy places of summits, on steep slopes and exposed cliffs at elevations (1500)1700–1860 m a. s. l. on any slope exposition at inclination 0–70(90)°. Bedrocks in these habitats are exclusively solid red-brown sandstone. Soils here are very thin, poor, well drained, with brown humus-containing horizon (0)1–3(5) cm thick. Ground surface is covered by leaf litter 0–3 cm thick with projected coverage 0–100 %. Vertical structure is very simple including actually only three strata.

First (woody) stratum of ericaceous scrub in Pha Luong Mountains includes small gnarled treelets and shrubs 1.5–2(3) m tall with trunks (1)3–10(15) cm in diameter. Projective coverage of this stratum is (30)40–90(100) %. Most common dominant species here are *Gaultheria fragrantissima, Gaultheria* sp., *Ilex* sp., *Leucothoe* sp., *Lyonia ovalifolia*, *Lyonia* spp., *Rhododendron* spp., and *Vaccinium* spp. More or less common associates in this plant community are *Eriobotrya* sp., *Fokienia hodginsii, Hypericum hookerianum, Lithocarpus* spp., *Melastoma* sp., *Myrsine* sp., *Photinia cucphuongensis, Podocarpus neriifolius, Psychotria* spp., *Quercus* sp., *Schefflera* sp., and *Viburnum* sp.

Second (herbaceous) stratum is not well pronounced having projective coverage not exceeding 10–15 %. It includes scattered herbs 0.03–1(1.5) m tall. Few dominant species here are such species as *Carex* sp., *Diplazium* sp., *Elatostema* spp., *Pellionia* spp., *Polystichum* sp., *Scleria* sp., *Selaginella* sp. In addition, occasionally following associates were also observed: *Calanthe alleizettii, Collabium chinense, Cymbidium ensifolium, C. lancifolium, Goodyera schlechtendaliana, Sonerila* spp., *Tainia* sp., and *Zeuxine nervosa*.

Moss and lichen stratum (0.1)0.5–3 cm tall has projective coverage (10)30–60(90) %. It includes mainly mixture of indeterminable juvenile species,

Fig. 2. A. Evergreen ericaceous montane scrub on main summit of Pha Luong Mountains at 1700–1860 m a. s. l. B – Bamboo montane thickets on main summit of Pha Luong Mountains at 1800 m a. s. l. C, D – Secondary sphagnum-herbaceous grasslands on flat rocks cleaned by fire on mains summit of Pha Luong Mountains at elevation 1800–1840 m a. s. l.). E – Landscape and fragments of *Pinus cernua* forest in location of subpopulation № 13, voucher herbarium collecting number *CPC 7959*. F–H – Fragments of *Pinus cernua* forest and individual trees in location of subpopulation № 17, voucher herbarium collecting number *CPC 8107*. I – Individual tree of *Pinus cernua* in locality of discovered subpopulation № 13, voucher herbarium collecting number *CPC 7959*.

as well as many cup lichens (*Cladonia* spp., Cladoniaceae) and haircap mosses (*Polytrichum* spp., Polytrichaceae).

Epiphytes here are not too common and numerous. Among them, the following rather cool growing species were found: *Bulbophyllum ambrosia, B. psychoon, B. reptans, Bulbophyllum* spp., *Ceratostylis himalaica, Cleisostoma williamsonii, Coelogyne* spp., *Davallia* sp., *Dendrobium nobile, Epigeneium chapaense*, *Huperzia* sp., *Lepisorus* sp., *Liparis viridiflora, Lycopodium* sp., *Microsorum* sp., *Pyrrosia* sp., and *Thelasis pygmaea*.

Lithophytes are occasionally abundant, but their species diversity is less than at lower elevations. Most typical species here are *Asplenium* sp., *Carex* sp., *Chirita* spp., *Cymbidium lowianum, Eria bambusifolia, E. carinata, E. globulifera, E. siamensis, Hedychium yunnanense*, *Hedyotis* spp., *Lilium poilanei*, *Liparis viridiflora*, *Oreocharis argyrophylla*, *O. blepharophylla,* and *Pyrrosia* spp.

Among climbers and lianas, *Dioscorea* sp., *Smilax* sp. and *Tetrastigma* sp. occasionally found in rather open rocky places and cliffs may be mentioned.

6. Bamboo montane thickets (Fig. 2B; Averyanov et al., 2016b, Appendix 1, 6).

Bamboo montane thickets are azonal plant community, which represents early successive stage of forest regeneration after forest fire. Meanwhile, this plant community remains more or less stable a long time on windy places, particularly on steep cliffy rocky outcrops or mountain tops (Fig. 2B). In Pha Luong Mountains bamboo montane thickets are common at elevation (1500)1700–1860 m on slopes of any exposition with inclination 0–70(90)°. They commonly cover mountain tops composed with red-brown sandstone. Leaf litter here is 0–3 cm thick with projected coverage 0–100 %. Soils are very thin, poor, well drained with brown humus-containing horizon commonly less than 5 cm thick. Structure of bamboo montane thickets in Pha Luong Mountains is very simple including three strata.

First stratum contains only one semi-woody species of indeterminable bamboo (*Arundinaria* aff.) with stems 1–2(2.5) m tall and 0.5–1(1.5) cm in diameter. It forms rather dense thickets with projective coverage (25)50–80(100) %. Sparsely scattered associate shrubby species here are immature samples of *Eriobotrya* sp., *Gaultheria fragrantissima, Gaultheria* sp., *Ilex* sp., *Leucothoe* sp., *Lithocarpus* spp., *Lyonia ovalifolia*, *Lyonia* spp., *Myrsine* sp., *Photinia cucphuongensis*, *Podocarpus neriifolius, Psychotria* spp., *Quercus* sp., *Rhododendron* spp., *Schefflera* sp., *Viburnum* sp.

Herbs are uncommon and sporadic. They form incomplete stratum 0.03–1 m tall with projective coverage (0)5–10(15) %. Recorded and documented species here are *Calanthe alleizettii, Carex* sp., *Collabium chinense, Cymbidium ensifolium, C. lancifolium, Diplasium* sp., *Elatostema* spp., *Goodyera schlechtendaliana, Polystichum* sp., *Scleria* sp., *Selaginella* sp., *Tainia* sp., and *Zeuxine nervosa*.

Mosses and lichens form stratum (0.1)0.5–3 cm tall with ground coverage (10)20–40(60) %. It includes species of *Polytrichum* spp. (Polytrichaceae) and numerous indeterminable juvenile bryophytes and lichens.

Epiphytes and semi-epiphytes are almost absent. Few recorded lithophytic species are *Asplenium* sp., *Carex* sp., *Hedychium yunnanense*, *Hedyotis* spp., *Lilium poilanei,* and *Pyrrosia* spp.

Among climbers and lianas, species of *Dioscorea*, *Smilax* and *Tetrastigma* were found.

7. Sphagnum-herbaceous montane grasslands (Fig. 2C, D; Averyanov et al., 2016b, Appendix 1, 7).

Montane grassy vegetation in Pha Luong Mountains is azonal plant community, which represents first initial successive stage of plant cover regeneration after forest fire. Mossy grasslands are well presented in main almost flat summit of Pha Luong Mountains at elevation 1800–1820 m a. s. l. Here this meadow-like plant community demonstrates certain stability in its structure and specific species composition on open sandstone rocky surface almost lacking of soil deposits. Only two strata may be recognized in this plant community.

