TAXONOMIC REVISION OF *Fissidens* Hedw. (FISSIDENTACEAE, BRYOPHYTA) IN THAILAND

KANJANA WONGKUNA

DOCTOR OF PHILOSOPHY
IN BIOLOGY

THE GRADUATE SCHOOL
CHIANG MAI UNIVERSITY
JANUARY 2010

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4 January 2010

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ABSTRACT

Forty-two species and 9 varieties of *Fissidens* are known in Thailand. These include 2 new species and 1 new variety, *viz. Fissidens irregulomarginatulus* K. Wongkuna & B. C. Tan, *F. pseudokinabaluensis* K. Wongkuna & B. C. Tan, and *F. flaccidus* Mitt. var. *percurrens* K. Wongkuna, and 15 new records, *viz. Fissidens angustifolius* Sull., *F. beckettii* Mitt., *F. bryoides* Hedw. var. *esquirolii* (Thér.) Z. Iwats. & T. Suzuki, *F. bryoides* Hedw. var. *schmidii* (C. Muell.) Chopra & Kumar, *F. flabellulus* Thwait. & Mitt., *F. flaccidus* Mitt. var. *flaccidus*, *F. geminiflorus* Dozy & Molk., *F. geppii* Fleisch., *F. guangdongensis* Z. Iwats. & Z. H. Li., *F. hyalinus* Hook. & Wils., *F. incognitus* Gangulee, *F. involutus* Wils. *ex* Mitt., *F. jungermannioides* Griff., *F. obscurus* Mitt., and *F. serratus* Muell. Hal. Two species are excluded from Thai *Fissidens* records, *i.e. F. aspledioides* Hedw. and *F. subspathulatus* Dix.. The specimens of *Fissidens* were collected from different forest types in Thailand and type specimens (holotype, lectotype, and isotypes) were borrowed from the Royal Forest Department Herbarium, Bangkok (BKF); National Herbarium Netherlands, Leiden, (L); Missouri Botanical Garden (MO); Finnish Museum of Natural History, Botanical Museum (H); Prince of Songkla University (PSU), and The Herbarium, National Museum of Nature and Science, Japan (TNS).

Twenty-six species (67%) of Thai *Fissidens* are terrestrial including one aquatic species, *F. sedgwickii* Broth. & Dix.. Eleven species (24%) are both terrestrial and epiphytic, and 3 species (9%) are epiphytic. Primary, evergreen, seasonal, hardwood forest has the highest number of *Fissidens* species (38 taxa), deciduous, seasonal, hardwood with bamboo forest (22 taxa), deciduous dipterocarp-oak (19 taxa), mixed evergreen+deciduous, seasonal, hardwood (16 taxa), and primary, evergreen, seasonal, hardwood with pine forest (13 taxa). Most Thai *Fissidens* taxa are found in tropical to temperate regions and in other Asiatic countries. Most Thai

Fissidens (76%) also occur in the northern region which also has the most uncommon species. More than half of Thai species are uncommon species and specific habitat. Several taxa are rare and are only known from places which are being developed. These species require immediate conservation.

This study shows that new species, a new variety, and new records of this genus can still be found. More taxonomic and ecological information on Thai *Fissidens* is needed. Collecting in other areas in Thailand is needed to determine if more species are in the country.

ชื่อเรื่องวิทยานิพนธ์	การทบทวนอนุกรมวิธานของ *Fissidens* Hedw. (Fissidentaceae, Bryophyta) ในประเทศไทย
ผู้เขียน	นางสาวกาญจนา วงค์กุฌา
ปริญญา	วิทยาศาสตรดุษฎีบัณฑิต (ชีววิทยา)

คณะกรรมการที่ปรึกษาวิทยานิพนธ์	ดร. กันยา สันทนะโชติ	ประธานกรรมการ
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	Mr. James Franklin Maxwell	กรรมการ

บทคัดย่อ

จากการศึกษาทบทวนอนุกรมวิธานของ *Fissidens* ในประเทศไทย พบ 42 ชนิด 9 ชนิดย่อย ซึ่งในจำนวนนี้รวมถึง *Fissidens* 2 ชนิดใหม่ และ 1 ชนิดย่อยใหม่ คือ *F. irregulomarginatulus* K. Wongkuna & B. C. Tan *F. pseudokinabaluensis* K. Wongkuna & B. C. Tan และ *F. flaccidus* Mitt. var. *percurrens* K. Wongkuna รวมทั้ง 15 ชนิดที่พบครั้งแรกในประเทศไทย คือ *Fissidens angustifolius* Sull. *F. beckettii* Mitt. *F. bryoides* Hedw. var. *esquirolii* (Thér.) Z. Iwats. & T. Suzuki *F. bryoides* Hedw. var. *schmidii* (C. Muell.) Chopra & Kumar *F. flabellulus* Thwait. & Mitt. *F. flaccidus* Mitt. var. *flaccidus F. geminiflorus* Dozy & Molk. *F. geppii* Fleisch. *F. guangdongensis* Z. Iwats. & Z. H. Li *F. hyalinus* Hook. & Wils. *F. incognitus* Gangulee *F. involutus* Wils. *ex* Mitt. *F. jungermanniodes* Griff. *F. obscurus* Mitt. และ *F. serratus* Muell. Hal. *Fissidens* จำนวน 2 ชนิดถูกตัดชื่อออกจากรายงานการพบ *Fissidens* ในประเทศไทย ได้แก่ *F. aspledioides* Hedw. และ *F. subspathulatus* Dix. ตัวอย่าง *Fissidens* ที่นำมาศึกษาเก็บจากพื้นที่ของประเทศไทยที่มีสภาพป่าต่างกัน และตัวอย่างแห้ง (holotype, lectotype, and isotypes) ซึ่งยืมจากหอพรรณไม้หลายแห่ง ได้แก่ the Royal Forest Department Herbarium, Bangkok (BKF), Leiden, Netherlands (L), Missouri Botanical Garden (MO); Finnish Museum of Natural History,

Botanical Museum (H); Prince of Songkla University (PSU) และ The Herbarium, National Museum of Nature and Science, Japan (TNS)

Fissidens จำนวน 24 ชนิด (67%) ในประเทศไทยเป็นชนิดที่ขึ้นบนพื้นดิน หรือหิน ในจำนวนนี้ยังรวม *F. sedgwickii* Broth. & Dix. เป็นพืชน้ำหนึ่งชนิดด้วย จำนวน 11 ชนิด (24%) เป็นชนิดที่ขึ้นทั้งบนพื้นดินหรือหินและพืชอิงอาศัย และ 3 ชนิด (9%) เป็นพืชอิงอาศัยเท่านั้น ในป่าปฐมภูมิไม่ผลัดใบ พบจำนวนชนิดของ *Fissidens* มากที่สุด (38 ชนิด) รองลงมาคือ ป่าผลัดใบที่มีไผ่ (22 ชนิด) ป่าผลัดใบ เต็ง รัง ก่อ (19 ชนิด) ป่าผสมระหว่างป่าไม่ผลัดใบและผลัดใบ (16 ชนิด) และป่าไม่ผลัดใบที่มีสน (13 ชนิด) ตามลำดับ *Fissidens* ส่วนใหญ่ที่พบในประเทศไทยพบในเขตอบอุ่นถึงเขตหนาวและเอเชีย ร้อยละ 76 ของ *Fissidens* ที่พบในประเทศไทยอยู่ในเขตภาคเหนือ ซึ่งส่วนใหญ่เป็นชนิดที่ไม่ได้พบทั่วไปในทุกพื้นที่ *Fissidens* ที่ไม่ได้พบทั่วไปนี้ มีจำนวนเกินครึ่งของ *Fissidens* ที่พบทั้งหมดในประเทศไทย และหลายชนิดยังมีความเฉพาะเจาะกับแหล่งที่อยู่อาศัย และจัดเป็นพืชหายาก ซึ่งพบเพียงพื้นที่เดียว ดังนั้นจึงควรมีแนวทางในการอนุรักษ์พืชกลุ่มนี้อย่างเร่งด่วน

การศึกษาครั้งนี้แสดงถึงการค้นพบ *Fissidens* ชนิดใหม่ ชนิดย่อยใหม่ของโลก และ ชนิดที่มีพบในประเทศไทยเป็นครั้งแรก ซึ่งทำให้ทราบว่า *Fissidens* ในประเทศไทยยังมีการค้นพบชนิดใหม่ได้ ดังนั้นการศึกษาอนุกรมวิธาน และข้อมูลทางนิเวศน์ของ *Fissidens* ยังคงต้องการการศึกษาและสำรวจต่อไป ในพื้นที่อื่นๆ ของประเทศ

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CHAPTER 1
INTRODUCTION

Fissidens Hedw. (Fissidentaceae) is one of the most diversified moss genera, which occur in temperate and tropical areas throughout the world. They can grow on soil, rocks, trees, and a few species even live in fresh water. Normally, they grow on moist habitats with moderate temperature and in a wide range of elevations.

Fissidens has an important role in the ecosystem, which affects the forest in many ways. This provides shelter and food for small animals, such as isopods, rotifers, and insects. With their high capacity of holding water, *Fissidens* can help forests store water and maintain its humidity. In addition, many *Fissidens* can grow well over the soil surface, thus helping to prevent soil erosion.

Many bryologists have studied *Fissidens* because of its high diversification in morphology. Several bryologists have published papers on *Fissidens*, *viz.* Iwatsuki and Suzuki (1982) study *Fissidens* in Japan, They described and explained the detailed characteristics of *Fissidens* especially comparing between closely related species. Li (1985) revised *Fissidens* of China with a total of 47 species and 5 varieties. Iwatsuki and Mohamed (1987) studied *Fissidens* in peninsular Malaysia and Singapore, which comprised 24 species. Yang & Lin (1992) found 45 species and 7 varieties of *Fissidens* from Taiwan. Tan and Meng-Shyan (2002) estimated more than 100 species of *Fissidens* occur in tropical south-east Asia. They found 16 species of *Fissidens* in Singapore, which included one new species, *viz. F. pseudoceylonensis* B. C. Tan & Choy M-S..

In Thailand, the information of *Fissidens* was reported within bryophyte and mosses checklist, *i.e.* 5 species of *Fissidens* listed in "The moss flora of Chang Island, Trat Province" by Brotherus (1901), and 39 species and 7 varities of *Fissidens* listed in "An annotated checklist and atlas of the mosses of Thailand", which complied by He (1996). The latest information was compiled by using previous information without making new specimen collections. Therefore, the names of Thai *Fissidens* still needed to be re-examined.

Presently, there are 107 collections of *Fissidens* specimens kept at the BKF herbarium. Twenty-seven of them are unidentified. Others were identified, but also needed to be revised. Besides, the amount of each specimen is meager, mostly incomplete and damaged. This caused the difficulty in identifying. Therefore, new collections must be made and studied. Moreover, the diversity and ecological information should be added to fulfill the information of Thai *Fissidens*.

Objectives

1. To study the taxonomy, diversity, ecology and abundance of Thai *Fissidens*.
2. To collect the herbarium specimens.
3. To construct the key to species of Thai *Fissidens*.

CHAPTER 2
LITERATURE REVIEW

Previous Studies of *Fissidens* in Thailand

The first information of Thai *Fissidens* was provided by Brotherus (1901). He reported about the moss flora of Chang Island, Trat Province with 44 species, among these 5 species were *Fissidens*, *viz. F. mittenii* Par., *F. papillulosus* Broth. *sp. nov.*, *F. siamensis* Broth. *sp. nov.*, *F. silvaticus* Griff., and *F. zippelianus* Dozy & Molk.. In 1932, Dixon published the first checklist of Thai mosses based on Kerr's collections, his own studies, and other specimens. He listed 220 species of mosses, among these 8 species were *Fissidens*. He reduced *F. zippelianus* Dozy & Molk. to a synonym of *F. silvaticus* Griff., while *F. javanicus* Dozy & Molk. was separated from *F. silvaticus*.

In 1964, Horikawa and Ando enumerated the mosses of Thailand from specimens collected from Doi Inthanon and Doi Suthep in northern Thailand. They listed 126 species, 4 of which were *Fissidens* (Table 1). In 1966, Tixier and Smitinand provided a detailed list of mosses in BKF and listed 172 species, among these 10 were *Fissidens*. Two new records were added, *viz. F. hollianus* Dozy & Molk. and *F. zollingeri* Mont..

In 1993, a checklist of Indochinese Mosses was done by Tan & Iwatsuki, which noted 22 *Fissidens* specices in Thailand. Several species became synonyms. For example, *F. mittenii* Par., recorded by Brotherus (1901), was reduced to *F. laxus* Sull. & Lesq., and *F. areolatus* Griff. became *F. polypodioides* Hedw. (Table 1).

In 1995, a checklist of *Fissidens* in Thailand based on papers from 1900-1979 was published (Sornsamran & Thaitong, 1995), which included 25 species of *Fissidens* (Table 1). Their work only provides distributions in the country and no synonyms or keys.

He (1996) compiled a list of mosses in Thailand based on Thai collections at the Missouri Botanical Garden (MO) and all known literature. It includes 620 species, including 34 species and 7 varieties of *Fissidens* (Table 1). For *Fissidens*, fifteen taxa were new records and updated binomials. *F. filiformis* Iwats., *F. obtuso-apiculatus* Dix., *F. papillulosus* Broth., *F. siamensis* Broth., and *F. semperfalcatus* Dix. were described from Thai specimens. Of these, three species, *viz. F. filiformis*, *F. obtuso-apiculatus*, and *F. siamensis* are endemic to Thailand. For synonyms, comparison between this checklist and the list of Tan & Iwatsuki (1993) is similar. These studies have added and synonymised many taxa (Table 1). His checklist provided good baseline data for Thai Bryologists to start with, but there still needed to be more detailed study of each taxon.

Since there was no revision for *Fissidens* in Thailand, I decided to do this as my Ph. D. research topic.

Table 1. Checklist of *Fissidens* from 1901 to 1996.

Reference	Amount	Taxon
Brotherus (1901)	5 species	*F. mittenii* Par. *F. papillulosus* Broth., *sp. nov.* *F. siamensis* Broth., *sp. nov.* *F. silvaticus* Griff. (syn.=*F. javanicus* Dozy & Molk.) *F. zippelianus* Dozy & Molk.
Dixon (1932)	8 species	*F. ceylonensis* Dozy & Molk. *F. javanicus* Dozy & Molk. *F. mittenii* Par. *F. nobilis* Griff. *F. obtuso-apiculatus* Dix., *sp. nov.* *F. papillulosus* Broth. *F. siamensis* Broth. *F. silvaticus* Griff. (syn.=*F. zippelianus* Dozy & Molk.)
Horikawa & Ando (1964)	4 species	*F. anomalus* Mitt. *F. cf. gymnogynus* Besch. *F. nobilis* Griff. *F.* sp.
Tixier & Smitinand (1966)	9 species 1 varieties	*F. anomalus* Mitt. *F. areolatus* Griff. *F. excedens* Broth. *F. hollianus* Dozy & Molk. *F. nobilis* Griff. *F. cf. papillosus* Broth. *F. semperfalcatus* Dix. *F. sylvaticus* Griff. *F. sylvaticus* Griff. var. *fontanus* (Fleisch.) Giesy & Richs. forma *minor* Giesy & Richards *F. zollingeri* Mont.
Tan & Iwatsuki (1993)	21 species 1 varieties	*F. anomalus* Mont. *F. ceylonensis* Dozy & Molk. *F. crassinervis* Lac. *F. excedens* Broth. *F. gymnogynus* Besch. *F. hollianus* Dozy & Molk. *F. javanicus* Dozy & Molk. *F. laxus* Sull. & Lesq. (syn.=*F. mittenii* Par.) *F. microcladus* Thwaites. & Mitt. *F. mittenii* Par. var. *javensis* Fleisch. *F. nobilis* Griff. *F. obtuso-apiculatus* Dix. *F. papilulosus* Hedw. *F. polypodioides* Hedw. (syn.=*F. areolatus* Griff.) *F. semperfalcatus* Dix. *F. siamensis* Broth. *F. thwaitesii* Par. (syn.=*F. papillosus* Thwaites & Mitt.) *F. virens* Thwaites & Mitt. *F. wichurae* Broth. & Fleisch.

Table 1. (continued)

Reference	Amount	Taxon
Tan & Iwatsuki (1993) (continued)	21 species 1 varieties	*F. zippelianus* Dozy & Molk.(syn.=*F. sylvaticus* Griff.) *F. zippelianus* Dozy & Molk. var. *fontanus* Fleisch. (syn. = *F. sylvaticus* Griff. var. *fontanus* (Fleisch.) Giesy & Richards. forma *minor* Giesy & Richards) *F. zollingeri* Mont. (syn.=*F. xiphioides* Fleisch.)
Sornsamran & Thaitong (1995)	22 species 3 varieties	*F. anomalus* Mont. *F. areolatus* Griff. *F. ceylonensis* Dozy & Molk. *F. choprai* Norkett. *F. crassinervis* Dozy & Molk. *F. excedens* Broth. *F. cf. gymnogynus* Besch. *F. hollianus* Dozy & Molk. *F. hollianus* Dozy & Molk.var. *semperfalcatus* (Dix.) Norkett. *F. javanicus* Dozy & Molk. *F. microcladus* Thwaites & Mitt. *F. mittenii* Par. *F. mittenii* Par. var. *javensis* Fleisch. *F. nobilis* Griff. *F. obtuso-apiculatus* Dix. *F. papillosus* Broth. *F. semperfalcatus* Dix. *F. siamensis* Broth. *F. sylvaticus* Griff. *F. sylvaticus* Griff. var. *fontanus* (Fleisch.) Giesy & Richards. *F. virens* Thwaites & Mitt. *F. wichurae* Broth. & Fleisch. *F. xiphioides* Fleisch. *F. zippelianus* Dozy & Molk. *F. zollingeri* Mont.
He (1996)	34 species 7 varieties	*F. anomalus* Mitt. *F. asplendioides* Hedw. *F. australiensis* Jaeg. (syn.=*F. papillosus* Broth.) *F. biformis* Mitt. *F. ceylonensis* Dozy & Molk. (syn.= *F. siamensis* Broth.) *F. crassinervis* Sande Lac. *F. crenulatus* Mitt. var. *crenulatus* *F. crenulatus* Mitt. var. *elmeri* (Broth.) Z. Iwats. & Suzuki *F. excedens* Broth. *F. filiformis* Z. Iwats. *F. firmus* Mitt. *F. geminiflorus* Dozy & Molk.

Table 1. (continued)

Reference	Amount	Taxon
He (1996) (continued)	34 species 7 varieties	*F. gymnogynus* Besch. *F. hollianus* Dozy & Molk. *F. javanicus* Dozy & Molk. *F. kinabaluense* Iwats. *F. laxitextus* Broth. *ex* Gangulee *F. laxus* Sull. & Lesq. var. *laxus* (syn.=*F. mittenii* Par. var *mittenii*, *F. crassinervis* Lac. var. *laxus* Sull. & Lesq.) *F. laxus* Sull. & Lesq. var. *javensis* (Fleisch) Tan & Mohamed (syn. =*F. mittenii* Par. var. *javensis* Fleisch.) *F. microcladus* Thwait. *F. nobilis* Griff. *F. oblongifolius* Hook. f. & Wils. *F. obtuso-apiculatus* Dix. *F. papillulosus* Broth. *F. polypodioides* Hedw. (syn.=*F. areolatus* Griff.) *F. sedgwickii* Broth. & Dix. *F. semperfalcatus* Dix. (syn.=*F. crenulatus* Mitt.) *F. subangustus* Fleisch. *F. subspathulatus* Dix. *F. taxifolius* Hedw. *F. virens* Thwaites & Mitt. *F. wichurae* Broth. & Fleisch. *F. zippelianus* Dozy. & Molk. var. *zippelianus* (syn.=*F. sylvaticus* Griff.) *F. zippelianus* var. *fontanus* Fleisch. (syn.=*F. sylvaticus* Griff. var. *fontanus* (Fleisch.) Giesy & Richards forma *minor* Giesy & Richards) *F. zippelianus* var. *robinsonii* (Broth.) Z. Iwats. & Suzuki *F. zollingeri* Mont. (syn.=*F. xiphioides* Fleisch.)

Classification of *Fissidens*

Fissidentaceae is the only family in Order Fissidentales, Division Bryophyta, Subdivision Bryidae, Class Bryopsida. Fissidentaceae is an erect moss group (acrocarpous), producing archaegonia and sporophytes mostly at the tip of the main stem. This family is consists of only one genus, *Fissidens* Hedw.

Fissidens is one of the most diversified moss genera which includes about 450 species (Pursell, 2007). The genus is found in temperate and tropical areas throughout the world. *Fissidens* occurs on soil, rocks, trees, and a few species live in fresh water. In Thailand, they can be found in moist habitats with moderate temperature, under wide range of elevations, *c.* 30-2565 m elevation.

Morphological characteristics

1. Gametophyte

1.1 Growth form and stem characters

Fissidens grow mostly in clusters and have erect, often parallel, stems. Plant sizes vary from a few millimeters to several centimeters, with the colors of light green, green to dark green or reddish-brown. *F. nobilis* is the largest species and *F. angustifolius* is the smallest in Thailand.

Stems are simple or irregularly branched (Figure 1). Most Thai *Fissidens* have a simple stem. Stems are with or without axillary hyaline nodules (Figure 2), a central strand is present or absent (Figure 3), and rhizoids are basal or axillary, smooth or papillose.

1.2 Leaf characters

The leaves are alternate, flat in one plane, distichous, and clasp the stem (Figure 4). Each leaf consists of three parts (Figure 5) 1. vaginant laminae or sheathing laminae (a sheath found in the lower inner half of leaf), 2. apical laminae (the part above vaginant laminae on the same side of costa), and 3. dorsal laminae (entire dorsal surface). A costa (midnerve) is almost always present.

Leaf shapes vary from, ovate, ovate-lanceolate, lanceolate, narrowly-lanceolate to linear and oblong (Figure 6). The apex is acute, acuminate or obtuse. The base either extend beyond the insertion (decurrent) or not.

The margin is entire, crenate, serrate, or dentate (Figure 8) and either bordered or not. The leaf border or limbidium is differentiated with elongate, hyaline, smooth, thick-walled cells, and usually with up to 3 rows, 1 cell thick (unistratose) or sometimes 2- to many cells thick (multi-stratose) (Figures 7 and 8).

Laminal cells are variable, *viz.* smooth, mammillose, unipapillose, or multipapillose. The leaf cells are mostly arranged in 1 layer, sometimes 2-multi-stratose. Leaf cell shapes vary from irregularly hexagonal to orbicular, isodiametric, or elongate. The costa is usually well-developed, percurrent (to the tip), excurrent (beyond the tip) (Figures 5b, 9), or ending below the leaf apex (Figures 5a, 9). It is rarely indistinct or lacking.

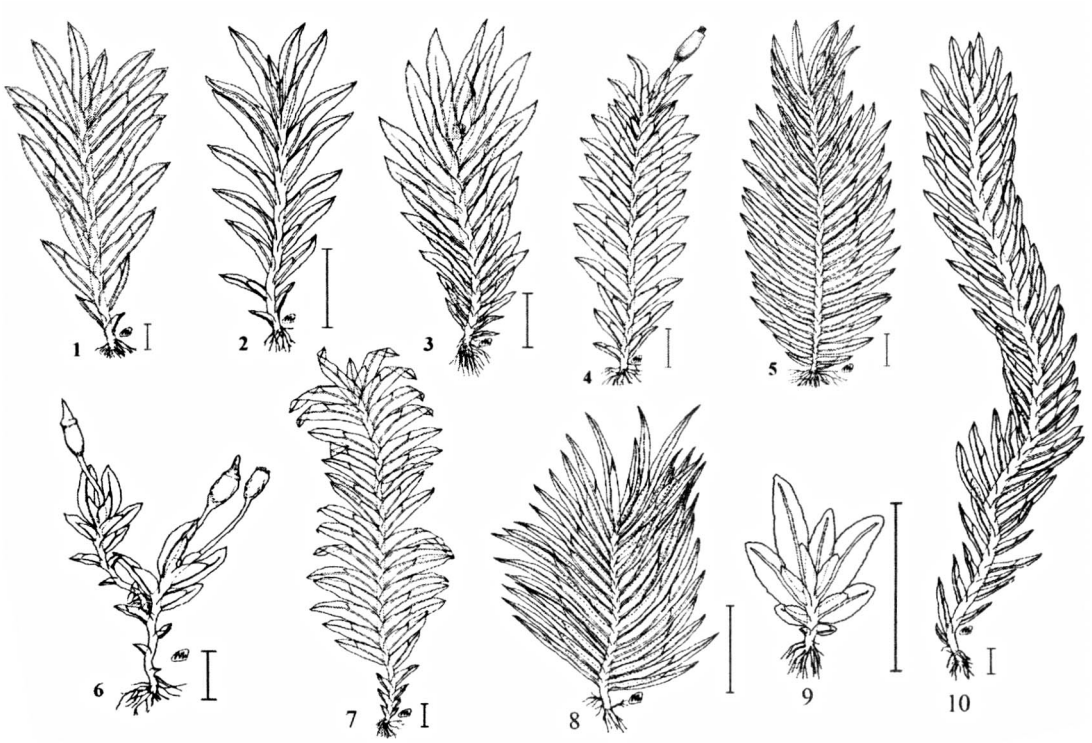


Figure 1. Stem.
1. *Fissidens anomalus*, 2. *F. flabellulus*, 3. *F. flaccidus* var. *flaccidus*, 4. *F. gymnogynus*, 5. *F. javanicus*, 6. *F. guangdongensis*, 7. *F. oblongifolius*, 8. *F. kinabaluense*, 9. *F. tenellus* var. *australiensis*, 10. *F. geminiflorus*. All scales = 1 mm.

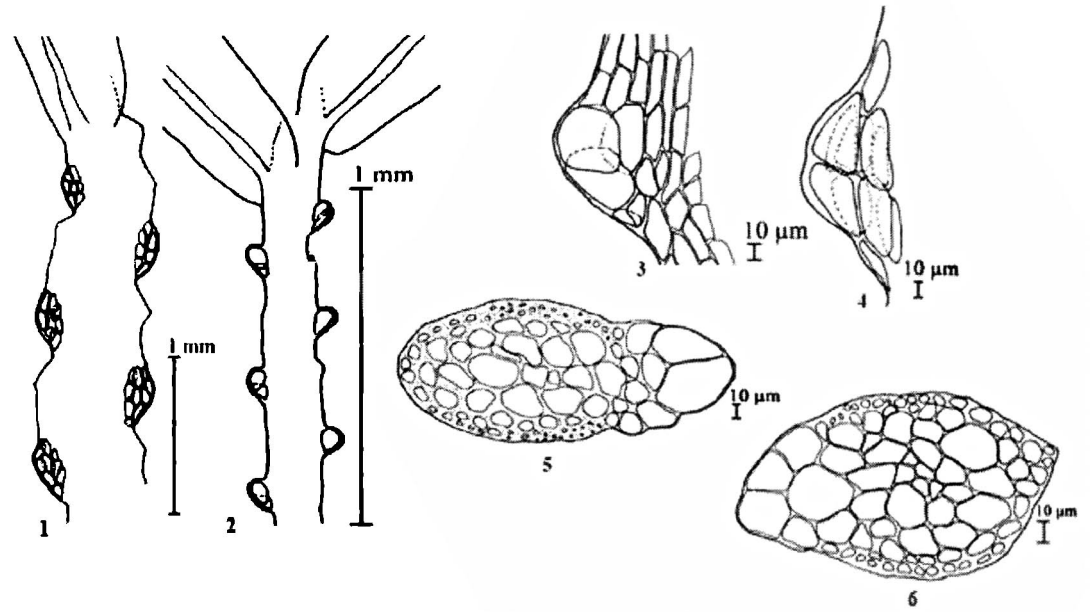


Figure 2. Hyaline nodules.
1-4. hyaline nodules, 5-6. hyaline nodules (cross-section), 1, 3, 5. *F. subangustus*, 2, 4, 6. *F. crispulus* var. *robinsonii*.

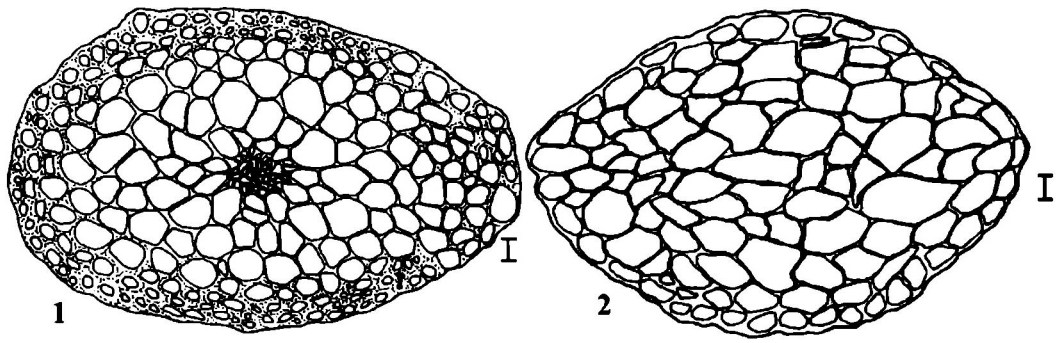


Figure 3. Stem cross-section.
1. central strand present (*F. anomalus*), 2. central strand absent (*F. beckettii*). All scales = 10 µm.



Figure 4. Distichous leaf arrangement.

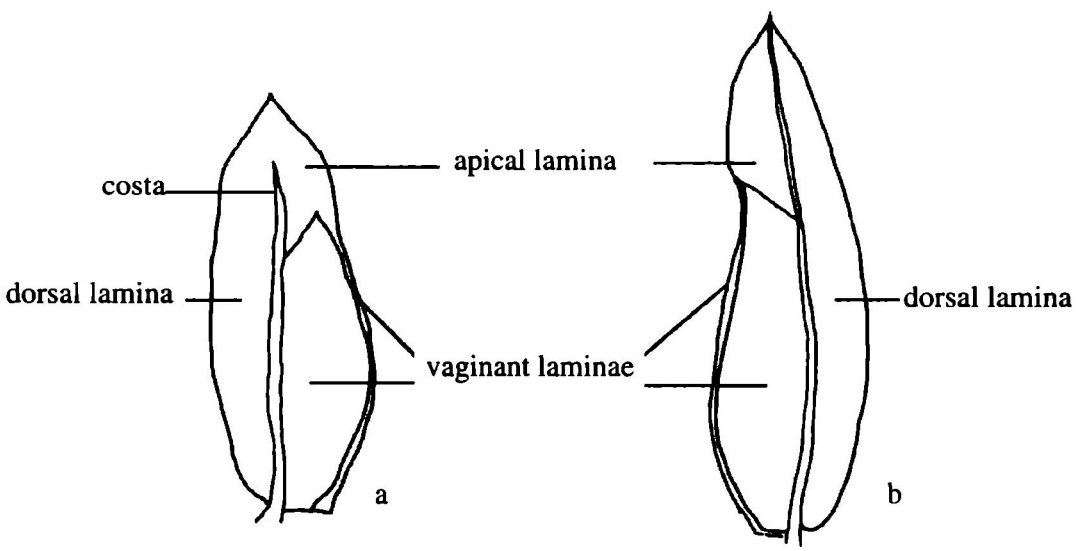


Figure 5. Leaf parts.

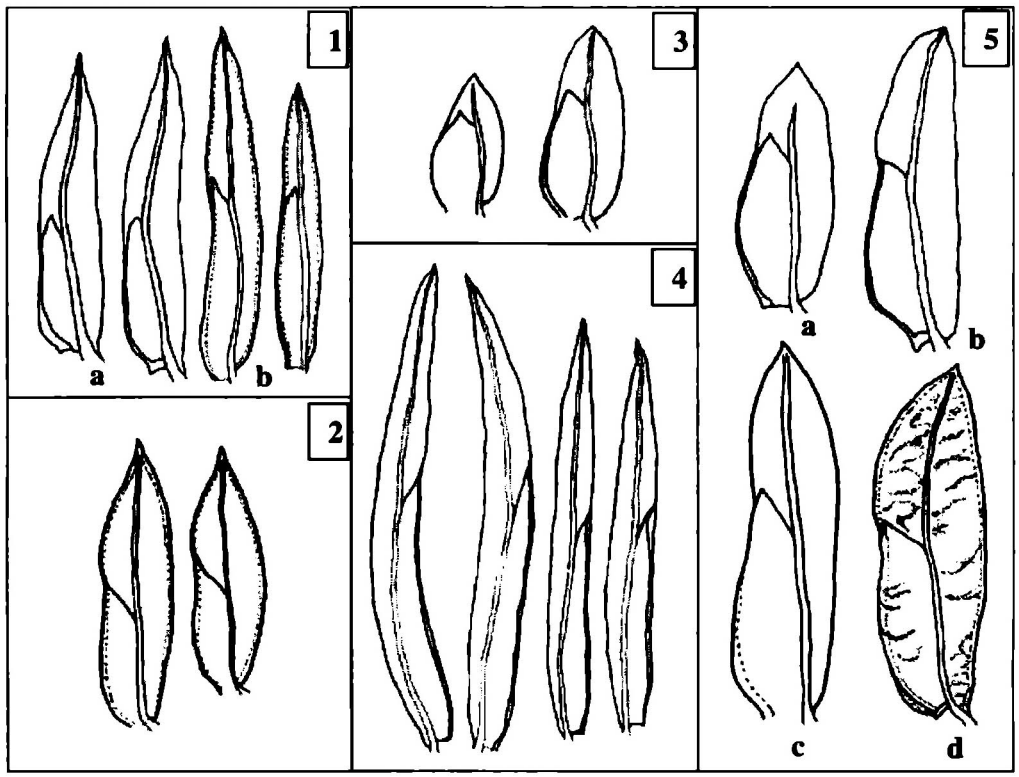


Figure 6. Leaf shapes.
1. lanceolate (a: *F. crassinervis*, b: *F. biformis*), 2. ovate-lanceolate (*F. bryoides* var. *schmidii*), 3. ovate (*F. filiformis*), 4. linear (*F. kinabaluense*), 5. oblong (a: *F. guangdongensis*, b: *F. polypodioides*, c: *F. firmus*, d: *F. anomalus*).

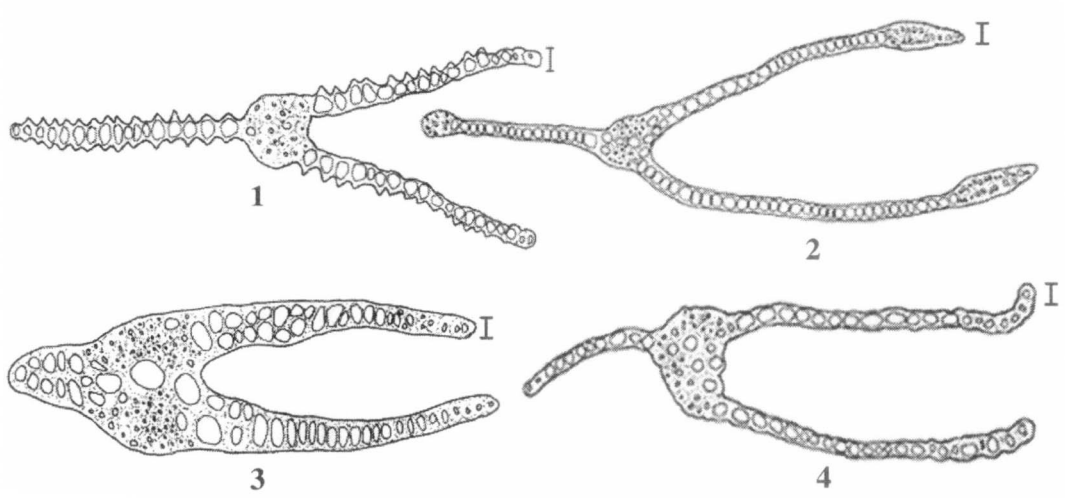


Figure 7. Leaf cross-section.
1. leaf limbidia unistratose and lamina cells unipapillose (*F. crenulatus* var. *crenulatus*), 2. leaf limbidia multi-stratose (*F. geppii*), 3. lamina cells multi-stratose (*F. sedgwickii*), 4. limbidia and lamina cells unistratose and lamina cells smooth (*F. beckettii*). All scales = 10 μm.

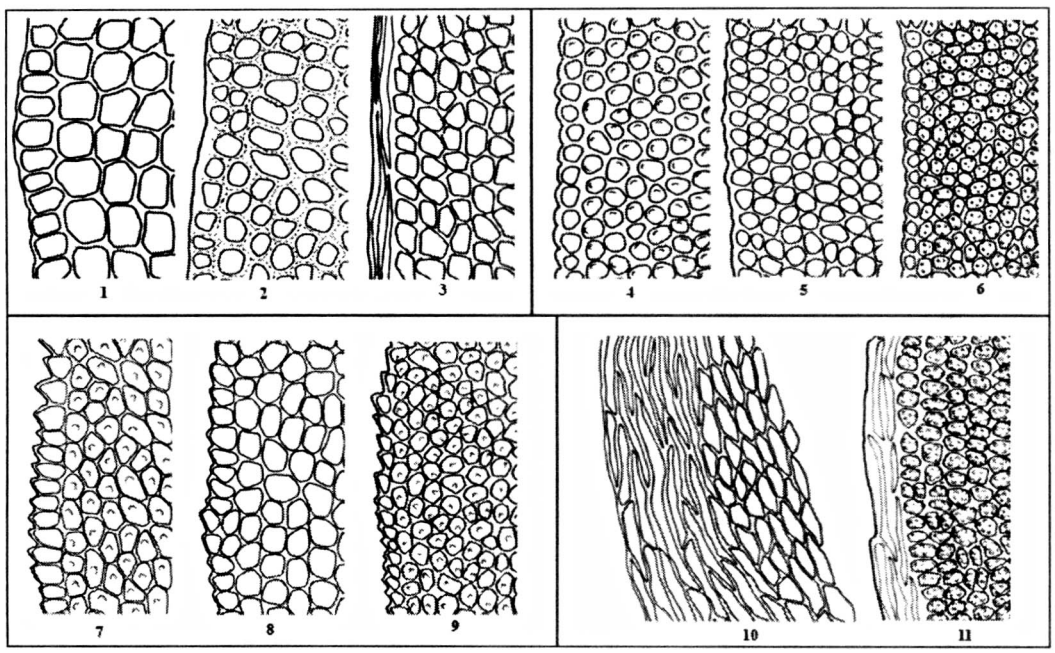


Figure 8. Leaf margin and lamina cells.
1. entire margin, leaf cells smooth, thin-walled (*F. guangdongensis*), 2. entire margin, leaf cells smooth, thick-walled (*F. crassinervis)* 3. entire margin, limbidia, smooth, thin-walled (*F. taxifolius*), 4. crenate margin, leaf cell mammillose, thin-walled (*F. involutus*) 5. crenate margin, leaf cell smooth, thin-walled (*F. firmus*) 6. crenate margin, leaf cell multipapillose, thin walled (*F. subangustus*), 7. serrate margin, leaf cells unipapillose, thin-walled (*F. serratus*), 8. serrate margin, leaf cells smooth, thin-walled (*F. flabellulus*) 9. serrate margin, leaf cells unipapillose, thin-walled (*F. crenulatus*), 10. limbidia, leaf cells smooth, thin-walled (*F. beckettii*), and 11. limbidia, leaf cell multipapillose, thin-walled (*F. ceylonensis*).

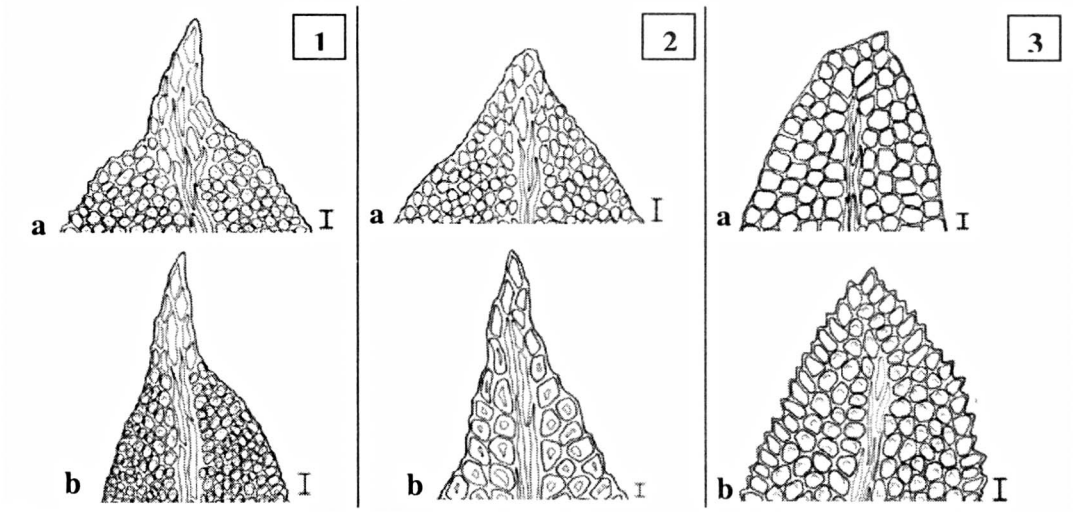


Figure 9. Leaf apex.
1. excurrent costa (a: *F. taxifolius*, b: *F. crispulus* var. *robinsonii*), 2. percurrent costa (a: *F. geminiflorus*, b: *F. pellucidus*), 3. costa ending below the leaf apex (a: *F. guangdongensis*, b: *F. tenellus* var. *australiensis*). All scales = 10 μm.

1.3 Reproduction of *Fissidens*

Fissidens is either be dioicous (plant with archegonia and antheridia on separate plants), or autoicous (plants with archegonia and antheridia on separate branches of the same plant), or synoicous (plant with archegonia and antheridia mixed in the same gametoecium). Most *Fissidens* are dioicous, some are autoicous such as *F. angustifolius* (Figure 10 a-f) and a few are synoicous. Perichaetial leaves are terminal or axillary; perichaetial and perigonal leaves are variable in size, smaller or larger than vegetative leaves, and ovate-lanceolate to subulate-lanceolate (Figure 11).

Gemmae are a type of vegetative diaspore with cylindric bodies consisting of a few cells. *F. flaccidus* var. *flaccidus* is only Thai *Fissidens* species producing gemmae (Figure 10 g-h).

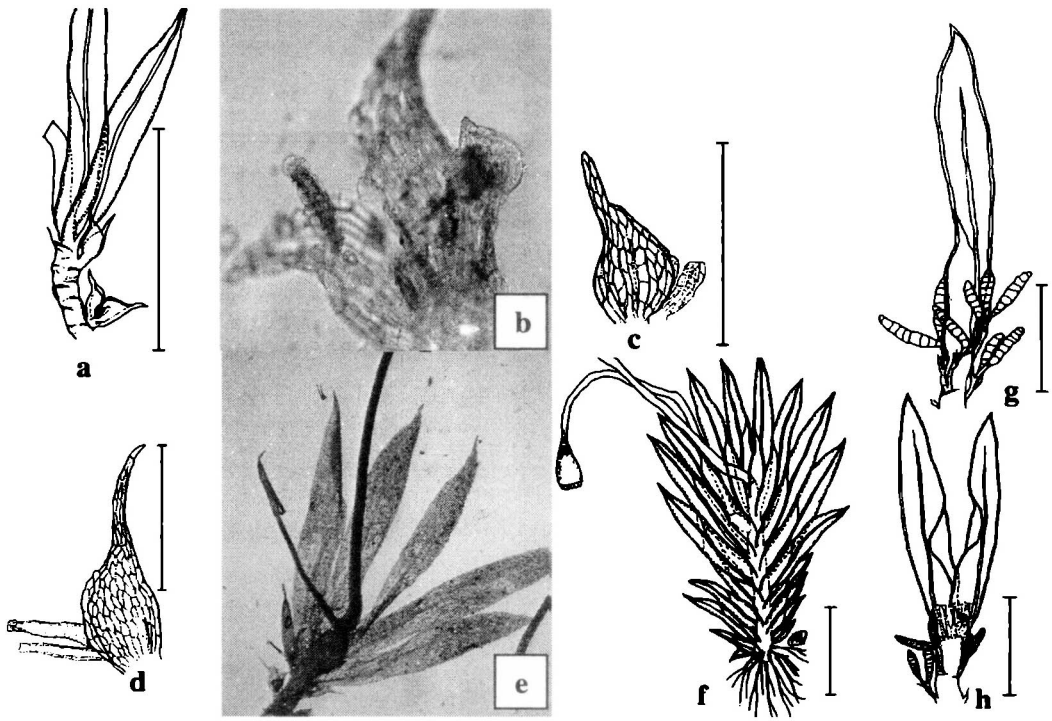


Figure 10. Autoicous and vegetative reproduction.
a. autoicous: plant with archegonia and antheridia on separate branches of the same plant (*F. angustifolius*), b, c. perigonia and antheridia (*F. angustifolius*), d. pericheatial and archegonia (*F. angustifolius*), e. f. plant with sporophyte (*F. angustifolius*), g, h. vegetative reproduction in cylindric gemmae of *F. flaccidus* var. *flaccidus*. All scales = 1 mm.