Herbaceous stratum 0.03–1(1.5) m tall forming projective coverage (5)15–55(70) % includes following dominant species: *Carex* sp., *Cyperus* sp., *Hedychium yunnanense*, *Hedychium* sp., *Melastoma* sp., *Scleria* sp., *Selaginella* sp., *Xyris indica*, *Xyris* sp. Many other species occurring only in this specific habitat were documented here. Among them, there are *Ainsliaea* sp., *Anemone* sp., *Anthogonium gracile, Blumea* sp., *Cyanotis* sp., *Drosera peltata, Hypericum hookerianum, Impatiens* sp., *Lilium poilanei*, *Lysimachia* sp., *Sedum* sp., *Strobilanthes taoana, Strobilanthes* sp., and *Clematis* sp. All these herbs grow here actually as true lithophytes.

Moss and lichen stratum (0.1)0.5–5(10) cm tall includes numerous indeterminable juvenile species

of mosses and lichens, as well as species of *Cladonia* (Cladoniaceae), *Polytrichum* (Polytrichaceae) and *Sphagnum* (Sphagnaceae) with total projective coverage (10)30–50(100) %. *Sphagnum* pillows here reach often 10 cm tall and more than 1 m across. They form sometime miniature peat bogs in small depressions (Fig. 2D), which provide home to many typical marshland species of such genera as *Xyris, Cyperus, Drosera, Eriocaulon,* etc.

Some climbers and lianas are more or less common here in open rocky outcrops and cliffs. Among such plants are species of such genera as *Ampelopsis, Crawfurdia, Dioscorea, Smilax,* and *Tetrastigma.*

Non strata vegetation of Pha Luong Mountains

Epiphytic and lithophytic plants form specific extra-strata plant communities, which belong to so-called non strata vegetation. Species composition of non-strata vegetation in Pha Luong Mountains is very rich due to relatively high humidity and numerous rocky outcrops, particularly in upper part of slopes.

Epiphytic plants are common in plant communities of Pha Luong Mountains at any elevations. Epiphytes here belong to many families, but ferns and orchids dominate in all habitats. Epiphytic species and their families are listed below.

Typical epiphytes in all kind of plant communities in Pha Luong Mountains

Lycopodiaceae
Huperzia sp.
Lycopodium sp.

Polypodiaceae s. l.
Davallia sp.
Drynaria sp.
Lemmaphyllum microphyllum
Lepisorus sp.
Microsorum sp.
Pyrrosia sp.

Asclepiadaceae
Dischidia sp.
Hoya sp.

Gesneriaceae
Aeschynanthus mendumiae
Aeschynanthus spp.
Lysionotus chingii

Piperaceae
Peperomia sp.

Orchidaceae
Bulbophyllum ambrosia
B. apodum
B. biesetoides
B. pecten-veneris
B. psychoon
B. reptans
Bulbophyllum spp.
Callostylis rigida
Ceratostylis himalaica
Cleisostoma striatum
C. williamsonii
Coelogyne fimbriata
*Coelogyn*e spp.
Cymbidium lowianum
Cymbidium spp.
Dendrobium brymerianum
D. chrysanthum
D. eriiflorum
D. falconeri
D. fimbriatum
D. hancockii
D. jenkinsii
D. nobile
D. spatella
D. thyrsiflorum
Epigeneium amplum
E. chapaense
Eria apertiflora
E. calcarea
E. pannea
E. rhomboidalis
E. siamensis
E. thao
Eria spp.
Hygrochilus parishii
Liparis longispica
L. pumila
L. viridiflora
Luisia zollingeri
Luisia spp.
Oberonia falconeri
Oberonia spp.
Ornithochilus difformis
Panisea spp.
Pholidota articulata
P. chinensis
P. recurva
Smitinandia helferi
Stereochilus brevirachis

Sunipia scariosa
Tainia latifolia
Thelasis pygmaea
Thrixspermum centipeda
T. stelidioides
Trichotosia microphylla
T. pulvinata
Vanda sp.

Lithophytic plant species are particularly common and even abundant in plant communities of Pha Luong Mountains at highest elevations on slopes and cliffs allied to mountain tops. Lithophytes here belong to many families, but ferns, gesneriads and orchids dominate in all habitats. Lithophytic species and their families are listed below.

Typical lithophytes in all kind of plant communities in Pha Luong Mountains

Polypodiaceae s. l .
Antrophium sp.
Asplenium antrophioides
A. rupestre
Asplenium sp.
Aglaomorpha acuminata
Vittaria elongata
V. hainanensis
Vittaria sp.

Cyperaceae
Carex sp.
Scleria sp.

Gesneriaceae
Boea spp.
Chirita spp.
Didymocarpus sp.
Oreocharis argyrophylla
O. blepharophylla
Oreocharis sp.
Paraboea sp.
Rhynchotechum sp.
Streptocarpus sp.

Liliaceae
Lilium poilanei

Melastomataceae
Sonerila spp.

Piperaceae
Peperomia sp.

Rubiaceae
Argostemma spp.
Hedyotis spp.

Zingiberaceae
Hedychium yunnanense
Hedychium sp.

Orchidaceae
Appendicula hexandra
Collabium chapaensis
C. chinense
Cymbidium lowianum
Eria bambusifolia
E. calcarea
E. carinata
E. corneri
E. globulifera
E. rhomboidalis
E. siamensis
Flickingeria fimbriata
Liparis averyanoviana
L. balansae
L. bootanensis
L. dendrochiloides
L. superposita
L. viridiflora

History of discovery and taxonomy of *Pinus cernua*

The history of *Pinus cernua* discovery was reported in details in earlier publications (Averyanov et al., 2014, 2015a; Phan Ke Loc et al., 2014a, b). The species was first recognized by Vietnamese geologists at the end of 2011 within the steep cliffs located in the peripheral zone of Pha Luong Mountains near Laos – Vietnam state boundary between Houaphan and Son La provinces. This discovery was announced in the January issue of the People's Army Newspaper (Luong Tu Chan, 2012) and was also shortly noted in Vietnam Environment Administration Magazine (Le Tran Chan et al., 2012). In middle 2012 the discovery of the new species was confirmed by collected of voucher herbarium specimens (Nguyen Duc To Luu et al., 2013; Phan Van Thang et al., 2013). These initial assessments and attempts to understand newly discovered pine species resulted in its tentative

identification as "*Pinus* aff. *armandii* Franchet" (Nguyen Duc To Luu et al., 2013; Phan Ke Loc et al., 2013). Meanwhile, authors indicated certain morphological differences found in the Vietnamese pine from true *P. armandii* (Phan Ke Loc et al., 2013). Almost simultaneously, the identification of the discovered plant as *P. fenzeliana* Hand.-Mazz., was proposed based on speculative studies of plant images entering to the Internet (Businsky, 2013). Further field and laboratory studies confirmed the obvious differences between the discovered plant from both *P. armandii* and *P. fenzeliana*, the latter known from isolated locations in southern China. Given the clear distinction of the discovered tree and its morphological differences from all known species of the genus, it was described as a new species under the name *Pinus cernua* L. K. Phan ex Aver., K.S. Nguyen et T. H. Nguyen in Averyanov et al. (2014, 2015a). Other scientists also accepted the segregation of new taxon, but in subspecies rank. It resulted in description of the same pine under the name *Pinus armandii* Franchet subsp. *xuannhaensis* L.K. Phan (Phan Ke Loc et al., 2014a, b). This study based on extensive field investigations of many newly discovered subpopulations revealed fairly uniform morphology and very low genetic variability of new taxon (Nguyen Minh Tam et al., 2015). At the same time, the another study based on observation of single marginal subpopulation of *Pinus cernua* (mixed with *P. latteri*) deny any differences of Pha Luong pine from internet-available herbarium specimens of *P. fenzeliana* originated from mainland SE China and Hainan (Businsky, 2016). New field investigation and species assessment was undertaken throughout all area of Pha Luong Mountains in September – October 2016. It resulted in discovery of 6 new subpopulations of *Pinus cernua* in addition to already verified 16 earlier known localities. Extinction of one subpopulation due to forest burning is detected in south-west corner of the pine distribution area.

A detailed updated description and assessment of this rare highly endangered, locally endemic species is presented below.

Pinus cernua L. K. Phan ex Aver., K. S. Nguyen et T. H. Nguyen in Aver. et al., 2014, Nordic J. Bot. 32, 6: 792; Aver. et al., 2015, Turczaninowia 18, 1: 7.

= *P. fenzeliana* auct. non Hand.-Mazz.: Businsky, 2004, Willdenowia 34: 218; id., 2011, Phyton 51, 1: 84; id., 2013, ibid., 53, 2: 247, 257; id., 2016, Phyton 56, 2: 143, p.p.

= *P. armandii* auct. non Franch.: Nguyen Duc To Luu et al., 2013, Proc. 5th Nat. Sci. Conf. Ecol. Biol. Res. (Hanoi): 152; Phan Van Thang et al., 2013, Guide Conif. Hoa Binh, Son La prov.: 20; Phan Ke Loc et al., 2013, Ecol. Econ. J. 45: 42.

= *Pinus armandii* subsp. *xuannhaensis* L. K. Phan, 2014, Vietnam National University Journ. Sci. Nat. Sci. Technol. (Hanoi) 30, 3S: 54, fig. 2; id., 2014, Journ. Ecol. Econ. (Hanoi) 46: 72, fig. 2.

Non *Pinus fenzeliana* Hand.-Mazz. var. *annamiensis* Silba, 2000, Journ. Int. Conifer Preserv. Soc. 7: 30.

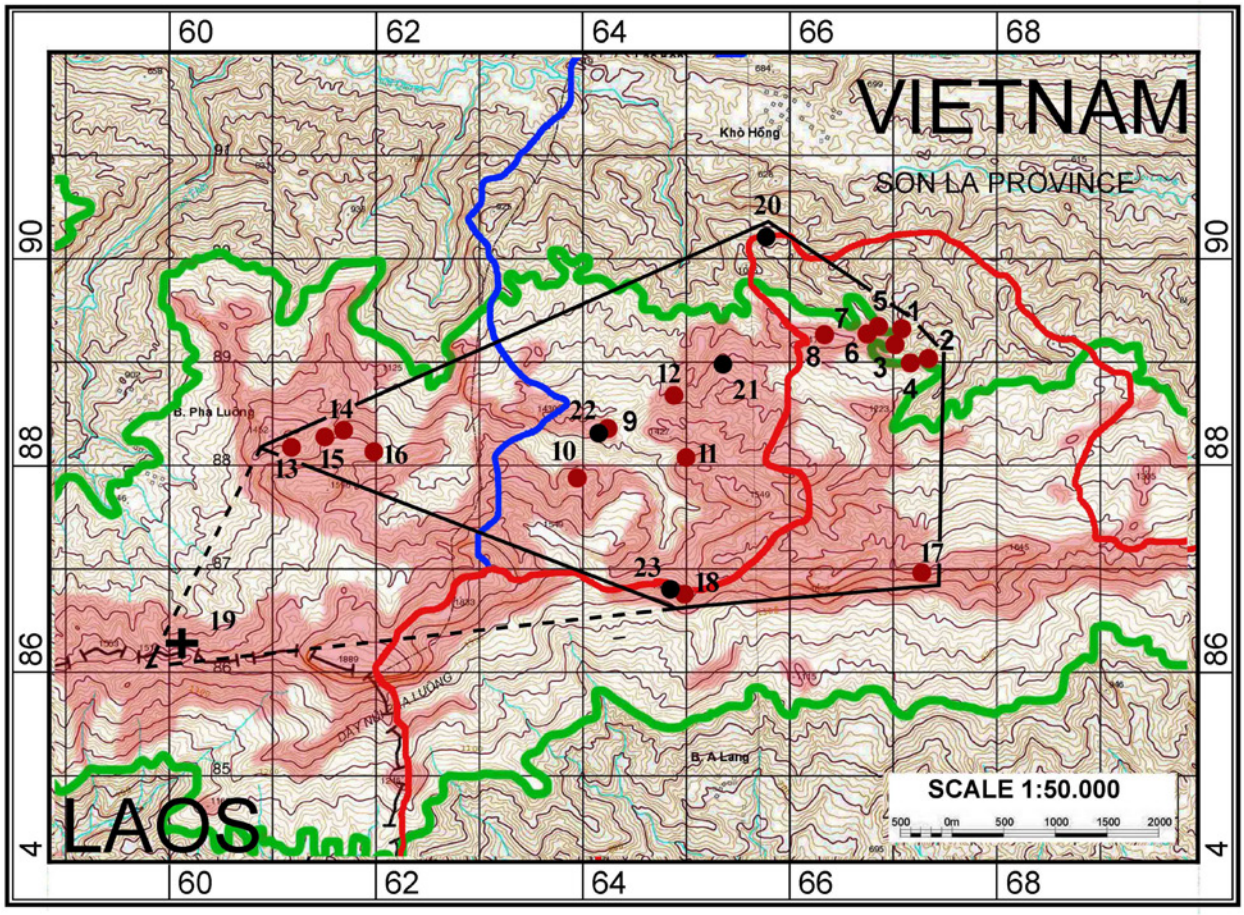
Non *Pinus fenzeliana* Hand.-Mazz. subsp. *annamiensis* (Silba) Silba, 2009, Journ. Int. Conifer Preserv. Soc. 16: 21.

Described from the border region of northern Laos and Vietnam ("Laos-Vietnamese border between Son La and Houaphan provinces").

Type. "Vietnam, Son La province, Van Ho district, Chieng Xuan municipality, Co Hong village, territory of Xuan Nha nature reserve, NE slopes of Pha Luong Mountains. Primary coniferous forest with *Pinus cernua* on very steep mountain slopes and cliffs composed of brown sandstone at elevations 1000–1050 m a. s. l., N20°42′14.2″, E104°43′53.9″, 12 November 2013, L. Averyanov et al. CPC 6992" (holotype – Herbarium of the Center for Plant Conservation!, isotype – LE!).