2. Sporophyte characters

Sporophytes are terminal or lateral (Figure 12). The setae are mostly smooth, rough in *F. hollianus* and *F. firmus*; mostly elongate, sometimes very short to immersed *e.g. F. anomalus* and *F. firmus*. Capsules are mostly symmetrical, rarely asymmetrical *e.g. F. beckettii*, erect, inclined, or curved. There is no annulus. The

operculum is mostly short to long-rostrate, sometimes conic. The calyptra is mostly cucullate, rarely mitrate, usually smooth, and in some species scabrous, *e.g. F. angustifolius* and *F. serratus*. The peristome is in one layer of 16 bifid teeth, red to reddish, brown, and smooth to papillose. The spores are spherical, mostly smooth, some finely papillose, 7-25 µm diameter.

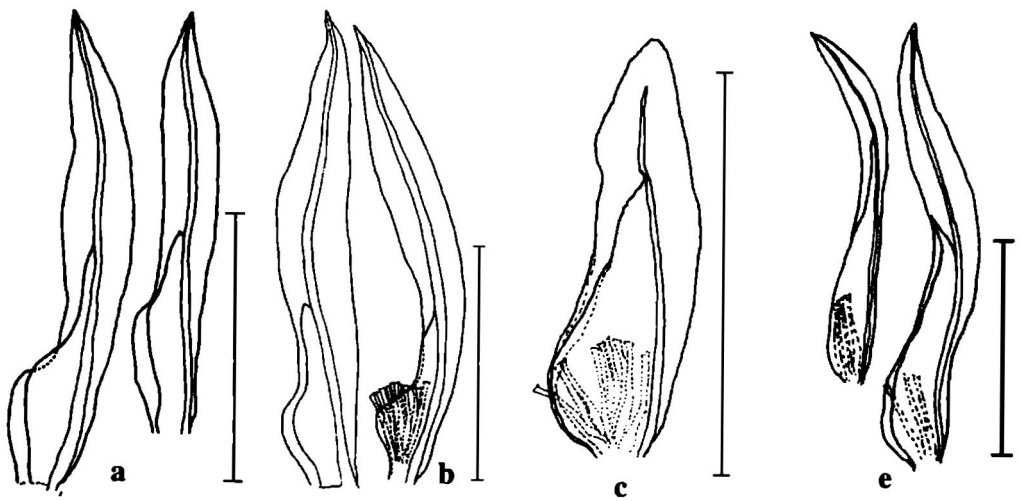


Figure 11. Perichaetial leaves.
a: *F. pellucidus*, b: *F. crassinervis*, c: F. *guangdongensis*, e: *F. taxifolius*. All scales = 1 mm.

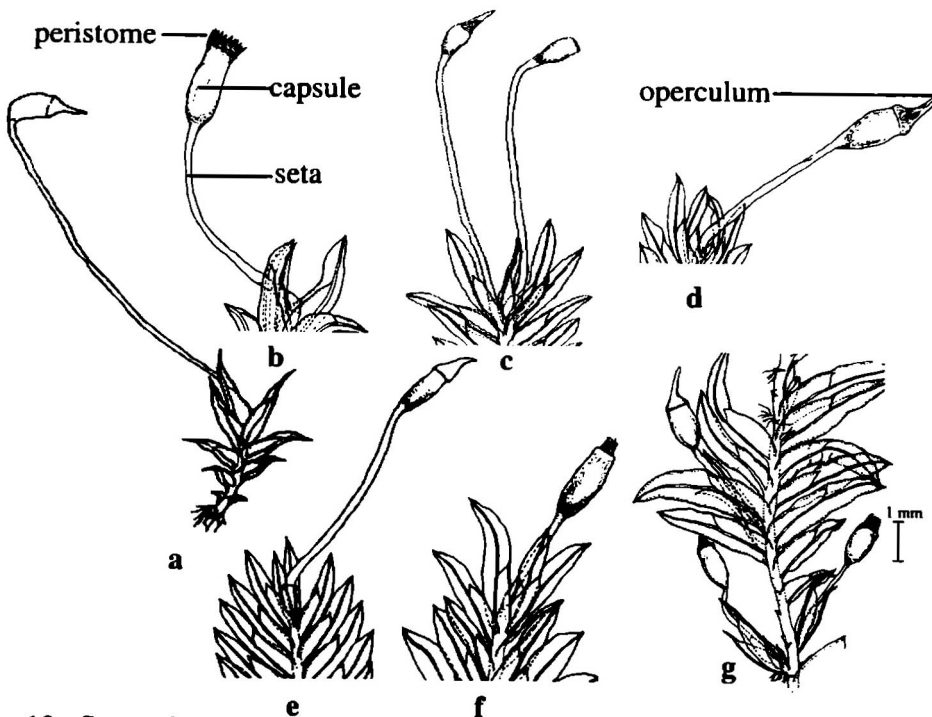


Figure 12. Sporophytes.
a-f: sporophytes terminal (a: *F. beckettii* b: *F. bryoides* var. *esquirolii*, c: *F. geppii*, d: *F. ceylonensis*, e: *F. firmus*, f: *F. gymnogynus*), g: sporophytes lateral (*F. anomalus*).

Phenology

The phenology of Thai *Fissidens* is poorly understood. I have included notes on this for all taxa, *i.e.* months when gametophytes and sporophytes have been found. For lowland (below 850 m elevation) deciduous forest taxa which grow on bare soil are presumed to be annual. Forests above 850 m the taxa are probably evergreen (*i.e.* perennial), especially in permanent streams and wet places. Since sporophytes for 15 taxa have not been during this research, I can only assume that they are seen produced during the rainy season.

Vegetation of Thailand

Thailand is situated Southeast Asia, between the latitudes 6°-20° N and longitudes 98°-105° E, sharing borders on west and northwest by Myanmar (Burma), on the northeast by Laos, southeast by Kampuchea (Cambodia), and in the south by Malaysia (Figure 13). The country is *c.* 1,620 km long, 780 km wide, with an area of 513,115 square kilometers. The elevation ranges from sea level to 2565 meters. Most of the mountains over 1000 m are in the north with the exception of Khao (Mt.) Kieo (1200 m) in the central area, Khao Soi Dao in the southeast (1556 m), and Khao Luang (1800 m) in the peninsula (Maxwell, 2001). Thailand is divided politically into 76 provinces. There are seven floristic regions (Figure 13), *i.e.* Northern (N), Northeastern (NE), Eastern (E), Central (C), Southeastern (SE), Southwestern (SW), and the Peninsular (PEN). The following are descriptions of the vegetation of each division (He, 1996; Maxwell, 2004).

In Thailand, there are two main types of forest, *viz.* evergreen and deciduous. During the past century the forest cover of Thailand has been reduced to 15% (Maxwell, 2001), most of which is in the north. The amount of forest cover has decreased throughout in this country because of increasing upland human population which has destroyed forests for agriculture; urban expansion, and economic development. A variety of forests are presented in Thailand, which can be divided into 24 forest types (Table 2) (Maxwell, 2001 and 2004).

Northern division (N): This division is under the Indo-Burmese floristic influence. The region is rich in mountains over 1500 m elevation having the highest peak (Doi (mt.) Inthanon, 2565 m) in Thailand. Types of forests range from deciduous dipterocarp-oak forest and deciduous hardwood with bamboo forest below 850 m, mixed evergreen+deciduous seasonal forest 850-1000 m, and primary, evergreen, seasonal, hardwood forest above 1000 m (Maxwell 2001 and 2004). Floristic affinities are close to southwestern China as well. Both historically and in recent times, northern Thailand has received the most attention of botanists who have collected bryophytes. The division includes 17 provinces.

Northeastern division (NE): This region corresponds to the Indochinese flora, but some Indo-Burmese elements can also be found here. Primary, evergreen, seasonal hardwood with pine forest is present above 1000 m. A significant number of bryophytes have been collected from this region. This division includes 11 provinces.

Eastern division (E): This region is under the influence of the central and southern Indochinese flora. Deciduous dipterocarp-oak forests are the main feature of the region. Deciduous dipterocarp-oak forest can be seen adjacent to deciduous, seasonal, hardwood+bamboo forest. No significant bryophyte collections have been made from this region. This division includes 8 provinces.

Central division (C): This division corresponds with the Bangkok plain or central valley. The region is mostly under cultivation. Original forests have almost totally disappeared. Little bryological field work has been carried out in this area. The division has 10 provinces.

Southeastern division (SE): This region is under the influence of both Indochinese and Malayan floras. Deciduous dipterocarp-oak forests are widespread in the plains and primary, evergreen, seasonal, hardwood forest in the mountains. Mangrove and beach vegetation are found along the coast and along the estuaries of the main rivers. Bryophyte collecting has been relatively well-done in this region. This division has 8 provinces.

Southwestern division (SW): This region is predominated by limestone topography and corresponds with the Burmese flora. Deciduous, seasonal, hardwood+bamboo forest is present in the region near the border between Myanmar and Thailand. This forest often gradually changes into deciduous dipterocarp-oak forests due to fire and logging. Only a few of bryophytes have been collected here. This division includes 8 provinces.

Peninsular division (PEN): This region is mostly under the influence of the Malayan flora. The Malayan elements are fairly common in the region although in the northern part of the region Burmese elements are present. The forests are mainly primary, evergreen, seasonal, hardwood forest. Mangrove vegetation in the region is rapidly disappearing. A large number of bryophyte collections have been made from this region. This division includes 14 provinces.

Table 2. Simplified classification for forest/vegetation types in Thailand (Maxwell, 2001 & 2004).

Forest Type		**Primary Growth**	**Secondary/Degraded Growth (da/sg)**	**Tertiary Growth (da/sg)**	**Elevation (m)**
Seasonal (Monsoonal)	Almost ever-wet (rain forest)	evergreen (egf)	evergreen scrub	bamboo thickets, grassland, cultivated areas, plantations	sea level – *c.* 1800
	Distinctly Seasonal	evergreen hardwood (egf)	evergreen + bamboo (eg/bb) deciduous dipterocarp-oak	bamboo thickets, grassland, cultivated areas	sea level – *c.* 1000 – *c.* 2565*
		deciduous hardwood with bamboo (bb/df)	bamboo thickets, grassland, deciduous dipterocarp-oak (dof)	cultivated areas	sea level – *c.* 850
		mixed evergreen+deciduous hardwood (mxf)	bamboo+ mixed evergreen+ deciduous scrub, deciduous dipterocarp-oak (dof)	bamboo thickets, grassland, cultivated areas	sea level – *c.* 1000
		evergreen+pine (eg/pine), deciduous dipterocarp-oak with pine (do/pine)	deciduous dipterocarp-oak (dof)	grassland, cultivated areas	*c.* 60– *c.* 1800
Aquatic	Saline	mangrove	no vegetation, mangrove scrub	no vegetation	sea level – 25
	Fresh	lakes, pond, swamps, marshes, river, *etc.*	scrub, grassland, cultivated areas	scrub, grassland, cultivated areas	sea level – 2550
Beach		beach vegetation	scrub, grassland	grassland, cultivated areas	sea level

*in peninsula and central Thailand egf can be found starting at or near sea level, but in northern Thailand, where the dry season is longer and more severe, it starts at about 1000 m.

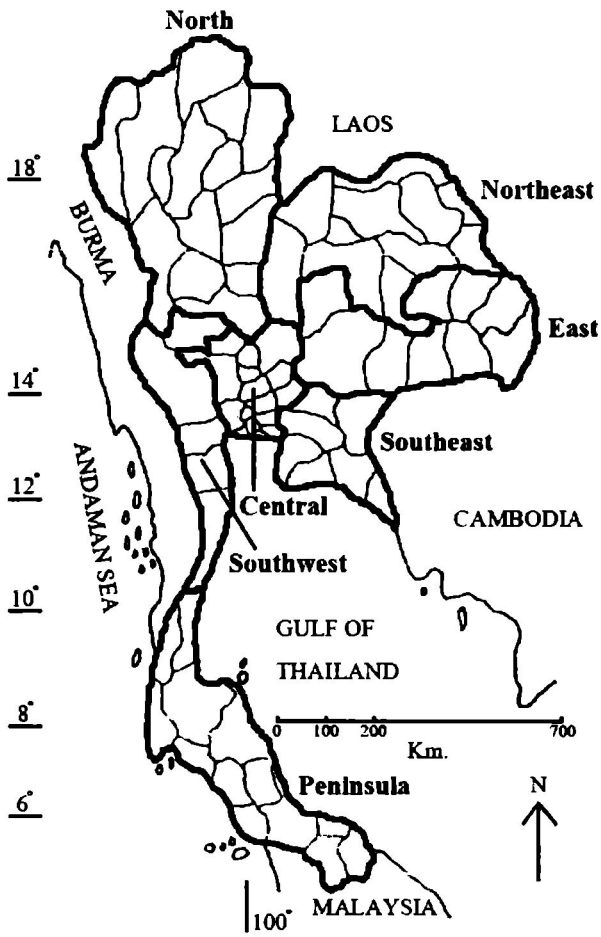


Figure 13. Floristic regions of Thailand.
Source: Backside of CMU Herbarium label, combined with Flora of Thailand 7:4 (2002) inside cover.

Climate

The climate in Thailand is characterized by a tropical monsoon system which reverses its cycle seasonally. The NE monsoon (dry) is from October-November to February-March and the SW monsoon (wet) lasts from April-May to October. Northern Thailand has three seasons, *viz.* rainy (May-October), cool-dry (November-February), hot-dry (March-April). The amount of rainfall decreases (3000-4000 mm/year) from the peninsula to the north (1000-2000 mm/ year) (Figure 14) (Maxwell, 2004).

The annual cycle for temperatures and rainfall in Thailand are show in Figure 15. The hottest periods are March-May and rainfall peaks during August-October.

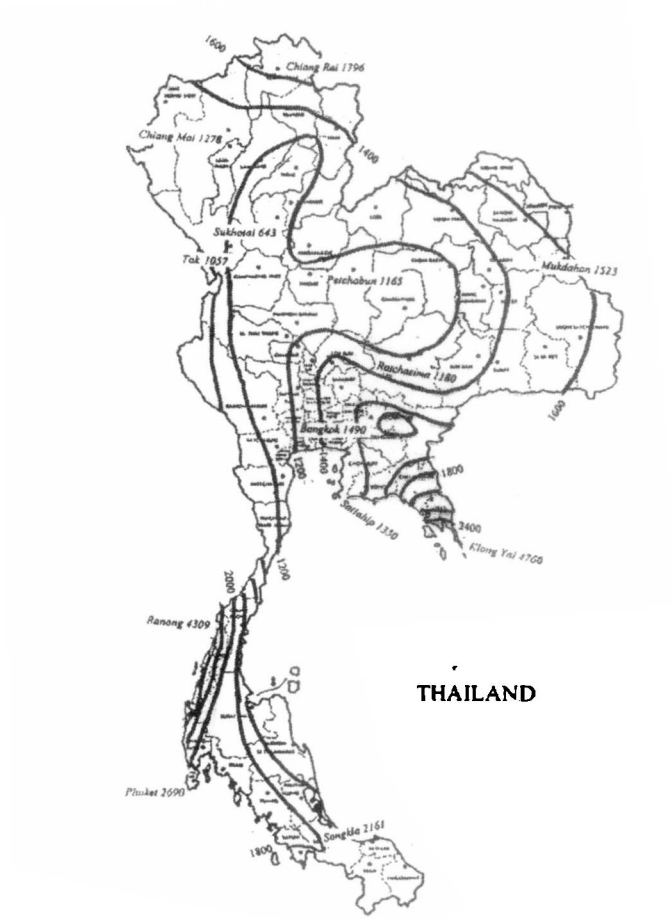


Figure 14. Annual Rainfall of Thailand in millimeters.
Source: Maxwell (2004).

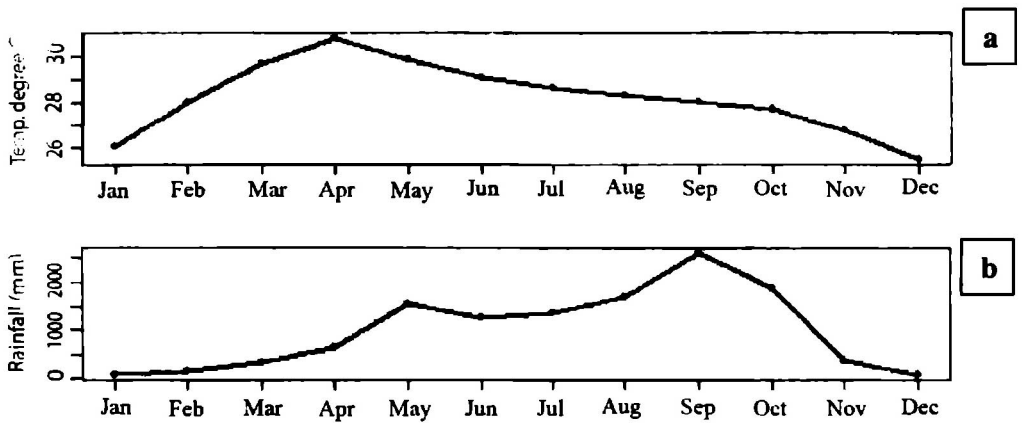


Figure 15. Annual monsoon cycle in Thailand: a: temperature, b: rainfall
Source: redrawn from "Interannual and Interdecadal Variablity of Thailand Summer Monsoon Season", Singhrattna *et al.*, (2005) 1701.

CHAPTER 3
MATERIALS AND METHODS

This research was divided into 2 parts, *viz.* field and laboratory work. For field work, specimens were collected from 21 National Parks and 2 Wildlife Sanctuaries, representing the seven different floristic parts of Thailand (Table 3 and Figure 16). Laboratory work was done at the Bryology Section, CMU Herbarium, Biology Department, Faculty of Science, Chiang Mai University.

Materials and Methods

1. Field work

Study sites were selected based on distribution records listed in the Moss Flora of Thailand (He, 1996) and the seven floristic parts of Thailand. After permit from Department of National Parks, Wildlife, and Plant Conservation of Thailand, field surveys and specimens collections conducted in different forest types for each site.

Equipment used for field work includes a pocket knife, scraper, hand lens (30 x), pencil, permanent pen, paper packets for specimens (17 x 13.5 cm), plastic bags, and a big bag to hold the specimens. In the field, *Fissidens* can be easily identified generically with the naked eye, but not to species level, which requires a microscope. The specimens were removed from their substrates by using a pocket knife or scraper and then put in envelope paper or plastic bags. Specimens growing on bark or rocks were collected by using a pocket knife and those on soil or decayed logs by using a scraper. Field notes, *i.e.* date, collection number, habit, habitat, location, bedrock, and elevation were noted in pencil on the envelope paper (Figure 17). If sporophytes were present, the color and other characters, *i.e.* capsule positions (erect or inclined), surface of capsule (smooth or rough), seta, *etc.* were noted. Habitat and forest type for all new collections follow Maxwell (2004).

From my experience of collecting specimens in the rainy season, paper packets are easily broken with wet specimens causing collection problems. Specimens should be kept in plastic bags while in the field and only a permanent marker pen used for recording notes on the plastic bags. Specimens were placed in paper packets after each day of field work. All specimens were air-dried and the envelope paper was changed if necessary.

Table 3. Study sites.

Floristic part of Thailand	Location	Province
Northern	1. Doi Inthanon National Park	Chiang Mai
	2. Doi Suthep-Pui National Park	Chiang Mai
	3. Pha Daeng National Park	Chiang Mai
	4. Chiang Dao Wildlife Sanctuary	Chiang Mai
	5. Phu Hin Rong Kla National Park	Phitsanulok
Northeastern	6. Phu Kradung National Park	Loei
	7. Phu Luang Wildlife Sanctuary	Loei
	8. Phu Kao-Phu Phan Kham National Park	Khon Kaen
	9. Phu Phan National Park	Sakon Nakhon
Eastern	10. Tat Ton National Park	Chaiyaphum
	11. Pha Taem National Park	Ubon Ratchathani
Southeastern	12. Khao Cha Mao- Khao Wong National Park	Rayong
	13. Khao Khitchakut National Park	Rayong
	14. Nam Tok Phlieo National Park	Chanthaburi
Central	15. Phu-Toei National Park	Suphanburi
	16. Khao Yai National Park	Nakhorn Nayok
Southwestern	17. Kaeng Krachan National Park	Phetchaburi
	18. Thong Pha Phum National Park	Kanchanaburi
	19. Hui Yang Waterfall National Park	Prachuap Khiri Khan
Peninsular	20. Nam Tok Ngao National Park	Ranong
	21. Khao Nan National Park	Nakhon Sri Thammarat
	22. Phanom Bencha National Park	Krabi
	23. Sri Phang-nga National Park	Phang-nga

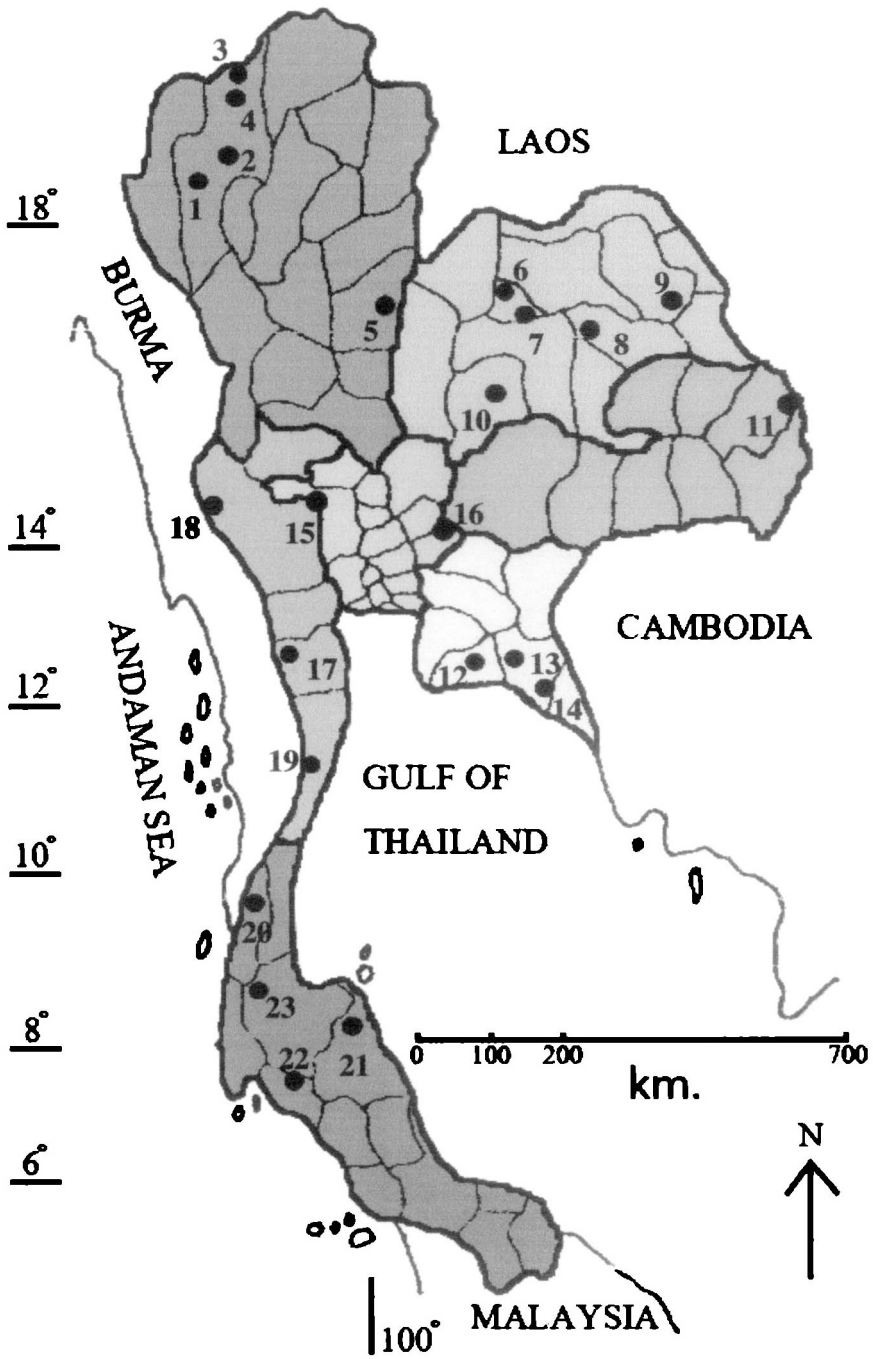


Figure 16. Map of study sites.
Source: Backside of CMU Herbarium label combined with the seven floristic parts of Thailand, from Flora of Thailand 7:4 (2002) inside cover.

BRYOPHYTES OF THAILAND
CMU Herbarium, Faculty of Science,Chiang Mai University,
Chiang Mai, Thailand 50200

FAMILY: FISSIDENTACEAE ..... Common Name: -

BOTANICAL NAME: *Fissidens anomalus* Mont.

Province: Chiang Mai ..... District: Jawm Tong

Location: Doi Inthanon National Park, summit area, Angka,

Elevation: 2,552 m. Date 30 November 2007

Habitat: on bark, shaded area; primary evergreen, seasonal, hardwood forest; granite bedrock

Notes: with sporophyte, capsule: red-brown, erect, operculum red-brown

Determinator: Kanjana Wongkuna and Benito C. Tan

Collected by: Kanjana Wongkuna ..... Number 713 ..... duplicates. 1. BKF 2. SING 3. L 4. MO

Figure 17. CMU Herbarium label.

2. Laboratory work

2.1. Herbarium collections

After air drying, the specimens were sorted to species and the paper packets stored in shoe boxes. After identifying the specimens, the specimens were put in better packets and final labels made. The specimens were registered and deposited in the CMU Herbarium. Duplicates will be sent to the Royal Forest Department Herbarium, Bangkok (BKF), Singapore Botanic Gardens (SING), Leiden, Netherlands (L), and Missouri Botanical Garden, USA (MO).

Some type specimens (holotype, lectotype, and isotypes) of *Fissidens* were borrowed from the Royal Forest Department Herbarium, Bangkok (BKF), Leiden, Netherlands (L), Missouri Botanical Garden (MO); Finnish Museum of Natural History, Botanical Museum (H); Prince of Songkla University (PSU), and The Herbarium, National Museum of Nature and Science, Japan (TNS). I also visited the Department of Botany, Chulalongkorn University, Bangkok (BCU) and the Singapore Botanic Gardens (SING) to study specimens and consult the bryophyte literature there.

2.2. Morphological study and descriptions

A stereo microscope (Olympus SZ-ST) and a compound microscope (Nikon ECLIPSE E200) with magnification up to 40 and 400, respectively, were used for identification. Equipment used for studying morphological characteristic includes a

pair of fine forceps, microscope slides, cover glasses, razor blades, and a dropper. The whole plant (gametophyte and sporophyte) was softened in room temperature water before any measurements were taken. A piece was placed on a microscope slide in a drop of water and a few leaves were stripped off by using a pair of fine forceps. The leaf shape and leaf margin were examined under a compound microscope. A cross-section of leaves and stems are usually needed for identification to species. The leaf and stem cross sections were done with a stereo-microscope by putting the specimen in a drop of water on the slide. The plant was then held with the index finger tip and was cut continuously with a new razor blade into thin sections. Finally, a wet mounted slide was made and examined under a compound microscope. All specimens were identified to species level with the aid of relevant literature, *viz.*

A Handbook of Malesian Mosses (Eddy, 1988),
Mosses of Eastern India and Adjacent Regions (Gangulee, 1971),
A Taxonomic revision of the Japanese species of *Fissidens* (Musci) (Iwatsuki and Suzuki, 1982),
The genus *Fissidens* in Peninsular Malaysia and Singapore (Iwatsuki and Mohamed, 1987), and
A revision of the Chinese species of *Fissidens* (Musci, Fissidentaceae) (Li, 1985).

Descriptions of each species were made from all new collections. Synonyms and extra-Thai distributions were from the taxonomic literature. Each description was divided into two parts, gametophyte and sporophyte. The gametophyte part includes plant characters and growth form, leaves, leaf cell characters, and sexual characters. For sporophytes, capsule and seta characters were described. A key to Thai species mostly based on their significant morphological characters was constructed.

2.3. Photographs and illustrations

Photographs were taken in the field and laboratory by "Nikon-COOLPIX P50". Illustrations were drawn by using both stereo and compound microscopes with a *camera lucida* from new collections of Thai *Fissidens* and type specimens of *Fissidens filiformis* Z. Iwats., *F. laxitextus* Broth. *ex* Gangulee, and *F. wichurae* Broth. & Fleisch. The drawings were retouched and recopied on new tracing paper by using a pen plotter (Rotring rapidograph). Then the drawings were scanned into a picture file. Both photographs and illustrations were edited by Adope Photoshop, version CS3.

Explanations and the format

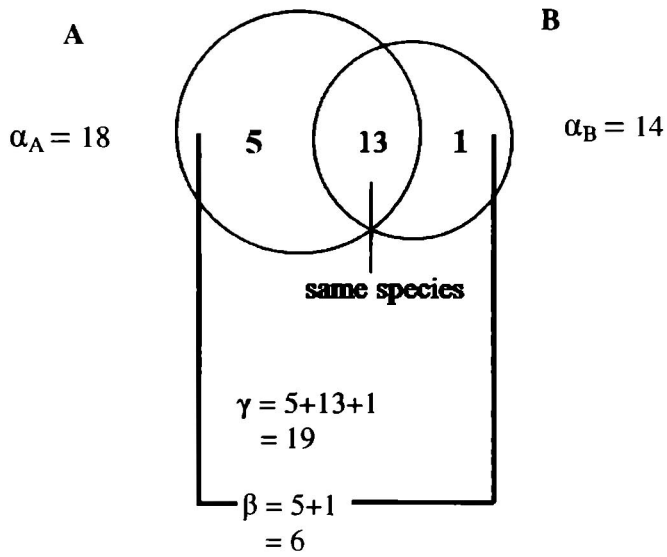
Each taxon name, specimens examined, type specimens, and herbaria in which type specimens are found are noted. An index of species and an identification list in the Appendix.

Alpha, Beta, and Gamma Diversity

Beta diversity can be used for finding "hot spot areas" of *Fissidens* in Thailand. By using three terms for measuring biodiversity over spatial scales, *viz.* alpha, beta, and gamma diversity (Whittaker, 1972). These are determine with pair of areas

alpha diversity (α) = the number of species within each area
beta diversity (β) = the sum of difference species between 2 areas
gamma diversity (γ) = the total species of both areas

For example, the diagram below showed alpha, beta, and gamma diversity of A and B areas



The critical zone, vulnerable zone, and not vulnerable zone

The three major zones of beta diversity can be classified into three zones, *i.e.* the critical, vulnerable, and not vulnerable zone. Three levels of status are determined by using average beta diversity to find the statistically significant of critical point at 95%.

Beta diversity can be calculated by using combination formula of 24 national parks with two random selections

$$N = \frac{n!}{r!(n-r)!}$$

N = number of national park pair wises
n = number of national parks
r = number of random samplings

The average beta diversity ($\bar{x}$) and standard deviation (SD) were calculated by using the formula below.

$$\bar{x} = \frac{\Sigma f_i x_i}{N}$$

$$SD = \sqrt{\frac{\Sigma f_i (x_i - \bar{x})^2}{N-1}}$$

N = number of national park pair wises
f_i = frequency
x_i = beta diversity value of each national park

CHAPTER 4
RESULTS

Taxonomic Part

Forty-two species and 9 varieties (46 taxa) of *Fissidens* are known in Thailand. These include 2 new species (in press) and 1 new variety (in preparation), *viz. F. irregulomarginatulus* K. Wongkuna & B. C. Tan, *F. pseudokinabaluensis* K. Wongkuna & B. C. Tan, and *F. flaccidus* Mitt. var. *percurrens* K. Wongkuna, and 15 new records (Table 4).

FISSIDENTACEAE

***Fissidens* Hedw.**, Sp. Musc. (1801) 152.

Gangulee (1971) 447; Iwatsuki (1982) 330; Eddy (1988) 57; Li and Iwatsuki (2001) 3.

Gametophyte in open tufts, 2-5 mm to 2-6 cm, with colors of light green, green, to dark green, or reddish-brown; stems mostly erect, simple or irregularly branched; with or without axillary hyaline nodules; central strand present or absent; rhizoids basal or axillary, smooth or papillose; leaves alternate, flat, lying in one plane (distichous), clasping the stem, consisting of three parts: vaginant laminae (a sheath found in the lower inner half of leaf), apical laminae (the part above the vaginant laminae on the same side of the costa), dorsal laminae (the entire dorsal surface); leaf margins entire, crenulate, serrate, or sometimes irregularly dentate; limbidia present or absent; leaf cells variable, smooth, mammillose, unipapillose, or multipapillose; dioicous, synoicous, or autoicous.

Sporophyte terminal or lateral; capsules distinct, erect, inclined or horizontal; cylindrical, rarely ovate; mostly symmetric, rarely asymmetric, smooth; seta smooth or rough; peristome of one layer with 16 bifid teeth; operculum usually rostrate, sometimes conial; calyptra smooth or rough, mostly cucullate, infrequently campanullate. Spores mostly smooth, some finely papillose, 7-25 μm diameter.

Fissidens consists of about 450 species in temperate and tropical areas throughout the world (Pursell, 2007). They occur on soil, rocks, tree trunks, branches, buttresses, and a few species in fresh water. Thai *Fissidens* grow in moist habitats with moderate temperature and in a wide range of elevations.

Key to species of Thai *Fissidens*

(Species in parenthesis have been reported from Thailand, but no specimens were seen in this study)

1. Leaves without costa.....24. *Fissidens hyalinus*
1. Leaves with costa.....2

2. Leaves limbate or partially limbate or on perichectial leaves.....3
2. Leaves not limbate..... 25

3. Limbidia all around the leaf margins.....4
3. Limbidia confined to the vaginant laminae 14

4. Cells of laminae irregularly rectangular, more than 20 µm long.....5
4. Cells of laminae quadrate, hexagonal or polygonal, not more than 20 µm long.....
.....6

5. Costa ending 6-9 cells below the leaf apex.....16. *Fissidens flaccidus* var. *flaccidus*
5. Costa percurrent .....17. *Fissidens flaccidus* var. *percurrens*

6. Axillary hyaline nodules well-developed 7
6. Axillary hyaline nodules not to weakly-developed 10

7. Leaves ovate-lanceolate to lanceolate, apex acute (45-55°).....
.....46. *Fissidens zollingeri*
7. Leaves narrowly lanceolate, apex narrowly acute to acuminate (less than 45°).....8

8. Apex narrowly acute to shortly acuminate (25-30°).....4. *Fissidens biformis*
8. Apex long and narrowly acuminate (about 20°).....9

9. Lamina cells smooth .....42. *Fissidens subbryoides*
9. Lamina cells multipapillose with more than tiny 8 papillae in each cell
.....37. *Fissidens pseudokinabaluensis*

10. Lamina cells smooth.....11
10. Lamina cells mammillose to strongly unipapillose.....13

11. Limbidia indistinct, limbidia usually found on lower half of margin of vaginant laminae of perichaetial leaves,.costa percurrent to excurrent.....
.....5. *Fissidens bryoides* var. *esquirolii*
11. Limbidia distinct, limbidia usually found on apical, dorsal and vaginant laminae, costa ending below apex 12

12. Plants on soil; limbidia 1 layer thick in cross-section; capsule curved, asymmetrical.....3. *Fissidens beckettii*
12. Plants on wet rocks; 2-3 layers thick in cross-section, capsule sub-erect, symmetrical.....20. *Fissidens geppii*

13. Lamina cells strongly unipapillose; seta 2-7 mm long.....1. *Fissidens angustifolius*
13. Lamina cells slightly mammillose; seta up to 4 mm long.....6. *Fissidens bryoides* var. *schmidii*

14. Lamina cells smooth 15
14. Lamina cells unipapillose, multipapillose, or mammillose.....17

15. Vaginant lamina often 1-2 cells thick, dorsal lamina 3-4 cells thick; leaf base decurrent; on rocks fresh water (aquatic).....38. *Fissidens sedgwickii*
15. Vaginant and dorsal laminae one cell thick; leaf base not decurrent; on rocks or soil, not aquatic.....16

16. Limbidia present on perichaetial and vegetative leaves; on wet rock.....14. *Fissidens firmus*
16. Limbidia restricted to upper perichaetial leaves; on soil.....31. (*Fissidens laxitextus*)

17. Lamina cells highly mamamillose or unipapillose 18
17. Lamina cells multipapillose 21

18. Cells unipapillose, papillae with a branching tip.....25. *Fissidens incognitus*
18. Cells highly mamamillose, if unipapillose, papilla without a branching tip 19

19. Costa ending below apex; limbidia none or weak on varginant lamina, restricted to upper perichaetial leaves .....10. *Fissidens crenulatus* var. *elmeri*
19. Costa excurrent; limbidia distinct on varginant lamina.....20

20. Leaf apex narrowly acute (35-40°); leaf cells strongly unipapillose; seta terminal and lateral.....39. *Fissidens semperfalcatus*
20. Leaf apex acute (45-55°); leaf cells highly mamamillose, at times with 1-2 papilla; seta terminal,.....9. *Fissidens crenulatus* var. *crenulatus*

21. Leaves oblong-lanceolate to lanceolate, apex obtuse to broadly acute (80-90°); costa more than 10 cells below ending far below apex.....18. *Fissidens gardneri*
21. Leaves lanceolate to extremely narrow, apex acute to acuminate, costa percurrent to excurrent 22

22. Leaves broadly lanceolate, apex acute.....23
22. Leaves narrowly lanceolate, apex long-acuminate 24

23. Seta smooth; plant usually on soil.....7. *Fissidens ceylonensis*

23. Seta rough; plant on roots or base of trees, rarely on soil ..... 23. *Fissidens hollianus*

24. Leaves lanceolate to narrowly lanceolate, 1-1.3 mm long; costa ending below apex to percurrent ..... 45. (*Fissidens wichurae*)
24. Leaves linear-lanceolate, 1.5-2 mm long; costa clearly excurrent ..... 30. (*Fissidens kinabaluense*)

25. Marginal cells light in color, forming a differentiated border of one cell thick in cross-section; epiphyte..... 2. *Fissidens anomalus*
25. Marginal cells dark in color, forming a differentiated border of 2-3 cells thick in cross-section; if without a dark coloured border, the marginal leaf cells not different from the inner laminal cells; not epiphytic..... 26

26. Marginal border cells different from the inner laminal cells, dark in color, 2 to several cells in thickness 27
26. Marginal border cells not different from the inner laminal cells, one cell thick 29

27. Axillary hyaline nodules well-developed ..... 28. *Fissidens javanicus*
27. Axillary hyaline nodules not developed 28

28. Marginal border around all leaf margins, multistratose, thick throughout ..... 32. *Fissidens nobilis*
28. Marginal border not continuous along all leaf margins and not thick throughout.... ..... 29. *Fissidens jungermannioides*

29. Axillary hyaline nodules well-developed 30
29. Axillary hyaline nodules not or weakly developed 34

30. Lamina cells multipapillose (2-4 papillae)..... 41. *Fissidens subangustus*
30. Lamina cells smooth to mammillose..... 31

31. Plants more than 1.5 cm long, costa ending below apex, surface cells on both sides of costa from middle to apex distinctly elongate; leaf base distinctly long-decurrent..... 19. *Fissidens geminiflorus*
31. Plants less than 1.5 cm long, costa percurrent to excurrent, elongate cells on both sides of costa absent; leaf base not or slightly decurrent 32

32. Margins of vaginant laminae very strongly and irregularly serrate to dentate, limbidia not clear, consisting of a few elongate cells, weakly differentiated intramarginally, limited to vaginant laminae of perichaetial leaves, leaf cells strongly mammillose, but smooth in vaginant laminae..... ..... 27. *Fissidens irregulomargnatulus*

32. Margins of vaginant laminae entire to crenulate, limbidia absent, leaf cells..... mammillose on all leaves.....33

33. Leaf apex broadly acute, costae ending below apex to percurrent..... .....11. *Fissidens crispulus* var. *crispulus*
33. Leaf apex narrowly acute, costae slightly excurrent..... .....12. *Fissidens crispulus* var. *robinsonii*

34. Leaves ovate, lamina cells multipapillose.....13. (*Fissidens filiformis*)
34. Leaves oblong-lanceolate to lanceolate, lamina cells smooth or mammillose.....35

35. Laminal cells smooth 36
35. Laminal cells mammillose 42

36. Plants more than 1.5 cm long.....37
36. Plants less than 1 cm long..... 38

37. Leaf apex mostly murconate, rarely obutusely acute; lamina cells 13-18 µm long, walls distinct.....36. *Fissidens polypodioides*
37. Leaf apex not murconate, obutusely acute; lamina cells 8-13 µm long, walls obscure.....34. *Fissidens obscurus*

38. Leaves oblong-lanceolate, apex broadly acute (60-70°)..... 39
38. Leaves lanceolate to narrowly lanceolate, apex narrowly acute.....40

39. Leaf margins nearly entire; dorsal lamina narrower at base, leaf cells quadrate to rounded-quadrate, 10-18 µm diameter; seta 1-1.5 mm long..... .....21. *Fissidens guangdongensis*
39. Leaf margins distinctly serrulate; dorsal lamina rounded at base, leaf cells quadrate to irregularly-hexagonal, 8-14 µm diameter; seta up to 2.9 mm long .....31. (*Fissidens laxitextus*)

40. Leaf margins distinctly serrate, apex acute (45-55°).....15. *Fissidens flabellulus*
40. Leaf margins crenulate or indistinctly serrate, apex long-acuminate (25-30°).....41

41. Leaf margins entire or subentire; leaf cells distinctly thick-walled..... .....8. *Fissidens crassinervis*
41. Leaf margins crenulate or serrate; leaf cells thin-walled to slightly thick-walled.... .....35. *Fissidens pellucidus*

42. Plants less than 0.5 cm long.....43
42. Plants 0.5-more than 1.5 cm long.....44

43. Leaves narrowly-lanceolate, apex narrowly acute to shortly acuminate (25-30°); costa percurrent to shortly excurrent, leaf margins distinctly serrate to very strongly dentate.....40. *Fissidens serratus*

43. Leaves oblong-lanceolate, apex broadly acute (60-70°); costa ending 2-3 cells below apex, leaf margins serrate to moderately dentate.....
.....44. *Fissidens tenellus* var. *australiensis*

44. Costa ending a few cells below apex; leaf base more or less decurrent; seta up to 2.3 mm long .....22. *Fissidens gymnogynus*
44. Costa percurrent to excurrent; leaf base not decurrent; seta more than 3 mm long.....45

45. Plants more than 1.5 cm long; leaf margins crenulate or indistinctly serrate; broadly ovate-lanceolate to oblong-lanceolate; apex broadly acute (60-70°), costa percurrent.....26. *Fissidens involutus*
45. Plants up to 1.5 cm long; leaf margins more or less distinctly serrate; lanceolate to oblong-lanceolate; apex narrowly acute to acute (less than 60°), costa excurrent.....46

46. Leaf apex narrowly acute (35- 40°), not mucronate; costa excurrent, lamina cells orbicular-hexagonal, 8-12 μm diameter.....33. *Fissidens oblongifolius*
46. Leaf apex acute (45-55°), mucronate; costa very clearly excurrent, lamina cells quadrate with thickened corners, 6-9 μm diameter.....43. *Fissidens taxifolius*

1. ***Fissidens angustifolius*** Sull., Proc. Amer. Acad. Arts. & Sci. 5, (1861) 275.
Li and Iwatsuki (2001) 6 (including extra-Thai synonyms) 7 (map).

Plant up to 4 mm long, yellow-green, stem usually simple; hyaline nodules; absent or weakly developed; leaves 10-24, densely arranged, lowest leaves small, middle to upper leaves much larger, narrowly lanceolate, 1-2 mm long, 0.2-0.3 mm wide, acute at apex, base decurrent, margin entire to slightly serrate at apex; lamina cells strongly mammillose, limbidia differentiated all around the leaves, with 1-2 rows of cells, weakly developed at apex; costa percurrent to shortly excurrent; vaginant lamina about half of leaf length; cells of leaf apical similar to those the dorsal lamina, polygonal, 10-15 μm long, 10-15 μm wide, thin-walled, strongly mammillose; cells of vaginant lamina similar to those of the lamina, but larger and becoming rectangular, 20-40 μm long, 15-20 μm wide. Archegonia 0.5-0.8 mm, perichaetial leaves longer and narrower than those of other leaves, male inflorescenes in axils of middle leaves, perigonial leaves ovate, about 1 mm long. Sporophyte terminal and lateral on stem; capsules ovate, symmetric, smooth, 0.5-0.8 mm long; seta 3-8 mm long, smooth; calyptra 0.3-.05 mm long; spores papillose, 15-20 μm.