Tree (12)20–30(35) m tall, 0.4–0.8(1) m DBH. Canopy conical, becoming with irregularly rounded with age; branches suberect to pendulous; leafy branchlets gray-green, olive or yellow-brown, slightly glaucous, glabrous. Bark dull gray-brown to dark brown, roughly fissured into irregular polygonal flat or slightly concave plates, often resinous, inner bark reddish-brown, finely fibrous. Winter buds orange-brown often cylindric, 1–2 cm long, 3–5 mm in diam.; scales narrowly triangular, (3)4–5 mm long, 1–2 mm wide at the base, acuminate, with slightly recurved scarious apex. Needles in fascicles of 5, (12)15–20(22) cm long, 0.6–0.8 mm thick, rich dark green, slender, cernuous, slightly twisted, serrulate, triangular in cross section, with 25–32 rigid erect denticles per cm along each edge and with 3–4 stomatal lines on the ventral lateral surfaces; vascular bundle 1, large; resin ducts 3, subequal, medial and two lateral; the sheath early deciduous. Pollen cones numerous, in spiral clusters at the base of new shoots, ovoid, later elongate, suberect, more or less stout, 0.8–1.5 cm long, 6–8 mm in diam. Seed cones on stout peduncles 1–2 cm long, commonly clustering 2–6 in a whorl, rarely alone, erect, later facing in all directions, persistent for many years, brown to dark brown, ovoid, 8–11

cm long, 5–7 cm in diam., dehiscent at maturity, often profusely resinous. Seed scales woody, rigid, obovate-deltoid, 2.4–2.8(3) cm long, 1.5–2.5 cm wide, apophysis deltoid, recurved and thickened at apex in form of transversal finely grooved cushion, umbo insignificant, without mucro. Seeds dark brown, smooth, oblique obovoid, 1–1.2 cm long, 0.5–0.7 mm in diam., with rudimentary scarious thin wing 1–2 mm wide disintegrating to seed maturity and occasionally remaining in form of low



Distribution of *Pinus cernua*
Former and present actual area of occurrence

Polygone of former occurrency area (≈20 km2, for about 2010)
Polygone of present actual occurrency area (≈15 km2, for 2016)
Presently existing subpopulations:1-12 - locations discovered in 2013-2015 (Averyanov et al., 2015); 13-18 - locations discovered by our research group in 2016; 20-23 - locations discovered by other researches in 2015-2016 (Nguyen Minh Tam et al., 2015; Businsky, 2016, pers.comm).
Location of extinct population (19) detected by our research group in 2016.
Estimated present actual occupancy area for 2016 less than 5 km2

Fig. 3. Former and present distribution of *Pinus cernua* in Pha Luong Mountains.
Polygon marked with dash and entire lines designates former occurrence area of *Pinus cernua* (≈20 km^2, for about year 2010). Polygon marked with entire line designates present actual occurrence area of *Pinus cernua* (≈15 km^2, for the year 2016). Red and black dots indicate positions of presently existing subpopulations: 1–12 – locations discovered in 2013–2015 (Averyanov et al., 2015a); 13–18 – locations discovered by our research group in September – October 2016; 20–23 – locations discovered by other researchers in 2015–2016 (Nguyen Minh Tam et al., 2015; Businsky, 2016). Black cross indicate location of extinct population (19) detected in September – October 2016. Estimated present actual occupancy area for the year 2016 less than 5 km^2.

irregular distal rim. Pollination February – March, seeds September – October.

Paratypes. Vietnam. Son La prov., Chieng Xuan (N. D. Luu et al., 2013): 4 XII 2012, P. V. Thang et al. 5 (VNU, PanNature Herbarium); 13 XII 2012, N. D. T. Luu et al. 24 (VNU, PanNature Herbarium); 16 IV 2013, P. K. Loc et al. P 11077; 16 IV 2013, P 11078-11080; 17 IV 2013, P 11081-11082; 18 IV 2013, 11084-11089 (LE, VNU, PanNature Herbarium).

Taxonomical notes. The discovered species probably has some relation to the variable complex of *Pinus fenzeliana*. However, our plant distinctly differs from representatives of this complex in having narrow, slender needles more than twice as long as the ripe seed cones (Fig. 4–5), ovoid small persistent seed cones clustering regularly in whorls of 2–6, smaller seed scales with deltoid apophysis recurved and thickened at the apex in the form of a transverse, finely-grooved cushion without a distinct mucro and in seeds with a rudimentary, scarious, early-disintegrating wing. These characteristic features have already been emphasized during the initial studies of the first discovered subpopulations (Nguyen Duc To Luu et al., 2013; Phan Ke Loc et al., 2013) and in later studies (Phan Ke Loc et al., 2014a, b) resulted in description of *Pinus armandii* subsp. *xuannhaensis*. Specimens from Hainan selected as a neotype for *P. fenzeliana* do not agree with the species protologue (Businsky, 2004, 2011). They resemble Vietnamese plants and may be close to our species described here. At the same time according to its original description, *P. fenzeliana* has a distinct morphologic resemblance with the previously described *P. kwangtungensis* Chun ex Tsiang, or it may belong to a hybrid of uncertain origin. Some comments and individual opinions on *P. cernua* taxonomy may be additionally found in some relevant publication (Phan Ke Loc et al., 2014a; Businsky, 2016).

The name of the assessed pine, *P. cernua*, refers to the long slender weeping needles, which represent bright diagnostic feature easy distinguishing Pha Luong pine from more or less related species.

Distribution, ecology and population structure of *Pinus cernua*

Pinus cernua in Pha Luong Mountains is an integral element of evergreen mixed and coniferous tropical forests at elevation (800)850–1500(1550) m a. s. l. (Fig. 1G, 2E–I; Averyanov et al., 2016b, Appendix 1–3). It is rather thermopile, warm-growing element in comparison with its more or less common coniferous associates like *Amentotaxus argotaenia, A. yunnanensis, Cephalotaxus mannii, Cunninghamia konishii, Dacrycarpus imbricatus, Fokienia hodginsii,* and *Podocarpus neriifolius*, which are occasionally observed at any elevations of Pha Luong mountain system (Phan Van Thang et al., 2013; Nguyen Minh Tam et al., 2015). Elevational distribution of *Pinus cernua* in studied mountains is strongly limited by 1500 (1550) m a. s. l. In most localities, *Pinus cernua* is observed as a co-dominant or occasional associate in mixed forests with high percentage of broad-leaved trees. True mono- and oligodominant coniferous forests with *Pinus cernua* are rather rare and confined to a very limited territory. At elevations of 1200–1550 m a. s. l. coniferous forests with *Pinus cernua* are often mixed with *Fokienia hodginsii*. On lower elevations, at (800)850–1200 m a. s. l. *Pinus cernua* forms monodominant coniferous forests, or sometimes sporadically mixed with scattered trees of *Pinus latteri* (Nguyen Minh Tam et al., 2015; Businsky, 2016). Such species assemblage in its typical form was observed on few narrow highly dissected ridges of northern slopes in peripheral zone of Pha Luong mountains allied to agricultural fields (Businsky, 2016).