Illustrations—Figures 18 and 128A

Habitat—on soil

Ecology—mixed evergreen+deciduous, seasonal, hardwood forest *c.* 600 m elevation; primary, evergreen, seasonal, hardwood forest *c.*1200 m elevation, granite bedrock

Phenology—gametophytes: March-November
sporophyte: November

Distribution—(Figure 120) China, Fiji, New Caledonia, Samoa, Central African Repubic, Nigeria, Togo, United States (type), Cuba, Haiti, French Guiana, Argentina, Barbados, Bolivia, Columbia, Ecuador, Jamaica, Peru, Puerto Rico, Venezuala.

New record for Thailand.

Distribution in Thailand—(Figure 70A) Chiang Mai: Doi Inthanon National Park, Doi Suthep-Pui National Park, Chiang Dao Wildlife Sanctuary. Phetchaburi: Kaeng Krachan National Park. Suphanburi: Phu-Toei National Park.

Specimen studied— (all CMU, gametophyte) Wongkuna 846B, 1014A, 1552; (CMU, gametophyte and sporophyte) Wongkuna 438A.

This species is up to 4 mm long. Other diagnostic features are the narrowly lanceolate leaves, margins entire to slightly serrulate, limbidia differentiated all around the leaves, and the apical and dorsal laminae cells are strongly mammillose.

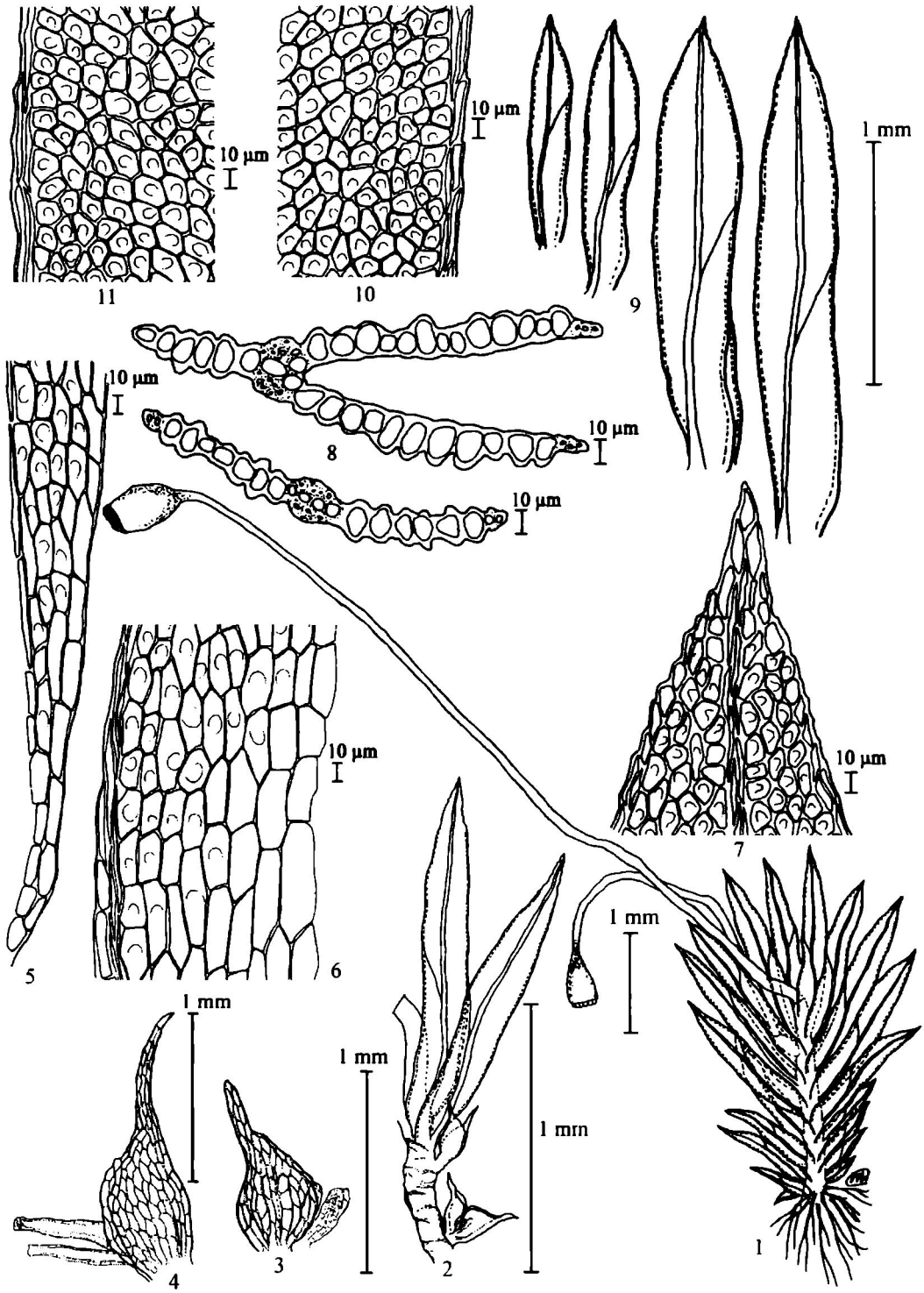


Figure 18. *Fissidens angustifolius* Sull.
1: plant with sporophyte. 2: part of stem with sex organs. 3: perigonial leaf with antheridia. 4: perichaetial leaf with archegonia. 5: leaf base cells. 6: vaginant lamina cells. 7: leaf apex. 8: cross section of leaf. 9: leaves. 10: cells of dorsal lamina. 11: apical lamina cells. Drawn from Wongkuna 438A.

2. ***Fissidens anomalus*** Mont., Ann. Sci. Nat. Bot. ser. 2; 17 (1842) 252.
Bartram (1939) 22-23 (plate+fig. 18).
Horikawa and Ando (1964) 4.
Gangulee (1971) 555 (including extra-Thai synonyms and map) 556 (fig.).
Eddy (1988) 60 (fig.), 61.
Li and Iwatsuki (2001) 7 (map), 8 (plate+fig.).

Plants 10-20 mm long, 4.5-6.0 mm wide, sometimes branching; green, light green to yellowish, but typically yellow-brown when mature; hyaline nodules not differentiated, central strand present; leaves closely set 14-16, straight or curved and deflexed, circinately curled distally when dry, lanceolate to oblong-lanceolate, 3.5-4.0 mm long, 0.7-1.0 mm wide, apex acute, base usually shortly decurrent in a short, undulate wing, margins elimbate, cells light colored, 2-3 rows, and 3-5 rows of vaginant marginal cells, differentiated border one cell thick, margins finely serrlulate to dentate; costa percurrent, rarely excurrent; vaginant lamina slightly unequal, about 1/2 leaf length, dorsal lamina broad; inner lamina cells of apical and dorsal laminae unistratose, 8.0-10.0 μm diameter, polygonal, thin-walled, strongly convex-mammillate; cells of vaginant lamina similar to those of the apical and dorsal laminae. Dioicous, male and female plants similar; perigonia bud-like, in axils of leaves; perichaetia usually several on a branch, occurring singly in leaf axils, smaller and narrower than sterile leaves. Sporophyte lateral on stem, seta 1.5-2.0 mm long; capsules cylindrical, erect, symmetric, about 1 mm long dark brown; operculum rostrate, 0.5 mm long, spores smooth, 22.5-25 μm.

Illustrations: Figures 19 and 128B

Habitat: epiphytic on trunks, branches and buttresses of forest trees in moist places.

Ecology: primary, evergreen, seasonal, hardwood, forest; granite, sandstone, and limestone bedrocks, 1250-2565 m elevation

Phenology—gametophytes: March-December
sporophytes: August-November

Distribution—(Figure 82) India (type), Nepal, Sri Lanka, China, Taiwan, Japan, Myanmar, Vietnam, Malaysia, Java, Philippines, New Guinea.

Distribution in Thailand—(Figure 70B) Chiang Mai: Doi Inthanon National Park, Doi Suthep-Pui National Park, Pha Daeng National Park, and Chiang Dao Wildlife Sanctuary.

Specimens studied—(CMU, gametophyte) Wongkuna 273A, 290, 711A, 712, 732, 749, 763, 777, 866, 867, 882, 883, 886, 892, 893, 895, 921, 922, 938, 945, 947, 956, 979, 983, 1156, 1117; (CMU, gametophyte and sporophyte) Wongkuna 705, 709, 713, 717, 733, 896, 867; (BKF, gametophyte) Robbins 3584, A.Touw 8729, 9275, 9547, 9663, 9844, 9902, 10176, 10212, 10503, 11101.

The species is characterized by being a medium to large plant. The leaves are oblong-lanceolate and the base of the lamina is slightly decurrent. Its margins are very finely serralulate, light green, and have differentiated border of one cell thick. The costa is percurrent and the leaf cells are polygonal, thin-walled, and mammillose.

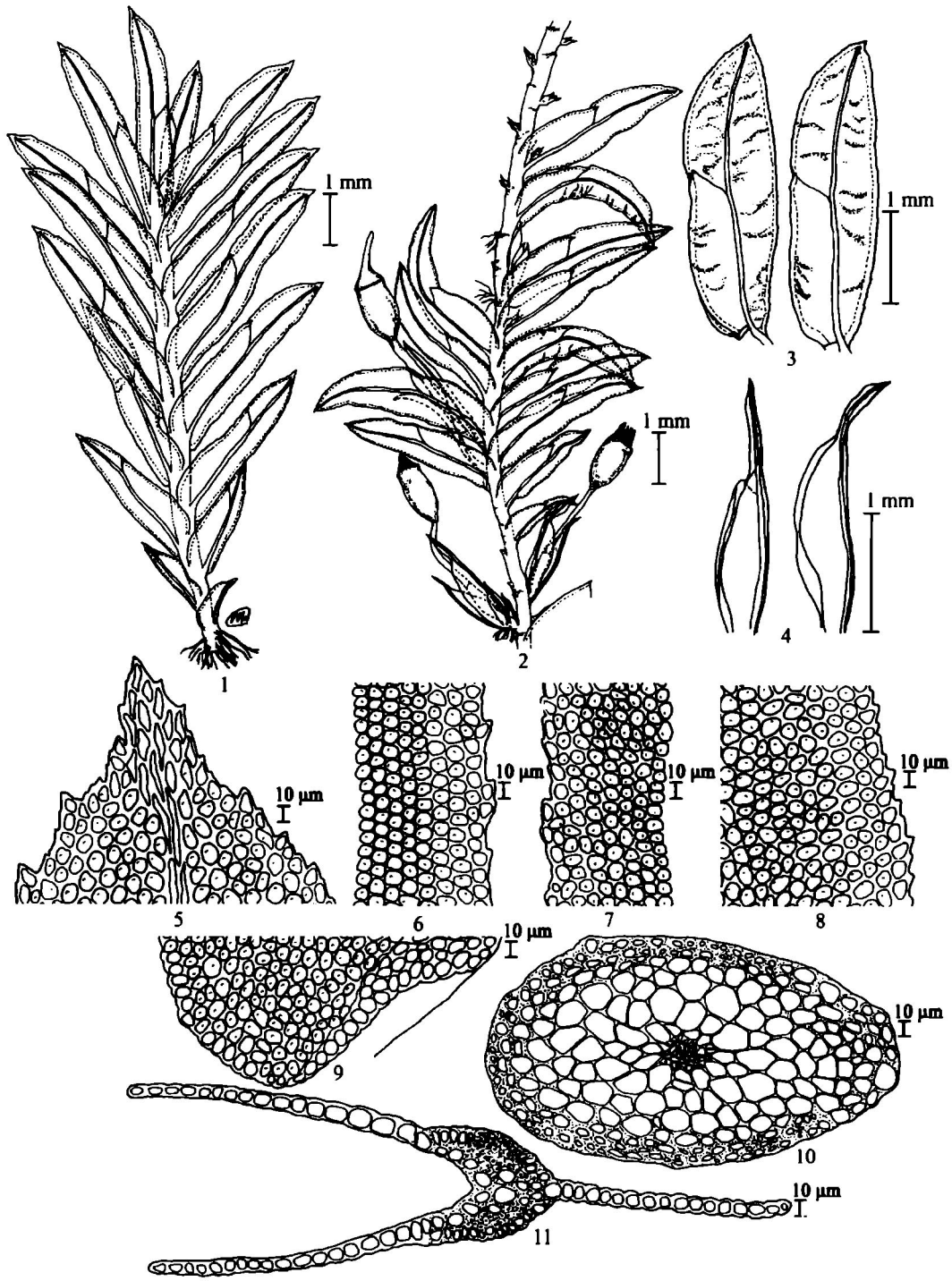


Figure 19. *Fissidens anomalus* Mont.
1: plant habit. 2: part of stem with sporophytes. 3: leaves. 4: perichaetial leaves. 5: leaf apex. 6: apical lamina cells. 7: dorsal lamina cells. 8: vaginant lamina cells. 9: leaf base cells. 10: cross section of stem. 11: cross section of leaf. Drawn from Wongkuna 713.

3. ***Fissidens beckettii*** Mitt., J. Linn. Soc. Bot. 13 (1873) 325.
Iwatzuki and Suzuki (1982) 371-372, 461 (fig.), 501 (map).
Eddy (1988) 88, 89 (fig.).
Li and Iwatsuki (2001) 9 (map), 10 (fig.).

Plants 1-3 mm tall, light-green, somewhat brownish when old, unbranched, sterile stem longer than fertile ones, without a central strand, axillary hyaline nodules not differentiated; leaves distant, 8-20, ovate-lanceolate to lanceolate, 1.0-1.6 mm long, 0.3-0.5 mm wide, apex acute to narrowly acute and often bent, base not decurrent, margins smooth and limbidia extending all around, 1-2 cell rows, one cell thick, 5-10 cell rows and 1-2 cells thick on vaginant laminae, costa strongly excurrent; vaginant lamina open almost to costa, about 1/2-2/3 leaf length; cells of apical and dorsal laminae rhombic to more or less hexagonal, thin-walled, smooth, 15-25 x 20-30 μm, cells of vaginant lamina larger than those of the apical and dorsal laminae. Autoicous, male inflorescence terminal on short male branches at the base of female stems with 4-10 of small leaves; female branches shorter than sterile ones. Sporophyte terminal, seta smooth, 4-10 mm long, smooth; capsule inclined to horizontal, curved, asymmetric, 0.8 mm long; operculum rostrate, 0.5 mm long. Spore not seen.

Illustrations: Figures 20 and 128C
Habitat: on bare soil, shaded area
Ecology: primary, evergreen, seasonal, hardwood forest; granite, bedrock, 1000-1250 m elevation
Phenology—gametophytes: June-November
sporophytes: June-November
Distribution—(Figure 109) India, Nepal, Sri Lanka (type), China, Japan, Malaysia, Myanmar, Cape of Good Hope, Central African Repubic, Madagascar, Natal, Tanzania, Transvaal, Zimbabwe.
New record for Thailand.
Distribution in Thailand—(Figure 70C) Chiang Mai: Doi Suthep-Pui National Park. Phitsanulok: Phu Hin Rong Kla National Park.
Specimens studied—(CMU, gametophyte and sporophyte) Wongkuna 150, 338A, 339A, 340A, 341A, 342A, 1066.

The species is distinctive in having well-developed limbidia extending all around the leaf lamina. The sporophyte is terminal and the capsules are inclined to horizontal, curved, and asymmetric.

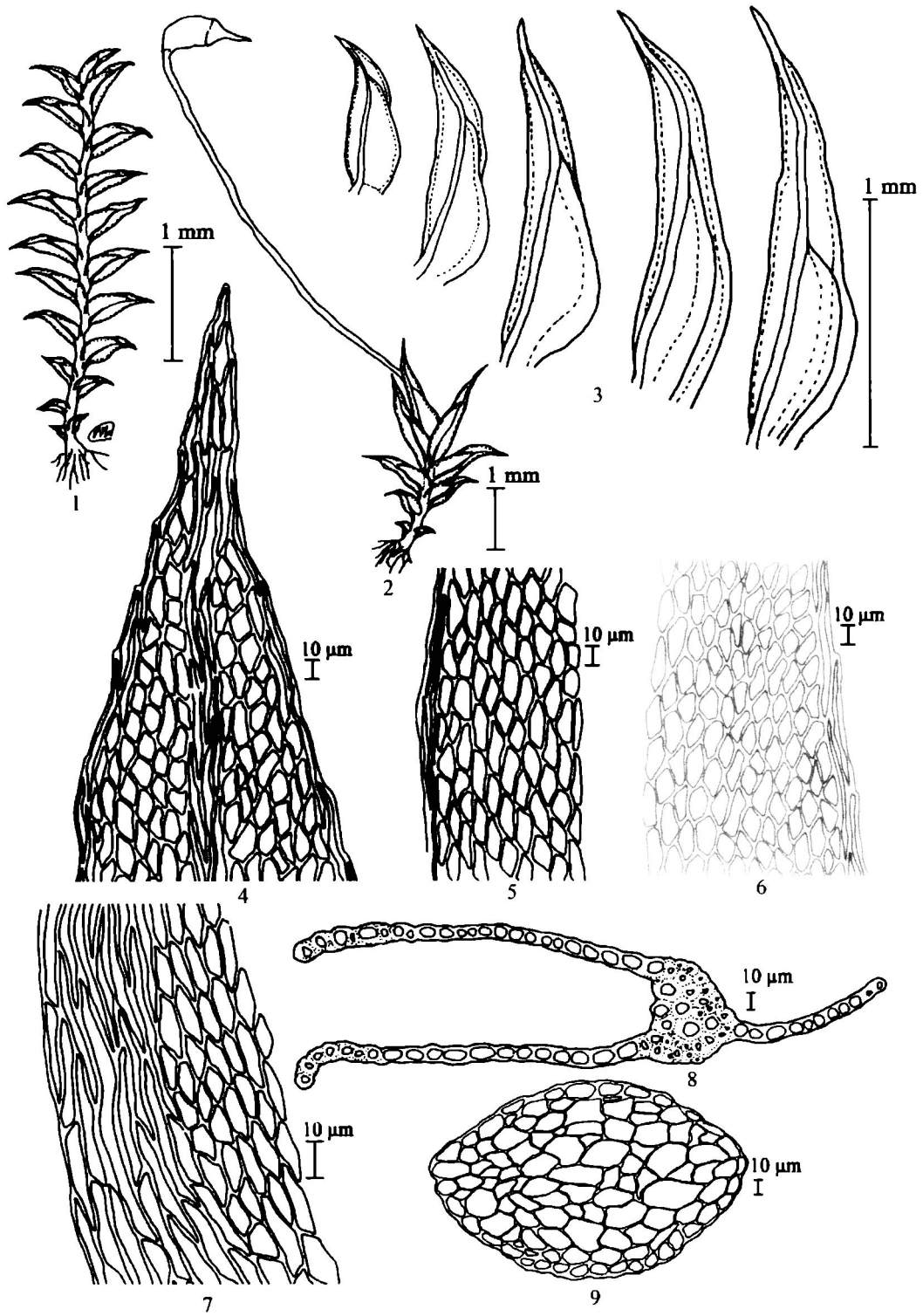


Figure 20. *Fissidens beckettii* Mitt.
1: plant habit. 2: plant with sporophyte. 3: leaves. 4: leaf apex. 5: apical lamina cells. 6: dorsal lamina cells. 7: vaginant lamina cells. 8: cross-section of leaf. 9: cross-section of stem. Drawn from Wongkuna 335A.

4. ***Fissidens biformis*** Mitt., Musc. Ind. Orient. (1859) 141.
Gangulee (1971) 483 (map), 484 (fig).
Fissdens xiphioides Fleisch., Hedwigia 38 (1899) 125; Eddy (1988) 90, *pro syn.*

Plants 2.5-5 mm tall, 2-2.5 mm wide; leaves 12-16, light green, hyaline nodules slightly to well differentiated; central strand lacking; narrowly lanceolate (especially the sub-perichaetial), up to 2.0 mm long, 0.2-0.3 mm wide, apex shortly acuminate (25-30°), base of lamina slightly decurrent, margins entire, limbate all around, 1-2 rows of cells, one cell thick; costa percurrent to shortly excurrent; lamina cells thin-walled or slightly incrassate, polygonal, smooth, about 10-15 μm wide, cells at base longer than apical and dorsal laminar cells, vaginant lamina about 1/2 leaf length, cells of vaginant lamina similar to those of other leaves. Autoicous and usually fertile, perichaetial leaves similar to those of other leaves. Sporophyte terminal; seta smooth, 3-5 mm long, smooth; capsules cylindrical, erect, symmetric, 0.3-0.4 mm long.

Illustrations: Figures 21 and 128D

Habitat: on soil in shade or by streams in more open situations, often on ground that has been recently exposed or disturbed

Ecology: deciduous dipterocarp-oak seasonal hardwood forest; granite bedrock, 250-*c.* 900 m elevation

Phenology—gametophytes: March-November
sporophytes: June and November

Distribution—(Figure 83) India, Nepal, Sri Lanka, Malaysia, Philippines, Java, Sulawesi, and New Guinea.

Distribution in Thailand—(Figure 70D) Chiang Mai: Doi Inthanon National Park, Doi Suthep-Pui National Park, and Chiang Dao Wildlife Sanctuary. Nakhon Nayok: Khao Yai National Park. Phetchaburi: Kaeng Krachan National Park. Prachuap Khiri Khan: Hui Yang Waterfall National Park.

Specimens studied—(CMU, gametophyte) Wongkuna 854, 1482, 1486, 1566, 1570, 1571; (CMU, gametophyte and sporophyte) Wongkuna 438A, 439, 1573, 1654; (BKF) Touw 8867.

This species is readily distinguished from the other limbate, smooth-celled species by its narrowed of base. It very close to *F. subryoides* in leaf shape, but that species has a different growth form and more open, unequal vaginant lamina. *F. biformis* has an acuminate leaf apex, while in *F. subryoides* it is narrowly acuminate (20°).

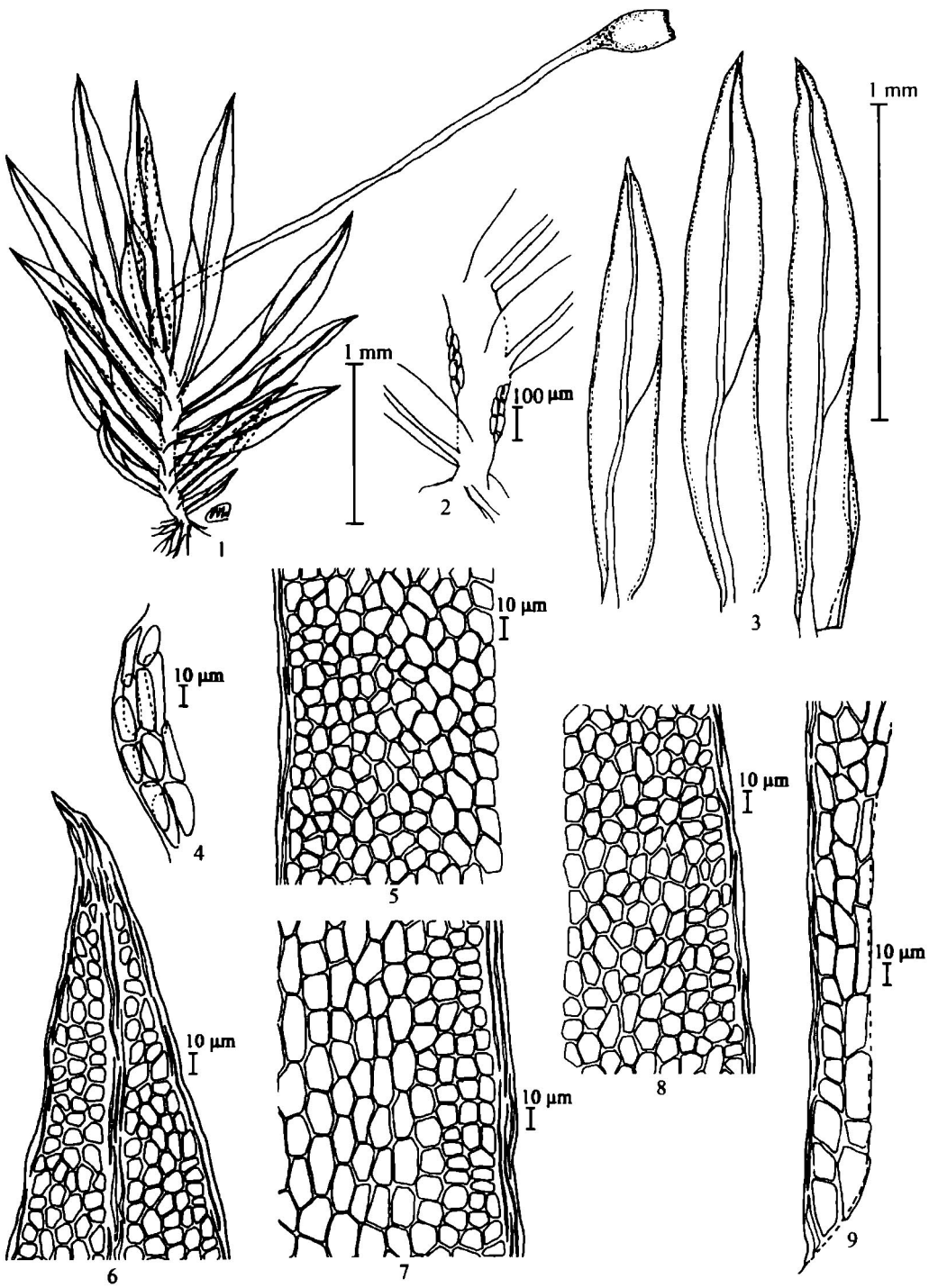


Figure 21. *Fissidens biformis* Mitt.
1: plant with sporophyte. 2: hyaline nodules on stem. 3: leaves. 4: hyaline nodules. 5: apical lamina cells. 6: leaf apex. 7: vaginant lamina cells. 8: dorsal lamina cells. 9: cells at leaf base. Drawn from Wongkuna 438B.

5. ***Fissidens bryoides*** Hedw. var. ***esquirolii*** (Thér.) Z. Iwats. & T. Suzuki, J. Hattori Bot. Lab. 51 (1982) 361.

Li and Iwatsuki (2001) 12 (map), 13, 14 (fig.).

Fertile and sterile stems often differentiated, sterile stems up to 5 mm long, 1.5 mm wide, light green to green; leaves up to 15; fertile stems up to 2 mm long with 2-3 pairs of leaves; all stems simple, central strand lacking; axillary hyaline nodules not differentiated; leaves lanceolate to linear-lanceolate, 0.5-1 mm long, 1.5-2.3 mm wide, apex acute, base of dorsal lamina slightly decurrent; limbidia variable, very weak to almost lacking, very often found only on vaginant laminae or completely lacking; margins serrulate; costa usually ending 6-8 cells below apex, rarely percurrent; vaginant laminae 1/2 to 3/5 of the leaf length; cells of apical lamina quadrate to hexagonal, 7-13 μm diameter, thin-walled, smooth or slightly mammillose; cells of vaginant laminae similar to those of the apical laminae, larger and longer towards base; dioicous; male inflorescence bud-like at base of female stem, rarely terminal on more or less elongate male stems; sterile, female, and male stems usually connected at base; archegonia 200-270 μ long; sporophyte terminal on female stem, seta 1-3 mm long; capsules symmetrical, 0.5-0.7 mm long; peristome teeth 0.15 mm long, 30-35 μm wide at base; spores 12-19 μm diameter, almost smooth.

Illustrations: Figures 22 and 129A

Habitat: on rocks in shaded places

Ecology: deciduous dipterocarp-oak forest, 400-500 m elevation and primary seasonal evergreen forest at 1100 m elevation; granite bedrock, sometimes in disturbed sites.

Phenology—gametophyte: March
sporophyte: March

Distribution—(Figure 84) China, Taiwan, Japan.

New record for Thailand.

Distribution in Thailand—(Figure 71A) Chiang Mai: Doi Suthep-Pui National Park. Suphanburi: Phu-Toei National Park.

Specimens studied: (CMU, gametophyte) Wongkuna 461, 486, 495, 502, 503; (CMU, gametophyte and sporophyte) Wongkuna 462, 466; (SING, gametophyte and sporophyte) Tan 05-106.

This variety is characterized by differentiated sterile and fertile stems, limbidia on apical lamina absent or weakly developed, and serrulate leaf margins. The lamina cells are smooth.

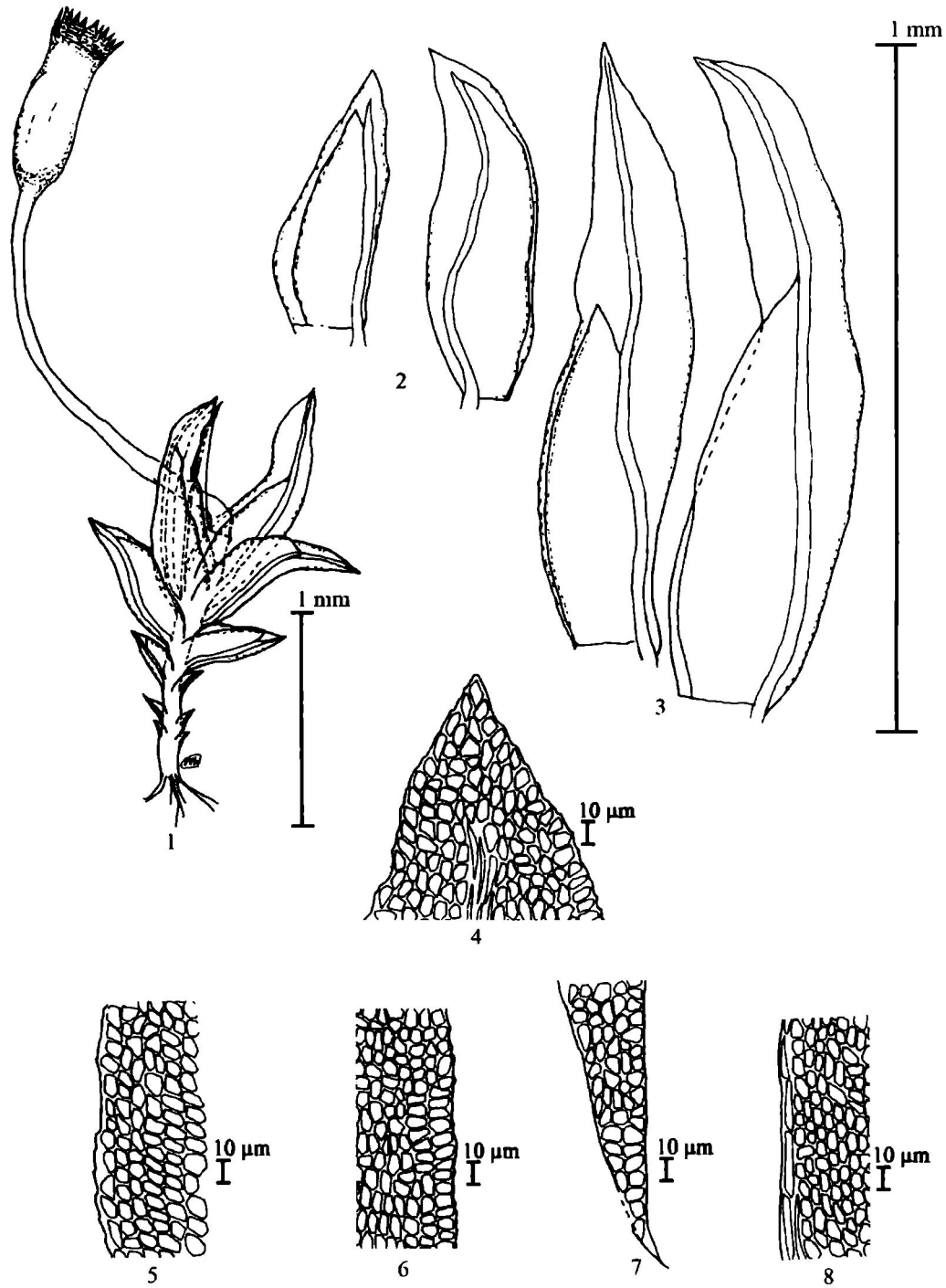


Figure 22. *Fissidens bryoides* Hedw. var. *esquirolii* (Thér.) Z. Iwats. & T. Suzuki
1: plant with sporophyte. 2: leaves. 3: perichaetial leaf. 4: leaf apex. 5: apical lamina cells. 6: dorsal lamina cells. 7: leaf base cells. 8: perichaetial leaf cells. Drawn from Tan 05-106 (SING).

6. ***Fissidens bryoides*** Hedw. var. ***schmidii*** (C. Muell.) Chopra & Kumar, Mosses West. Himalayas Adjadent Plains (1981) 43.

Iwatsuki and Suzuki (1982) 362-363 (including extra-Thai synonyms), 456 (fig.), 502 (map).

Li and Iwatsuki (2001) 17, 16 (plate+fig.), 18 (map).

Plants 4-8 mm long, 1.5-2 mm wide; green, stems simple, often elongate; axillary hyaline nodules lacking or weakly differentiated; central strand lacking or weak in cross-section; leaves 16-24, lanceolate to oblong-lanceolate, 1.2-2.3 mm long, 0.3-0.5 mm wide, apex acute to widely acute, base often more or less decurrent; margin entire; limbidia weak, usually 1-2 cells wide or often partly lacking on apical and dorsal laminae, 2-4 cells wide on vaginant laminae, 1 cell thick; costa percurrent; vaginant laminae 1/2 of leaf length; cells of apical lamina hexagonal to quadrate, 4-10 μm diameter, mammillose, walls thin and not distinct because of convexity of cell surfaces; dioicous; archegonia terminal, *c.* 300 μm long; sporophytes terminal, seta smooth, 2-3 mm long; capsules symmetric, 0.6-0.8 mm long,

Illustrations: Figures 23 and 129B

Habitat: Moist to wet rocks in shaded sites, less often on soil in shade or by streams in more open situations, often on soil that has been recently exposed or disturbed.

Ecology: mixed evergreen+deciduous, seasonal, hardwood forest; granite, bedrock, 400-1250 m elevation

Phenology—gametophytes: June-November
sporophytes: August-November

Distribution—(Figure 115) India, Nepal, Pakistan, Sri Lanka, China, Taiwan, Hong Kong, Japan, Malaysia, Indonesia, Java, Philippines, New Guinea, Australia, Cameroons, Central African Repubic, Gabon, Guinea, Nigeria, Uganda.

New record for Thailand.

Distribution in Thailand—(Figure 71B) Chiang Mai: Doi Inthanon National Park, Doi Suthep-Pui National Park. Rayong: Khao Khitchakut National Park

Specimens studied—(CMU, gametophyte) Wongkuna 444B, 724, 728, 734, 960, 1821A; (CMU, gametophyte and sporophyte) Wongkuna 174, 175, 176, 271, 338C, 441, 446, 447, 731, 735, 736, 737, 738, 865, 878, 888, 890, 891; (BKF) Robbin 3556.

This variety is similar to *F. bryoides* Hedw. var. *esquirolii* (Thér.) Z. Iwats. & T. Suzuki, but differs in having similar sterile and fertile stems, well-developed limbidia on the apical lamina, leaf margins entire, leaf cells mammillae and distinct. The base of the lamina is slightly decurrent and weakly mammillose.

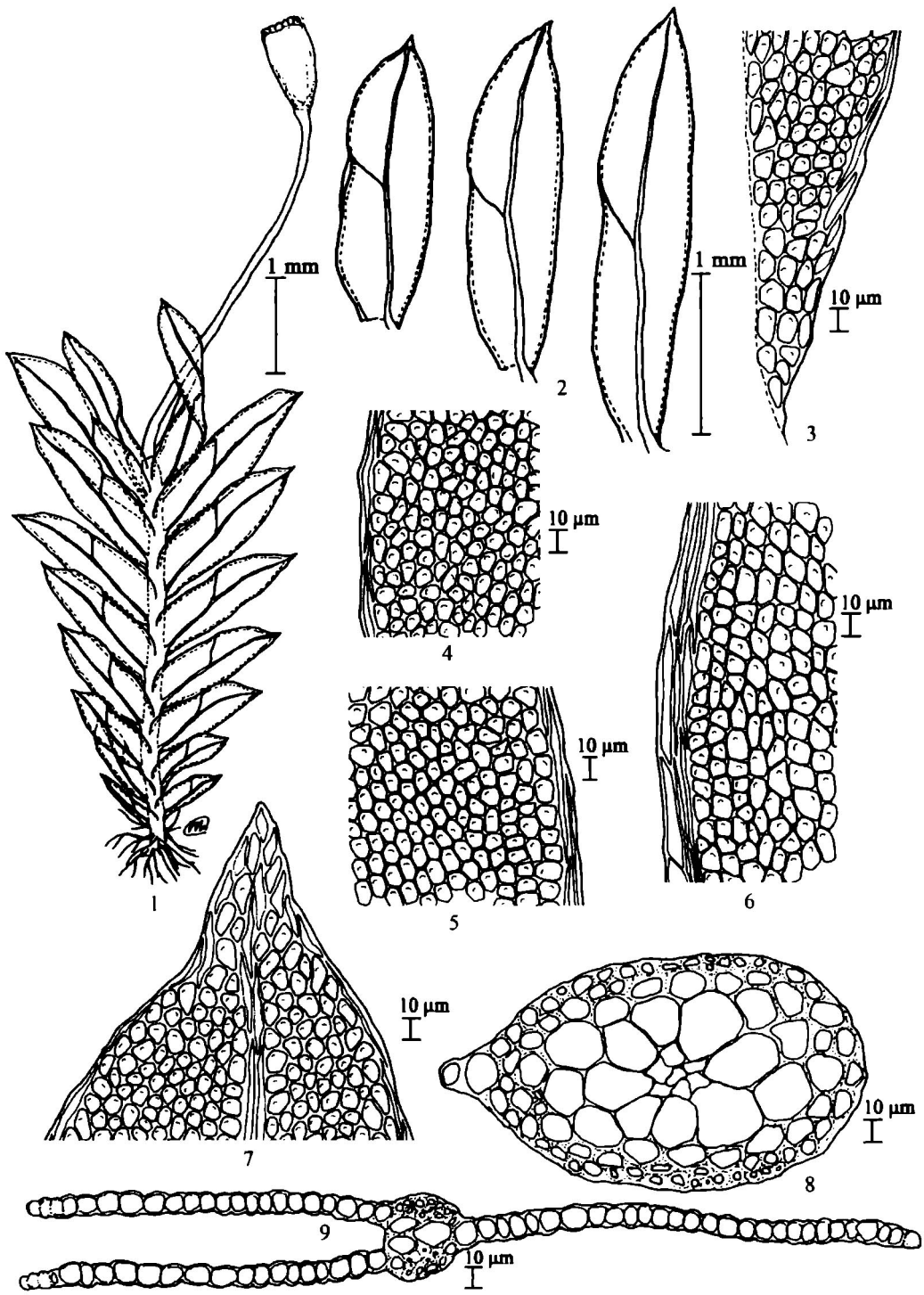


Figure 23. *Fissidens bryoides* var. *schmidii* (C. Muell.) Chopra & Kumar
1: plant with sporophyte. 2: leaves. 3: leaf base cells. 4: apical lamina cells. 5: dorsal lamina cells. 6: vaginant lamina cells. 7: leaf apex. 8: cross section of stem. 9: cross section of leaf. Drawn from Wongkuna 734.

7. ***Fissidens ceylonensis*** Dozy & Molk., Ann. Sci. Nat. Bot. ser. 3, 2 (1844) 304.

Gangulee (1971) 511 (including extra-Thai synonyms) 512 (map), 513 (fig.), 514.

Eddy (1988) 81 (fig.), 82-83.

Li and Iwatsuki (2001) 19-20 (map.)

Iwatsuki and Mohamed (1987) 345, 346 (fig.), 347.

Fissdens siamensis Broth., Bot. Tidsskr. 24 (1901) 63., S. He (1996), *pro syn.*

Plants up to 9 mm long, 1-1.5 mm wide; green to dark green; hyaline nodules not to weakly differentiated; cenral strand weakly differentiated; leaves 20-40, broadly lanceolate to oblong-lanceolate, 0.8-1.2 mm long, 2-2.5 mm wide, apex acute, base not decurrent, margins nearly entire; limbidium limited on vaginant lamina, 1-2 rows of cells, one cell thick; costa excurrent; vaginant lamina about 1/2-2/3 leaf length; laminae cell quadrate to polygonal, about 6-10 μm diameter, thin-walled, multipapilose with 4-6 tiny papillae per cell; perichaetial leaves narrower than those of other leaves. Sporophyte terminal, seta smooth, 2-4 mm long; capsules cylindrical, erect, symmetrical, *c.* 0.8 mm long, *c.* 0.5 mm wide, operculum rostrate, about 0.8 mm long; spores not seen.

Illustrations: Figures 24 and 129C

Habitat: on rocks and soil in moist, shaded places

Ecology: deciduous dipterocarp-oak seasonal forest at 250-*c.*900 m elevation; mixed evergreen+deciduous seasonal hardwood forest at 900-*c.*1000 m elevation, and primary, evergreen, seasonal, hardwood forest at *c.*1000-2565 m, granite, sandstone, and limestone bedrocks, sometimes in disturbed sites.

Phenology—gametophytes: March-December

sporophytes: March-December

Distribution—(Figure 116) India, Nepal, Sri Lanka, Taiwan, Hong Kong, Cambodia, Laos, Vietnam, Malaysia, Singapore, Borneo, Philippines, Java, Sumatra, Papua New Guinea, Seychelles, Australia, and New Zealand

Distribution in Thailand—(Figure 71C) Chiang Mai: Doi Inthanon National Park, Doi Suthep-Pui National Park, Pha Daeng National Park, Chiang Dao Wildlife Sanctuary. Phitsanulok: Phu Hin Rong Kla National Park. Loei: Phu Luang Wildlife Sanctuary. Khon Kaen: Phu Kao-Phu Phan Kham National Park. Sakon Nakhon: Phu Phan National Park. Chaiyaphum: Tat Ton National Park. Ubon Ratchathani: Pha Taem National Park. Rayong: Khao Cha Mao- Khao Wong National Park, Khao Khitchakut National Park. Chanthaburi: Nam Tok Phlieo National Park. Suphanburi: Phu-Toei National Park. Nakhon Nayok: Khao Yai National Park. Phetchaburi: Kaeng Krachan National Park. Prachuap Khiri Khan: Hui Yang Waterfall National Park, Ranong: Nam Tok Ngao National Park. Nakhon Sri Thammarat: Khao Nan National Park. Krabi: Phanom Bencha National Park

Specimens studied—(CMU, gametophyte) Wongkuna 151, 170A, 172, 327, 328, 334, 352, 346, 349, 519, 522, 573, 590, 599, 604, 611A, 617, 681, 771, 809, 816, 817, 818, 831, 862, 1002, 1216, 1269, 1276, 1319, 1353, 1375, 1417, 1594, 1606, 1692, 1699, 1768, 1807, 1814, 1826, 1841, 1868; (CMU, gametophyte and sporophyte) Wongkuna 152, 155, 168, 169, 234, 238, 242, 282, 283, 284, 285, 286, 287, 288, 289, 291, 292, 293, 312, 353, 358, 360, 363, 370, 377, 379, 382, 383, 384,

385, 399, 400, 483, 484, 518, 548, 550, 581, 616, 677, 694, 698, 761, 797, 807, 810, 812, 813, 814, 821, 823, 824, 832, 833, 926, 934, 935, 943, 951, 966, 972, 974, 975, 977, 991, 992, 996, 1008, 1058, 1090, 1218, 1225, 1230, 1231, 1239, 1255, 1258, 1259, 1261, 1264, 1277, 1279, 1282, 1285, 1286, 1287, 1289, 1291, 1295, 1304, 1307, 1320, 1325, 1326A, 1327, 1329, 1331, 1332, 1338, 1346, 1356, 1357, 1361, 1365, 1369, 1371, 1382, 1384, 1387, 1572, 1576, 1626, 1632, 1676, 1688, 1747, 1800, 1809, 1832A, 1837, 1855, 1861, 1865; (BKF) Robbins 3633, 3554, Smitinand 1296, Suvarnasara 40, Tixiex 1066, Touw 8406, 9015, 10193.

This species is very closely related to *F. hollianus* Dozy and Molk. with multipapillose cells, no hyaline nodules on the stem, and no limbate. *F. hollianus* has rough seta, while *F. ceylonensis* has smooth setae.

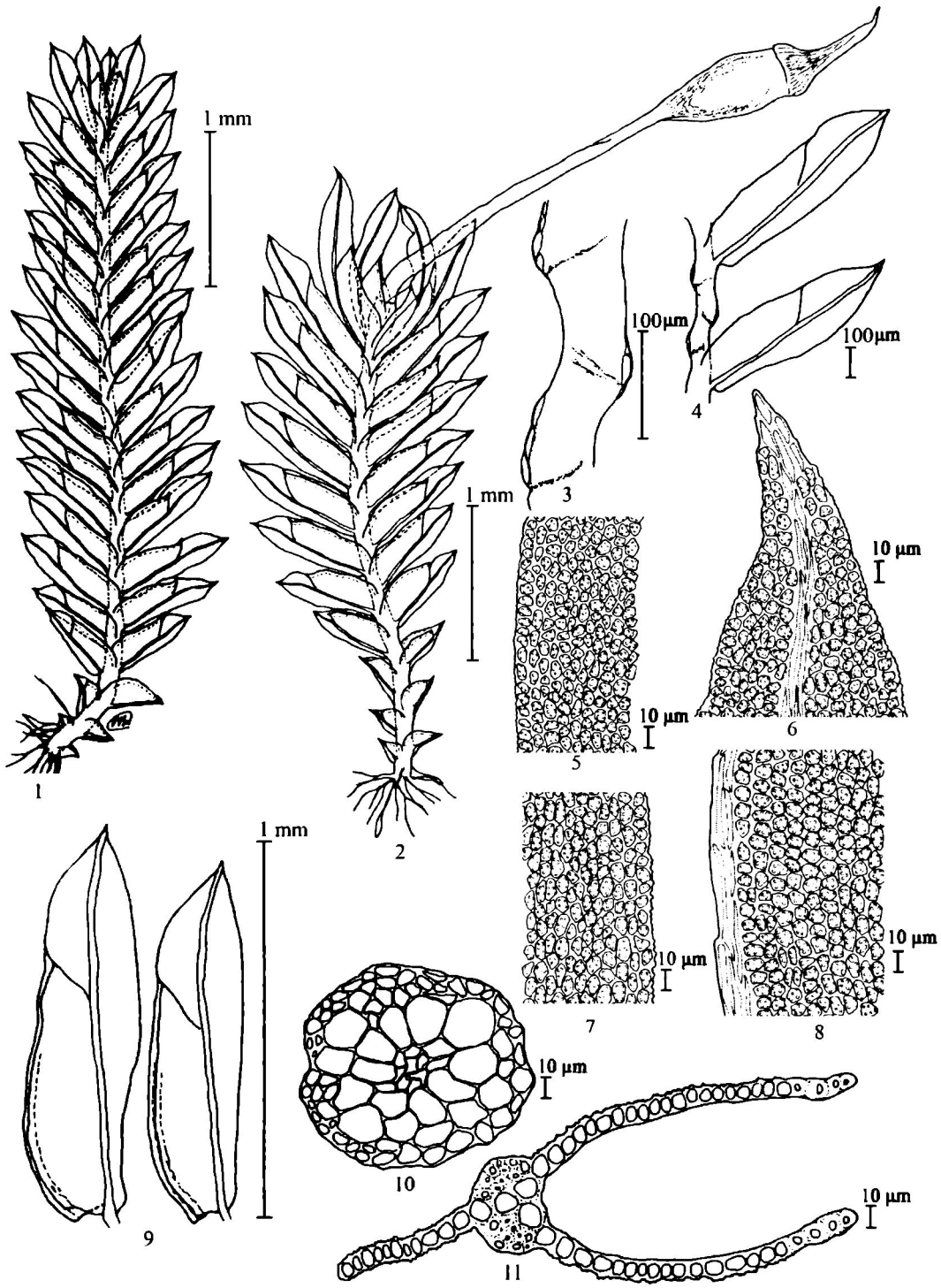


Figure 24. *Fissidens ceylonensis* Dozy & Molk.
1: plant habit. 2: plant with sporophyte. 3-4: hyaline nodules on stem. 5: apical lamina cells. 6: leaf apex. 7: dorsal lamina cells. 8: vaginant lamina cells. 9: leaves. 10: cross section of stem. 11: cross section of leaf. Drawn from Wongkuna 385.

8. ***Fissidens crassinervis*** Sande Lac., Verh. Koh. Ned. Akad. Wetensch. Amaterdam Natuurk 13 (1872) 2.

Iwatzuki and Suzuki (1982) 392, 472 (fig.) 505 (map).

Eddy (1988) 68, 71 (fig).

Li and Iwatsuki (2001) 21, 23 (plate+fig.), 24 (map).

Plants 5-8 mm long, 1-1.3 mm wide, green to brownish; hyaline nodules not differentiated; central strand differentiated; leaves 16-30, lanceolate, 1.2-1.5 mm long, 0.25-0.3 mm wide; apex long-acuminate (25-30°); base decurrent; margins entire or subentire and without limbate; costa usually reddish, at least in the lower half, percurrent to shortly excurrent, vaginant lamina less than 1/2 leaf length, very unequal at apex and open almost to costa; leaf cells polygonal, 5-12 μm long, elongate at base, 2-5 μm wide, distinctly thick-walled. Dioicous; archegonia terminal 0.3 mm long; perichaetial leaves narrowly lanceolate to linear, 1.6-2 mm long, 0.25-0.3 mm wide. Sprophyte not seen.

Illustrations: Figures 25 and 129D

Habitat: on rocks and soil in moist, shaded places

Ecology: deciduous dipterocarp-oak seasonal forest, 60-850 m elevation; mixed evergreen+deciduous seasonal hardwood forest, 850-*c.*1000 m elevation, and primary evergreen seasonal forest, 1000-2565 m elevation.

Phenology—gametophytes: February-September

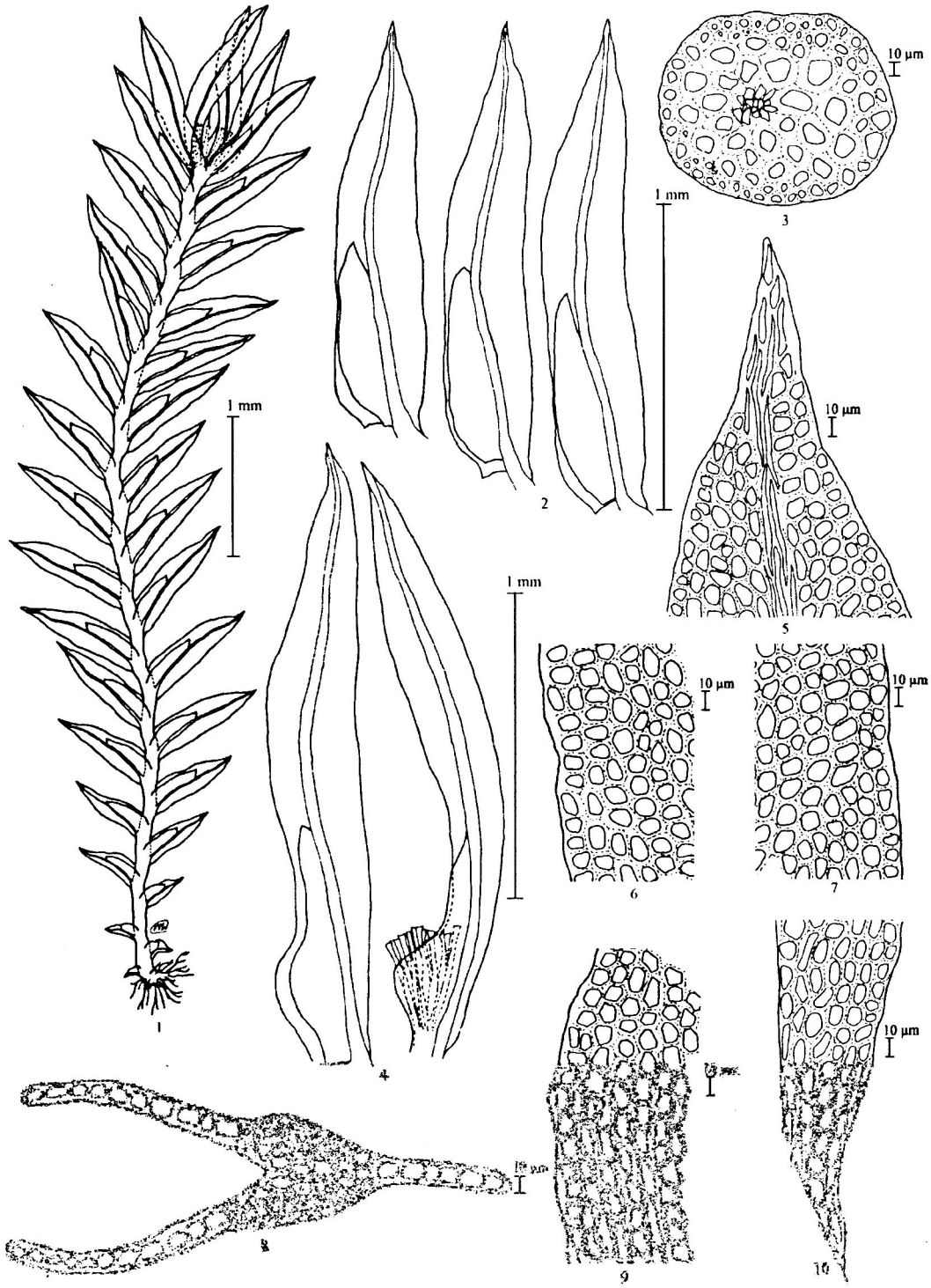
sporophytes: February-July

Distribution—(Figure 110) India, Sri Lanka, Taiwan, Japan, Malaysia, Singapore, Java, Sumatra Philippines, New Guinea, Australia.

Distribution in Thailand—(Figure 71D) Loei: Phu Luang Wildlife Sanctuary. Rayong: Khao Cha Mao-Khao Wong National Park, Khao Khitchakut National Park. Chanthaburi: Nam Tok Phlieo National Park Nakhon Nayok: Khao Yai National Park. Phetchaburi: Kaeng Krachan National Park Kanchanaburi: Thong Pha Phum National Park Ranong: Nam Tok Ngao National Park. Nakhon Sri Thammarat: Khao Nan National Park. Phang-nga: Sri Phang-nga National Park

Specimens studied—(PSU, gametophyte) Chantanaorrapint 2116, (CMU, gametophyte) Wongkuna 530A, 554, 1142, 1402, 1408, 1500, 1511, 1531, 1593, 1631, 1664, 1787, 1788, 1789, 1871, 1873; (CMU, gametophyte and sporophyte) Wongkuna 260, 1401, 1512, 1663, 1683, 1811, 1827, 1830, 1831, 1833, 1880; (BKF, gametophyte) Touw 8309, 11187.

This species is closely allied to *F. pellucidus* Hornsch., but the leaf shape, inflorescence, and the nature of laminal cells distinguish them. The costa is excurrent and the leaf cells are distinctly thick-walled in *F. pellucidus*.



Figrue 25. *Fissidens crassinervis* Sande Lac.
1: plant habit. 2: leaves. 3: cross section of stem. 4: perichaetial leaves and perichaetial leaves with archegonia. 5: leaf apex. 6: apical lamina cells. 7: dorsal lamina cells. 8: cross section of leaf. 9: vaginant lamina cells. 10: leaf base cells. Drawn from Wongkuna 530A.

9. ***Fissidens crenulatus*** Mitt., Musc. Ind. Orient. (1859) 140.
Gangulee (1971) 504 (fig.), 505 (map).
Li and Iwatsuki (2001) 21 (map), 23 (plate+fig.), 24 (including extra-Thai synonyms)
Fissidens virens Thwait & Mitt. J. Lin. Soc., Bot. 13 (1873) 324. Li and Iwatsuki (2001) 21 (map), 23 (plate+fig.), 24, *pro syn.*
Fissidens semperfalcatus Dix., J. Siam. Soc. Nat. Hist. Suppl. 10 (1935) 2.; Eddy (1988) 79, *pro syn.*
Fissidens papillulosus Broth., Bot. Tidsskr. 24; (1901) 63., Wongkuna *et al.* (2009) 308, *pro syn.*
var. ***crenulatus***

Plants 4-6 mm tall, green, usually unbranced; hyaline nodules not differentiated; central strand lacking; leaves 12-30, densely arranged, lowest leaves small, middle to upper leaves larger, lanceolate, 1-1.3 mm long, 2-2.5 mm wide, perichaetial leaves only slightly longer and narrower; apex acute (45-55°), base slightly narrowed, margins crenulate; costa percurrent or very shortly excurrent; vaginant lamina half of leaf length, limbidium half to as along as vaginant lamina, in 2-4 rows of cells, one cell thick; lamina cells 6.0-9.0 μm diameter, irregularly quadrate-hexagonal, pellucid with slightly thickened walls, highly mamamillose, at times with 1-2 papilla. Autoicous, archegonia terminal, 0.1 mm long; perichaetial leaves similar to other leaves. Sporophtye terminal; seta smooth, 3-5 mm long; capsules erect and symmetrical, 3-5 mm long.

Illustrations: Figures 26 and 130A

Habitat: on soil and rocks, in shaded places

Ecology: deciduous dipterocarp-oak forest at 60-850 m elevation; mixed evergreen+deciduous seasonal hardwood forest, 850-1000 m elevation, and primary, evergreen, seasonal, hardwood forest 1000-1650 m elevation; granite, sandstone and limestone bedrock.

Phenology—gametophytes: February-December
sporophytes: March-October

Distribution—(Figure 111) Nepal (type), India, Sri Lanka, China, Taiwan, Hong Kong, Japan, Myanmar, Vietnam, Malaysia, Java, Philippines, New Guinea, Australia.

Distribution in Thailand—(Figure 72A) Chiang Mai: Doi Suthep-Pui National Park, Pha Daeng National Park, Chiang Dao Wildlife Sanctuary. Loei: Phu Luang Wildlife Sanctuary. Ubon Ratchathani: Pha Taem National Park. Rayong: Khao Cha Mao- Khao Wong National Park, Khao Khitchakut National Park. Chanthaburi: Nam Tok Phlieo National Park. Nakhon Nayok: Khao Yai National Park. Phetchaburi: Kaeng Krachan National Park. Kanchanaburi: Thong Pha Phum National Park. Ranong: Nam Tok Ngao National Park. Nakhon Sri Thammarat: Khao Nan National Park Krabi: Phanom Bencha National Park

Specimens studied—(PSU, gametophyte) Chantanaorrapint 1031, 1105; (CMU, gametophyte) Wongkuna 405B, 553, 612B, 689, 849A, 850A, 860A, 1148, 1482C, 1483B, 1495, 1610, 1651, 1726, 1728, 1852; (CMU, gametophyte and sporophyte) Wongkuna 173, 181A, 685, 825, 1149, 1305, 1449, 1464, 1604, 1634,

1641, 1666, 1667, 1720, 1797, 1798; (BKF) Touw 8040, 8255, 9415, 122275, 12395, 12415.

This species is very closely related to *Fissidens semperfalcatus* Dix. and *F. crenulatus* Mitt. var. *elmeri* (Broth.) Z. Iwats. & Suzuki by having similar apical and dorsal laminae cells which are quadrate to polygonal, thin walled, unipapillose, and leaf margins slightly serrulate. The limbidea is confined to the vaginant lamina. The distinctions of *Fissidens semperfalcatus* and *F. crenulatus* var. *elmeri* and *F. crenulatus* var. *crenulatus* are listed below:

character	*F. crenulatus* var. *crenulatus*	*F. crenulatus* var. *elmeri*	*F. semperfalcatus*
1. Limbidia	confined to half of the vaginant lamina and present on all leaves	confined to half of the vaginant lamina and present on perichaetial leaves	all to above of the vaginant lamina and present on all of leaves
2. Costa	percurrent or very shortly excurrent	ending below apex	shortly excurrent
3. Leaf shape	oblong- lanceolate	oblong- lanceolate	narrowly lanceolate
4. Tip of apex	acute	acute	narrowly acute
5. Sporophyte	terminal	terminal	terminal and lateral

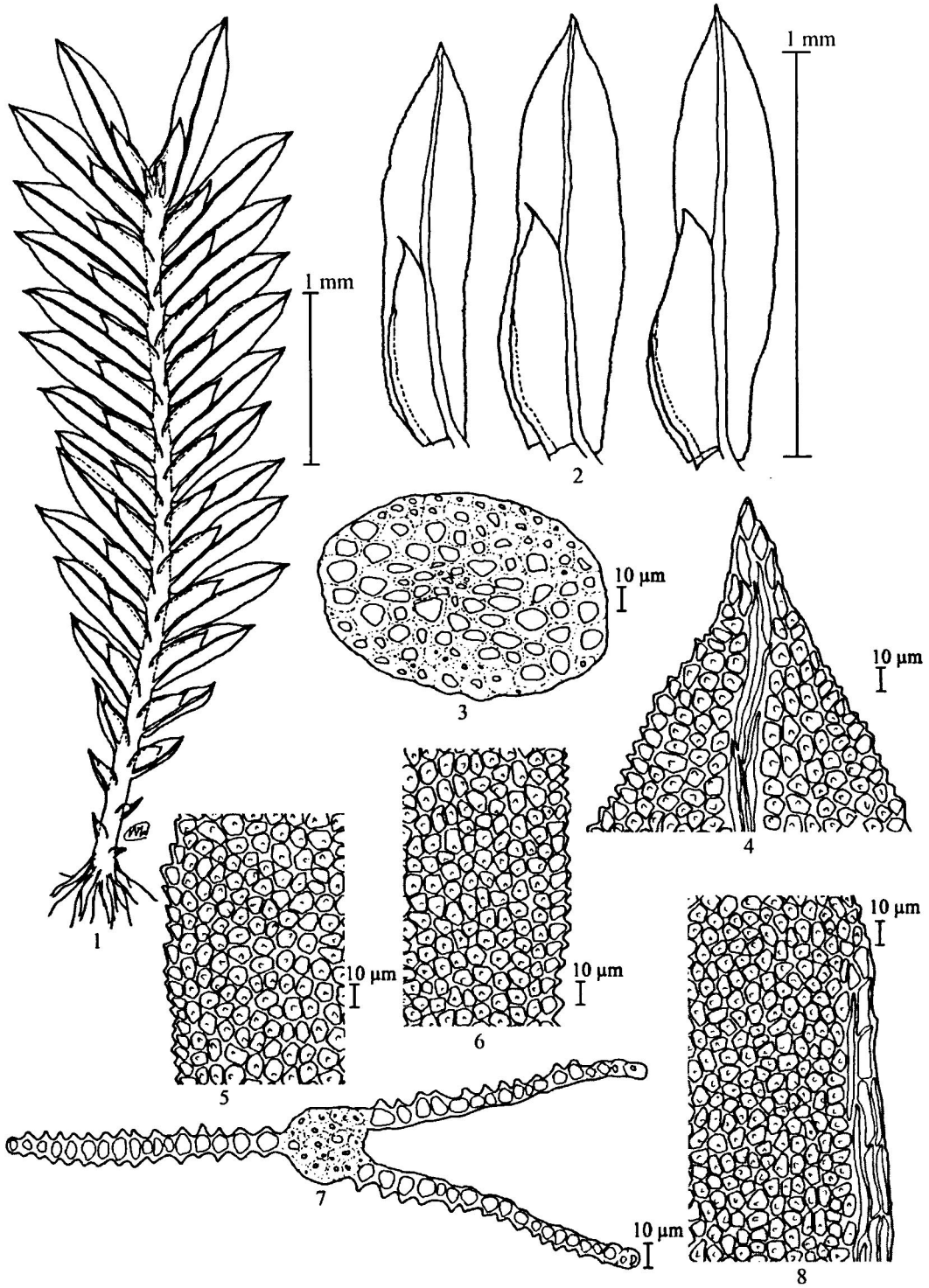


Figure 26. *Fissidens crenulatus* Mitt. var. *crenulatus*
1: plant habit. 2: leaves. 3: cross section of stem. 4: leaf apex. 5: apical lamina cells. 6: dorsal lamina cells. 7: cross section of leaf. 8: vaginant lamina cells. Drawn from Wongkuna 553.

10. ***Fissidens crenulatus*** Mitt. var. ***elmeri*** (Broth.) Z. Iwats. & T. Suzuki, J. Hattori Bot. Lab. 51 (1982) 343.

Fissidens elmeri Broth., Leafl. Philip. Bot. 2 (1909) 652., Z, Iwats. & Suzuki (1982) 386, 469 (fig.), *pro. syn.*

Plants 3-5 mm tall, 1.5-2 mm wide, green to dark green, simple; hyaline nodules not differentiated; central strand indistinct; stems densely foliated leaves 12-18; upper leaves lanceolate to oblong-lanceolate, 0.6-0.8 mm long, 0.2-0.3 mm wide, perichaetial leaves much larger than median and lower leaves, apex acute, rounded to cuneate at base, not decurent; margins crenulate; limbidia none or weak on varginant lamina, restricted to lower half of margin of vaginant laminae of perichaetial leaves, 1-2 rows of hyaline, elongate, smooth cells; costa ending below apex; vaginant lamina 1/2 -2/3 leaf length, cells of apical lamina orbicular-hexagonal to orbicular-quadrate, with a prominent mammillae, usually 6.0-9.0 μm diameter, cell walls thin; Dioicous, Sporophyte terminal; setae 0.8-1.3 mm long, smooth; capsules ureolate, erect and symmetrical; 0.3-0.6 mm long; operculum rostrate, 0.4-0.5 mm long.

Illustrations: Figures 27 and 130B

Habitat: on soil and on base of trees

Ecology: primary, evergreen, seasonal, hardwood forest; granite bedrock, 1250-2565 m elevation.

Phenology—gametophytes: February-November
sporophytes: March-June

Distribution—(Figure 85) Taiwan, Japan, Vietnam, Malaysia, Singapore, Philippines.

Distribution in Thailand—(Figure 72B) Chiang Mai: Doi Inthanon National Park. Phitsanulok: Phu Hin Rong Kla National Park. Nakhon Sri Thammarat: Khao Nan National Park.

Specimens studied—(CMU, gametophyte) Wongkuna 720B, 923, 1055, 1067B, 1430, 1431, 1436, 1439, (CMU, gametophyte and sporophyte) Wongkuna 1404, 1405, 1406A, 1440, 1441, 1447, 1448.

This variety is characterized by having laminal cells each with one prominent papilla and the costa ending below the leaf apex.

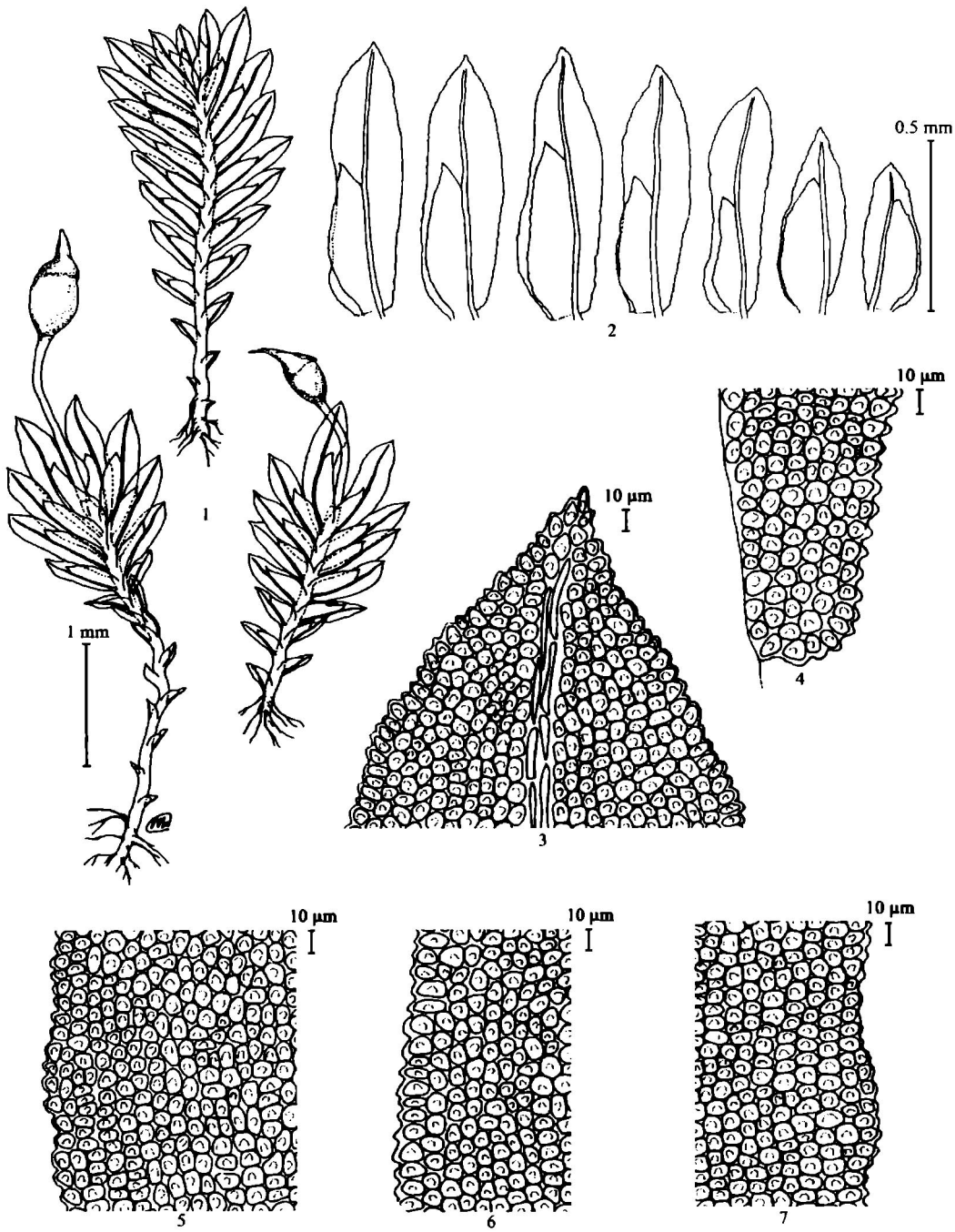


Figure 27. *Fissidens crenulatus* Mitt. var. *elmeri* (Broth.) Z. Iwats. *et* T. Suzuki 1: plant habit with sporophyte. 2: leaves. 3: leaf apex. 4: leaf base cells. 5: apical lamina cells. 6: dorsal lamina cells. 7: vaginant lamina cells. Drawn from Wongkuna 1405.

11. ***Fissidens crispulus*** Brid. var. ***crispulus*** Musc. Rec. Suppl. 4 (1819) 187.

Fissidens sylvaticus Griff. var. *zippelianus* (Dozy & Molk.) Gangulee (1971) 537 (fig.), 538; Iwatsuki and Suzuki (1982) 477 (fig.), 505 (map); Li & Iwatsuki (2001) 25 (map), *pro syn.*.

Fissidens zippelianus Dozy & Molk., Syst. Verzeichn. (1854) 29., Iwatsuki & Suzuki (1982) 398, 477 (fig.); (1854) 29; Eddy (1988) 73, 74 (fig.), *pro syn.*.

Fissidens zippelianus Dozy & Molk. var. fontanus (Fleisch.) Grosy & Rich. Forma *minar* Giosy & Rich., Tan & Iwatsuki (1993), *pro syn.*

Plants 3-4 mm tall, 2.5-3 mm wide, green, unbranched, hyaline nodules well-differentiated; central strand lacking; leaves 12-20, lanceolate, 1.5-1.8 mm long, 0.2-0.3 mm wide, apex acute, base slightly decurrent, margins slightly crenulate, without limbidia; costa ending below apex to percurrent; lamina cells thin-walled, polygonal, mammillose, about 5-7 μm in diameter; vaginant lamina half to more than 1/2 leaf length, cells of vaginant laminae-similar to those of other leaves, distinctly crisped when dry, Autoecious and usually fertile. Sporophyte terminal; seta smooth, 4-5 mm long; capsules erect, cylindrical, symmetrical, 0.4-0.5 mm long.

Illustrations: Figures 28 and 130C

Habitat: on soil in shade or by streams in more open places

Ecology: deciduous diterocarp-oak forest 60-850 m elevation; mixed evergreen+deciduous, seasonal, hardwood forest 850 to 1000 m elevation, and primary, evergreen, seasonal, hardwood forest 1000-2565 m; granite, sandstone, and limestone bedrocks.

Phenology—gametophytes: February-December
sporophytes: June-December

Distribution—(Figure 117) India, Sri Lanka, Nepal, China, Taiwan, Hong Kong, Japan, Cambodia, Myanmar, Vietnam, Malaysia, Singapore, Java, Sumatra, Philippines, New Guinea, Australia, Central African Cameroon, Repubic, Chad, Comoros, Eritrea, Ethiopia, Fernando Po, Gabon, Ivory Coast, Kenya, Madagascar, Malawi, Mauritius, Nigeria, Reunion, Rio Muni, Rodrigues, Rwanda, Seychelles, Sierra Leone, Sudan, Tanzania, Togo, Vganda, Zaire, Zambia, Zimbabwe.

Distribution in Thailand—(Figure 72C) Chiang Mai: Doi Inthanon National Park. Pitsanulok: Phu Hin Rong Kla National Park. Loei: Phu Kradung National Park and Phu Luang Wildlife Sanctuary. Khon Kaen: Phu Kao-Phu Phan Kham National Park. Sakon Nakhon: Phu Phan National Park. Chaiyaphum: Tat Ton National Park. Chanthaburi: Nam Tok Phlieo National Park. Nakhon Nayok: Khao Yai National Park. Phetchaburi: Kaeng Krachan National Park. Kanchanaburi: Thong Pha Phum National Park. Nakhon Sri Thammarat: Khao Nan National Park.

Specimens studied—(CMU, gametophyte) Wongkuna 189, 235, 236, 239, 244, 245, 247, 248, 250, 251, 252, 253, 256, 257, 259, 261, 263, 264, 265, 267, 268, 272, 273, 275, 278, 279, 280, 316, 317, 318, 320, 322, 323, 324, 325, 326, 331, 338B, 343, 371, 468, 480, 510, 515, 523, 524, 536, 544, 557, 559, 564, 567, 569, 570, 572, 575, 576, 577, 580, 582, 587, 589, 593, 597, 598, 600, 606, 607, 622, 690, 691, 700, 701, 839, 840, 864, 990, 1001, 1003, 1006, 1038, 1039, 1040B, 1041A, 1043, 1063, 1065, 1068, 1146, 1147, 1172, 1174A, 1118, 1220B, 1222, 1227, 1236, 1238, 1263,

1273, 1274, 1275, 1283, 1284, 1374, 1385, 1400, 1411, 1419B 1422, 1565, 1584, 1598, 1602, 1613, 1615, 1621, 1668, 1678, 1680, 1685, 1727, 1738, 1748, 1752, 1753, 1755, 1757, 1758, 1762, 1763, 1767, 1769, 1778, 1779, 1792, 1802, 1828, 1832B, 1851, 1856, 1858, 1859, 1862, 1863, 1872, 1875, 1878, 1887, 1890, 1896, 1899; (CMU, gameophyte and sporophyte) Wongkuna 230, 232, 233, 237, 249, 254, 255, 337, 375, 520, 526, 537, 540, 563, 578, 596, 652, 680, 687, 820, 847, 985, 993, 1045, 1222, 1229, 1389, 1585, 1751, 1799, 1874A; (BKF) Richards 28502, 28503, Robbin 3563, Touw 3537, 8392, 9461, 12416, 12210, 12351, 10852.

The distinguishing characters of this variety are the strongly developed hyaline nodules on the stem, mammillose laminal cells no limbate and margins slightly crenulate, and costa ending below apex to percurrent.

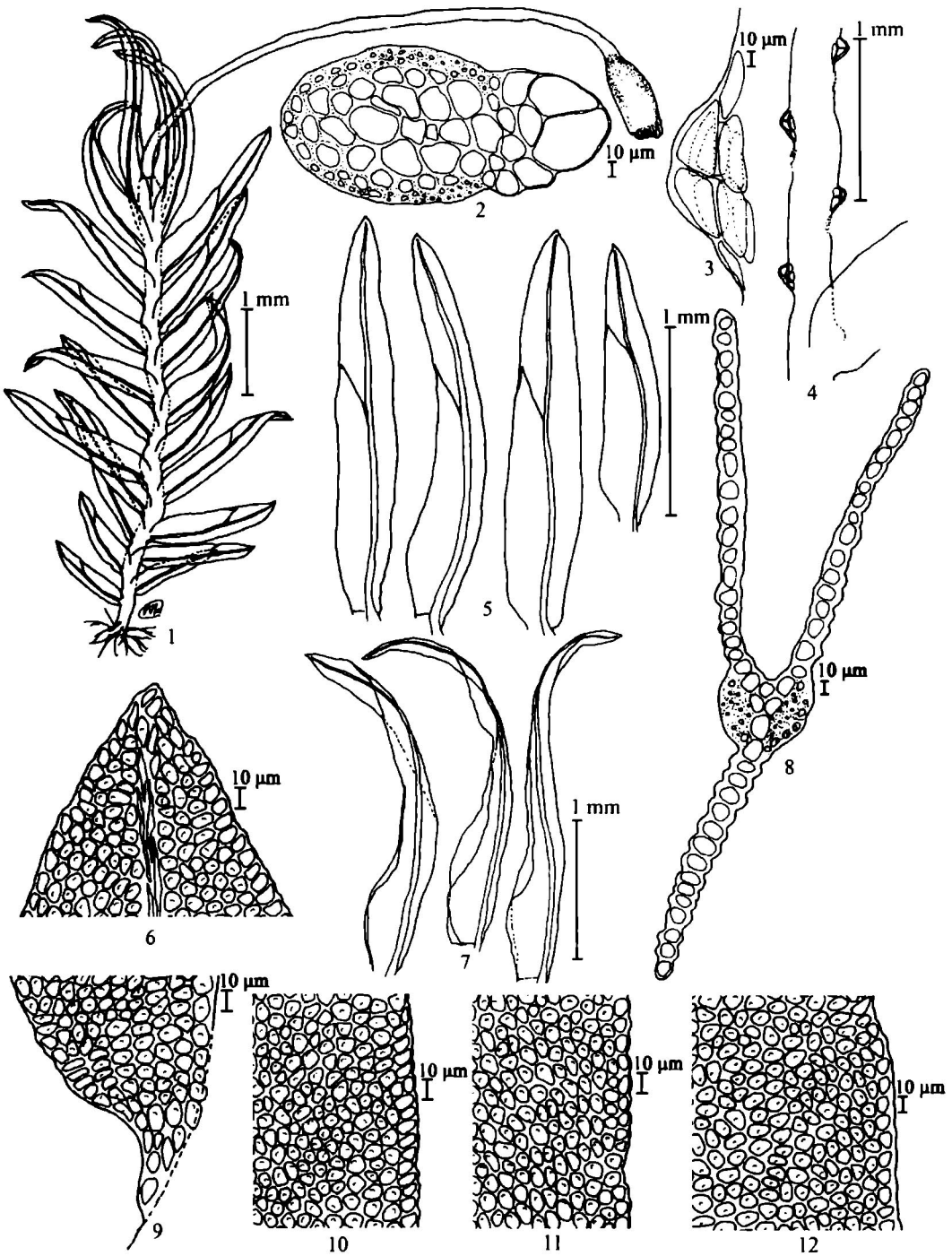


Figure 28. *Fissidens crispulus* Brid. var. *crispulus*
1: plant with sporophyte. 2: cross section of stem. 3: hyaline nodules. 4: hyaline nodules on stem. 5: leaves. 6: leaf apex. 7: perichaetial leaves. 8: cross section of leaf. 9: leaf base cells. 10: apical lamina cells. 11: dorsal lamina cells. 12: vaginant lamina cells. Drawn from Wongkuna 337.

12. ***Fissidens crispulus*** Brid. var. ***robinsonii*** (Broth.) Z. Iwats. & Z. H. Li, (2001) 26, 27 (fig.).

basionym=*Fissidens robinsonii* Broth., Philip. Journ. Sci. 63 (1939) 21.

Iwatsuki and Mohamed (1987) 354, 355 (fig.).

Li and Iwatsuki (2001) 25, 26 (map), 27 (plate+ fig.).

Fissidens zippelianus Dozy & Molk. var. *robinsonii* (Broth.) Z. Iwatsuki & Suzuki., J. Hattori. Bot. Lab 67 (1989) 289.

Plants up to 5 mm tall, 2-2.5 mm wide, green; stem unbrached, hyaline nodules well-differentiated; central strand lacking; leaves 16-24, distinctly crisped when dry, narrowly lanceolate (especially the sub-perichaetial), 1.3-2.0 mm long, 0.2-0.3 mm wide, apex acute, base slightly decurrent, margins slightly crenulate, without limbate; costa excurrent; lamina cells thin-walled, polygonal, mammillose, about 5-10 μm diameter; vaginant lamina more than 1/2 leaf length, cells of vaginant lamina similar to those of other leaves. Autoicous and usually fertile. Sporophyte terminal, seta smooth, 4-5 mm long; capsule cylindrical, erect, symmetrical, 0.4-0.5 mm long.

Illustrations: Figures 29 and 130D

Habitat: on bare soils in shaded areas

Ecology: deciduous dipterocarp-oak forest 90-850 m elevation, mixed evergreen+deciduous, seasonal, hardwood forest at 850-1000 m elevation, and primary, evergreen, seasonal, hardwood forest at 1000-1800 m, granite, bedrock

Phenology—gametophytes: March-November

sporophytes: March-September

Distribution—(Figure 86) India, China, Hong Kong, Malaysia, Singapore, Indonesia, Philippines.

Distribution in Thailand—(Figure 72D) Chiang Mai: Doi Suthep-Pui National Park, Pha Daeng National Park, Chiang Dao Wildlife Sanctuary. Suphanburi: Phu-Toei National Park. Nakhon Nayok: Khao Yai National Park. Phetchaburi: Kaeng Krachan National Park. Ranong: Nam Tok Ngao National Park. Nakhon Sri Thammarat: Khao Nan National Park. Krabi: Phanom Bencha National Park

Specimens studied—(CMU, gametophyte) Wongkuna 188, 241, 243, 410, 411, 452, 453, 458, 459, 460, 463, 465, 467, 471, 476, 493, 496, 498, 499, 513, 517, 521, 547, 620, 621, 632, 637, 808, 826, 828, 834, 841, 842, 843, 844, 848, 851, 859, 861, 863, 1360, 1390, 1538, 1568, 1773, 1774, 1775, 1813, 1889 (CMU, gametophyte and sporophyte) Wongkuna 455, 456, 464, 479, 481, 511, 512, 634, 638, 639, 640, 672, 829, 830

Fissidens crispulus var. *robinsonii* mainly differs from *F. crispulus* Brid. var. *crispulus* by having more acuminate leaf apices with excurrent costae.

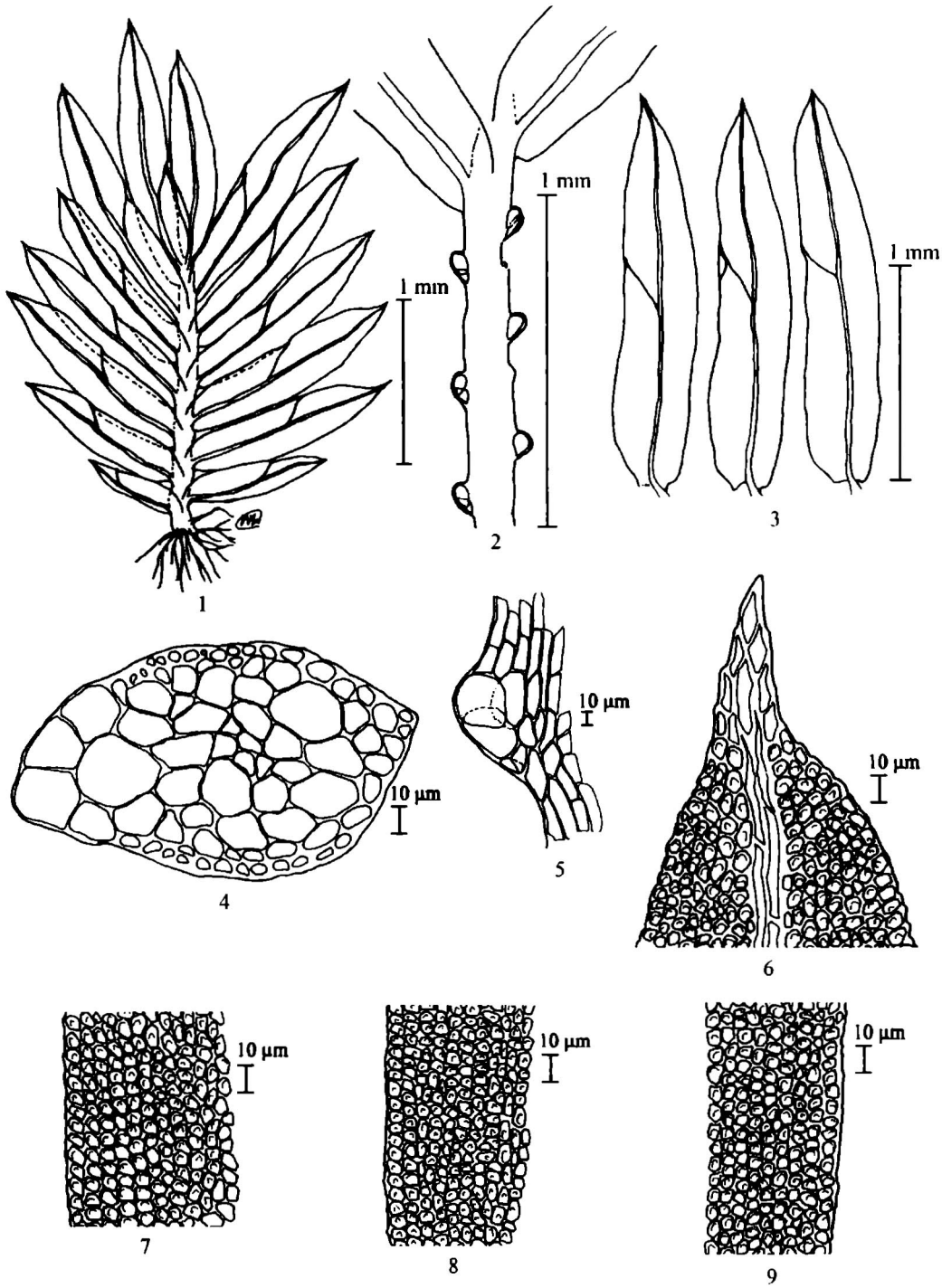


Figure 29. *Fissidens crispulus* Brid. var. *robinsonii* (Broth.) Z. Iwats. & Z. H. Li
1: plant habit. 2: hyaline nodules on stem. 3: leaves. 4: cross section of stem. 5: hyaline nodules. 6: leaf apex. 7: vaginant lamina cells. 8: apical lamina cells. 9: dorsal lamina cells. Drawn from Wongkuna 410.

13. ***Fissidens filiformis*** Z. Iwats., Mem. New York Bot. Gard. 45 (1987) 635.

Plants mostly 20-30 mm tall, 0.6-0.8 mm wide, yellowish-green, to yellowish brown when dry; stem simple, very rarely branched, hyaline nodules not differentiated; rhizoids present; central strand lacking; laxly foliate leaves 100-140, ovate, 0.3-0.5 mm long, 0.15-0.2 mm wide, broad-acute apex, base rounded, not decurrent; margins slightly crenulate, without limbate; costa percurrent; lamina cells thin-walled, quadrate to irregularly hexagonal, about 5-6 μm diameter, mostly with 4 minute papillae per cell; vaginant lamina 2/3 leaf length, cells of vaginant lamina similar to those of other leaves. No sexual organs, sporophyte seen.

Illustrations: Figures 30 and 131A
Habitat: on soil
Ecology: primary, evergreen, seasonal, hardwood with pine forest, 1200-1300 m elevation, granite bedrock
Phenology—gametophyte: February
Distribution—(Figure 103) Thailand (holotype)
Distribution in Thailand—(Figure 73A) Loei: Phu Kradung National Park,
Specimen studied—Kurokawa 4176 (TNS, gametophyte, holotype)

This species is recognized by being 20-30 mm tall, hyaline nodules not differentiated, ovate leaves, multipapillose laminal cells, and percurrent costa.