According to the present knowledge, *Pinus cernua* is a local endemic of Pha Luong Mountains occurring on the Laos-Vietnamese state boundary between Houaphan and Son La provinces. Deep erosion of the solid red-brown sandstones forms here unique picturesque landforms with numerous rocky ridges, very steep cliff slopes and rocky outcrops on the tops of remnant mesas (Fig. 1A, C, D, F, and 2 E–G). The species almost exclusively inhabits steep rocky slopes and cliffs composed with sandstone (Fig. 2E–H) at elevation (800)850–1500(1550) m a. s. l. It was not found anywhere in Vietnam despite special extensive field searches.

Locations of all 22 presently extant and one extinct subpopulations are indicated (by appropriate numbers) on *Pinus cernua* distribution map (Fig. 3). Localities 1–12 discovered during 2011–2013 listed also in Table 2 were reported in earlier publications (Nguyen Duc To Luu et al., 2013; Averyanov et al., 2014, 2015a).

Locations of 6 extant and 1 extinct subpopulations (numbered respectively as 13–18 and 19) discovered in September – October 2016 are listed in Table 3 and indicated on Fig. 3.

Locations of 4 extant subpopulations (numbered respectively as 20–23) discovered in 2015–2016 by other research groups and individuals (Nguyen Minh Tam et al., 2015; Businsky, 2016) are listed in Table 4 and indicated on Fig. 3.

Table 2

Documented locations of *Pinus cernua* in Pha Luong Mountains reported in early publications presented on distribution map

№ of location	POSITION	ELEVATION	VOUCHER SPECIMENS or/and PHOTOS
1	N20°42′11″, E104°41′04″	949 m	P. V. Thang et al. 5, 4 XII 2012; P. K. Loc et al. P 11077, 16 IV 2013
2	N20°42′07″, E104°41′12″	1000 m	N. D. T. Luu et al. 24, 13 XII 2012
3	N20°42′10″, E104°41′04″	955 m	P. K. Loc et al. P 11078, 11079, 11080, 16 IV 2013
4	N20°42′07″, E104°41′12″	1000 m	P. K. Loc et al. P 11081, 17 IV 2013
5	N20°42′05″, E104°41′08″	1002 m	P. K. Loc et al. P 11082, 17 IV 2013
6	N20°42′13″, E104°40′54″	1010 m	P. K. Loc et al. P 11084, 11085, 11086, 11087, 11088, 11089, 18 IV 2013
7	N20°42′11.4″, E104°40′53.4″	1050 m	Averyanov L. et al. CPC 6992, 12 IV 2013
8	N20°42′07.5″, E104°40′41.7″	1150 m	Averyanov L. et N. S. Khang photos, CPC s. n., 12 IV 2013
9	N20°41′39.4″, E104°39′22.9″	1400 m	N. S. Khang photos, CPC s. n., 13 IV 2013
10	N20°41′24.7″, E104°39′13.8″	1380 m	N. S. Khang photos, CPC s. n., 13 IV 2013
11	N20°41′31.0″, E104°39′53.2″	1450 m	N. S. Khang photos, CPC s. n., 13 IV 2013
12	N20°41′47.9″, E104°39′45.6″	1430 m	N. S. Khang photos, CPC s. n., 13 XI 2013

Table 3

Documented locations of *Pinus cernua* in Pha Luong Mountains discovered during fieldworks in September – October 2016 presented on distribution map

№ of LOCATION	ADMINISTRATIVE POSITION	ELEVATION in m a. s. l.	POSITION	NUMBER of INDIVIDUALS	HEIGHT and DBH	DATE of OBSERVATION	COLLECTING №
13	Moc Chau distr., Chieng Son comm., Pha Luong village	1400–1500	N20°41′33.2, E104°37′37.0	2	15–20 m, 40-45 cm	22 IX 2016	CPC 7959
14	Moc Chau Distr., Chieng Son comm., Pha Luong village	1350–1400	N20°41′36.9, E104°37′47.6; N20°41′37.9, E104°37′51.1	20	10–15 m	23 IX 2016	CPC 8013
15	Moc Chau Distr., Chieng Son comm., Pha Luong village	1350	N20°41′36.4, E104°37′46.6	6	8–10 m	24 IX 2016	CPC 8019
16	Moc Chau Distr., Chieng Son comm., Pha Luong village	1425	N20°41′30.9, E104°38′08.9	3	10–12 m	25 IX 2016	CPC 8022
17	Van Ho Distr., Tan Xuan comm., Bun village	1500–1550	N20°40′58.4, E104°41′02.8	20	10–15 m	27 IX 2016	CPC 8107
18	Van Ho Distr., Tan Xuan comm., A Lay village	1500	N20°40′46.2, E104°39′49.6	3	15–20 m, 70–80 cm	1 X 2016	CPC 8169
19	Moc Chau distr., Chieng Son comm.	≈1500	≈N20°40′27, ≈E104°36′50	extinct	–	29 IX 2016	–

Table 4

Locations of *Pinus cernua* in Pha Luong Mountains reported in 2015–2016 by other sources presented on distribution map

№ of LOCATION	ADMINISTRATIVE POSITION	ELEVATION in m a. s. l.	POSITION	NUMBER of INDIVIDUALS	HEIGHT & DBH	DATE of OBSERVATION	COLLECTING №
20	About 550 m to SW above Kho Hong village	800–1000	N20°42′43″, E104°40′20″	∞	to 20 m, to 0.8 m	14 III 2016	R. Businsky, no data
21	Chieng Xuan commune (“Thac Nuoc” et “Gan VTV2” et “Dinh Pomu”	890–1050	N20°42′, E104°40′	≥71	no data	no data	no data
22	Chieng Xuan commune, “Dinh VTV2”	1410	N20°41′40″, E104°39′23″	≥25	no data	no data	no data
23	Tan Xuan commune, “Tan Xuen”	1502	N20°40′46″, E104°39′46″	≥21	no data	no data	no data

Actually, all discovered extant and extinct *Pinus cernua* subpopulations occupy total area less than 15 km^2 that spreads on 7.5 km from W to E (E104°36′50 – E104°41′03) and on 4.5 km from N to the S (N20°40′27″ – N20°42′43″). At the same time, all locations are within 2 km of each other or less. Therefore, they may be reasonably regarded as lone population according to IUCN Red List criteria (IUCN Red List Categories and Criteria, 2001).

Mono- and oligodominant stands of *Pinus cernua* with more than 50–100 trees within locality are observed only in north-eastern part of distribution area (locations 1–8, 20, 21). Very few saplings and young immature trees (less than 1 %) were observed in these subpopulations. Only 1 to 25 mature trees commonly scattered in broad-leaved forests were recorded in all other locations (9–18, 22, 23). One recently extinct subpopulation (19) was detected in south-western corner of the distribution area (Fig. 3). Seedlings were not found in all observed locations. Burned, human-cut and naturally felled trunks have been seen in some locations.

Newly found locations of *Pinus cernua* (numbered on figure 3 as 13–18) discovered during fieldwork in September – October 2016 expand known distribution area essentially (Fig. 3).

Discovered locations 13–16 were found on rocky north-western offset of Pha Luong Mountains (Fig. 3) at N20°41′30.9″–N20°41′37.9″ and E104°37′37.0″–E104°38′08.9″. They form close group within 1 km^2 including each from 2 to 20 mature trees 8–20 m tall and (25)30–45 cm DBH (Table 3). All trees grow here on very steep north faced slopes and cliffs in upper part on rocky eroded mesas often with association with *Fokienia hodginsii* at elevations 1350–1500 m a. s. l. Discovered locations are situated here at distance 150–500 m from each other (Fig. 3). No seedlings and saplings were found in these locations.

Discovered location 17 outlines south-eastern corner of *Pinus cernua* distribution at point N20°40′58.4″, E104°41′02.8″ (Fig. 2F–H). This subpopulation includes 20 mature trees 10–15 m tall growing on rocky outcrops at elevation 1500–1550 m a. s. l. (Table 3). This is highest elevation of known *Pinus cernua* habitats. Trees here inhabit upper parts of humid cliffy slopes of narrow ravines and canyons, as well as tops of remnant eroded mountaintops and mesas. *Fokienia hodginsii* is another common conifer at this location. No seedlings and saplings were observed here. Squirrels damaged many ripening cones in some trees in this location.

Newly found location 18 defines southern border of *Pinus cernua* distribution. It situated in point N20°40′46.2″, E104°39′49.6″ at elevation 1500 m a. s. l. (Fig. 3). Only 3 old trees 15–20 m tall and 70–80 cm DBH, as well as few naturally fallen trunks were located in this subpopulation. Surviving *Pinus cernua* trees were observed here mostly on tops of remnant hills in association with *Fokienia hodginsii*. No young trees or seedlings were found in this locality.

The location of extinct subpopulation destroyed by forest fire 3–5 years ago was detected on the

base of timber remnant and information obtained from local people. This locality is situated on Laos – Vietnam state border at elevation about 1500 m around point N20°40′27″, E104°36′50″ (Fig. 3). Wide forest burning around this locality, as well as on all southern slopes of Pha Luong main summit (Fig. 1B) leaded to probably full extinction of *Pinus cernua* on Laos territory. The extinction of *Pinus cernua* due to extensive uncontrolled forest fires decreased its distribution area on at least 25 % during last 5–15 years.

Pinus cernua forms primary humid coniferous and mixed forests on steep slopes, cliffs and rocky outcrops of remnant, highly-eroded solid red-brown sandstone at elevations (800)8500–1500(1550) m a. s. l. Often it was observed also as a scattered tree in closed evergreen, broad-leaved forests. Its occasional gymnosperm associates are *Amentotaxus argotaenia, A. yunnanensis, Cephalotaxus mannii, Cunninghamia konishii, Dacrycarpus imbricatus, Fokienia hodginsii* and *Podocarpus neriifolius*. Habitat character, plant community structure and common associates are described above under characteristics of evergreen mixed tropical submontane forest (Averyanov et al., 2016b, Appendix 1, 2) and evergreen coniferous tropical submontane forest (Averyanov et al., 2016b, Appendix 1, 3) listed in commonly accepted classification as II.A.2a formation – Evergreen needle-leaves woodland composed of trees at least 15 m tall with crown coverage more than 40 % (International classification …, 1973).

The seed cones in most subpopulations develop high percentage of mutilated abnormal or abortive seeds (Fig. 4–6), or no seed at all. At the same time, squirrels and other rodents eat almost all normally developed seeds in ripening cones. This is serious factor preventing successful natural seed germination. Seed fertility of *P. cernua* varies between 50–60 % according to observations on germination of seeds collected during autumn of 2013 and 2016 (Averyanov et al., 2015a). It was observed that most seedlings in nature die soon after germination (Phan Ke Loc et al., 2013). Meanwhile, seedlings demonstrate good growth and development under cultivation *ex situ* at least during first and second year age (Averyanov et al., 2015a).

Very few saplings are found on open rocky slopes and cliff shelves only in several locations in south-east corner of *Pinus cernua* distribution area. In shady forests on mountain summits regeneration is very poor or absent. Data are available regarding the successful cultivation by seeds and cuttings (Nguyen Duc To Luu et al., 2013; Phan Van Thang et al., 2013; Averyanov et al., 2015a). In natural habitats trees grow rather slow. Winter buds form new leaves in March–April. Male strobili spread pollen for pollination in February – early April. Seeds ripening in 20–22 months later, in October–December (Phan Ke Loc et al., 2014a, b). Annual growth of individual trees of *P. cernua* in observed populations is very variable and depends on habitat conditions. Timber of plants found on relatively dry open rocky summits exhibits annual rings (0.3)0.5–1(1.5) mm wide, which indirectly estimates the age of the oldest observed trees between 150–200 years.

Conservation assessment of *Pinus cernua*

Previous assessments of *Pinus cernua* conservation IUCN Red List status according to standard categories and criteria based on available knowledge were undertaken in a series of earlier publication (Averyanov et al., 2014, 2015a; Phan Ke Loc et al., 2014a, b; Nguyen Minh Tam et al., 2015). In these publications the preliminary status of this species was assessed as undoubtedly critically endangered (CR) under criteria "A4c, d; B1b (iii); B2b (iii, iv, v); C1" (Phan Ke Loc et al., 2014a, b), "B1a, b (i, iii), B2a, b (iii); C1; C2a (ii)" (Averyanov et al., 2014, 2015a) and "B1a, b (iii, iv)" (Thomas, 2015).

The review of all earlier data and results of present field studies confirm current global status of *Pinus cernua* as a critically endangered species according to The IUCN Red List Categories and Criteria, version 3.1 (IUCN 2001).

A. Population reduction

Actual present day data: reduction of species distribution area on 25–30 % during last 3–5 years approximately from 20 to 15 km^2 (Fig. 3) and on at about **≥ 30 %** during 5–15 past years.

Present actual species conditions match with following criteria:

A2. Population reduction observed, estimated, inferred, or suspected in the past where the causes of reduction may not have ceased OR may not be understood OR may not be reversible: – **≥ 30 %**

(a) direct observation

(c) a decline in area of occupancy (AOO), extent of occurrence (EOO) and/or habitat quality

(d) actual or potential levels of exploitation

A3. Population reduction projected or suspected to be met in the future (up to a maximum of 100 years): – **≥ 30 %**

(c) a decline in area of occupancy (AOO), extent of occurrence (EOO) and/or habitat quality

(d) actual or potential levels of exploitation

A4. An observed, estimated, inferred, projected or suspected population reduction (up to a maximum of 100 years) where the time period must include both the past and the future, and where the causes of reduction may not have ceased OR may not be understood OR may not be reversible: – **≥ 30 %**

(c) a decline in area of occupancy (AOO), extent of occurrence (EOO) and/or habitat quality

(d) actual or potential levels of exploitation

Status according to formal criteria A: A2a, c, d; A3c, d; A4c, d = **VU**

B. Geographic range

Actual present day data: present species distribution area (extent of occurrence – EOO) is less than 15 km^2 (Fig. 3); present species occupancy area (AOO) is less than 3 km^2; 22 localities are currently known but these are within 2–3 km of each other and may be regarded as a single known population with close species locations.

Present actual species conditions match with following criteria:

B1. Extent of occurrence (EOO): – **< 100 km²**

(a) Severely fragmented, (b) Continuing decline in any of: (i) extent of occurrence; (ii) area of occupancy; (iii) area, extent and/or quality of habitat; (iv) number of locations or subpopulations; (v) number of mature individuals.