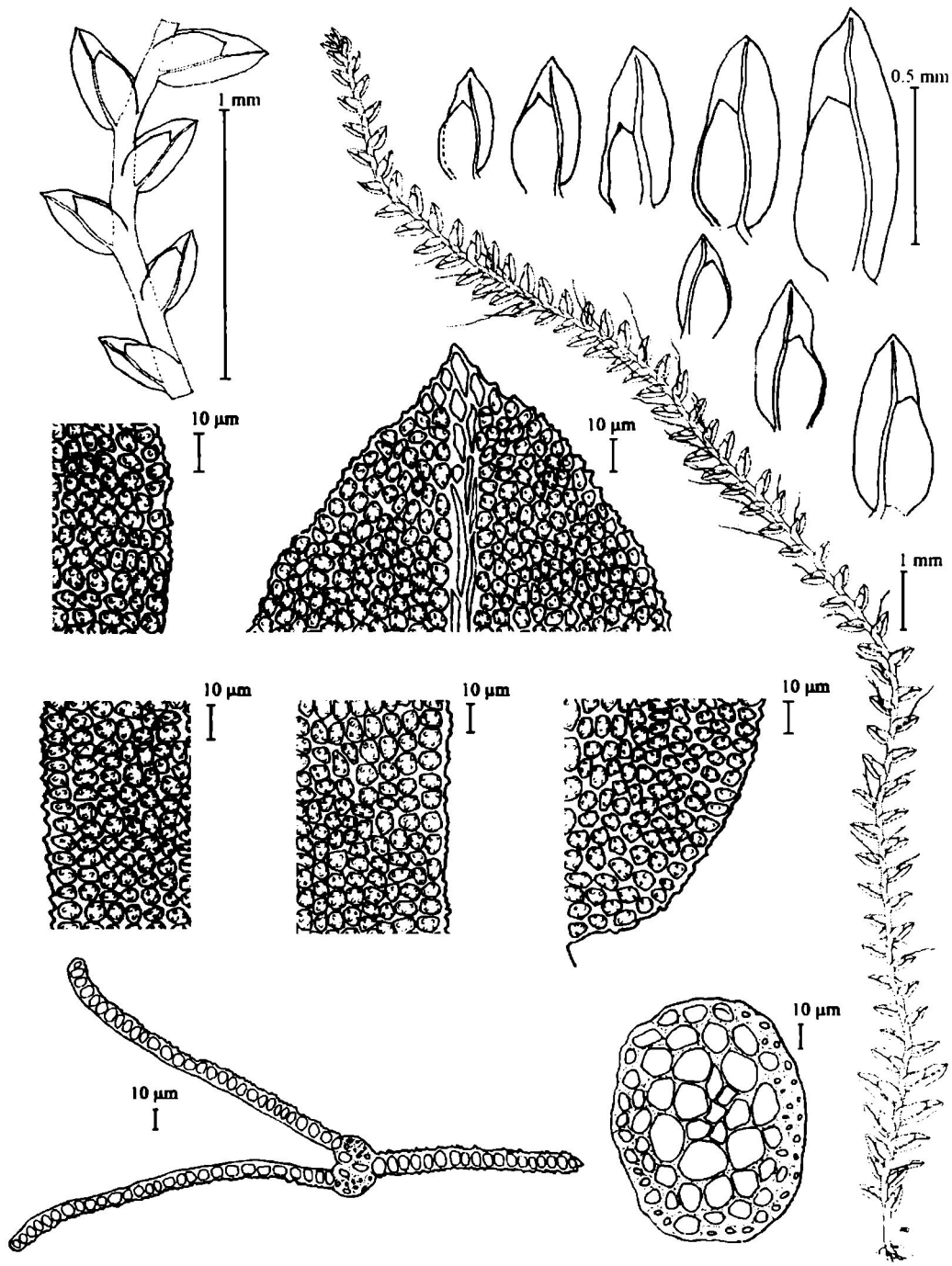


Figure 30. *Fissidens filiformis* Z. Iwats.
1: part of plant. 2: plant habit. 3: leaves. 4: apical lamina cells. 5: leaf apex. 6: dorsal lamina cells. 7: vaginant lamina cells. 8: leaf base cells. 9: cross section of leaf. 10: cross-section of stem. Drawn from Kurokawa 4176 (holotype).

14. ***Fissidens firmus*** Mitt., J. Linn. Soc. Bot. supp 1 (1859) 139.
Iwatsuki and Mohamed (1987) 349 (fig.) 350.

Plants 6-10 mm tall, 1.5-2 mm wide, green to dark green, stem simple; hyaline nodules not differentiated; without a central strand; stems more or less densely foliated, leaves 30-36, upper leaves lanceolate, 1.6-1.8 mm long, 0.4-0.5 mm wide, perichaetial leaves smaller than upper and median leaves, apex acute, base sligthly decurent; margin weakly crenulate; costa ending below apex; vaginant lamina 2/3-3/5 leaf length, cells of apical lamina orbicular-hexagonal to orbicular-quadrate, smooth, usually 6-9 μm diameter, cell walls thin; limbidia found usually on half of vaginant laminae, with 4-5 rows of hyaline, elongate, smooth cells. Dioicous. Sporophyte terminal; setae 2-2.3 mm long, rough; capsules cylindrical, erect, symmetrical; 0.6-0.8 mm long; operculum rostrate, 0.5 mm long.

Illustrations: Figures 31 and 131B

Habitat: on wet rocks in streams and waterfalls

Ecology: deciduous dipterocarp-oak forest 60-850 m elevation; mixed evergreen+deciduous seasonal hardwood forest 850-1000 m elevation; and primary, evergreen, seasonal, hardwood forest 1000-1800 m; granite bedrock

Phenology—gametophytes: June-December
sporophytes: June-September

Distribution—(Figure 104) India, Sri Lanka, Malaysia.

Distribution in Thailand—(Figure 73B) Phitsanulok: Phu Hin Rong Kla National Park. Loei: Phu Kradung National Park, Phu Luang Wildlife Sanctuary. Khon Kaen: Phu Kao-Phu Phan Kham National Park. Sakon Nakhon: Phu Phan National Park. Chaiyaphum: Tat Ton National Park. Rayong: Khao Cha Mao-Khao Wong National Park. Chanthaburi: Nam Tok Phlieo National Park. Nakhon Nayok: Khao Yai National Park. Ranong: Nam Tok Ngao National Park

Specimens studied—(CMU, gametophyte) Kornochalert 585; (CMU, gametophyte and sporophyte) Wongkuna 535, 558, 1059, 1122, 1175, 1241, 1262, 1392, 1393, 1394, 1395, 1596, 1614, 1616, 1630, 1681, 1742, 1780, 1781, 1782, 1866, 1877, 1897; (BKF) Touw 11094, 12336.

This species is 6-10 mm long, the limbate is limited on the vaginant lamina; costa percurrent; sporophyte terminal on stem, and rough seta 2-3 mm long.

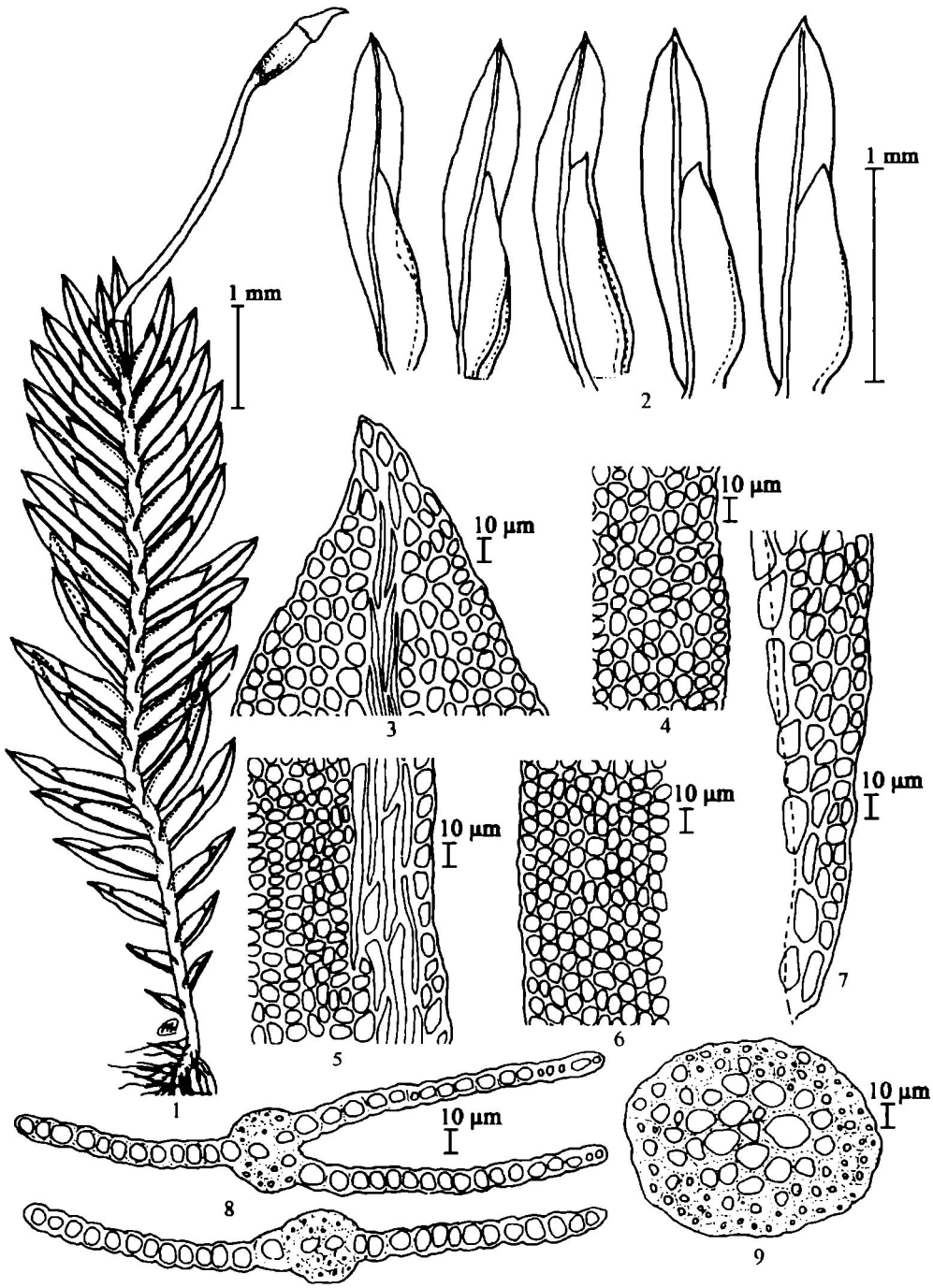


Figure 31. *Fissidens firmus* Mitt.
1: plant with sporophyte. 2: leaves. 3: leaf apex. 4: dorsal lamina cells. 5: vaginant lamina cells. 4: apical lamina cells. 7: leaf base cells. 8: cross section of leaf. 9: cross section of stem. Drawn from Wongkuna 535.

15. ***Fissidens flabellulus*** Thwait. & Mitt., J. Linn. Soc. Bot. 13 (1873) 324.
Iwatsuki and Suzuki (1982) 397-398, 476 (fig.), 505 (map).
Li and Iwatsuki (2001) 29 (plate+fig.), 30 (map), 31.

Plants 3-4 mm long, 1.6-2 mm wide, stem simple to rarely branched, axillary hyaline nodules not differentiated; central strand lacking; leaves 12-16 pairs; upper leaves lanceolate to narrowly lanceolate, 1-1.3 mm long, 0.2-0.3 mm wide, apex acute (45-55°), base slightly decurrent; margin distinctly serrate; costa percurrent; vaginant laminae less than 1/2 of leaf-length; apical lamina cells polygonal, 10-15 μm long, smooth, thin-walled; upper part of vaginant lamina cells similar to those of the apical lamina. Autoicous; male inflorescences often terminal; archegonia terminal, 160-170 μm long. Sporophyte not seen.

Illustrations: Figures 32 and 131C
Habitat: on soils in shaded areas
Ecology: primary, evergreen, seasonal, hardwood forest 1000-2565 m elevation, granite, bedrocks
Phenology—gametophyte: December
Distribution—(Figure 112) China, Taiwan, Japan, Sri Lanka (type), Papua New Guinea, Australia.
New record for Thailand.
Distribution in Thailand—(Figure 73C) Chiang Mai: Doi Inthanon National Park
Specimen studied—(CMU, gametophyte) Wongkuna 782A.

This species has lanceolate leaves with apex acute, costa ending below leaf apex, and lamina base slightly decurrent. The leaf margins are serrulate elimbate. The leaf cells are quadrate to polygonal, thin-walled, and smooth.

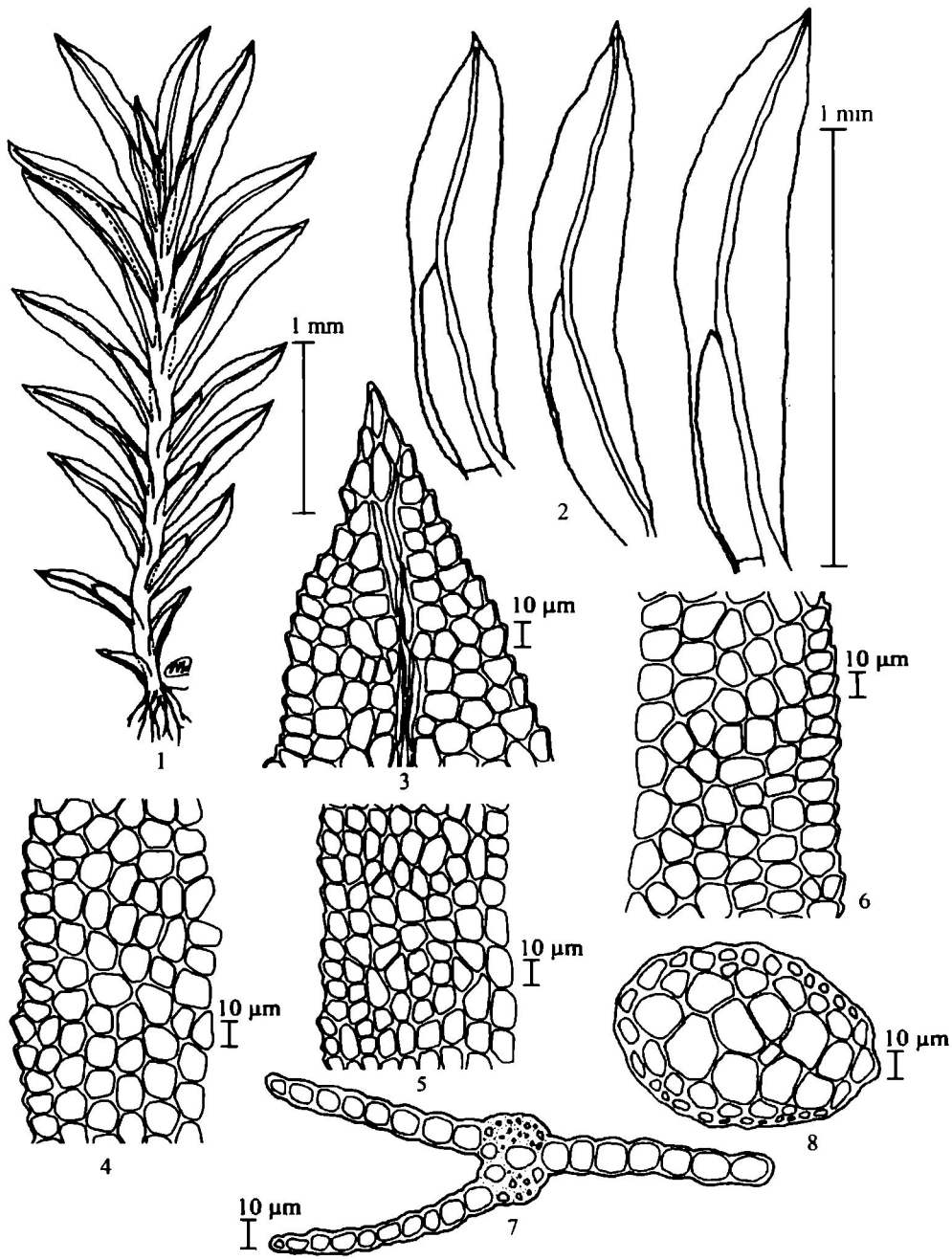


Figure 32. *Fissidens flabellulus* Thwait. & Mitt.
1: plant habit. 2: leaves. 3: leaf apex. 4: apical lamina cells. 5: vaginant lamina cells. 6: dorsal lamina cells. 7: cross section of leaf. 8: cross section of stem. Drawn from Wongkuna 782A.

16. ***Fissidens flaccidus*** Mitt., Trans. Linn. Soc. London 23 (1860) 56.
Li and Iwatsuki (2001) 31, 32 (map).
var. ***flaccidus***

Plants up to 8 mm long, 1.5-3.0 mm wide, pale green, lower part brownish; stem usually simple; hyaline nodules and central strand not differentiated; stems densely foliated, leaves 20-30; lowest leaves small, upper leaves much larger, lanceolate, 1.6-2.4 mm long, 2.5-3 mm wide, apex acute, base not decurrent, margin entire, limbidia distinct, present on vaginant apical and dorsal laminae, consisting of 2-3 rows of narrow and thick-walled cells, borders of vaginant laminae thicker, consisting 2-4 rows of linear cells; costa ending 6-9 cells below the apex; vaginant lamina about half of leaf length; cells of apical lamina irregularly rectangular and similar to dorsal lamina, 25-40 μ long, 13-15 μ wide, smooth, thin-walled; cells of vaginant lamina, rectangular, up to 60 μ long, smooth. Dioicous; terminal archegonia often present, 0.2-0.25 mm long; gemmae elongate, consisting of several cells, often found in leaf-axils, 0.15-0.2 mm long.

Illustrations: Figures 33 and 131D

Habitat: on soil in shaded areas

Ecology: deciduous diptercarp-oak seasonal hardwood forest, 30-850 m elevation; mixed evergreen+deciduous, seasonal, hardwood forest, 850-1000 m elevation; and primary, evergreen, seasonal, hardwood forest 1000-2565 m elevation, granite, bedrock.

Phenology—gametophytes: June-October
sporophytes: June-August

Distribution—(Figure 121) India, Nepal, Sri Lanka, Taiwan, Hong Kong, Japan, Myanmar, Vietnam, Malaysia, Singapore, Philippines, Borneo, Java, New Guinea, Fiji, Argentina, Bolivia, Colombia, Costa Rica, Cuba, Dominican Repubic, Ecuador, French Guiana, Haiti Jamaica, Mexico, Netherland Antilles, Peru, Rodrigues, Saint Kitts, Nevis, Saint Lucia, Seychelles, Sierra Leone, Venezuela, Cape Verde, Central African Repubic, Nigeria, Zimbabwe.

New record for Thailand.

Distribution in Thailand—(Figure 73D) Chiang Mai: Doi Inthanon National Park, Doi Suthep-Pui National Park, Chiang Dao Wildlife Sanctuary. Sakon Nakhon: Phu Phan National Park. Rayong: Khao Cha Mao-Khao Wong National Park, Khao Khitchakut National Park. Nakhon Nayok: Khao Yai National Park. Phetchaburi: Kaeng Krachan National Park. Krabi: Phanom Bencha National Park

Specimens studied—(CMU, gametophyte) Wongkuna 163, 166, 178, 180, 183, 187, 350, 359, 361A, 362, 364B, 367, 376, 405A, 409A, 508A, 653B, 994, 1450, 1453, 1457A, 1459, 1472, 1537, 1540, 1542, 1543, 1544, 1556, 1597, 1619, 1623, 1764, 1791, 1793, 1817B, 1821B, 1825, 1826B; (CMU, gametophyte and sporophyte) Wongkuna 167, 1011, 1620.

The lamina cells of this species are large, rectangular to ovate-oblong, smooth, thin-walled, 25-40 μm long, and 13-15 μm wide. The cells of the vaginant lamina are elongate and up to 60 μm long. The leaf margins are entire and limbate all around, and the costa ends below the apex. The hyaline nodules are not differentiated.

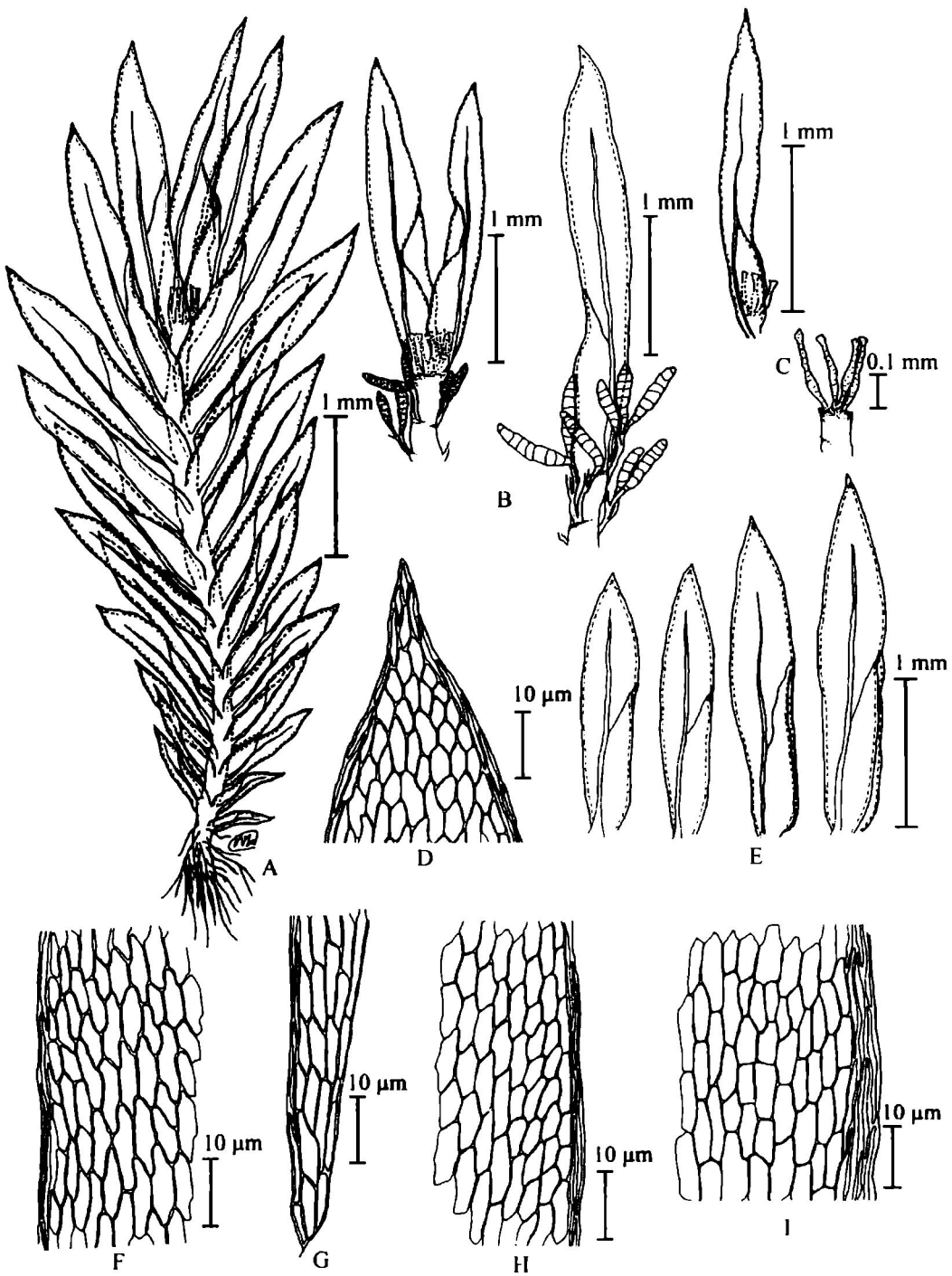


Figure 33. *Fissidens flaccidus* Mitt. var. *flaccidus*
1: plant habit. 2: plant with sex organs and gemma. 3: perichaetial leaf with archegonia. 4: archegonia. 5: leaf apex. 6: leaves. 7: apical lamina cells. 8: leaf base cells. 9: dorsal lamina cells. 10: vaginant lamina cells. Drawn from Wongkuna 362.

17. ***Fissidens flaccidus*** Mitt. var. ***percurrens*** K. Wongkuna, *var. nov.*

A varietae flaccidus, foliis 10-24 costis percurrentibus differt.
Holotype: Thailand, Chantaburi Province, Pliew Falls, Lam Sing District; primary, evergreen, seasonal, hardwood forest, granite bedrock, 300 m elev. 3 July 2009, Wongkuna 1894 (CMU), *isotpyes* L, SING.
Paratypes

Nakorn Nayok, Kow Yai National Park, Dong Tiew, 780 m 23 June 2009, Wongkuna 1675 (CMU, L, SING)

Chantaburi, Pliew Falls, Lam Sing District, 320 m, 3 July 2009, Wongkuna 1879 (CMU, L, SING), topotype

Kanchanaburi, Thong Pha Phum National Park, 15 Oct. 2005, 200 m, Chantanaorrapint 1104 (PSU)

Plants up to 4 mm tall, 2-2.5 mm wide pale green; stem usually simple; hyaline nodules and central strand not differentiated; densely foliated, leaves 10-14; lowest leaves small, upper leaves much larger, lanceolate, 1.5-2 mm long, 2.5-3 mm wide, apex acute, base acute, margin entire, limbidia present on apical part of the vaginant lamina and dorsal laminae, consisting of 2-3 rows of narrow and thick-walled cells, limbidia of vaginant lamina thicker, consisting of 2-4 rows of linear cells; vaginant lamina about half of leaf-length; costa percurrent; cells of apical lamina irregularly rectangular and similar to dorsal lamina, 25-40 µm long, 13-15 µm wide, smooth, thin-walled; cells of vaginant lamina, rectangular, up to 50 µ long, smooth. Sporophyte not seen.

Illustrations: Figures 34 and 132A

Habitat: on soil in shaded places near waterfalls.

Ecology: deciduous diptercarp-oak forest, 120 - 780 m elevation, granite bedrock

Phenology—gametophytes: June-October

Distribution—(Figure 105)

Distribution in Thailand—(Figure 74A) Chanthaburi: Nam Tok Phlieo National Park. Nakhon Nayok: Khao Yai National Park.

Specimens studied—(CMU, gametophyte) Wongkuna 1675, 1772, 1879, 1894 (holotype, CMU)

This variety differs from var. *flaccidus* by having 10-14 leaves with percurrent costa.

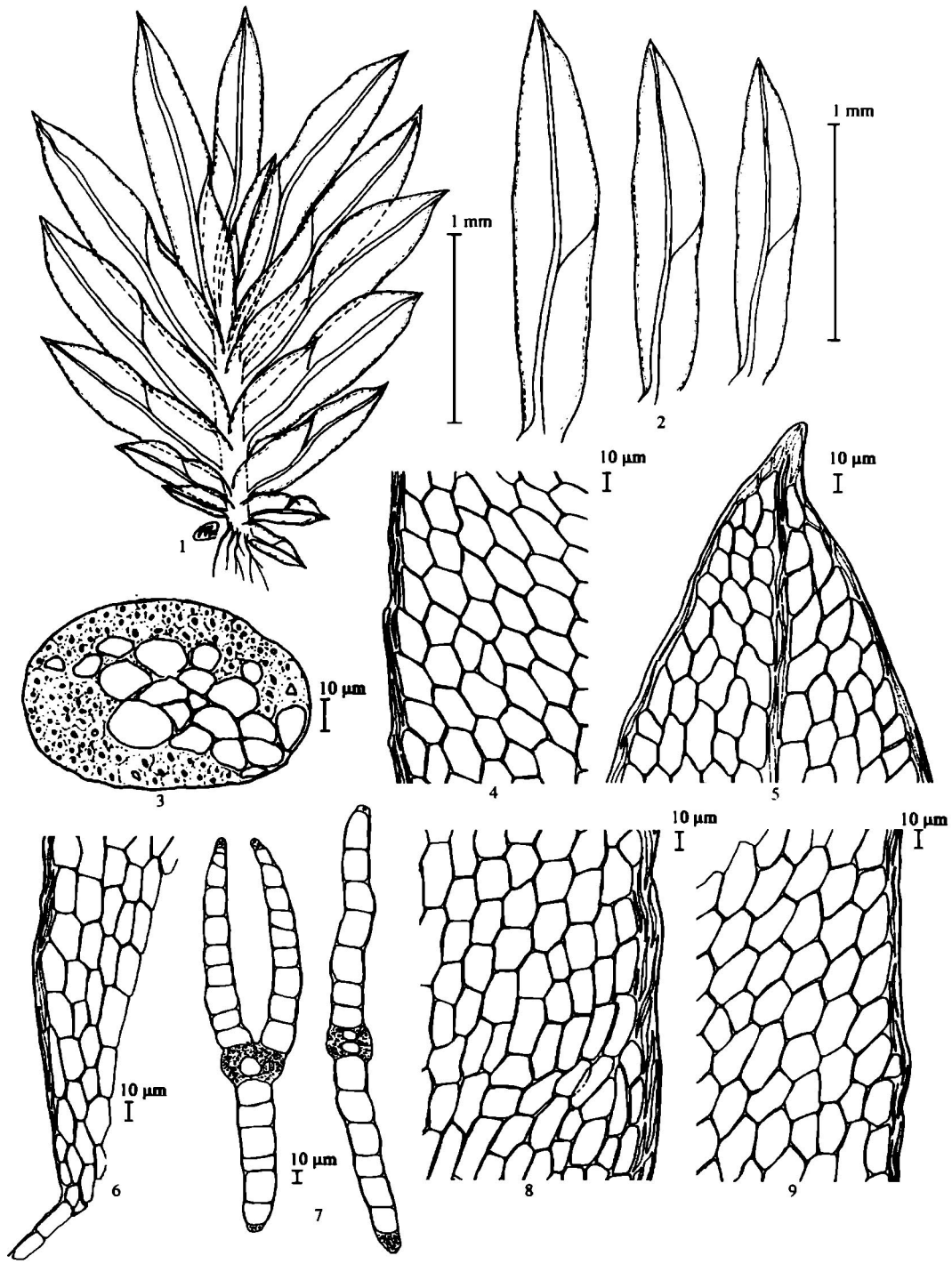


Figure 34. *Fissidens flaccidus* Mitt. var. *percurrens* K. Wongkuna
1: plant habit. 2: leaves. 3: cross section on stem. 4: apical lamina cells. 5: leaf apex. 6: leaf base cells. 7: cross section on leaves. 8: vaginant lamina cells. 9: dorsal lamina cells. Drawn from Wongkuna 1894 (holotype).

18. ***Fissidens gardneri*** Mitt., J. Linn. Soc. Bot. 12 (1869) 593.
Li and Iwatsuki (2001) 32, 33 (map).
Iwatsuki and Suzuki (1982) 377-381, 465 (fig.) 504 (map).
Fissidens microcladus Thwait. & Mitt., J. Linn. Soc. Bot. 13 (1873) 323., Eddy (1988) 92; Li and Iwatsuki (2001) 32, 33 (map), *pro syn.*.

Plants up to 3 mm long, green to dark green; stem usually simple; hyaline nodules and central strand not differentiated; leaves 10-28, densely arranged, lowest ones small; middle to upper leaves much larger, oblong-lanceolate, 0.3-1.5 mm long, 0.3-0.4 mm wide, apex obtuse to broadly acute (80-90°), rarely acute in perichaetial leaves, base not decurrent, margin serrulate, with minute papillae, limbidia only on lower half of vaginant laminae of upper and perichaetial leaves, composed of hyaline, elongate, smooth cells in 2-5 rows; costa distinct, ending more than 10 cells below the apex, costa about 5/6 of leaf length; vaginant lamina about half to 2/3 of leaf-length; cells of apical lamina quadrate to hexagonal, 5 μm diameter, walls thin to thick, obscure, with several large papillae each cell 1 μm long; cells of dorsal and vaginant lamina similar to those of the upper ones; perichaetial leaves longer than other leaves, limbidium present. Archegonia terminal 2.5-3 mm long. Sporophyte terminal, seta 2-2.2 mm long, smooth, mature capsules not seen.

Illustrations: Figures 35 and 132B
Habitat: on soil and tree bark
Ecology: deciduous dipterocarp-oak seasonal, hardwood forest, 30-850 m elevation; mixed evergreen+deciduous seasonal hardwood forest, 850-1000 m elevation; and primary, evergreen, seasonal, hardwood forest, 1000-2565 m granite bedrock and sometimes villages
Phenology—gametophytes: March-December
sporophtyes: March-December
Distribution—(Figure 122) Nepal, India, Sri Lanka, China, Taiwan, Japan, Hong Kong, Myanmar, Laos, Vietnam, Malaysia, Philippines, Borneo, Java, Sumatra, Papua New Guinea, Australia, Costa Rica, French Guiana, United States, Venezuela, Central African Repubic, Guinea, Ivory Coast, Mozambique, Nigeria, Senegal, Tanzania and Togo
Distribution in Thailand—(Figure 74B) Chiang Mai: Doi Inthanon National Park, Chiang Dao Wildlife Sanctuary. Phitsanulok: Phu Hin Rong Kla National Park. Loei: Phu Kradung National Park. Sakon Nakhon: Phu Phan National Park. Ubon Ratchathani: Pha Taem National Park. Rayong: Khao Cha Mao-Khao Wong National Park. Chanthaburi: Nam Tok Phlieo National Park. Phetchaburi: Kaeng Krachan National Park. Kanchanaburi: Thong Pha Phum National Park.
Specimens studied—(PSU, gametophyte) Chantonroraprint 1126. (CMU, gametophyte); Wongkuna 177, 179, 270B, 387, 391, 393, 398, 401, 785, 852, 853, 1363, 1458, 1502, 1519, 1525, 1536, 1551, 1553, 1554, 1555, 1560, 1790, 1853; (CMU, gametophyte and sporophyte) Wongkuna 309, 661, 857, 858, 1352, 1549, 1550; (BKF) Touw 9187, 9562.

The species has leaves which are oblong-lanceolate, apex broadly acute, and the costa ends far below the apex. The margins are serrulate and limbidia are

differentiated or not. The leaf cells are quadrate to polygonal, thin-walled, and multipapilose. The perichaetial leaves are longer than those of other leaves and limbidia.

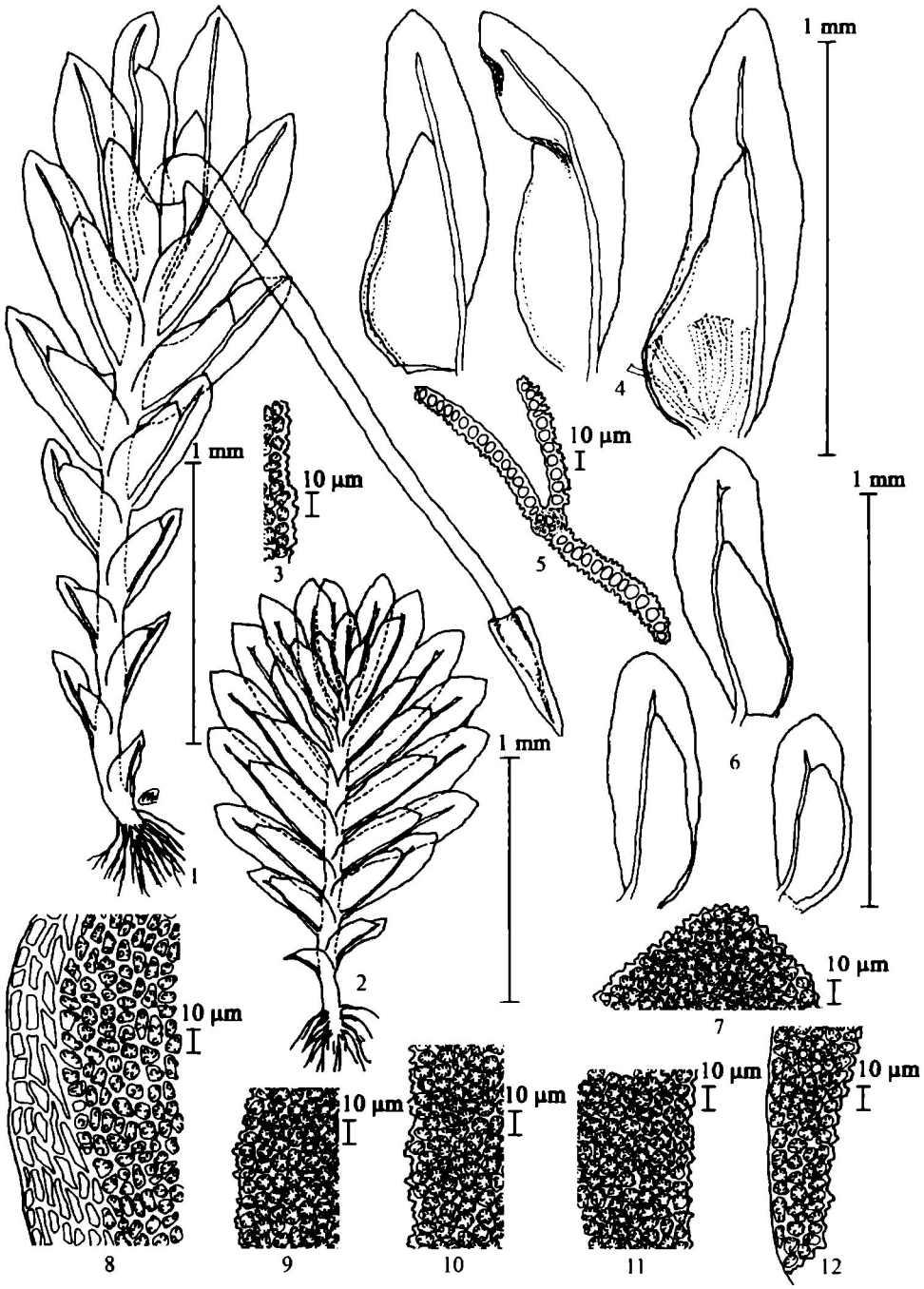


Figure 35. *Fissidens gardneri* Mitt.
1: plant with sporophyte. 2: plant habit. 3: margin of leaf. 4: perichaetial leaves. 5: cross-section of leaf. 6: leaves. 7: leaf apex. 8: margin of perichaetial leaf showing limbidium. 9: apical lamina cells. 10: vaginant lamina cells. 11: dorsal lamina cells. 12: leaf base cells. Drawn from Wongkuna 661.

19. ***Fissidens geminiflorus*** Dozy & Molk., Pl. Jungh. (1854) 316.

Iwatsuki and Mohamed (1987) 359.

Eddy (1988) 73 (fig.), 74.

Iwatsuki and Suzuki (1982) 421-424 (including extra-Thai synonyms) 495 (fig.), 508 (map).

Li and Iwatsuki (2001) 33 (map), 34 (including extra-Thai synonyms) (plate+fig.).

Plants up to 2.5 cm long, 2-2.3 mm wide, yellow-green; stem usually simple; hyaline nodules and central strand not differentiated; leaves 50-60, not densely arranged, laxly arranged in lower part; lowest leaves small, middle to upper leaves much larger, lanceolate to narrowly-lanceolate, 2-2.3 mm long, 0.3-0.4 mm wide, apex acute, base decurrent, margin slightly crenulate; limbidia not differentiated; costa ending below apex; vaginant lamina about half of leaf length; lamina cells smooth, cells of leaf apical similar to those on dorsal lamina, quadrate to orbicular-hexagonal, 5-6 μm diameter, thin-walled, cells on both sides of costa from middle to apex distinctly elongate; cells of vaginant lamina similar to those of the lamina. Sporophyte not seen.

Illustrations: Figures 36 and 132C

Habitat: on wet rocks in waterfalls

Ecology: mixed evergreen+deciduous, seasonal, hardwood forest *c.*700 m elevation

Phenology—gametophytes: June-July

Distribution—(Figure 87) China, Hong Kong, Taiwan, Japan, Bangladesh, Vietnam, Malaysia, Philippines, Java, Sumatra, Papua, New Guinea.

New record for Thailand.

Distribution in Thailand—(Figure 74C) Chiang Mai: Doi Suthep-Pui National Park.

Specimens studied—(CMU, gametophyte) Porompa 3, Narin 2576; (BKF) Touw 12219, 12220

This species is recognized by being more than 1.5 cm long. The hyaline nodules are slightly differentiated and the leaves are lanceolate to narrowly-lanceolate, apex acute, leaf base decurrent, and costa ending below the apex. The surface cells on both sides of costa from middle to apex are distinctly elongate.

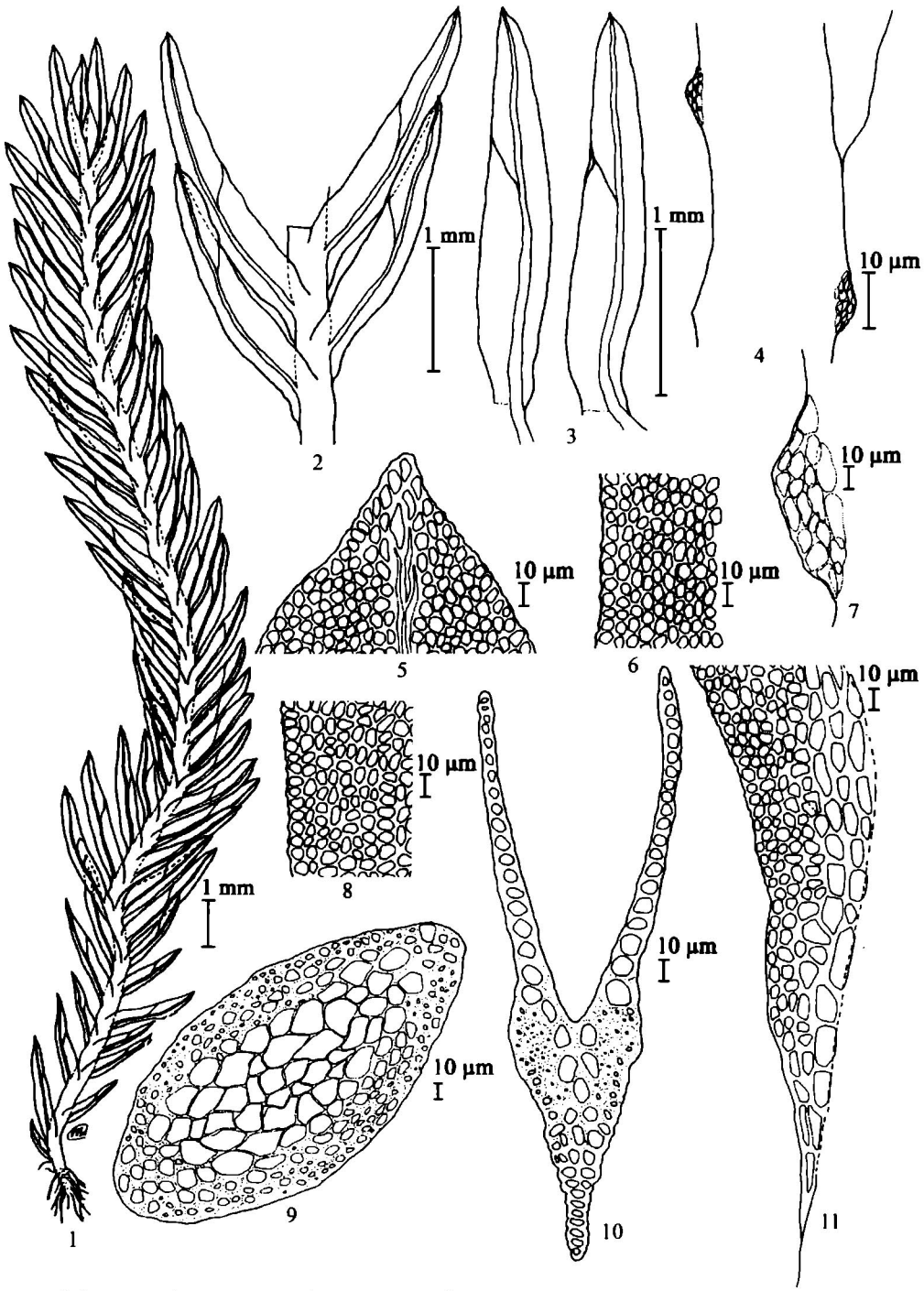


Figure 36. *Fissidens geminiflorus* Dozy & Molk.
1: plant habit. 2: part of stem. 3: leaves. 4: hyaline nodules on stem. 5: leaf apex. 6: apical lamina cells. 7: hyaline nodules. 8: dorsal lamina cells. 9: cross section of stem. 9: cross section of leaf. 11: leaf base cells. Drawn from Porompa 3.

20. ***Fissidens geppii*** Fleisch., Musci Fl. Buitenz. 1 (1904) 26.

Iwatsuki and Suzuki (1982) 365-367 (including extra-Thai synonyms), 458 (fig.), 503 (map).

Eddy (1988) 92 (fig.).

Li and Iwatsuki (2001) 35-36 (map).

Plants 5-9 mm long, 1.5-2 mm wide, light to dark green; stems erect, central strand indistinct and cortical stem-cells small and thick-walled; axillary hyaline nodules not differentiated; leaves 18-26, upper leaves narrowly lanceolate to lanceolate, 1.6-2 mm long, 0.4-0.5 mm wide, apex acute, base decurrent; costa prominent, reddish in older leaves, ending below apex or percurrent; margin entire; vaginant laminae about 1/2 of leaf-length; limbidia very thick, and broad, yellowish-brown on older leaves, 3-4 rows of cell wide, 2-3 layers thick in cross-section; usually 3-4 cells thick on dorsal lamina; limbidia on perichaetial leaves, with 3-7 rows of cells, 2-3 layer thick; cells in apical portion of lamina quadrate to irregularly hexagonal, 5-10 μm, thin-walled, smooth; cells of vaginant laminae similar to those of other leaves, laminane unistratose, perichaetial leaves narrowly and slightly longer than upper stem leaves or nearly equal. Synoicous. Sprophyte terminal, seta smooth, 3.5-4 mm long; capsules urnceolate, erect, sometimes very slightly asymmetrical, neck distinct, 0.4-0.8 mm long; operculum long, conic to rostellate, 0.3-0.4 mm long.

Illustrations: Figures 37 and 132D

Habitat: wet rocks, by a stream or submerged in streams, wet sides of water falls

Ecology: primary, evergreen, seasonal, hardwood forest; 1225-2565 m elevation, granite, bedrock

Phenology—gametophytes: August-October

sporophyte: August

Distribution—(Figure 88) India, Nepal, China, Taiwan, Hong Kong, Japan, Malaysia, Borneo, Java.

New record for Thailand.

Distribution in Thailand—(Figure 74D) Chiang Mai: Doi Inthanon National Park and Doi Suthep-Pui National Park.

Specimens studied—(CMU, gametophyte) Suchit 37/2, Wongkuna 933, 965, 967, 986, 989, 995.

The essential characters of this species are broad limbidia in apical and dorsal laminae, 3-4 rows of cells wide, 2-3 layers thick in cross-section of leaves. The costa ends below the apex to percurrent. The leaf cells are quadrate to irregularly hexagonal, more or less thick-walled, and smooth.



Figure 37. *Fissidens geppii* Fleisch.
1: plant habit with sporophytes. 2: leaves. 3: perichaetial leaves. 4: leaf apex. hyaline nodules on stem. 5: apical lamina cells. 6: vaginant lamina cells. 7: dorsal lamina cells. 8: leaf base cells. 9: cross section of leaf. 10: cross section of stem. Drawn from Suchit 37/2.

21. ***Fissidens guangdongensis*** Z. Iwats & Z. H. Li, Acta Bot. Fennica 129 (1985) 35.
Li and Iwatsuki (2001) 37, 36 (plate+fig.), 38 (map).

Plants up to 4 mm long, 1.8-2 mm wide, yellow-green to green; stem usually simple, sometimes branched; hyaline nodules none; leaves 8-12, densely arranged, lowest leaves small, middle and upper leaves much larger, lanceolate to oblong-lanceolate, 0.7-1.5 mm long, 0.4-0.5 mm wide, apex broadly acute (60-70°), base not decurrent, margin entire, without limbate; costa ending 5-8 cells below leaf apex; vaginant lamina about half to 2/3 of leaf length; cells of leaf apical similar to those on dorsal lamina, quadrate to polygonal, 10-15 μm diameter, thin-walled, smooth; cells of vaginant lamina similar to those of the lamina, but larger; perichaetial leaves longer and narrower than those of other leaves. Archegonia terminal, 0.2-0.3 mm long. Sporophytes terminal; seta 1-1.5 mm long, smooth; capsules cylindrical, erect, symmetrical, smooth, about 0.6-0.8 mm long; operculum rostrate, *c.* 0.5 mm long.

Illustrations: Figures 38 and 133A

Habitat: on soil and tree bark

Ecology: primary, evergreen, seasonal, hardwood forest; granite bedrock, 1250-2565 m elevation.

Phenology—gametophytes: June-December
sporophyte: December

Distribution—(Figure 89) China (type), Taiwan, Hong Kong, Japan, Malaysia, Singapore.

New record for Thailand.

Distribution in Thailand—(Figure 75A) Chiang Mai: Doi Inthanon National Park, Chiang Dao Wildlife Sanctuary. Phitsanulok: Phu Hin Rong Kla National Park. Nakhon Nayok: Khao Yai National Park.

Specimens studied—(CMU, gametophyte) Wongkuna 303, 310, 750A, 751, 759, 762, 783, 786A, 788, 791 898, 903, 906, 907, 908, 911A, 918, 920, 924, 925, 927, 930, 936, 937, 940, 944; (CMU, gametophyte and sporophyte) Wongkuna 756, 758, 784, 790A, 1599.

This species is recognized by having lanceolate to oblong-lanceolate leaves with an acute apex, and costa ending 5-8 cells below apex. The leaf margins are entire to slightly serrulate and not limbate. The leaf cells quadrate, polygonal, thin-walled, and smooth.

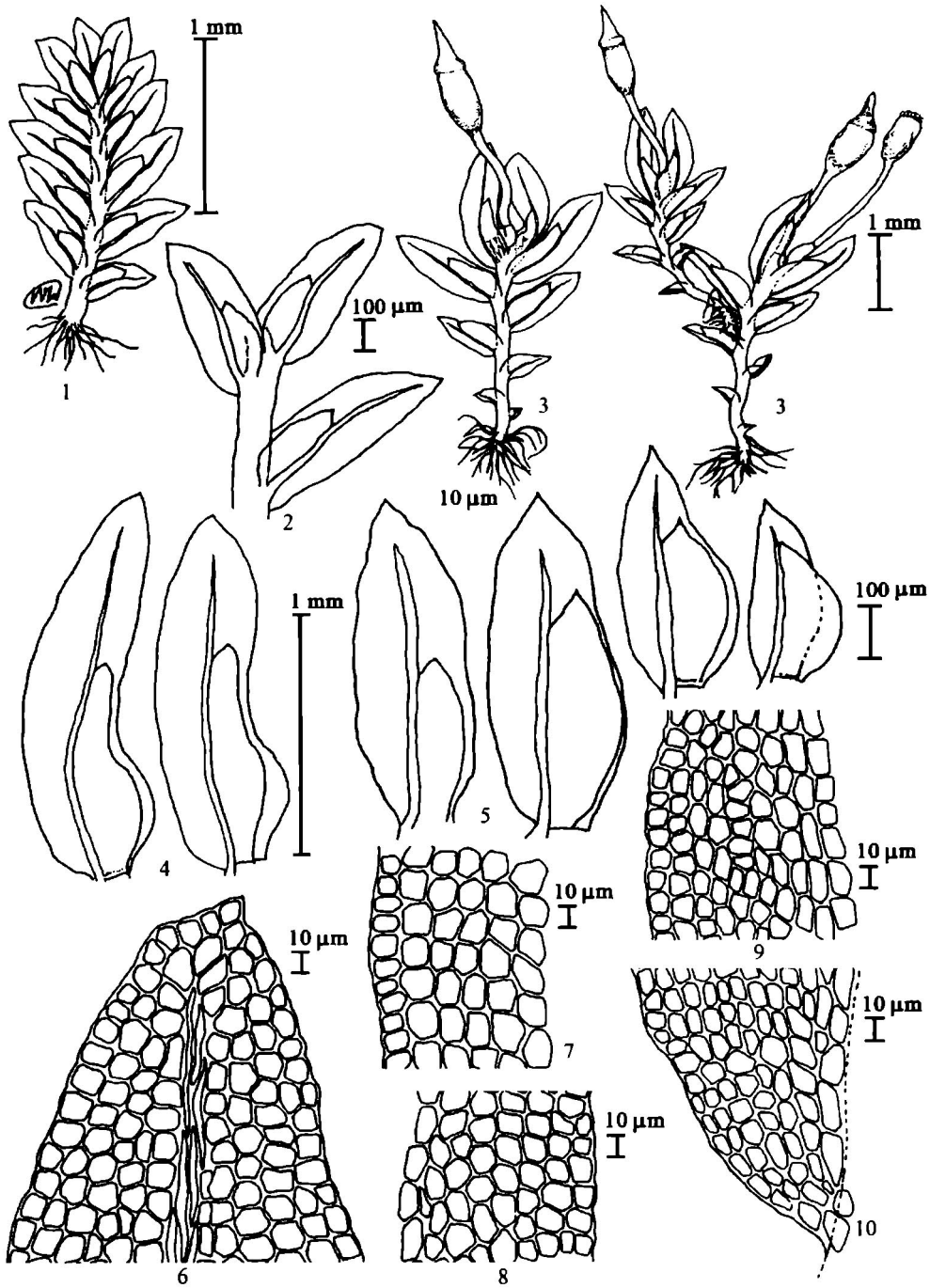


Figure 38. *Fissidens guangdongensis* Z. Iwats & Z. H. Li
1: plant habit. 2: part of stem. 3: plant with sporophyte. 4: perichaetial leaves. 5: leaves. 6: leaf apex. 7: apical lamina cells. 8: dorsal lamina cells. 9: vaginant lamina cells. 10: leaf base cells. Drawn from Wongkuna 787.

22. ***Fissidens gymnogynus*** Besch., J. de Bot. 12 (1898) 292.

Iwatsuki and Suzuki (1982) 405-407 (including extra-Thai synonyms) 482 (fig.), 506 (map).

Li and Iwatsuki (2001) 34 (plate+fig.), 38-39 (map).

Plants 6.0-13 mm long, 2.2-3 mm wide; yellowish-green to green, brownish when old; stems simple, rarely branched; axillary hyaline nodules not differentiated; cortical stem cells small and thick-walled, central strand not to weakly differentiated; leaves 16-32, densely arranged, distinctly crisped when dry; middle to upper leaves lanceolate to oblong-lanceolate, 1.3-1.8 mm long, 0.3-0.6 mm wide, apex acute to mucronate; base rounded or cuneate, weakly decurrent; margin serrulate to crenulate; costa stout, usually ending in a few cells below apex; vaginant lamina 1/2 of the leaf length; apical lamina cells hexagonal to round-hexagonal, 8-10 μm long, highly mammillose and obscure, walls thin; vaginant lamina cells similar to those of the lamina. Dioicous. Sporophyte terminal; seta smooth, 1.3-1.5 mm long, reddish-brown; capsules erect and symmetrical, cylindrical, 0.8-1.2 mm long; operculum long-rostrate, 0.8-1.0 mm long.

Illustrations: Figures 39 and 133B

Habitat: on soil and rocks (rare) in moist areas

Ecology: deciduous, seasonal, hardwood with bamboo forest and deciduous dipterocarp-oak forest at 300-850 m elevation; mixed evergreen+deciduous, seasonal, hardwood forest 850-1000 m elevation; and primary, evergreen, seasonal, hardwood forest 1000-2565 m, granite, bedrock.

Phenology—gametophytes: March-December
sporophytes: March-December

Distribution—(Figure 90) Pakistan, China, Hong Kong, Korea, Japan, peninsular Malaysia, Singapore, Philippines.

Distributions in Thailand—(Figure 75B) Chiang Mai: Doi Inthanon National Park, Chiang Dao Wildlife Sanctuary, and Suphanburi: Phu-Toei.

Specimens studied—(CMU, gametophyte) Wongkuna 231, 730, 769B, 790B; (CMU, gametophyte and sporophyte) 815, 822, 500, 711, 767, 889, 939, 942; (BKF) Touw 8949, 9248, 10144, 10248.

This species less than 1.5 cm long with ovate-lanceolate to lanceolate leaves, apex acute to mucronate, margins crenulate to slightly serrulate, without limbate, costa ceasing a few cells below apex, base of leaf cuneate; laminae cells hexagonal, thick-walled, mammillose, obscure; seta up to 1.5 mm long.

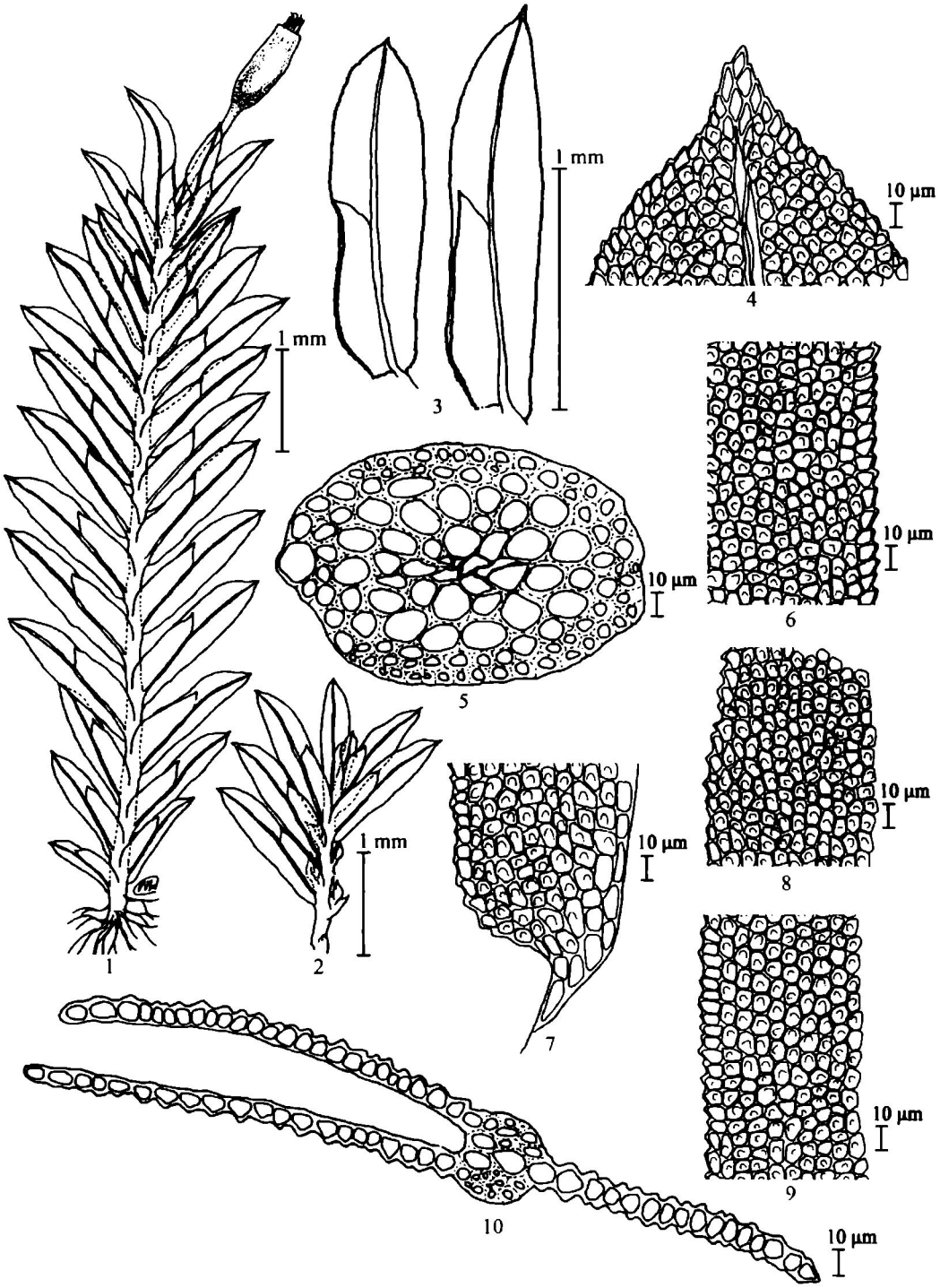


Figure 39. *Fissidens gymnogynus* Besch.
1: plant habit with sporophyte. 2: sex organs on stem 3: leaves. 4: leaf apex. 5: cross section of stem. 6: dorsal lamina cells. 7: leaf base cells. 8: apical lamina cells. 10: vaginant lamina cells. 10: cross section of leaf. Drawn from Wongkuna 711.

23. ***Fissidens hollianus*** Dozy & Molk., Bryologia Javanica 1 (1855) 4 and tab. 4.
Bartram (1939) 18 (plate+fig.).
Eddy (1988) 82 (fig.), 83-84.
Iwatsuki and Suzuki (1982) 381-384, 466 (fig.), 504 (map).
Iwatsuki and Mohamed (1987) 345.
Li and Iwatsuki (2001) 39, 40 (map).

Plants 4- 6 mm tall, 1.5-2.2 mm wide; stem simple; axillary hyaline nodules not differentiated; central strand indistinctly differentiated; densely and evenly foliated with 12-30 leaves, relatively uniform in size, lanceolate, 1.1-1.5 mm long, 0.3-0.4 mm wide; apex acute to broadly acute, base rounded to cuneate, not decurrent; vaginant laminae 1/2 of leaf length; margin crenulate; costa ending below apex to percurrent, rarely slightly excurrent; limbidia on vaginant laminae of most of leaves, composed of 2-4 rows of hyaline cells, one cell thick, elongate, smooth, thick-walled; lamina cells quadrate to hexagonal, 5-8 μm long, thin-walled, dark and obscure, pluripapillose with 4-6 papillae. Autoicous. Sporophyte terminal; seta distinctly roughened, 2-3 mm long; capsules cylindrical, 0.6-0.9 mm long, erect, almost symmetrical.

Illustrations: Figures 40 and 133C

Habitat: mostly on tree roots, sometimes on soil

Ecology: deciduous dipterocarp-oak seasonal hardwood forest 30-850 m elevation; mixed evergreen+deciduous seasonal hardwood forest 850-1000 m elevation; and primary, evergreen, seasonal, hardwood forest 1000-2500 m elevation, granite and sandstone bedrock, sometimes in disturbed sites.

Phenology—gametophytes: February-December
sporophytes: June-October

Distribution—(Figure 113) India, Nepal, Taiwan, Hong Kong, Japan, Myanmar, Vietnam, Cambodia, peninsular Malaysia, Borneo, Sumatra, Java, Philippines, New Guinea, Australia.

Distribution—(Figure 75C) Distribution in Thailand: Chiang Mai: Doi Inthanon National Park, Chiang Dao Wildlife Sanctuary. Rayong: Khao Cha Mao-Khao Wong National Park, Khao Khitchakut National Park. Chanthaburi: Nam Tok Phlieo National Park. Suphanburi: Phu-Toei National Park. Nakhon Nayok: Khao Yai National Park. Phetchaburi: Kaeng Krachan National Park. Prachuap Khiri Khan: Khao Yai National Park. Ranong: Nam Tok Ngao National Park. Nakhon Sri Thammarat: Khao Nan National. Park. Krabi: Phanom Bencha National Park.

Specimens studied—(BKF) Smitinand 1232, Tixier 658, Touw 8022, 8045, 9019, 9421, 10380, 11193, 11215, 11219, 12274, 12289; (CMU, gametophyte): Kornochalert 1068, Wongkuna 185, 200, 206, 207, 208, 209, 213, 214, 216, 217, 218, 221A, 616B, 619, 623, 626, 636, 748,1424, 1428, 1435, 1557, 1601, 1603, 1629, 1639, 1643, 1645, 1646, 1647, 1649, 1653, 1657, 1658, 1659, 1660, 1669, 1670, 1677, 1689, 1697, 1701, 1705, 1709, 1713, 1730, 1732, 1733, 1848, 1867, 1884, 1886, 1891, 1895; (CMU, gametophyte and sporophyte) Wongkuna 200, 208, 213, 214, 216, 217, 218, 630, 631, 633, 976A, 984, 1000, 1197, 1427, 1445, 1469, 1474, 1569, 1575, 1595A, 1605, 1608, 1609, 1612, 1617, 1618, 1624, 1628, 1638, 1640,

1642, 1644, 1648, 1652, 1655, 1671, 1672, 1674, 1686, 1693, 1694, 1700, 1731, 1740, 1743, 1785, 1815, 1829, 1885.

This species is related to *Fissidens ceylonensis* Dozy & Molk., but differs with the costa ending below apex to percurrent and rough seta.

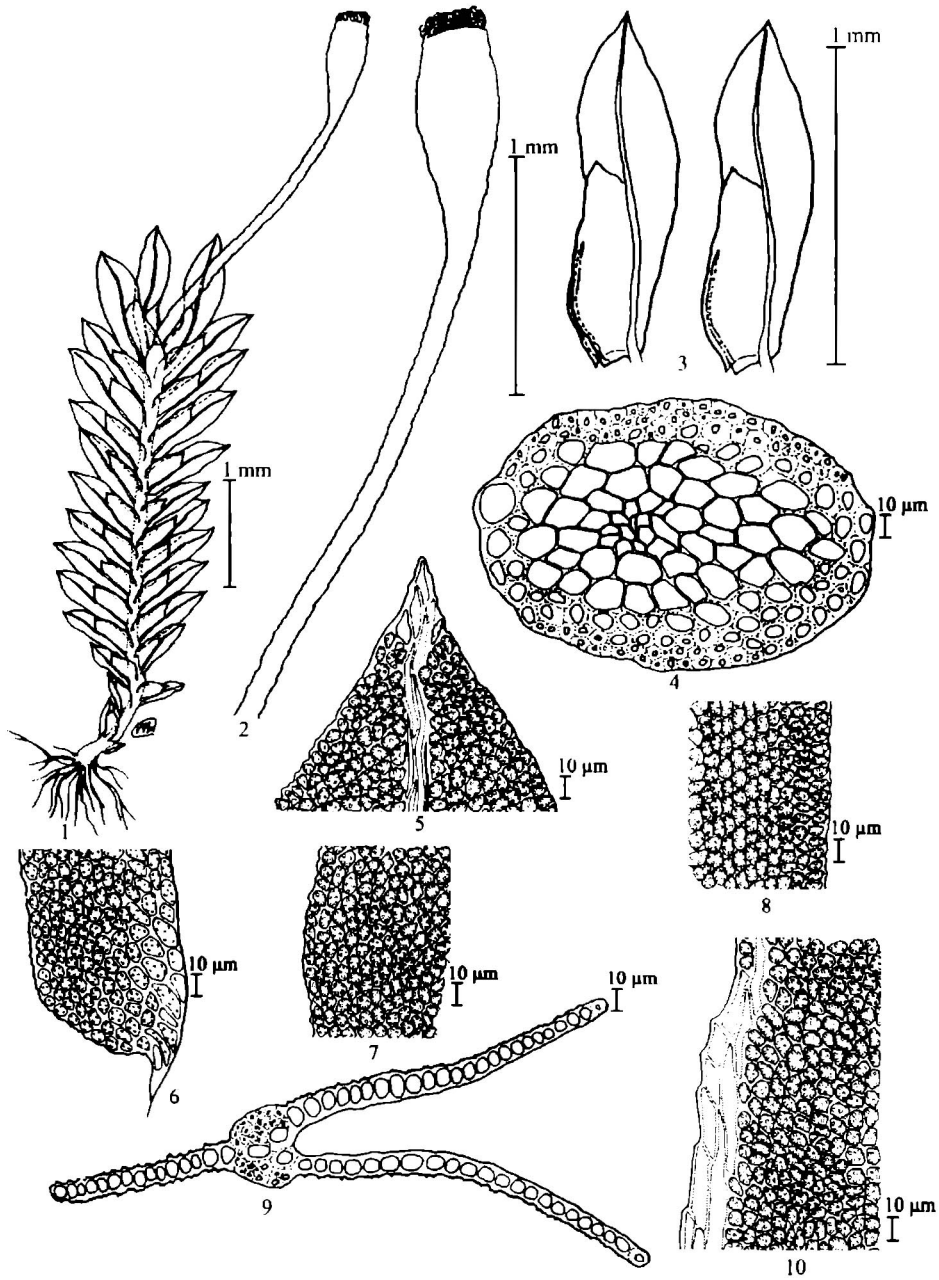


Figure 40. *Fissidens hollianus* Dozy & Molk.
1: plant habit with sporophyte. 2: seta and capsule. 3: leaves. 4: cross section of stem. 5: leaf apex. 6: leaf base cells. 7: apical lamina cells. 8: dorsal lamina cells. 9: cross section of leaf. 10: vaginant lamina cells. Drawn from Wongkuna 786 .

24. ***Fissidens hyalinus*** Hook. & Wils., J. Bot. 3 (1840) 89 (fig.).

Iwatsuki and Suzuki (1982) 350-352 (includind extra-Thai synonyms) 447 (fig.), 501 (map).

Iwatsuki and Mohamed (1987) 341.

Li and Iwatsuki (2001) 39, 40 (map).

Plants 3-4 mm long, 2.5-3 mm wide, laxly gregarious; soft; pale to dark green; stems usually simple, central strand not differentiated; axillary hyaline nodules not differentiated; leaves 4-10, upper leaves much larger than lower leaves, lanceolate, 1.3-2.2 mm long, 0.4-0.6 mm wide, apex acute, base cuneate, not decurrent; margin entire, but slightly serrulate near apex; without costa; vaginant lamina about 1/2 the leaf; limbidia with 1-2 rows of narrow marginal cells throughout the leaves, laminar and margin of one layer of cells; cells of apical lamina usually hexagonal, smooth, thin-walled, 35-55 μm long, 2-3 μm wide; cells of vaginant laminae almost the same as those of the apical lamina. Autoicous. Sporophytes terminal mature parts not seen.

Illustrations: Figures 41 and 133D

Habitat: on soil in moist areas

Ecology: primary, evergreen, seasonal, hardwood forest; 1250-2565 m elevation, granite bedrock

Phenology—gametophyte: August
sporophyte: August

Distribution—(Figure 118) India, Nepal, China, Taiwan Japan, Malaysia, Philippines, Papua New Guinea, Australia, North America and South America.

New record for Thailand.

Distribution in Thailand—(Figure 75D) Chiang Mai: Doi Inthanon National Park, Doi Suthep-Pui National Park.

Specimens studied—(CMU, gametophyte and sporophyte) Wongkuna 448, 981, 982.

This species is easily distinguished by the lack of a costa, limbidium of 1-2 rows of cells, and leaf with very lax areolation.

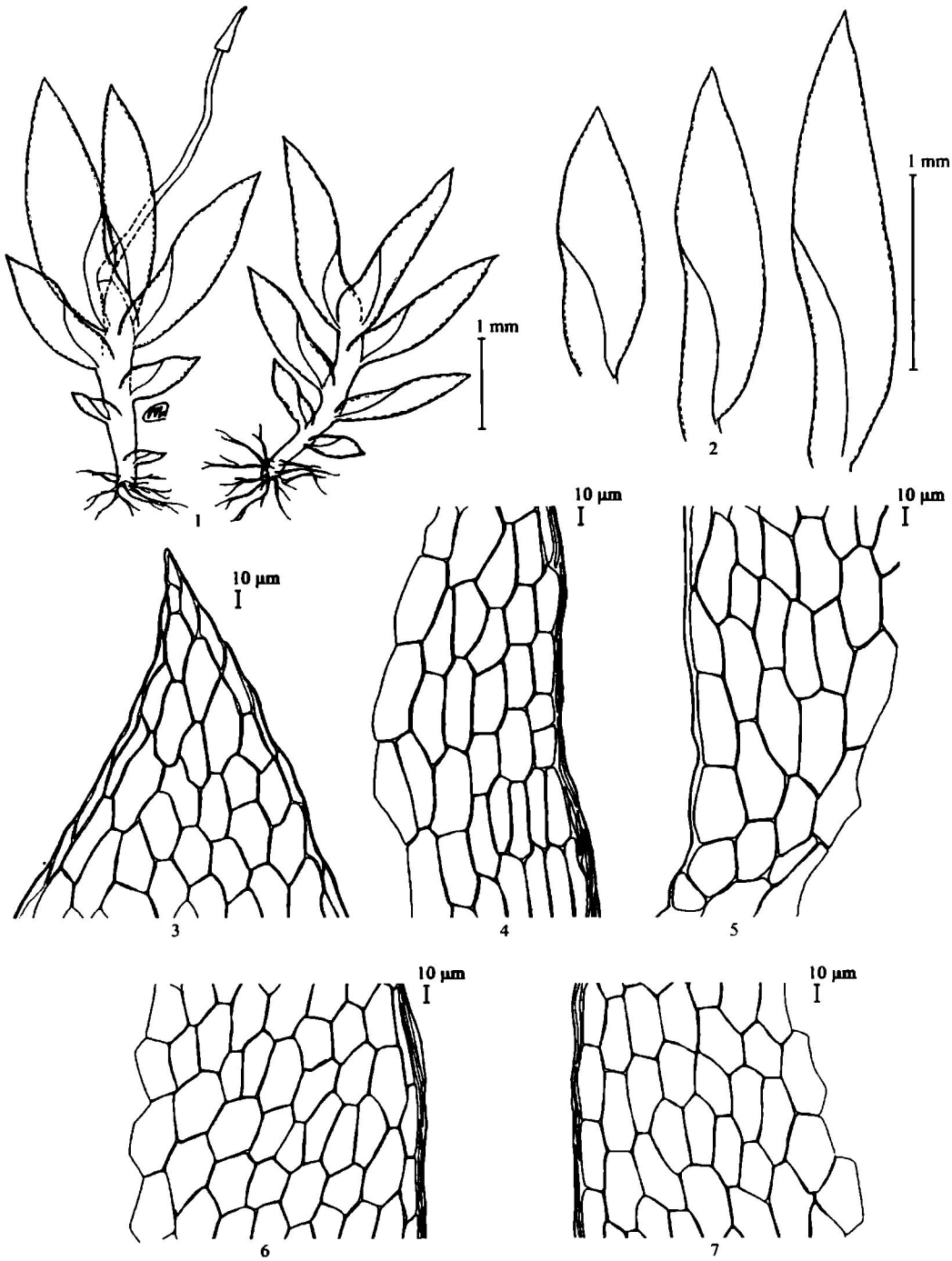


Figure 41. *Fissidens hyalinus* Hook. & Wils.
1: plant habit and sporophyte. 2: leaves. 3: leaf apex. 4: vaginant lamina cells. 5: leaf base cells. 6: apical lamina cells. 7: dorsal lamina cells. Drawn from Wongkuna 981.

25. ***Fissidens incognitus*** Gangulee, Bull. Bot. Soc. Bengal 11 (1957) 70.
Gangulee (1971) 500, 501 (fig.), 502 (map).
Li and Iwatsuki (2001) 40 (map), 41(plate+fig.).

Plants 4-5 mm long, 2-3 mm wide, yellow-green to green; stem simple; hyaline nodules not differentiated; cortical stem cells small, thick-walled; central strand not to weakly differentiated; leaves 16-20, densely arranged, lanceolate, lower leaves small, upper leaves larger, 1.7-2 mm long, 0.4-0.5 mm wide, apex acute, base not decurrent, margin serrate, limbidia confined to the vaginant laminae, with 1-2 rows of cells, one cell thick; costa excurrent; vaginant lamina about half of leaf length; cells of apical and dorsal lamine polygonal, about 3-5 μm long, thin-walled, unipapillose with branching tips, cells of vaginant lamina similar to other leaf cells. Sporophyte terminal and lateral; seta 3-8 mm long, smooth; capsules ovoid, symmetrical, smooth, about 0.5-0.8 mm long;

Illustrations: Figures 42 and 134A
Habitat: on soil in open areas.
Ecology: deciduous dipterocerp-oak forest, 250-850 m elevation; mixed evergreen+deciduous, seasonal, hardwood forest, 850-1000 m elevation; and primary, evergreen, seasonal, hardwood forest 1000-2500 m elevation; granite and sandstone bedrocks.
Phenology—gametophytes: June-December
sporophyte: December
Distribution—(Figure 91) India, Bangladesh, China, Hong Kong.
New record for Thailand.
Distribution in Thailand—(Figure 76A) Chiang Mai: Doi Inthanon National Park Doi Suthep-Pui National Park. Rayong: Khao Cha Mao- Khao Wong National Park. Khao Khitchakut National Park. Chanthaburi: Nam Tok Phlieo National Park. Suphanburi: Phu-Toei National Park. Ubon Ratchathani: Pha Taem National Park. Nakhon Nayok: Khao Yai National Park. Kanchanaburi: Thong Pha Phum National Park.
Specimens studied—(CMU, gametophyte), Wongkuna 335B, 345A, 968B, 1349A, 344, 347, 1586 (CMU, gametophyte), (CMU, gametophyte and sporophyte) Wongkuna 1349; (PSU, gametophyte) Chantornoraprint 886.

This species is easily recognized by the prominently unipapillate laminal cells, with the papilla having branching tips. The limbidia are confined to the vaginant laminae and the hyaline nodules are not differentiated.

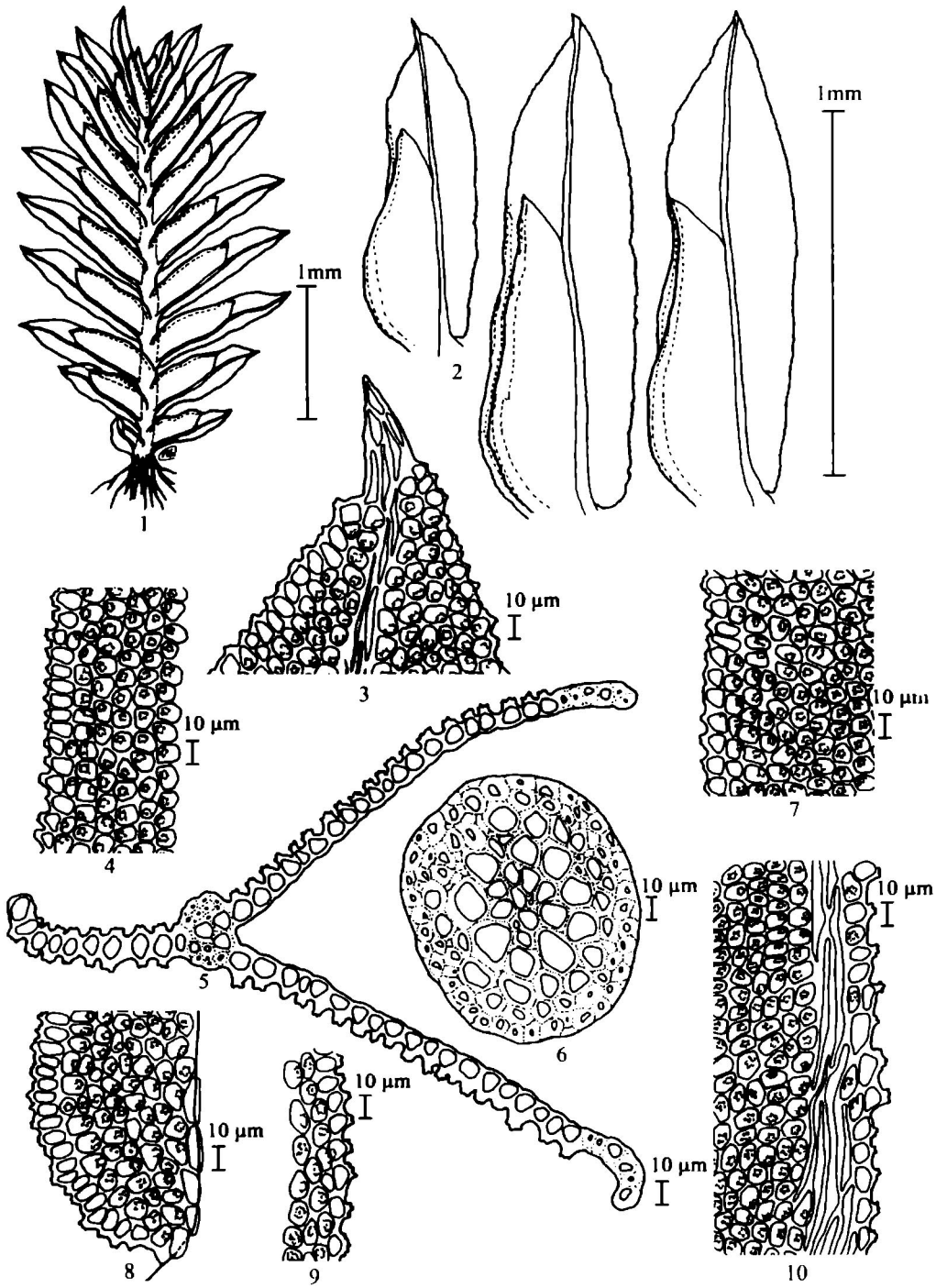


Figure 42. *Fissidens incognitus* Gangulee
1: plant habit. 2: leaves. 3: leaf apex. 4: cells at apical lamina. 5: cross section of leaf. 6: cross section of stem. 7: dorsal lamina cells. 8: leaf base cells. 9: leaf margin showing limbidium. 10: vaginant lamina cells. Drawn from Wongkuna 345.

26. ***Fissidens involutus*** Wils. *ex* Mitt., J. Proc. Linn. Soc. Bot. Suppl. 1 (1859) 138.
Gangulee (1971) 546 (map), 547 (fig.) 548.
Li and Iwatsuki (2001) 40 (map), 41 (including extra-Thai synonyms) (plate+fig.).
Fissidens obtuso-apiculatus Dix., J. Siam Soc. Nat. Suppl. IX (1932) 6., Wongkuna *et al.* (2009) 302.

Plants 10-15 mm long, 15-25 mm wide, green, stem simple; hyaline nodules differentiated; leaves 32-44, densely arranged, ovate-oblong, oblong-lanceolate, lower leaves small, upper leaves larger, 1.5-2.5 mm long, 0.4-0.6 mm wide, apex broadly acute (60-70°), base of dorsal lamina not decurrent, margin crenulate, limbidia none, costa percurrent to shortly excurrent; vaginant lamina about 2/3 of leaf-length; cells of apical and dorsal laminae polygonal, about 6-9 μm long, 6-8 μ wide, thin-walled, mammillose, cells of vaginant lamina similar to other leaf cells. Sporophyte terminal; capsule cylindrical, erect, symmetrical, smooth, about 0.5-0.8 mm long; seta 13-14 mm long, smooth; calyptra 0.3-.05 mm long.

Illustrations: Figures 43 and 134B
Habitat: on soil near waterfalls
Ecology: primary, evergreen, seasonal, hardwood forest; granite, sandstone bedrocks, 1250-2565 m elevation.
Phenology—gametophytes: March-October
sporophyte: October
Distribution—(Figure 92) India, Sri Lanka, Nepal, Pakistan, China, Taiwan, Japan, Myanmar, Vietnam, Philippines
New record for Thailand.
Distribution in Thailand—(Figure 76B) Chiang Mai: Pha Daeng National Park, Chiang Dao Wildlife Sanctuary. Suphanburi: Phu-Toei National Park.
Specimens studied—Wongkuna (CMU, gametophyte) 457, 475, 477, 659, 660, 662, 663, 666, 667, 671, 688, 697, 811; (CMU, gametophyte and sporophyte) Wongkuna 667, 668, 669, 670.

This species is 10–15 mm tall. The leaves are ovate- crenulate and elimbate. It looks like a larger *F. gymnogynus* Besch. with a percurrent leaf costa. The specimens examined have exceptionally long seta measuring to 13-14 mm long.

My specimens keyed to *F. plagiochiloides* Besch. and not *F. involutus*. Wils. *ex* Mitt. by using Iwatsuki and Suzuki (1982) and Li (1885). I follow Li and Iwatsuki (2001) on the updated taxonomy of this species. For *F. involutus* and *F. curvato-involutus* Dix. in Iwatsuki and Suzuki (1999), my specimen fits *F. involutus* better in nearly all characters, except the seta length. The specimens also look like *F. curvato-involutus* Wils. *ex* Mitt from India, with its very long setae.

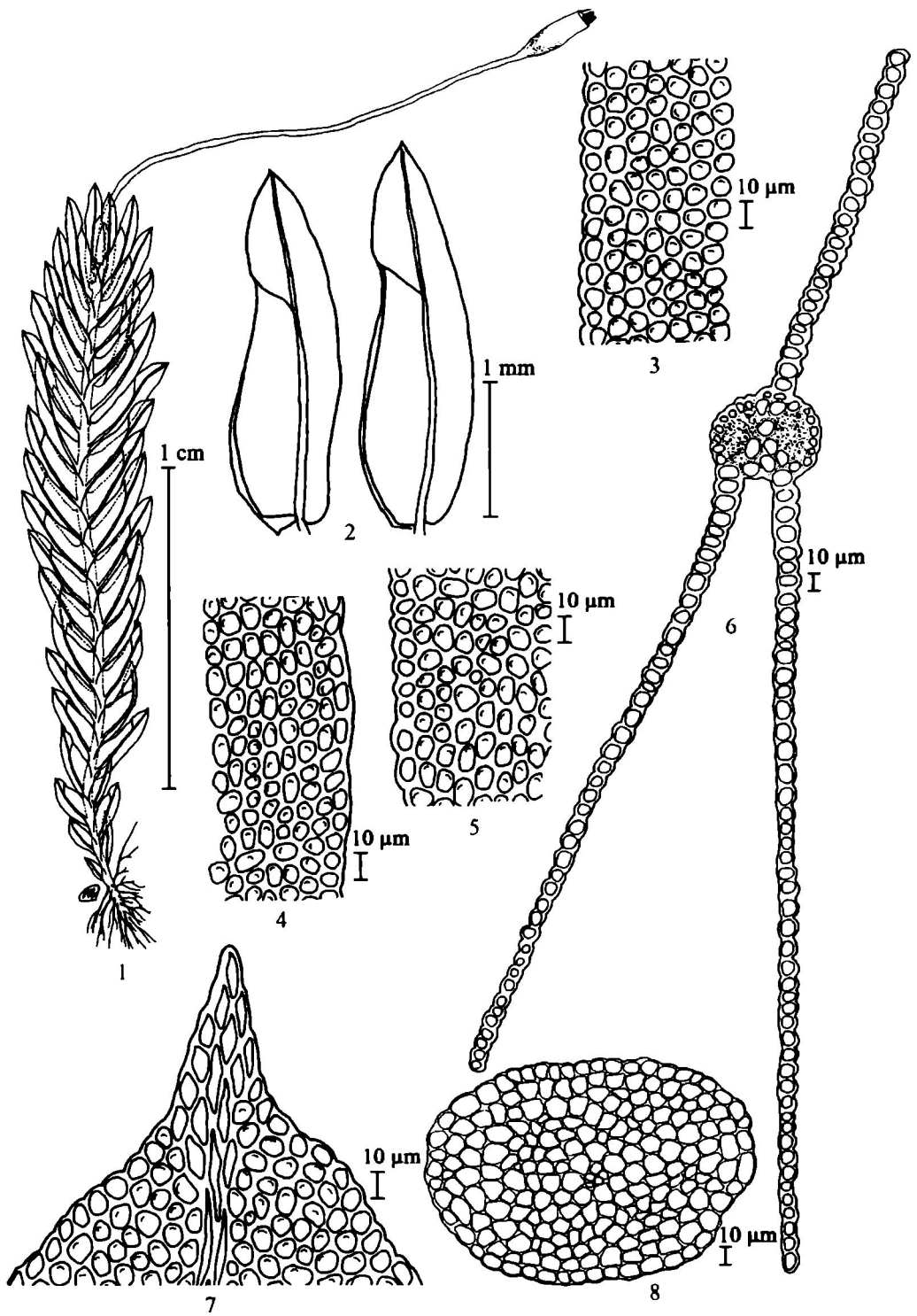


Figure 43. *Fissidens involutus* Wils. *ex* Mitt.
1: plant with sporophyte. 2: leaves. 3: apical lamina cells. 4: dorsal lamina cells. 5: vaginant lamina cells. 6: cross section of leaf. 7: leaf apex. 8: cross section of stem. Drawn from Wongkuna 660.

27. ***Fissidens irregulomarginatulus*** K. Wongkuna & B. C. Tan, *sp. nov.* (in press)

Plants up to 2 mm long, *c.* 1 mm wide; yellow-green and reddish when older; stem usually simple; hyaline nodules well differentiated; leaves 8-12, densely arranged, narrowly lanceolate, lowest leaves small, upper leaves much larger 1-2 mm long, 0.2-0.3 mm wide, apex acute, base decurrent, margin serrate, limbidia obscure, cells elongate, poorly differentiated, intramarginally, limited to the vaginant lamina, limbidia cells longer than other cells; costa percurrent to shortly excurrent; vaginant lamina about half to 2/3 of leaf length; cells of apical lamina polygonal and similar to the dorsal lamina, 5-10 μ long, 5-10 μ wide, strongly mammillose, thick-walled; cells of vaginant lamina, rectangular, 10-15μ long, 4-5 μ wide, smooth; perichaetial leaves longer and narrower than other leaves, 1-2 mm long, 0.1-0.2 mm wide, margin very strongly and irregularly serrate to dentate. Sporophyte terminal, seta 4-6 mm long, smooth, capsule cylindrical, erect, symmetrical, smooth, about 0.5 mm long; peristome not seen.

Illustrations: Figures 44 and 134C

Habitat: on soil in shaded areas

Ecology: primary, evergreen, seasonal, hardwood forest; granite bedrock, *c.* 1350 m elevation.

Phenology—gametophyte: August
sporophyte: August

Distribution—(Figure 106) Thailand.

Distribution in Thailand—(Figure 76C) Chiang Mai: Doi Suthep-Pui National Park

Specimen studied—(CMU holotype, SING isotype, gametophyte) Wongkuna 162 (CMU holotype).

This species is up to 2 mm long and the stem has district hyaline nodules. The leaves are narrowly-lanceolate and the apical and dorsal lamina cells are polygonal, thick-walled, and strongly mammilloseth. Perichaetial leaf margins very strongly and irregularly serrate to dentate and limbidia are present.