B2. Area of occupancy (AOO): – **< 10 km²**

(a) Severely fragmented, (b) Continuing decline in any of: (i) extent of occurrence; (ii) area of occupancy; (iii) area, extent and/or quality of habitat; (iv) number of locations or subpopulations; (v) number of mature individuals.

Status according to formal criteria B: B1a, b (i-v); B2a, b (i-v) = **CR**

C. Small population size and decline

Actual present day data: number of mature individuals more than 250, but less than 2500, affected undoubtedly by decreasing on 20 % during 2 generations; 1 population is known, consisting of about 95 % mature individuals.

Present actual species conditions match with following criteria:

Number of mature individuals – **< 2,500**

C1. An estimated continuing decline of at least – **20 % in 2 generations**

C2. An observed, estimated, projected or inferred continuing decline AND at least 1 of the following 3 conditions: a i – number of mature individuals in each subpopulation **≤ 250**; a ii – % of mature individuals in one subpopulation = **95–100 %**

Status according to formal criteria C: C1; C2a (i, ii) = **EN**

D. Very small or restricted population

Actual present day data: AOO less than 3 km^2.

Present actual species conditions match with following criteria:

D2. Restricted area of occupancy or number of locations with a plausible future threat that could drive the taxon to CR or EX in a very short time, – **AOO < 20 km²**

Status according to formal criteria D: D2 = **VU**

E. Quantitative Analysis

Actual present day data: AOO less than 3 km^2.

Present actual species conditions match with following criteria:

Indicating the probability of extinction in the wild to be: – **≥ 20 % in 20 years or 5 generations (100 years max.)**

Status according to formal criteria EC: E = **EN**

The status of *Pinus cernua* based on assessment summarized data according to various formal IUCN Red List criteria (A–E) are follow:

A2a, c, d; A3c, d; A4c, d – VU
B1a, b (i-v); B2a, b (i-v) – CR
C1; C2a (i, ii) – EN
D2 – VU
E – EN

Following to the highest rank of the accepted status category of *Pinus cernua* should be respectively assessed as globally critically endangered species B1a, b (i-v) and B2a, b (i-v) according to IUCN Red List criteria and categories (IUCN Red List Categories and Criteria, 2001).

The habitat loss caused by occasional uncontrolled forest fires connected with primitive agriculture is the main fatal factor of *Pinus cernua* extinction. Additional, but also important damage factors are deforestation caused by forest logging, selected felling for fragrant soft pine timber, over-exploitation by local people and forestry enterprises, clearing forest for agriculture fields, as well as miserable area of actual occupancy, seed mutilation and very poor regeneration. Anthropogenic pressure over many years has resulted in a great fragmentation of surviving coniferous forests with *Pinus cernua* and lead to their deep degradation in most of habitats. Presently *Pinus cernua* often survives only in small patches of secondary forests surrounded by agricultural fields. Some discovered subpopulations

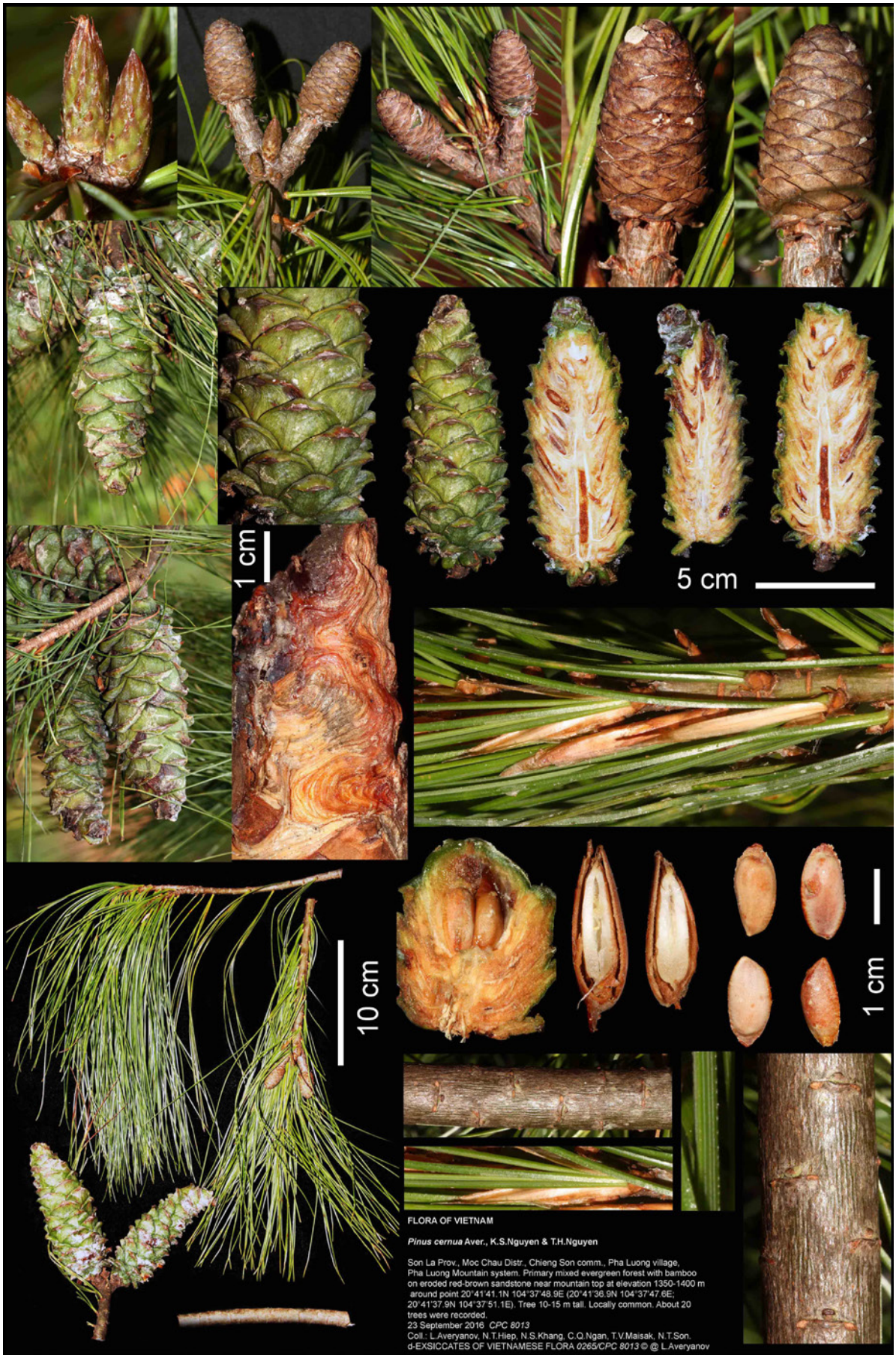


Fig. 4. Digital plate of *Pinus cernua* made from voucher herbarium specimens Aver. et al. *CPC 8013*, documented discovered subpopulation № 14.

Fig. 5. Digital plate of *Pinus cernua* made from voucher herbarium specimens Aver. et al. *CPC 8019*, documented discovered subpopulation № 15.

Fig. 6. Digital plate of *Pinus cernua* made from voucher herbarium specimens Aver. et al. *CPC 8107*, documented discovered subpopulation № 17.

are situated outside Xuan Nha nature reserve on lands having no any protected status.

Protection and monitoring of all known subpopulations of *Pinus cernua* located within and outside the Xuan Nha nature reserve may be critically important action for the species effective conservation. The including of newly discovered locations into proper Xuan Nha nature reserve territory or into its buffer zone may well be a step on this way. The studies of seed biology and germination, as well as artificial seed propagation, plantation and reforestation may seriously support species conservation. The attempts of the initiation of a community based conservation programme that involves seed collecting, cultivation and reintroduction for the reinforcement of existing stands may be very fruitful initiative (Phan Van Thang et al., 2013; Nguyen Duc To Luu, 2014; Averyanov et al., 2015a). Mature samples of *Pinus cernua* form nodding shoots with long slender weeping needles. The species is therefore highly desirable for cultivation as ornamental tree, particularly in rock gardens of the Asian style. Ex-situ propagation and introduction into cultivation of this species as an ornamental plant may be additional effective measures to its conservation. More surveys on mountainous boundary areas in Vietnam and particularly in the Lao PDR should be undertaken as soon as possible for searches of more possibly surviving populations.

Plant diversity and flora of Pha Luong Mountains

Flora of Pha Luong Mountains belongs to typical tropical floras of North Indochinese floristic province of Indochinese floristic region belonging to Indomalesian subkingdom of Holarctic (Averyanov et al., 2003). It contains many representatives of true tropical families such as Acanthaceae, Anacardiaceae, Annonaceae, Apocynaceae, Balanophoraceae, Begoniaceae, Burmanniaceae, Gesneriaceae, Melastomataceae, Meliaceae, Rubiaceae, Sapindaceae, Sapotaceae, Simaroubaceae and Zingiberaceae. The largest family here like in all other tropical floras is orchids – Orchidaceae. Meanwhile, subtropical Holarctic plant representatives participate and even dominate in plant communities at elevation higher than 1200–1500 m. These are representatives of families like Aceraceae, Betulaceae, Cornaceae, Cupressaceae, Cyperaceae, Ericaceae, Fagaceae, Hamamelidaceae, Magnoliaceae, Pinaceae, Polygonaceae, Primulaceae, Ranunculaceae, Rosaceae and Taxaceae, as well as subtropical ferns and ferns of moderate climate (*Adiantum, Asplenium, Diplazium, Polystichum, Thelypteris* etc.). The combination of different geographic elements makes diversity and richness of the flora of Pha Luong Mountains particularly high and diverse.

At least 1131 plant species belonging to 650 genera and 189 families were reported recently in Xuan Nha nature reserve including western part of Pha Luong Mountains (Tran Huy Thai, 2012). Among them there are 33 rare threatened species recorded in the Red Data Book of Vietnam, 356 woody species, 400 medicinal and 90 essential oil plants, as well as 180 other species used in national economy including oleiferous, tannin-bearing, fibre, edible and ornamental plants.

During fieldwork for conservation assessment of *Pinus cernua*, about 550 species of vascular plants belonging to 180 genera and 99 families were additionally collected which are listed in Appendix 2 of technical project report for Mohamed bin Zayed Species conservation fund (Averyanov et al., 2016b). For all these species, voucher herbarium specimens as a scientific base for habitat and plant communities descriptions (Averyanov et al., 2016b, Appendix 1) were prepared. Voucher herbaria are presently housed at Herbaria of Komarov Botanical Institute of the Russian Academy of Sciences in St.-Petersburg (LE) and in The Center for Plant Conservation of Vietnam Union of Science and Technology Associations in Hanoi. Among 10 largest families in preliminary assessed flora of Pha Luong Mountais there are Orchidaceae (130 species), Polypodiaceae s.l. (55 spp.), Gesneriaceae (30 spp.), Rubiaceae (27 spp.), Convallariaceae (26 spp.), Ericaceae (21 spp.), Melastomataceae (14 spp.), Begoniaceae (11 spp.), Acanthaceae (10 spp.) and Magnoliaceae (9 spp.).

Among collected plants, 6 species are discovered as a new species for the flora of Vietnam. Firstly recorded species in the country are *Calanthe puberula* Lindl., *Cymbidium kanran* Makino, *Hoya lyi* H. Lev., *Ophiopogon bockianus* Diels, *Phylacium majus* Collett et Hemsl., *Smitinandia helferi* (Hook. f.) Garay, and *Stereochilus brevirachis* Christenson.

At least 30 species detected here and confirmed by voucher herbaria are threatened local endemics desirable for special protection on the national level. They are:

Anoectochilus annamensis Aver.
Bulbophyllum violaceolabellum Seidenf.
Calanthe alleizettii Gagnep.
Calocedrus rupestris Aver. et al.
Collabium chapaensis (Gagnep.) Seidenf. et Ormerod
Cycas collina K. D. Hill et al.
Diplopanax vietnamensis Aver. et T. H. Nguyen
Epigeneium chapaense Gagnep.
Eria calcarea V. N. Long et Aver.
E. pachyphylla Aver.
E. thao Gagnep.
Eriodes barbata (Lindl.) Rolfe
Habenaria medioflexa Turrill
Hedychium yunnanense Gagnep.
Lecanorchis vietnamica Aver.
Lilium poilanei Gagnep.
Liparis averyanoviana Szlach.
L. balansae Gagnep.
L. dendrochiloides Aver.
L. pumila Aver.
L. superposita Ormerod
Lysionotus chingii Chun ex W. T. Wang
Photinia cucphuongensis T. H. Nguyen et Yakovlev
Pinus cernua Aver. et al.
Podochilus oxystophylloides Ormerod.
Rhomboda petelotii (Gagnep.) Ormerod
Spatholirion puluongense Aver.
Thrixspermum stelidioides Aver. et Averyanova
Trachycarpus geminisectus Spanner et al.
Trevesia vietnamensis J. Wen et P. K. Loc

About 12 plant species found in Pha Luong Mountain and in closely allied territories are appeared as a new for science. Among them 5 species are described in recent publications (Vislobokov et al., 2014; Averyanov et al., 2015b, 2016a; Averyanov, Tillich, 2016). These species are *Aspidistra nutans* Aver. et Tillich, *Liparis longispica* Aver. et K. S. Nguyen, *Ophiopogon alatus* Aver. et N. Tanaka, *Peliosanthes kenhilloides* Aver. et N. Tanaka, and *Tupistra khangii* Aver. et al. Descriptions of four species are presently submitted for publication. These are *Aspidistra bifolia* Aver., Tillich et K. S. Nguyen, *Gastrodia khangii* Aver., *Oreocharis argyrophylla* W. H. Chen et al., and *Oreocharis blepharophylla* W. H. Chen et al. A number of endemic or sub-endemic plant species native to Pha Luong Mountains and allied lands have large significance as ornamental plants desirable for cultivation and breeding. Among them, there are many species of such families as Arecaceae, Begoniaceae, Convallariaceae, Cupressaceae, Ericaceae, Gesneriaceae, Liliaceae, Magnoliaceae, Orchidaceae, Pinaceae, Podocarpaceae, Theaceae, Zingiberaceae, etc.

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