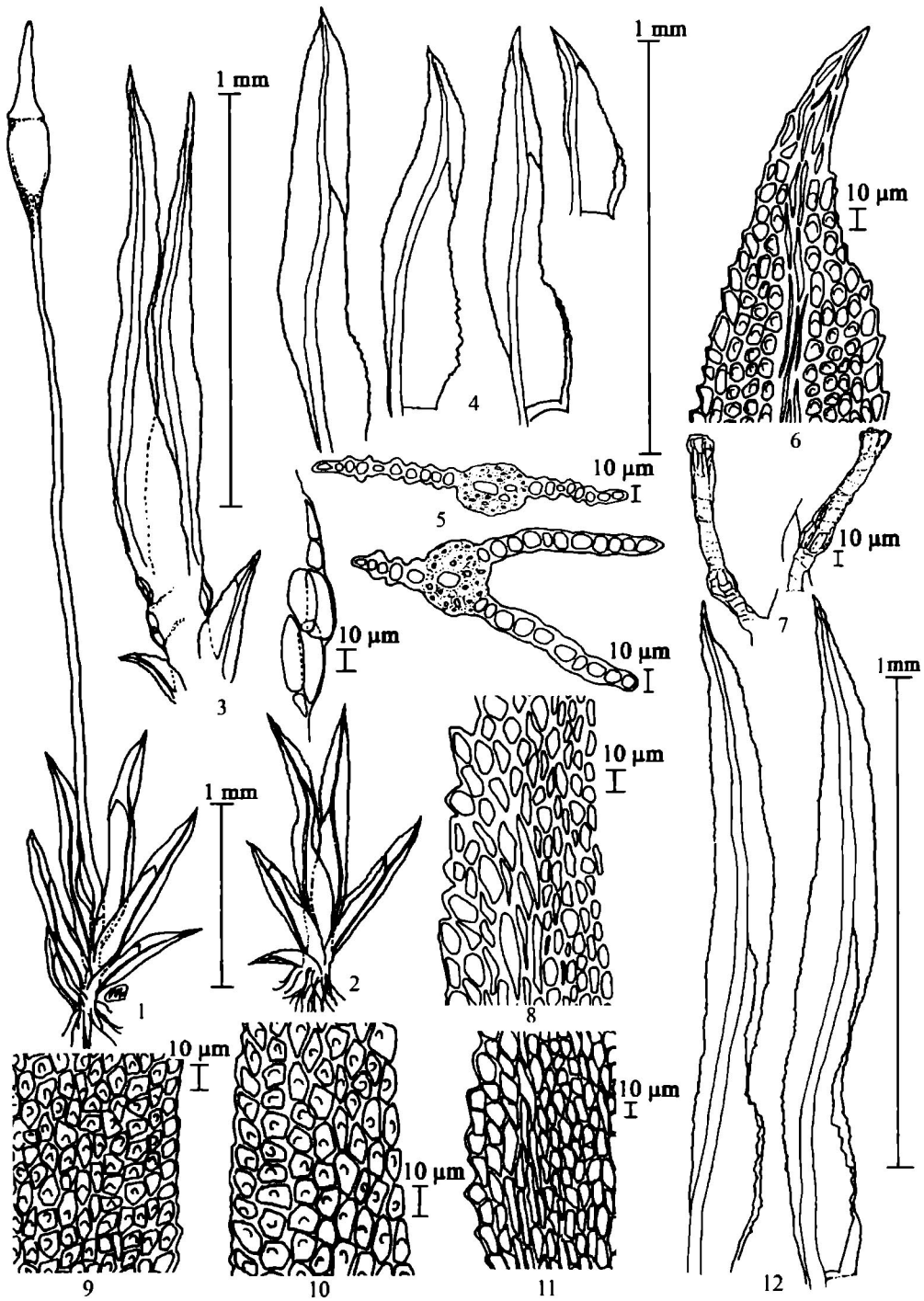


Figure 44. *Fissidens irregulomarginatulus* K. Wongkuna & B. C. Tan.
1: plant with sporophyte. 2: plant habit. 3: hyaline nodules on stem. 4: leaves. 5: cross-section of leaf. 6: leaf apex. 7: archegonia. 8: margin of perichaetial leaf showing the not well-differentiated limbidium. 9: cells at dorsal lamina. 10: cells at apical lamina. 11: cells at vaginant lamina. 12. perichaetial leaf. Drawn from Wongkuna 162 (holotype, CMU).

28. ***Fissidens javanicus*** Dozy & Molk., Bryol. Jav. 1 (1855) 11.

Gangulee (1971) 542 (map), 543 (fig.), 544 (including extra-Thai synonyms).
Iwatsuki and Suzuki (1983) 401-402, 479 (fig.), 506 (map).
Eddy (1988) 84, 85 (fig.), 86.
Iwatsuki and Mohamed (1987) 356.
Li and Iwatsuki (2001) 42 (map), 43.

Plants robust, 10-15 mm tall, 3-4 mm wide, dark green to yellowish-green, usually brownish when old; stems simple or branched; axillary hyaline nodules very distinctly differentiated; central strand weakly differentiated; leaves 40-46, densely and regularly arranged, lanceolate to narrowly lanceolate, 1.8-2.7 mm long, 0.3-0.5 mm wide, apex acute to narrowly acute, base of dorsal lamina usually rounded, not decurrent, margins minutely crenulate, margins thick and dark, making an obscure band 2-3 rows of cells. in cross-sections, composed of 2-3 layers of thick-walled cells; vaginant lamina about 1/2 leaf length, apex oblique, costa percurrent; apical and dorsal laminae of 1 layer; cells quadrate to hexagonal, 5.0-8.0 μm diameter in apical lamina, mammillose, cells thick-walled; cells of vaginant laminae similar to those of the apical lamina, Dioicous. Sporophyte not seen.

Illustrations: Figures 45 and 134D

Habitat: on wet rocks in streams

Ecology: primary, evergreen, seasonal, hardwood forest; granite, sandstone bedrocks, 1200-1400 m elevation.

Phenology—gametophytes: February-November

Distribution—(Figure 93) India, Nepal, Sri Lanka, Bangladesh, Hong Kong, Taiwan, Japan, Laos, Myanmar, Vietnam, Malaysia, Java, Sumatra, Philippines, New Guinea.

Distribution in Thailand—(Figure 76D) Rayong: Khao Cha Mao- Khao Wong National Park. Nakhon Nayok: Khao Yai National Park. Prachuap Khiri Khan: Hui Yang Waterfall National Park. Nakhon Sri Thammarat: Khao Nan National Park. Phang-nga: Sri Phang-nga National Park.

Specimens studied—(BKF) Touw 10838, 11324; (CMU, gametophyte) Wongkuna 1413, 1414, 1418, 1419A, 1420, 1426, 1442, 1443, 1446, 1673, 1719, 1721, 1723, 1741, 1744, 1745; (PSU) Chantanaorrapint 611, 1092.

The hyaline nodules are well-differentiated and the leaf margins are entire to slightly crenulate, forming a thick band 2-3 cells wide and 2-3 cells thick. These cells are quadrate to hexagonal, thick-walled, and mammillose.

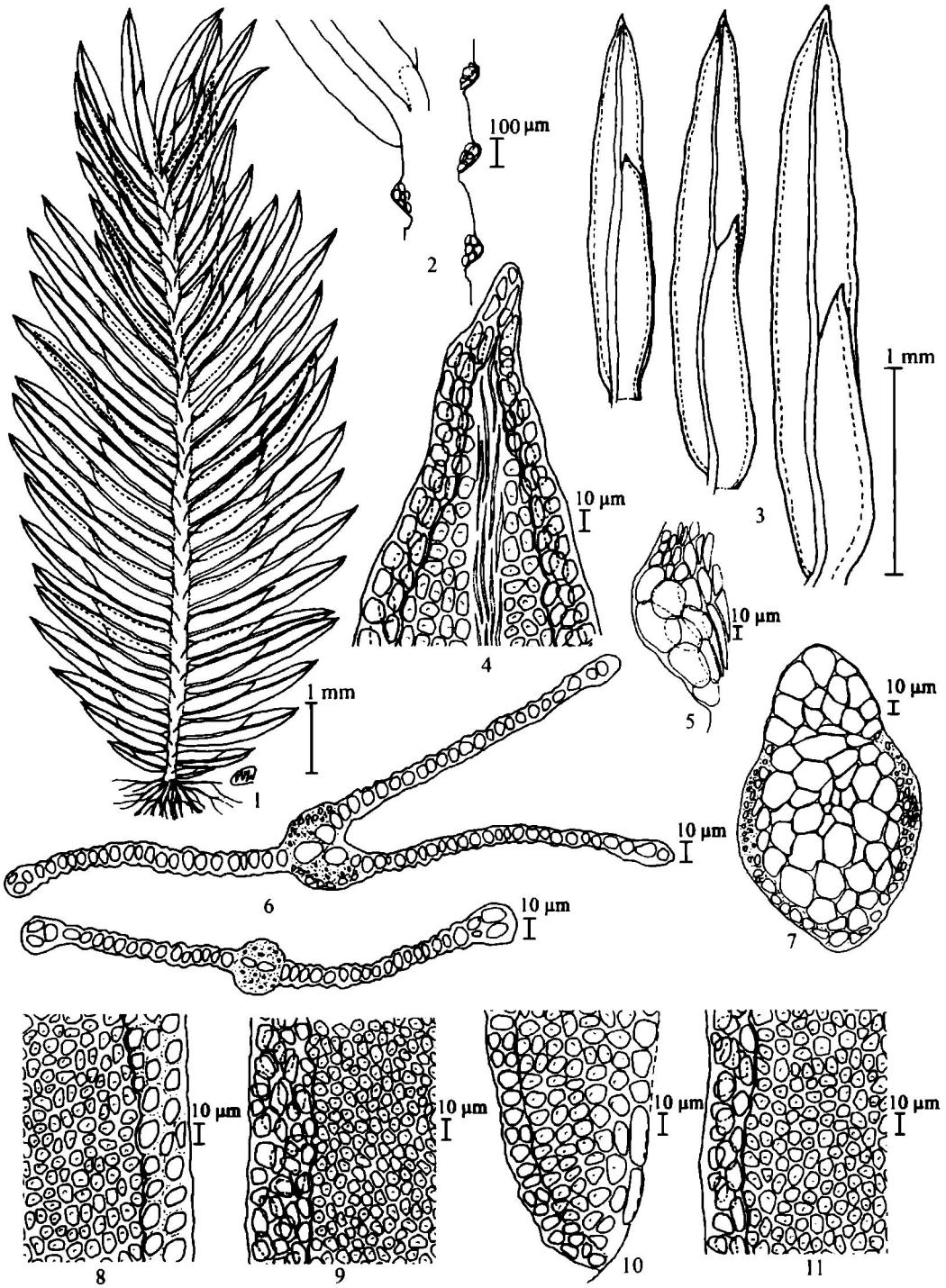


Figure 45. *Fissidens javanicus* Dozy & Molk.
1: plant habit. 2: hyaline nodules on stem. 3: leaves. 4: leaf apex. 5: hyaline nodules. 6: cross section of leaf. 7: cross section of stem. 8: dorsal lamina cells. 9: apical lamina cells. 10: leaf base cells. 11: vaginant lamina cells. Drawn from Chantanaorrapint 1092.

29. ***Fissidens jungermannioides*** Griff., Calcutta J. Nat. Hist. 2 (1842) 504.
Gangulee (1971) 551, 552 (fig.), 553 (map).
Li and Iwatsuki (2001) 42 (map), 44 (plate+fig.).

Plants 4-13 mm long, 1.5-2 mm wide green to reddish when older; stem simple or with some branches; hyaline nodules and central strand not differentiated; leaves 12-64, lower leaves small and lax, upper leaves larger and densely arranged, lanceolate, 1-1.5 mm long, 0.3-0.4 mm wide, apex acute, base cuneate and decurrent, margin weakly crenulate to nearly entire; limbidia partially differentiated, often coloured, consisting of 2-3 rows of cells at the margin, rectangular to oblong, longer and darker than the inner lamina cells, 2 layers thick; costa brownish, percurrent to shortly excurrent; vaginant lamina about half of leaf length; cell of apical and dorsal laminae quadrate to irregularly hexagonal, 5-10 μ long, one cell thick, thick-walled, smooth; cells of vaginant lamina similar to those of other leaf cells, but larger in the lower part of stem. Sporophyte not seen.

Illustrations: Figures 46 and 135A
Habitat: on wet rocks in shaded areas.
Ecology: primary, evergreen, seasonal, hardwood forest; granite bedrock, 1000-1300 m elevation.
Phenology—gametophytes: June-November
Distribution—(Figure 94) India, China, Taiwan, Hong Kong.
New record for Thailand.
Distribution in Thailand—(Figure 77A) Phitsanulok: Phu Hin Rong Kla National. Park. Loei: Phu Luang Wildlife Sanctuary.
Specimens studied—(CMU, gametophyte) Wongkuna 306, 1037, 1139, 1141.

This species is characterized by having partially or incompletely differentiated limbidia around the leaf that is often coloured in surface view. In cross-section, the interrupted leaf limbidium is clearly 2-3 rows of cells thick. The lamina cells are quadrate to irregularly hexagonal, thick-walled, and smooth to slightly mammillose.

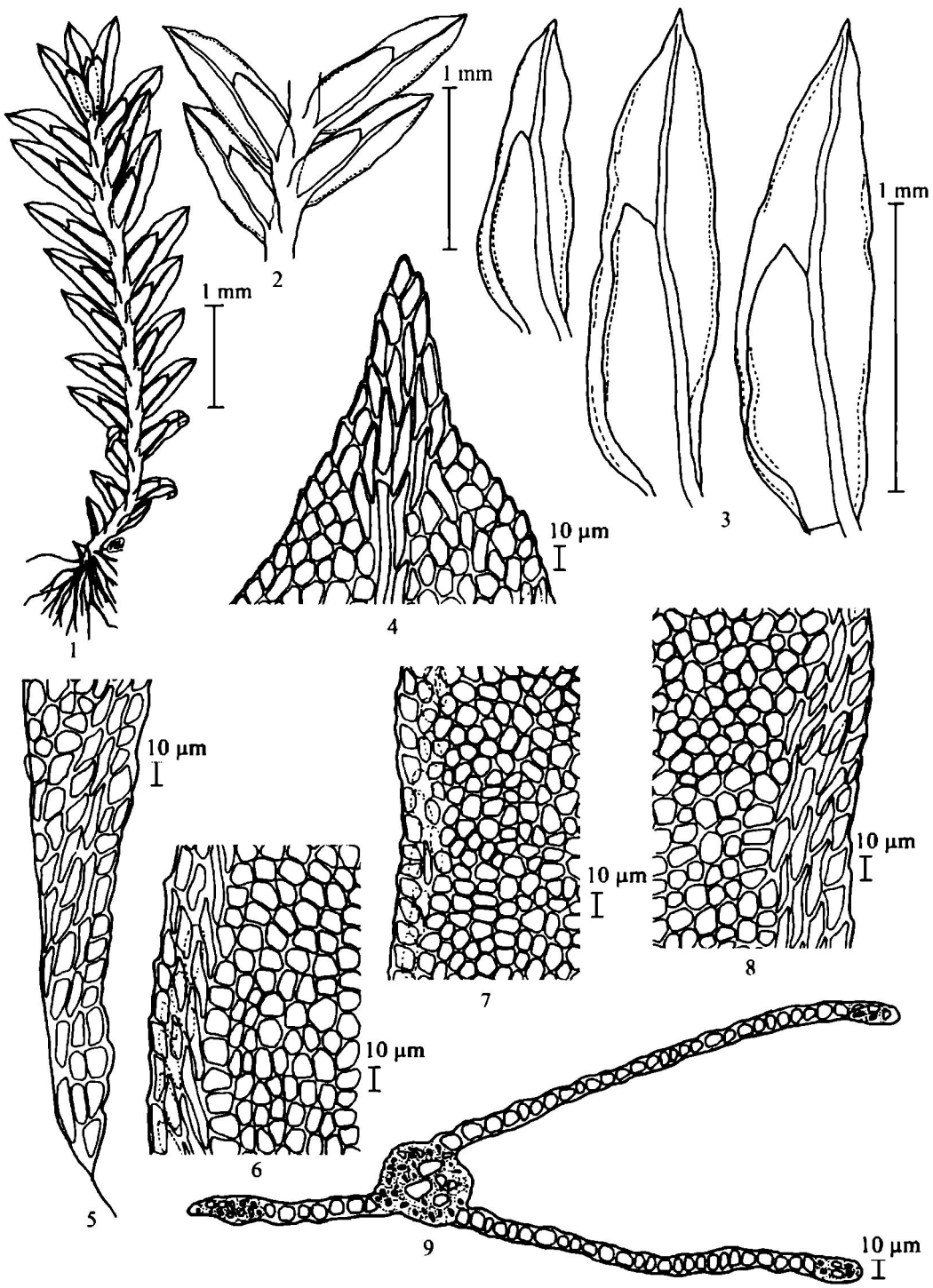


Figure 46. *Fissidens jungermannioides* Griff.
1: plant habit. 2: part of stem. 3: leaves. 4: leaf apex. 5: leaf base cells. 6: leaf cells and thick limbidium at apical lamina. 7: dorsal lamina cells with part of the limbidium. 8: margin of vaginant lamina showing limbidium. 9: cross section of leaf. Drawn from Wongkuna 360.

30. ***Fissidens kinabaluense*** Z. Iwats., J. Hattori Bot. Lab. 32 (1969) 269.
Eddy (1988) 80 (fig.), 81.
Li and Iwatsuki (2001) 44 (map), 45 (plate+fig.).

Plants 3-6 mm tall, about 2.0 mm wide, laxly gregarious; stem simple, yellowish, green, central strand not differentiated; axillary hyaline nodules well-differentiated; leaves 28-36, linear, stiff, densely imbricated, apex tapering to narrowly acute, base slightly decurrent, margins minutely crenulate, costa excurrent; vaginant lamina more than half of leaf length; limbidia 2-3 cells wide, one cell thick, limited to vaginant lamina; lamina cells more or less quadrate, about 4.0-6.0 μm diameter, densely multi-papillose, the papillae scattered over the lumen and walls. Sporophyte not seen.

Illustrations: Figures 47 and 135B
Habitat: on soil with completely decayed wood in shaded areas
Ecology: primary, evergreen, seasonal, hardwood forest; granite bedrock, 1400 m elevation
Phenology—gametophyte: February
Distribution—(Figure 95) China, Taiwan, Hong Kong, Vietnan, Borneo, peninsular Malaysia, New Guinea.
Distribution in Thailand—(Figure 77B) Nakhon Sri Thammarat: Khao Luang
Specimens studied—(BKF, gametophyte) Touw 11549; (SING, gametophyte) Tan 02-201.

This species is distinguished by having linear, imbricate, 1.5-2 mm long leaves, limbidiam limited on the vaginant lamina; excurrent costa, obscure laminae cells, which are densely and minutely papillose.

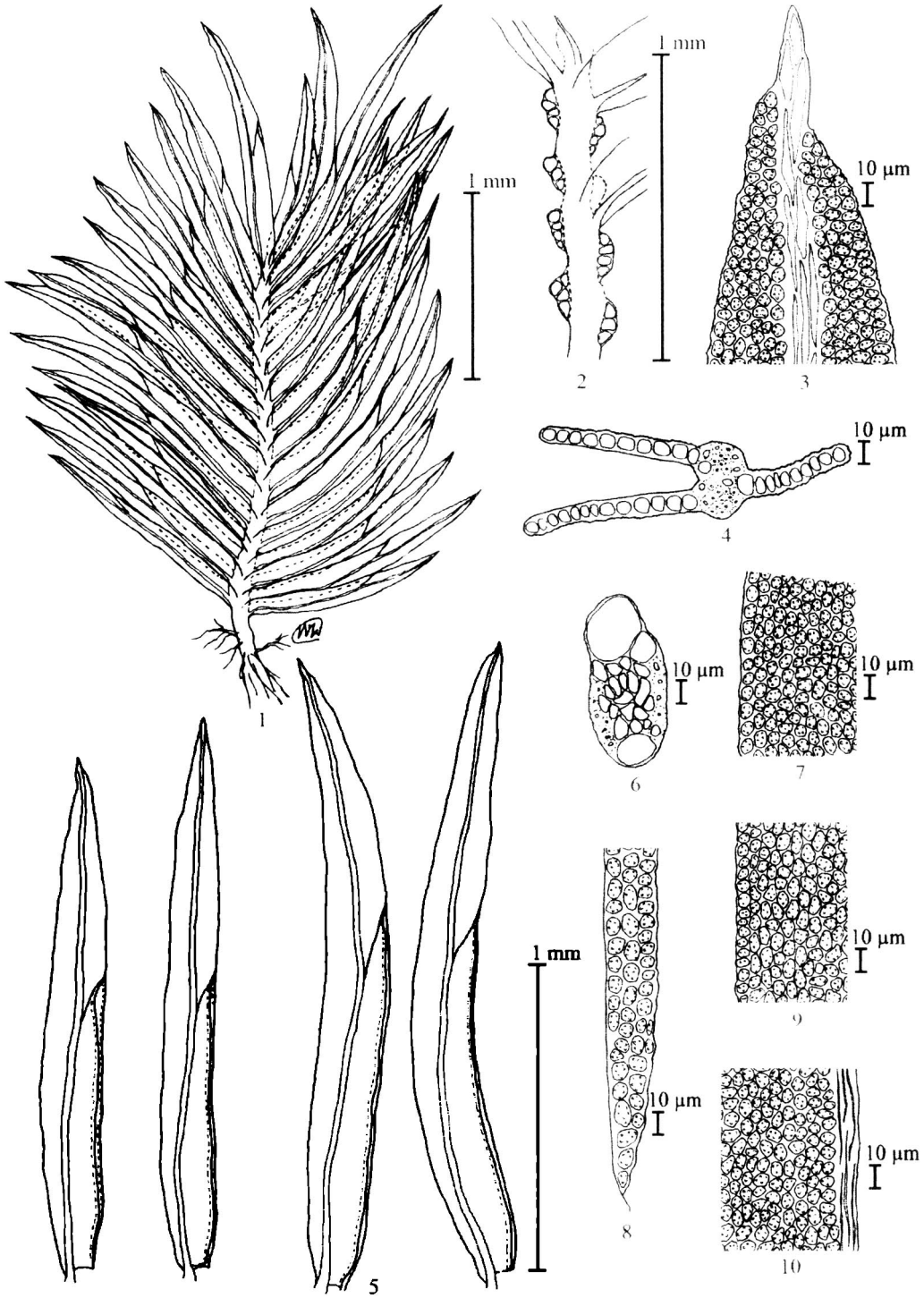


Figure 47. *Fissidens kinabaluense* Z. Iwats.
1: plant habit. 2: hyaline nodules on stem. 3: leaf apex. 4: cross section of leaf. 5: leaves. 6: cross section of stem. 7: apical lamina cells. 8: leaf base cells. 9: dorsal lamina cells. 10: vaginant lamina cells. Drawn from Touw 11549 (BKF).

31. ***Fissidens laxitextus*** Broth. *ex* Gangulee, Nova Hedwigia 8 (1964) 144.
Gangulee (1971) 530 (map), 531 (fig.).

Plants 3-5 mm tall, 1.5-2 mm wide; stem simple drying yellowish-green; axillary hyaline nodules not differentiated; central strand weakly differentiated; leaves 40-46, densely and regularly arranged, lanceolate to narrowly lanceolate, 1.8-2.7 mm long, 0.3-0.5 mm wide, apex broadly acute (60-70°), base usually rounded, not decurrent, margins minutely crenulate, thick and dark, making an obscure band of 2-3 rows of cells in cross-section, composed of 2-3 layers of thick-walled cells, vaginant lamina about 1/2 leaf length, apex obligue; costa percurrent; apical and dorsal laminae 1 cell thick, quadrate to hexagonal, 5.0-8.0 μm diameter in apical lamina, mammillose cells thick-walled; cells of vaginant laminae similar to those of the apical lamina, Dioicous. Sporophytes not seen.

Illustrations: Figures 48 and 135C
Habitat: on soil in sheded areas.
Ecology: primary, evergreen, seasonal, hardwood forest, granite bedrock, 2565 m elevation,
Phenology—gametophyte: December
Distribution—(Figure 96) India, Nepal.
Distribution in Thailand—(Figure 77C) Chiang Mai: Doi Inthanon National Park
Specimens studied—(MO, gametophyte) Touw 10214; (CMU, gametophyte) Wongkuna 1060.

The distinguishing characters of this species are the distinctly serrulate leaf margins, lamina rounded at the base, leaf cells quadrate to irregularly-hexagonal, 8-14 μm diameter and the limbidia restricted to upper perichaetial leaves.

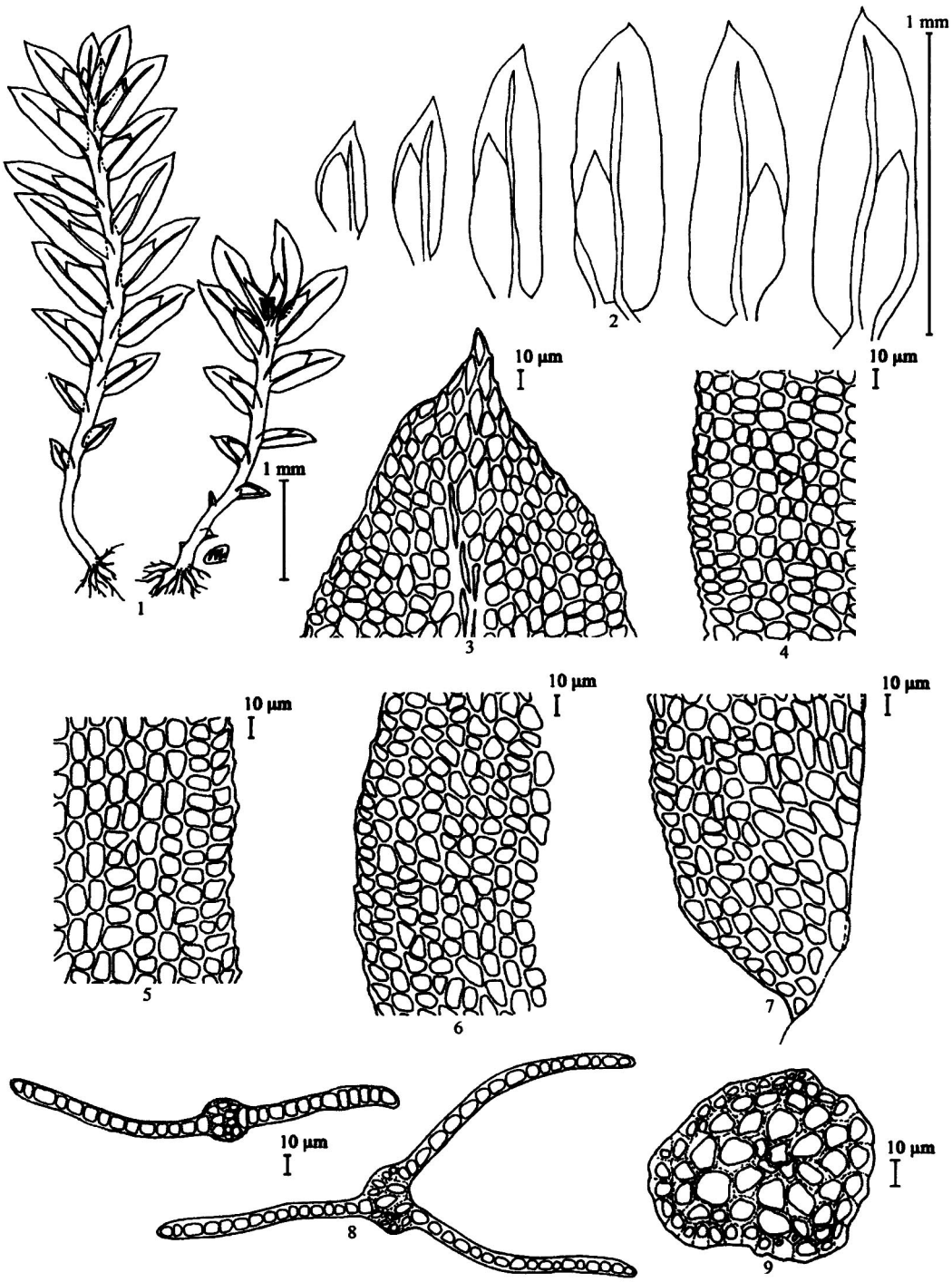


Figure 48. *Fissidens laxitextus* Broth. *ex* Gangulee
1: plant habit. 2: leaves. 3: leaf apex. 4: apical lamina cells 5: dorsal lamina cells 6: vaginant lamina cells. 7: leaf base cells. 8: cross section of leaf. 9: cross section of stem. Drawn from Touw 10214 (MO).

32. ***Fissidens nobilis*** Griff., Not. Ic. Pt. Asiat. 2; 83 (1841) 427.
Bartram (1939) 22, (plate+fig.).
Gangulee (1971) 550 (including extra-Thai synonyms +fig.), 551 (map).
Eddy (1988) 84, 85 (fig.).
Iwatsuki and Suzuki (1982) 416-418, 490-491(fig.), 507 (map).
Li and Iwatsuki (2001) 47 (map) 49 (including extra-Thai synonyms).
Iwatsuki and Mohamed (1987) 357–359.

Plants 20-50 mm tall, 7-8 mm wide, dark green, brownish when old, stem commonly branching; axillary hyaline nodules not differentiated, without a central strand; leaves 36-72; densely arranged, middle to upper leaves lanceolate, 5.0-8.0 mm long, 1.0-1.6 mm wide, apex acute, base districtly decurrent; margin irregularly dentate to coarsely serrate, bordered throughout by a darker colored band of 2-4 cells thick; costa stout, percurrent; vaginant lamina symmetric at apex, about 1/2 leaf length; lamina cells quadrate to hexagonal, smooth, some cells mammillose, about 10-13 μm diameter, very thick-walled; marginal cells larger and elongate; cells of vaginant lamina similar to those of the apical lamina; Dioicous. Sporophyte not seen.

Illustrations: Figures 49 and 135D
Habitat: on wet rocks along waterfalls and streams in shaded places
Ecology: primary, evergreen, seasonal, hardwood, forest *c.* 1000-2565 m elevation; granite bedrock
Phenology—gametophytes: March-November
Distribution—(Figure 97) India, Nepal, Sri Lanka, Bangladesh, China, Hong Kong, Taiwan, Korea, Japan, Cambodia, Vietnam, Myanmar, Malaysia, Philippines, Borneo, Java, Sumatra, New Guinea, Fiji.
Distribution in Thailand—(Figure 77D) Chiang Rai: Doi Tong. Chiang Mai: Doi Inthanon National Park, Doi Suthep-Pui. Phitsanulok: Phu Hin Rong Kla National Park. Loei: Phu Luang Wildlife Sanctuary. Nakhon Nayok: Khao Yai National Park.
Specimens studied—(CMU, gametophyte) Wongkuna 190, 276, 277, 297B, 331B, 987, 988, 1110, 1119, 1121, 1125, 1152; Maxwell B-203, B-204.

This is a large species with many large leaves with dark margins, 2-4 cells thick, irregularly dentate to coarsely serrate, districtly decurrent at the base.

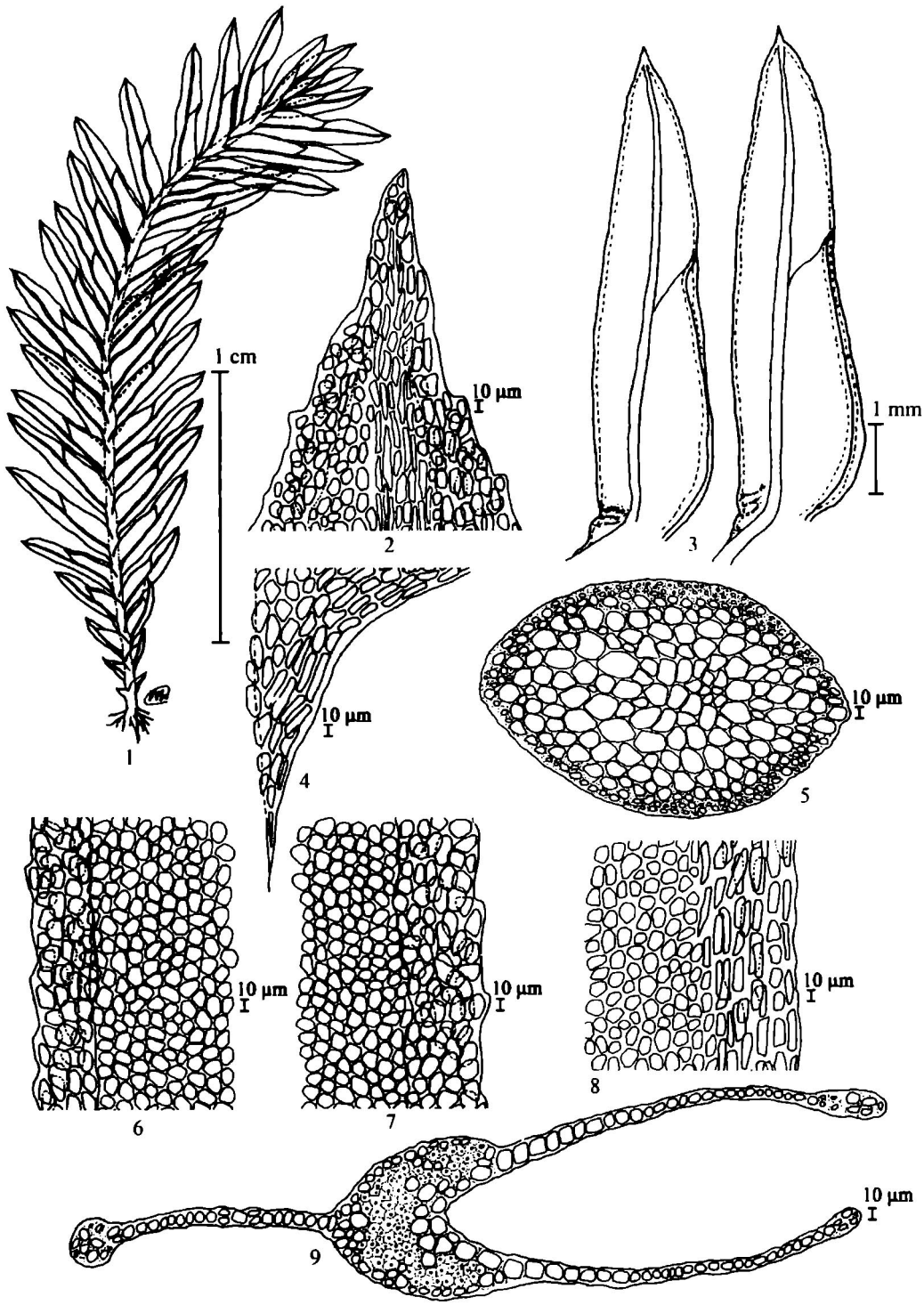


Figure 49. *Fissidens nobilis* Griff.
1: plant habit. 2: leaf apex. 3: leaves. 4: leaf base cells. 5: cross section of stem. 6: apical lamina cells. 7: dorsal lamina cells. 8: vaginant lamina cells. 9: cross section of leaf. Drawn from Wongkuna 277.

33. ***Fissidens oblongifolius*** Hook. f. & Wils. London J. Bot. 3 (1844) 547.

Fissidens oblongifolius Hook. f. & Wils. var. *oblongifolius*, Li & Iwatsuki (2001) 50 (map).

Plants 13-20 mm long, 4-5 mm wide, gregarious; yellowish-green to dark green; stems simple or with some branches; axillary hyaline nodules not differentiated; cortical stem cells small and thick-walled, central strand differentiated; leaves 34-42, lower leaves small and lax, upper and middle leaves much larger and densely arranged, lanceolate to oblong-lanceolate, falcate 2.5-3.5 mm long, 0.6-0.8 mm. wide; apex narrowly acute (35- 40°); base cuneate, not decurrent; margin serrulate; costa narrow, excurrent; vaginant lamina about a half of leaf length; cells of apical and orbicular to hexagonal, 8-12 μm long, thin-walled, distinctly mammillose except those at extreme apex; cells of vaginant laminae similar to those of apical lamina. Sporophyte not seen.

Illustrations: Figures 50 and 136A

Habitat: on soil in shaded areas

Ecology: primary, evergreen, seasonal, hardwood forest; granite, bedrock, 2565 m elevation

Phenology—gametophytes: August-December

Distribution—(Figure 123) China, Hong Kong, Japan, Malaysia, Singapore, Philippines, Java, Australia, New Zealand, Central African Repubic, Gabon, Surinam, Togo, United States, Mexico, Cuba, Belize, Chile, Dominican Repubic, French Guiana, Guadeloupe, Jamica, Venezuela

Distribution in Thailand—(Figure 78A) Chiang Mai: Doi Inthanon National Park.

Specimens studied—(CMU, gametophyte) Wongkuna 769A, 945B, 880, 949.

The leaves are falcate with narrowly acute apex, margins serrulate, and with mammillose cells.

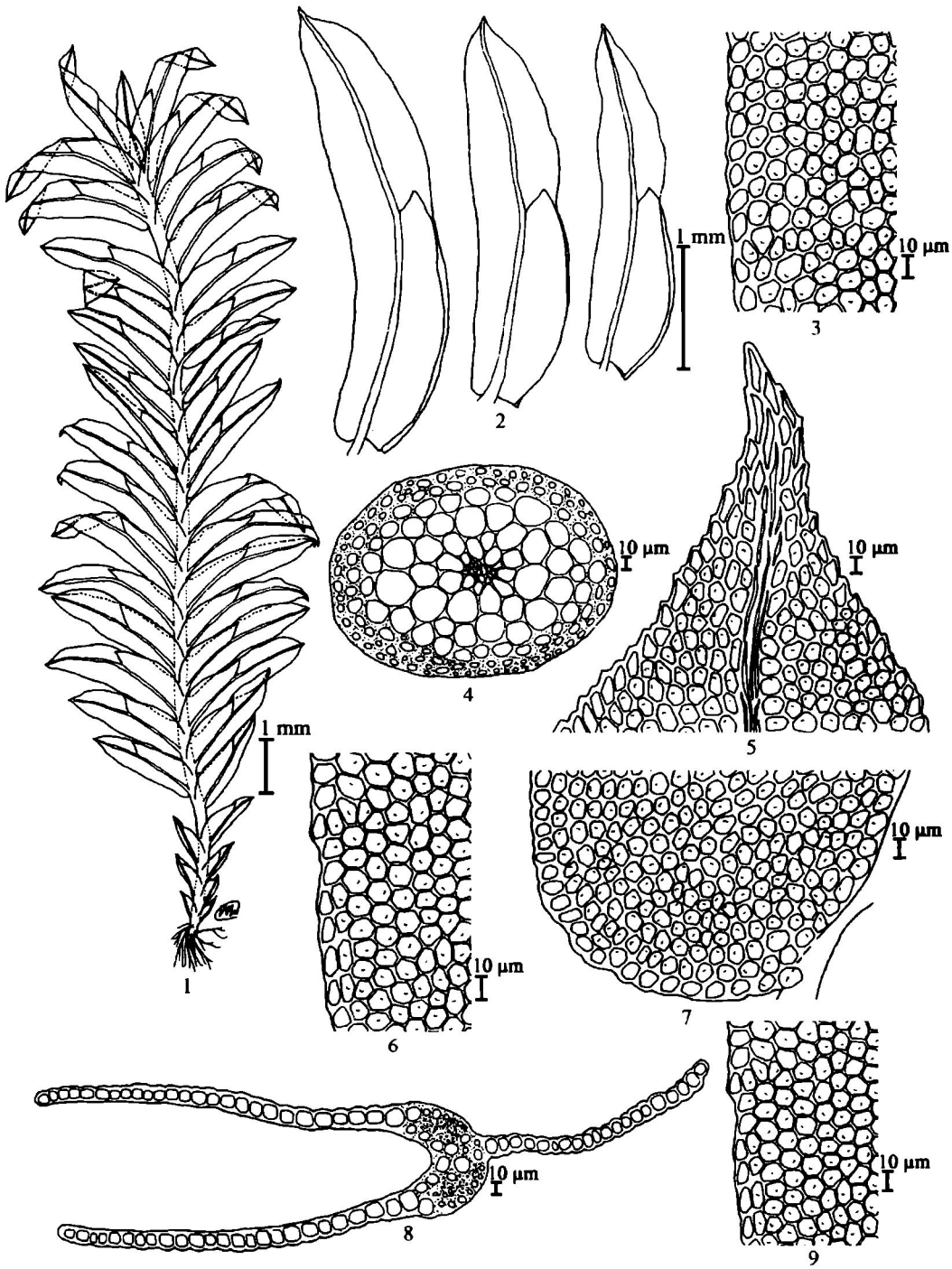


Figure 50. *Fissidens oblongifolius* Hook. f. & Wils.
1: plant habit. 2: leaves. 3: vaginant lamina cells. 4: cross section of stem. 5: leaf apex. 6: apical lamina cells. 7: leaf base cells. 8: cross section of leaf. 9: dorsal lamina cells. Drawn from Wongkuna 769A.

34. ***Fissidens obscurus*** Mitt., Musc. Ind. Or. (1859) 138.
Gangulee (1971) 557 (fig.), 558 (map), 559.
Li and Iwatsuki (2001) 45 (plate+fig.), 51, 52 (map).

Plants 1-4 cm long, 0.5-0.7 mm wide, dark green; stem simple; axillary hyaline nodules not differentiated; central strand lacking, leaves 34-80, more or less densely arranged, crisped when dry; middle to upper leaves lanceolate, 3.2- 4.0 mm long, 0.5-0.6 mm wide, apex obtuse to obtusely acute, base rounded to cuneate, not decurrent; vaginant lamina 1/2 to 3/5 of leaf length, upper part more or less asymmetric; costa stout, ending several cells below apex; cells of apical lamina irregularly quadrate to hexagonal, often rounded, tick-walled, 8-13 μm long, obscure, smooth; cells of vaginant lamina similar to those of the apical lamina. Dioicous. Sporophytes not seen.

Illustrations: Figures 51B and 136B
Habitat: on wet rocks near streams in shaded places
Ecology: primary, evergreen, seasonal, hardwood, forest, granite bedrock, 2119-2217 m elevation
Phenology—gametophyte: June
Distribution—(Figure 98) Nepal, India, China, Japan.
New record for Thailand.
Distribution in Thailand—(Figure 78B) Nakhon Sri Thammarat: Khao Nan National Park.
Specimen studied—(BCU, gametophyte) Nathi 1024.

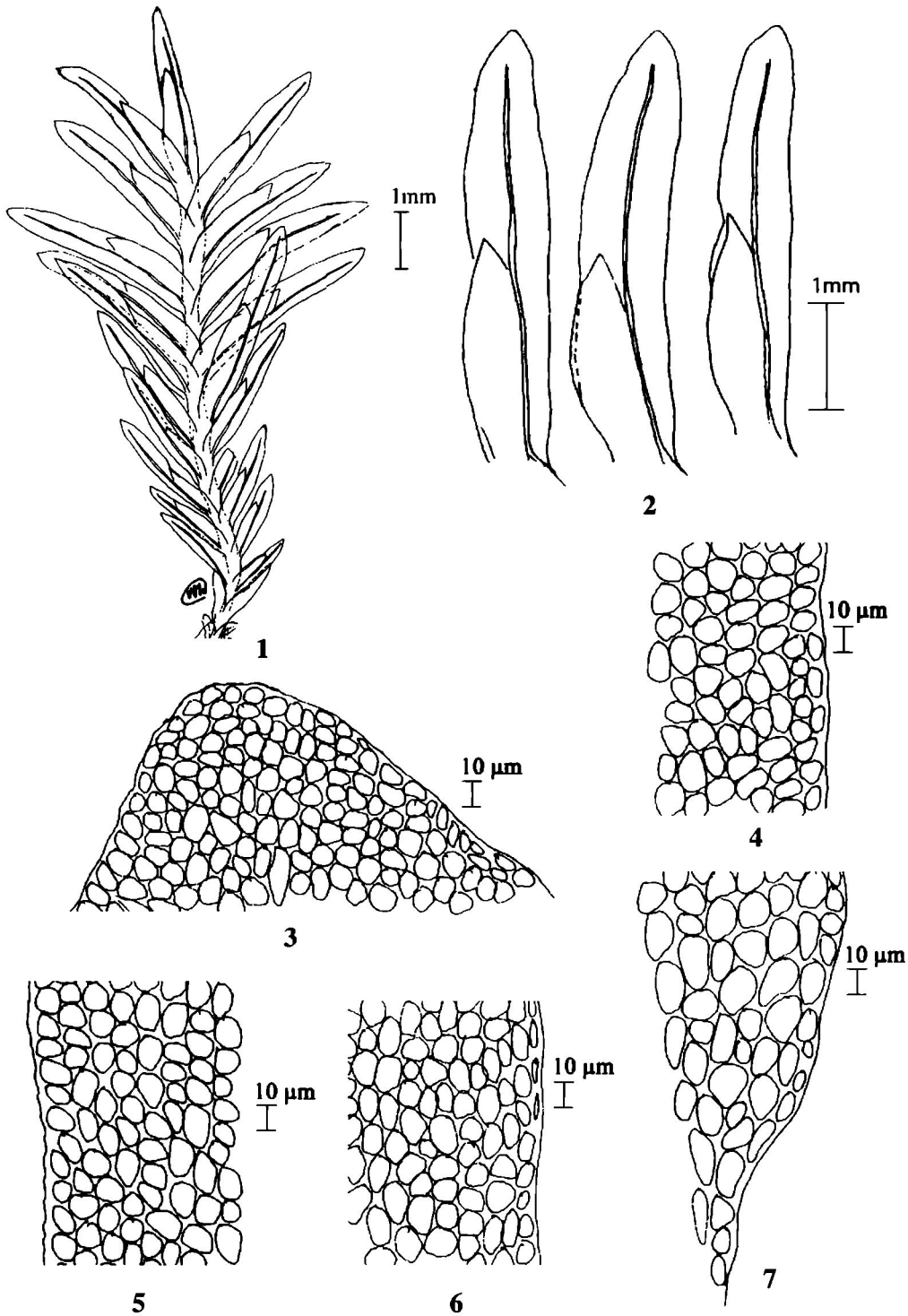


Figure 51. *Fissidens obscurus* Mitt.
1: plant habit. 2: leaves. 3: leaf apex 4: apical lamina cells. 5: vaginant lamina cells. 6: dorsal lamina cells. 7: leaf base cells. Drawn from Nathi 1024.

35. ***Fissidens pellucidus*** Hornsch., Linnaea 15 (1841) 146.

Fissidens laxus Sull. & Lesq. var. *laxus* Proc. Amer. Acad. Arts Sci. 4 (1859) 275., S. He (1996); Li & Iwatsuki (2001) 53, *pro syn.*

Fissidens crassinervis Sand. Lac. var. *laxus* (Sull. & Lesq.) Eddy (1988) 70; Li & Iwatsuki (2001) 53, *pro syn.*

Fissidens mittenii Par. var *mittenii* Ind. Bryol (1894) 477; Eddy (1988) 70, *pro syn.*

Plants up to 5 mm long, 1.1-2 mm wide, laxly gregarious; dark green, usually brownish; stems usually simple; axillary hyaline nodules not differentiated; cortical stem cells small, distinctly thick-walled, central strand not differentiated; leaves 12-28, lower leaves small and lax, upper leaves much large, lanceolate, 0.8-1.5 mm long, 0.2-0.4 mm wide; apex long-acuminate (25-30°); base cuneate, not decurrent; margin indistinctly serrulate, without limbate; costa prominent, percurrent to shortly excurrent; vaginant laminae1/2 to 1/3 leaf length, almost symmetry but open to costa at upper end in perichaetial leaves; cells of apical lamina quadrate to irregularly hexagonal, 10-30 μm long, 10.5-20 μm wide, evenly thin-walled, smooth, pellucid, in most of the specimens each laminal cell has a nucleus-like hyaline spot inside which are persistent in dried specimens; cells of upper portion of vaginant laminae similar to those of apical lamina, but those of perichaetial leaves elongate, usually long hexagonal, thin-walled; perichaetial leaves usually with rounded upper end of vaginant laminae which is open to costa. Sporophyte terminal; setae 2.5-3 mm long, smooth; capsules erect and symmetrical; ovate, 0.4-0.5 mm long; operculum conicrostrate, about 0.5 mm long.

Illustartions: Figures 52 and 136C

Habitate: on soil in open areas

Ecology: deciduous, dipterocarp-oak forest 60-250 m elevation; mixed evergreen+deciduous, seasonal, hardwood forest 850-1000 m elevation; and primary evergreen, seasonal, hardwood forest 1000-2565 m; granite, sandstone, and limestone bedrocks, sometimes in disturbed sites.

Phenology—gametophytes: February-December
sporophytes: June-September

Distribution—(Figure 124) Nepal, India, Sri Lanka, Bangladesh, Taiwan, Hong Kong, Myanmar, Vietnam, Malaysia, Singapore, Philippines, Borneo, Java, Sumatra, Papua New Guinea, Australia, United States, Brazil, Cambodia, Costa Rica, French Guiana, Jamaica, Peru, Suriname Dominican Repubic, Ecaudor, Fernando Po, Ivory Coast, Rio Muni, Bolivia, Venezuela

Distribution in Thailand—(Figure 78C) Chiang Mai: Doi Inthanon National Park, Doi Suthep-Pui National Park, Chiang Dao Wildlife Sanctuary and Chiang Dao Wildlife Sanctuary. Loei: Phu Kradung National Park, Phu Luang Wildlife Sanctuary. Sakon Nakhon: Phu Phan National Park. Ubon Ratchathani: Thong Pha Phum National Park. Rayong: Khao Cha Mao- Khao Wong National Park, Khao Khitchakut National Park. Chanthaburi: Nam Tok Phlieo National Park. Nakhon Nayok: Khao Yai National Park. Phetchaburi: Kaeng Krachan National Park. Ranong: Nam Tok Ngao National Park. Nakhon Sri Thammarat: Khao Nan National Park.

Specimens studied: (BKF) Touw 12079; (CMU, gametophyte) Wongkuna 184, 199, 297, 299, 300, 305, 307, 315, 386, 516, 442, 594, 1020, 1053, 1128, 1161, 1162, 1176, 1185, 1212, 1328, 1388, 1425, 1498, 1589, 1661, 1662, 1665, 1691, 1695, 1710, 1715, 1724, 1734, 1736, 1746, 1794, 1816, 1835, 1881, 1882, 1883, 1869, (CMU, gametophyte and sporophyte) Wongkuna 186, 204, 212, 219, 220, 222, 224, 262, 301, 529, 532, 533, 543, 561, 1022, 1190, 1322, 1343, 1607, 1637, 1687, 1711, 1714, 1716, 1717, 1735, 1796, 1818, 1819, 1839, 1846, 1849, 1870.

This species is closely related to *Fissidens crassinervis* Sande Lac. but differs in having crenulate or serrate leaf margins, thin-walled to slightly thick walled cells, and acute to shortly acuminate leaf apex.

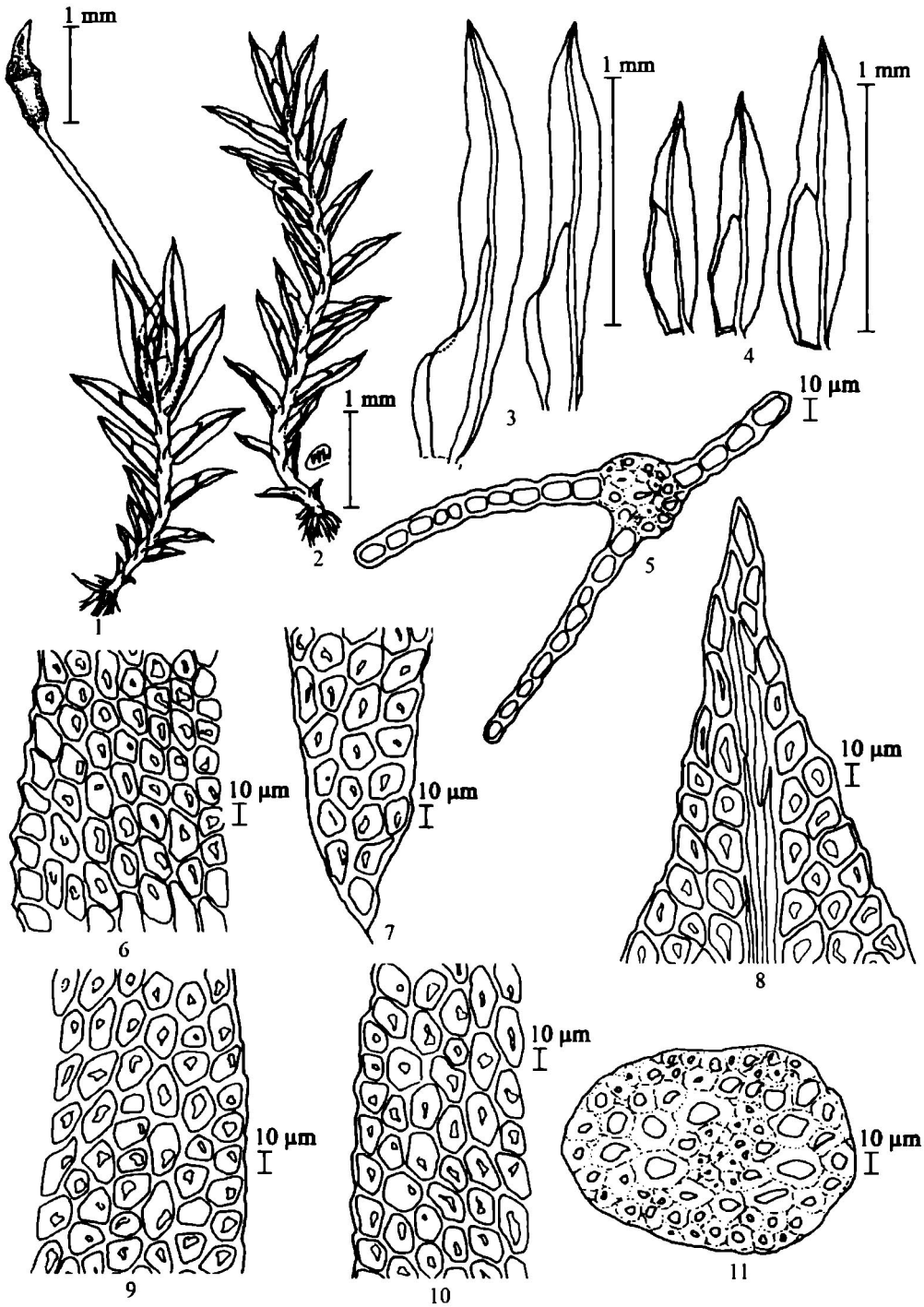


Figure 52. *Fissidens pellucidus* Hornsch.
1: plant with sporophyte. 2: plant habit. 3: perichaetial leaves. 4: leaves. 5: cross section of leaf. 6: apical lamina cells. 7: leaf base cells. 8: leaf apex. 9: dorsal lamina cells. 10: vaginant lamina cells. 11: cross section of stem. Drawn from Wongkuna 529.

36. ***Fissidens polypodioides*** Hedw., Sp. Musc. Frond. (1801) 154.

Li and Iwatsuki (2001) 55, 56 (map).

Fissidens areolatus Griff., Calcutta J. Nat. Hist. 2 (1842) 506. Eddy (1988) 62, Li & Iwatsuki (2001) 55, *pro syn.*

Fissidens polypodioides Hedw. var. *areolatus* (Griff.) Wils., Kew J. Bot. 2 (1857) 294, Li & Iwatsuki (2001) 55, *pro syn.*

Plants 35-64 mm long, 5.8-9.5 mm wide; green to dark green, brownish when old; stem simple, central strand well differentiated; axillary hyaline nodules not differentiated; leaves in 40-56, more or less densely arranged; middle to upper leaves oblong lanceolate, 2.5-3.8 mm long, 0.6-1.2 mm wide apex, rounded to obtusely acute; base usually rounded, not decurrent; margins more or less entire to slightly serrate; costa stout, ending 4-5 cells below apex; vaginant lamina mostly 1/2 the leaf length, upper part almost symmetric; cells of apical lamina quadrate to hexagonal, with thick walls, often orbicular with thickened corners, 13-18 μm long, smooth to slightly mammillose, pellucid, walls clear; cells of vaginant lamina similar to those of the apical lamina, but larger toward costa and base. Dioicous; Sporophytes terminal and on short lateral branches; setae 10-12 mm long, smooth; capsules slightly inclined, symmetrical; 1.5-2 mm long.

Illustrations: Figures 53 and 136D

Habitat: on soil or wet rocks in moist and shaded habitats.

Ecology: primary, evergreen, seasonal, hardwood forest; granite bedrock, 1250-2565 m elevation

Phenology —gametophytes: February-December
sporophytes: June-August

Distribution—(Figure 119) Nepal, India, Bangladesh, China, Taiwan, Hong Kong, Japan, Myanmar, Vietnam, Malaysia, Singapore, Philippines, Sumatra, Borneo, New Guinea, Australia, United States, Central America, Colombia, Ecuador, Mexico, Nicar, Peru, Venezuela, West Indies.

Distribution in Thailand—(Figure 78D) Chiang Mai: Doi Inthanon National Park. Phitsanulok: Phu Hin Rong Kla National Park. Loei: Phu Kradung National Park, Phu Luang Wildlife Sanctuary. Nakhon Nayok: Khao Yai National Park. Nakhon Sri Thammarat: Khao Nan National Park.

Specimens studied—(CMU, gametophyte) Wongkuna 304, 313, 314, 321, 899, 904, 912, 915, 954, 959, 1016, 1021, 1035, 1040, 1057, 1064, 1087, 1114, 1123, 1135, 1137, 1138, 1140, 1171, 1178, 1180, 1183, 1188, 1198, 1200, 1202, 1407, 1409, 1410, 1412, 1415, 1416, 1421; (CMU, gametophyte and sporophyte) Wongkuna 765, 902, 909, 910, 931, 932, 958, 1084.

This species is more than 3 cm long with oblong-lanceolate leaves, costa ending below apex, smooth laminae cells. Its perichaetial leaves are smaller and narrower than those of other leaves. The sporophyte is on lateral branches.

Differences between *F. polypodioides* and *F. obscurus*

	F. polypodioides	*F. obscurus*
1. plant height	3.5-6.4 cm	1-4 cm
2. leaves	round to obtusely acute to more or less mucronate	obtuse to obtusely acute
3. costa	ending few cells below apex or almost percurrent	ending a few cells below apex
4. cells	13-18-(22) μ, smooth to slightly mammillose, pellucid	10-13-(16) μ, smooth, obscure
5. central strand	well-differentiated	not differentiated

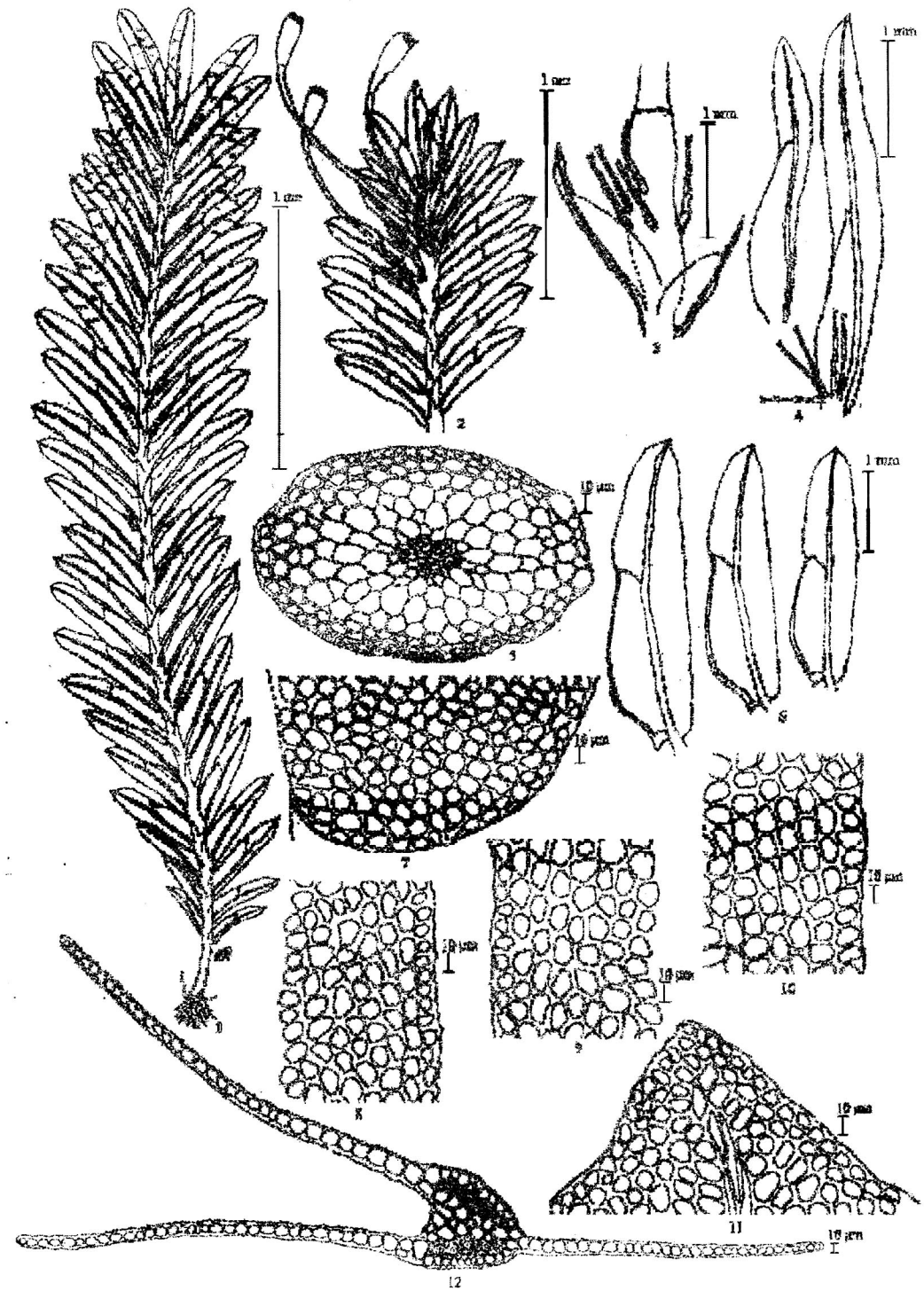


Figure 53. *Fissidens polypodioides* Hedw.
1: plant habit. 2: part of stem with sporophyte. 3: archegonia on foot. 4: perichaetial leaves. 5: cross section of stem. 6: leaves. 7: leaf base cells. 8: apical lamina cells. 9: dorsal lamina cells. 10: vaginant lamina cells. 11: leaf apex. 12: cross section of leaf. Drawn from Wongkuna 304.

37. ***Fissidens pseudokinabaluensis*** K. Wongkuna & B. C. Tan, *sp. nov.* (in press)

Plants up to 5 mm tall, yellow-green; stem usually simple; central strand not differentiated, hyaline nodules well developed; leaves 18-24, densely arranged, lowest leaves small, middle to upper leaves much larger, narrowly lanceolate, 1.5-2 mm long, 0.2-0.25 mm wide, apex long and narrowly acuminate (about 20°), base acute, not decurrent; margin entire; limbidia differentiated all around the leaves with 1-2 rows of cells, weakly developed at apex; costa excurrent; vaginant lamina about 3/5 of leaf length; cells of leaf apex similar to those on dorsal lamina, polygonal, 6-10 μm long, 5-8 μm wide, thin-walled, multipapillose with more than tiny 8 papillae per cell; cells of vaginant lamina similar to those of the apical lamina. Sporophyte not seen.

Illustrations: Figures 54 and 137A

Habitat: on soil in shaded areas

Ecology: mixed evergreen+deciduous, seasonal, hardwood forest; 960 m elevation, granitic badrock.

Phenology—gametophytes: June

Distribution—(Figure 107) Thailand

Distribution in Thailand—(Figure 79A) Phetchaburi: Kaeng Krachan National Park.

Specimens studied—(CMU, gametophyte) Wongkuna 1532 (holotype, CMU), 1533 (paratype, CMU).

This species is closely allied to *F. kinabaluense* Z. Iwats. in which the limbidia is limited to the vaginant lamina.

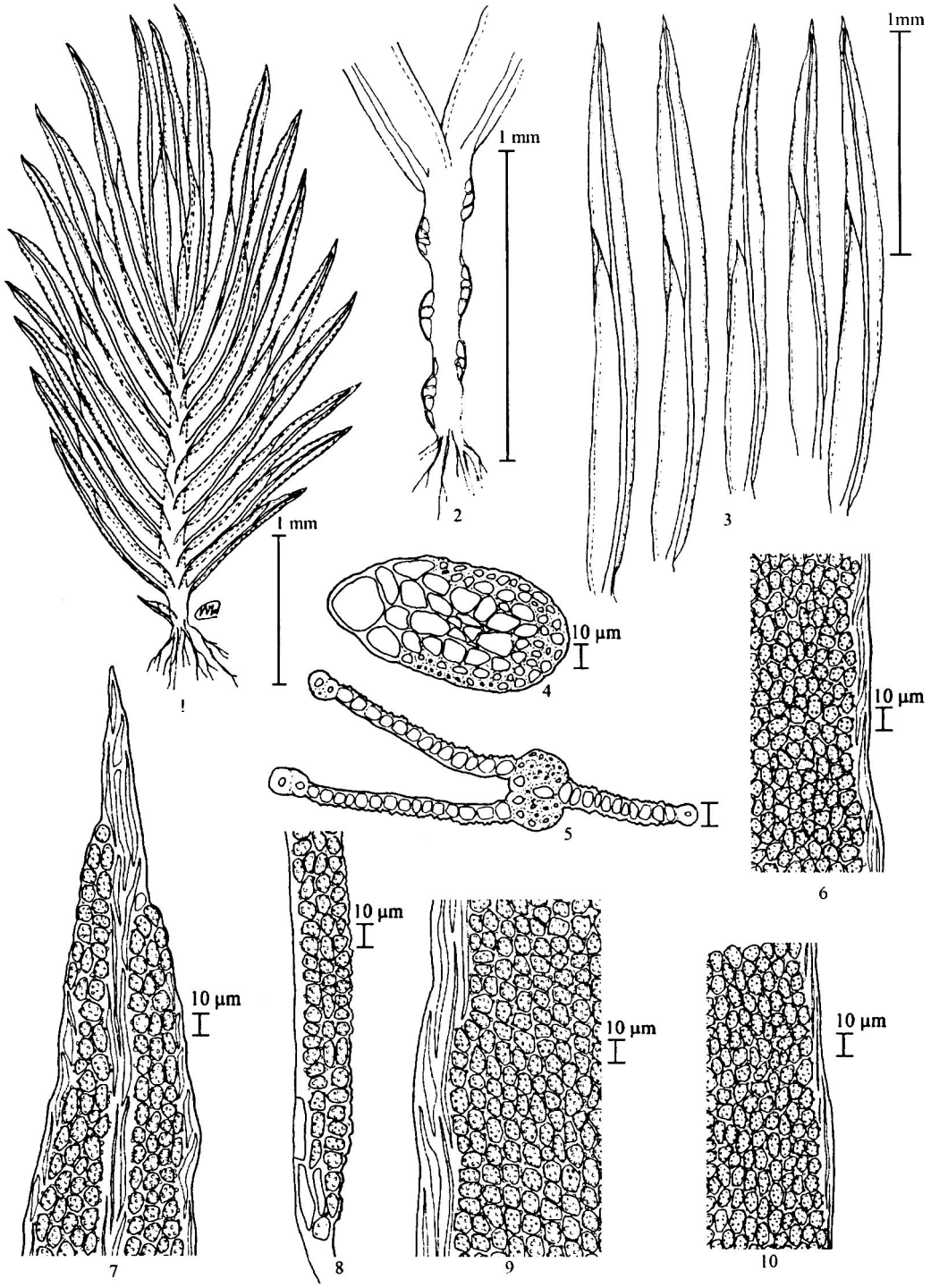


Figure 54. *Fissidens pseudokinabaluensis* K. Wongkuna & B. C. Tan
1: plant habit. 2: hyaline nodules on stem. 3: leaves. 4: cross section of stem. 5: cross section of leaf. 6: dorsal lamina cells. 7: leaf apex. 8: leaf base cells. 9: vaginant lamina cells. 10: apical lamina cells. Drawn from Wongkuna 1532 (holotype).

38. ***Fissidens sedgwickii*** Broth. & Dix., J. Bot. 48 (1901) 305.

Plants aquatic, 10-13 mm tall, 1.7-2 mm wide, green, brownish when old, stems simple; axillary hyaline nodules not differentiated, without a central strand; leaves 36-44; densely arranged, middle to upper leaves lanceolate, 5.0-8.0 mm long, 1.0-1.6 mm wide, apex acute, base decurrent; margin entire, costa ending below apex; limbidia 2-5 cells wide, 1-2 cells thick, limited on vaginant lamina; vaginant lamina about 2/3 of leaf length; lamina cells quadrate to hexagonal, about 6-12 μm diameter, smooth, very thick-walled, 1-2 cells thick in apical lamiana, 3-4 cells thick in dorsal lamina; cells of vaginant lamina similar to those of apical lamina, but thin-walled, 1-2 cells thick. Dioicous. Sporophyte not seen.

Illustrations: Figures 55 and 137B

Habitat: on rocks under fresh water in shaded streams, sometimes in disturbed places

Ecology: primary, evergreen, seasonal, hardwood forest; granite, bedrock, *c.* 1200 m elevation.

Phenology—gametophytes: November-December

Distribution— (Figure 108) India.

Distribution in Thailand—(Figure 79B) Loei: Phu Kradung National Park, Phu Luang Wildlife Sanctuary.

Specimens studied—Touw 10788 (BKF, gametophyte); (CMU, gametophyte) Wongkuna 1124, 1126, 1153, 1169, 1173.

This is an aqautic plant with thick-walled cells. The vaginant lamina is often 2 cells thick and the dorsal lamina 2-4 cells thick.

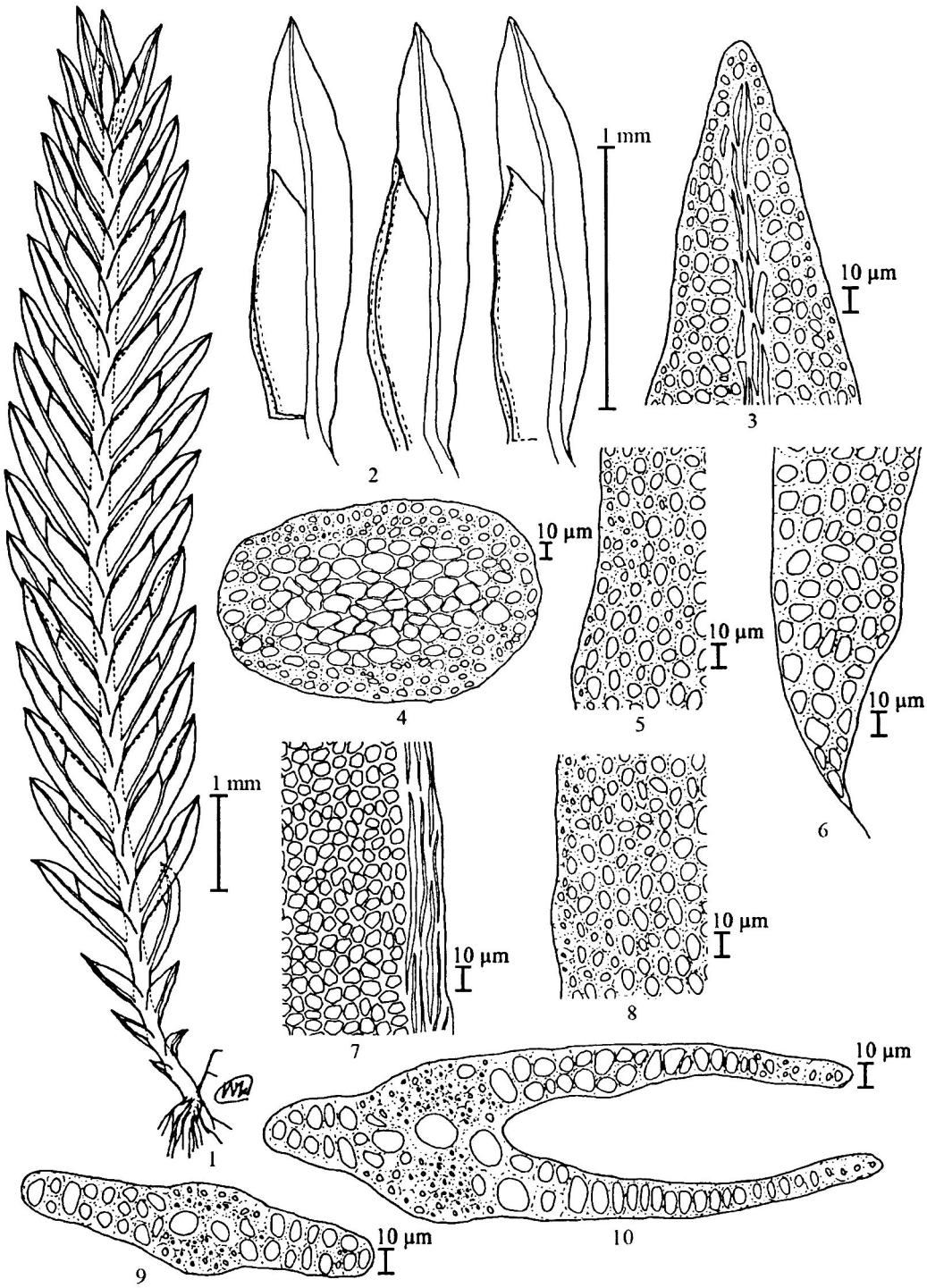


Figure 55. *Fissidens sedgwickii* Broth. & Dix.
1: plant habit. 2: leaves. 3: leaf apex. 4: cross section of stem. 5: apical lamina cells. 6: leaf base cells. 7: vaginant lamina cells.8: dorsal lamina cells. 9-10: cross sections of leaf. Drawn from Wongkuna 1126.

39. ***Fissidens semperfalcatus*** Dix., J Siam Soc. Nat. Hist. Suppl. 10 (1935) 2.
Gangulee (1971) 501, 502 (map), 503 (fig.).

Plants 3-6 mm tall; 1.8-2 mm wide; green; stem usually unbranched; hyaline nodules not differentiated; central strand lacking; leaves 12-24, densely arranged, lowest leaves small, middle to upper leaves larger, narrowly lanceolate, 1-1.3 mm long, 0.2-0.25 mm wide, apex narrowly acute (35-40°), base slightly narrowed, margins undulate; costa shortly excurrent; vaginant lamina half of leaf length, falcate when dry; limbidium above vaginant lamina, in 2-4 row of cells, thick-walled, one cell thick; lamina cells 6.0-9.0 μm diameter, irregularly quadrate-hexagonal, walls slightly thickened, strongly unipapillose. Autoicous. Sporophyte terminal and lateral; seta smooth, 2.5-4 mm long; capsules erect, cylindric to urceolate, symmetrical, 0.4-0.5 mm long.

Illustrations: Figures 56 and 137C

Habitat: on bare soil in opened areas

Ecology: deciduous dipterocarp-oak, seasonal, hardwood forest, 60-850 m elevation; mixed evergreen+deciduous, seasonal, hardwood forest, 850-1000 m elevation; and primary, evergreen, seasonal, hardwood forest, 1000-2565 m granitic, sandstone and limestone bedrocks.

Phenology—gametophytes: March-December
sporophytes: March-December

Distribution—(Figure 99) Nepal, India, Bangladesh, Myanmar.

Distribution in Thailand—(Figure 79C) Chiang Mai: Doi Inthanon National Park, Doi Suthep-Pui National Park, Pha Daeng National Park. Phitsanulok: Phu Hin Rong Kla National Park. Chaiyaphum: Tat Ton National Park. Ubon Ratchathani: Pha Taem National Park. Rayong: Khao Cha Mao-Khao Wong National Park. Chanthaburi: Nam Tok Phlieo National Park. Nakhon Nayok: Khao Yai National Park. Nakhon Sri Thammarat: Khao Nan National Park, Krabi: Phanom Bencha National Park.

Specimens studied—(BKF) Bartram 8, Suvarnasara 53, 68, Touw 10308; (CMU, gametophyte) Wongkuna 489, 605, 1684, 1754, 1893; (CMU, gametophyte and sporophyte) Wongkuna 197, 202, 205, 294, 295, 311, 454, 487, 497, 501, 644, 676, 1012, 1253, 1254, 1314, 1315, 1323, 1336, 1367, 1368, 1376, 1381, 1600, 1874.

This species is recognized by the limbidium situated above the vaginant lamina, the leaves becoming falcate when dry, terminal and lateral sporophytes.

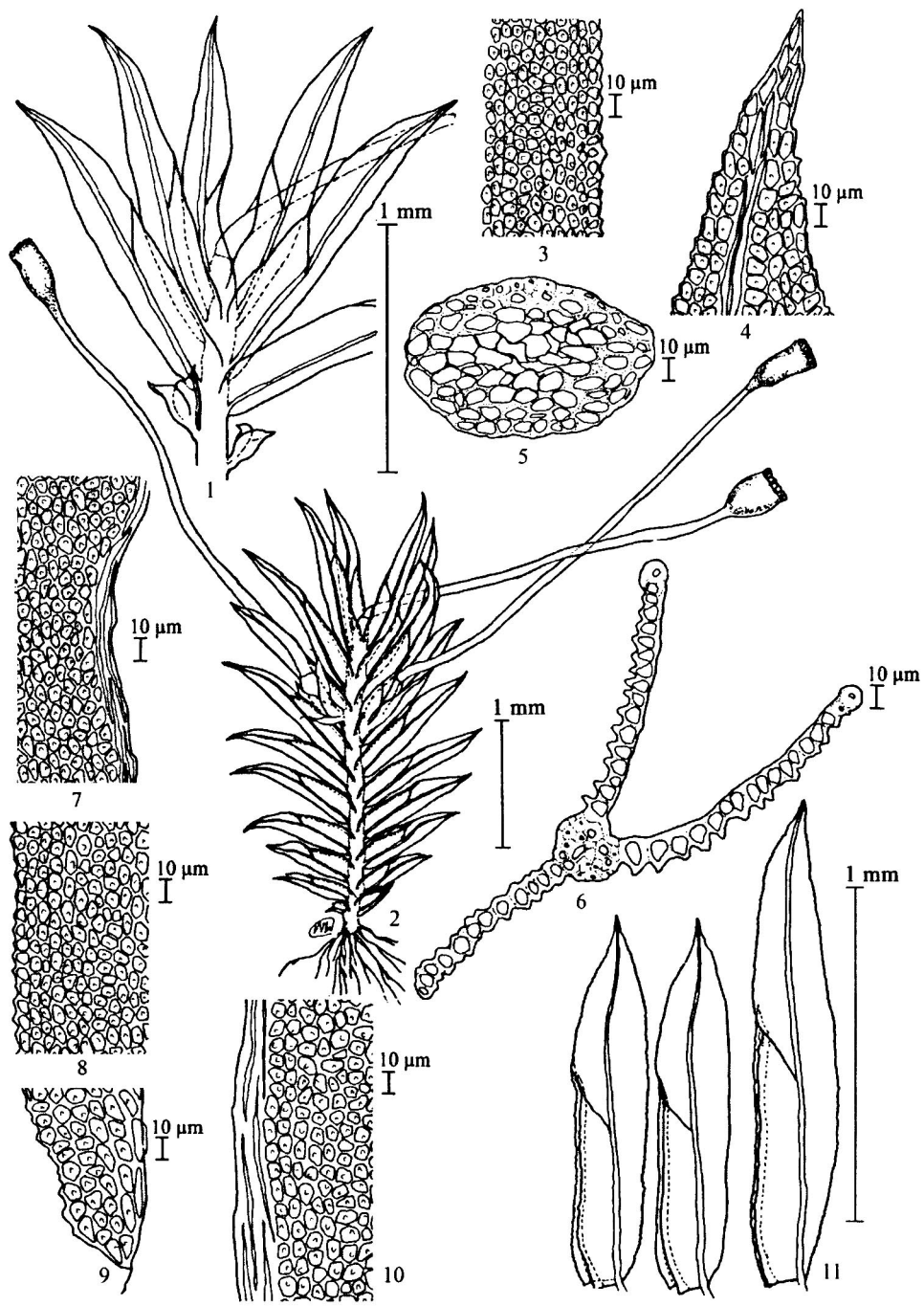


Figure 56. *Fissidens semperfalcatus* Dix.
1: part of stem with sex organs and sporophyte. 2: plant with sporophyte. 3: apical lamina cells. 4: leaf apex. 5: cross section of stem. 6: cross section of leaf. 7: vaginant lamina cells. 8: dorsal lamina cells. 9: leaf base cells. 10: vaginant lamina cells. 11: leaves. Drawn from Wongkuna 197

40. ***Fissidens serratus*** Muell. Hal., Bot. Zeitung 5 (1847) 804.
Eddy (1988) 64 (including extra-Thai synonyms) 67 (fig.).
Li and Iwatsuki (2001) 58, 59 (map).

Plants usually 1-1.5 mm long, 0.5-0.8 mm wide; green to dark green; stems simple, without axillary hyaline nodules; central stand lacking; densely foliated with 6-10 leaves; upper stem leaves lanceolate, 0.33-0.4 mm long, 0.1-0.12 mm wide; apex narrowly acute to shortly acuminate (25-30°); wedge shaped at base not decurrent; margin distinctly serrate; vaginant laminae about a half of leaf length, upper part unequal; costa strongly excurrent; cells apical lamina quadrate to hexagonal, 8-12 μm diameter, with a large central papilla at center, walls clear, moderately thick, cells at upper part of vaginant lamina similar to those of apical lamina, but larger toward base, cells at extreme base of vaginant lamina rectangular to 25 μm long, smooth. Autoicous; Sporophyte terminal; seta 5-5.3 mm long, smooth; capsules cylindrical, erect, symmetrical, 0.3-0.5 mm long; operculum long rostrate, 0.2-0.4 mm long. spore smooth, 7.5-9 μm.

Illustrations: Figures 57 and 137D
Habitat: on soil and one on rocks in partially shaded moist sites,
Ecology: primary, evergreen, seasonal, hardwood forest, granite, bed rock, 1250-2565 m elevation
Phenology—gametophytes: June-November
sporophyte: June
Distribution—(Figure 125) Hong Kong, Taiwan, Japan, India, Sri Lanka, Malaysia, Papua New Guinea, Philippines, Singapore, Australia, Cape of Good Hope, Ivory Coast, Kenya, Madagascar, Mauritius, Mozombique, Natal, Seychelles, Socota, Tanzania, Transvaal, Zimbabwe, United States, Central America, South America, Mexico, West Indies.
New record for Thailand.
Distribution in Thailand—(Figure 79D) Chiang Mai: Doi Suthep-Pui National Park. Phitsanulok: Phu Hin Rong Kla National Park.
Specimens studied—(CMU, gametophyte), Wongkuna 154, 436A, 437A, 438D, 444C; (CMU, gametophyte and sprophyte) Wongkuna 336A

This species is 1-1.5 mm long having 6-10 leaves with serrulate margins, and no hyaline nodules on the stem. It different from *F. tenellus* Hook. f. & Wils. var. *australiensis* (A. Jaeger) Beever & Stone by having excurrent costa and acut leaf apex.

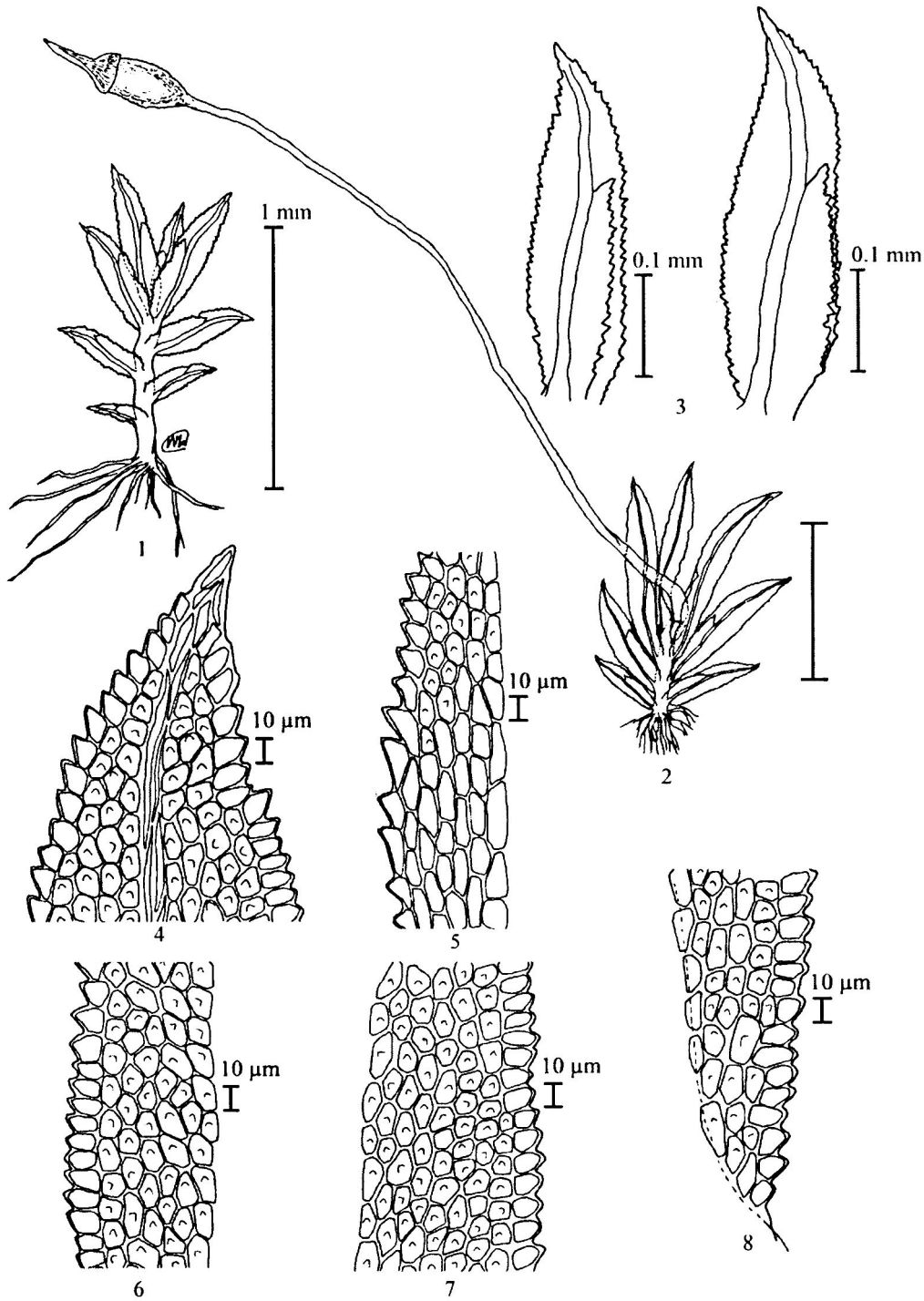


Figure 57. *Fissidens serratus* Muell. Hal.
1: plant habit. 2: plant with sporophyte. 3: leaves. 4: leaf apex. 5: vaginant lamina cells. 6: dorsal lamina cells. 7: apical lamina cells. 8: leaf base cells. Drawn from Wongkuna 336.

41. ***Fissidens subangustus*** Fleisch., Musci Fl. Buitenzorg 1 (1904) 47.
Li and Iwatsuki (2001) 55 (map), 59 (plate+fig.).

Plants 3-3.6 mm long, 3-3.4 mm wide, gregarious; green to dark green; stems usually simple; axillary hyaline nodules developed; central strand not differentiated; leaves 14-24, upper leaves narrowly lanceolate, 2-2.7 mm long, 0.2-0.3 mm wide, apex acute to narrowly acute; base cuneate, not decurrent; vaginant laminae half of leaf length; margin crenulate; without limbate; costa excurrent; cells of apical and dorsal laminae quadrate to irregularly hexagonal, moderately thick-walled, 5-8 μm diameter, with 2-3 small paplillae at each corner; cells of vaginant laminae similar to those of the apical lamina; marginal cells of vaginant laminae of upper leaves often elongate. Dioicous. Sporophyte not seen.

Illustrations: Figures 58 and 138A
Habitat: on bare soil in shaded areas
Ecology: primary, evergreen, seasonal, hardwood forest; granite, bedrock, 1250-2565 m elevation
Phenology—gametophytes: February-December
sporophtye: December
Distribution—(Figure 100) India, Taiwan, Japan, peninsular Malaysia, Philippines, Sumatra, Java
Distribution in Thailand—(Figure 80A) Chiang Mai: Doi Inthanon National Park, Doi Suthep-Pui National Park, Chiang Dao Wildlife Sanctuary.
Specimens studied—(CMU, gametophyte) Wongkuna 240, 266A, 269A, 417, 418A, 419, 444A, 792, 796A, 806, 819B, 846A, 998A.

This species is closely related to *F. crispulus* Brid. var. *crispulus* and *F. crispulus* var. *robinsonii* (Broth.) Z. Iwats. & Z. H. Li. These two taxa have distinctly mammillose, not multi-papillose, laminal cells.

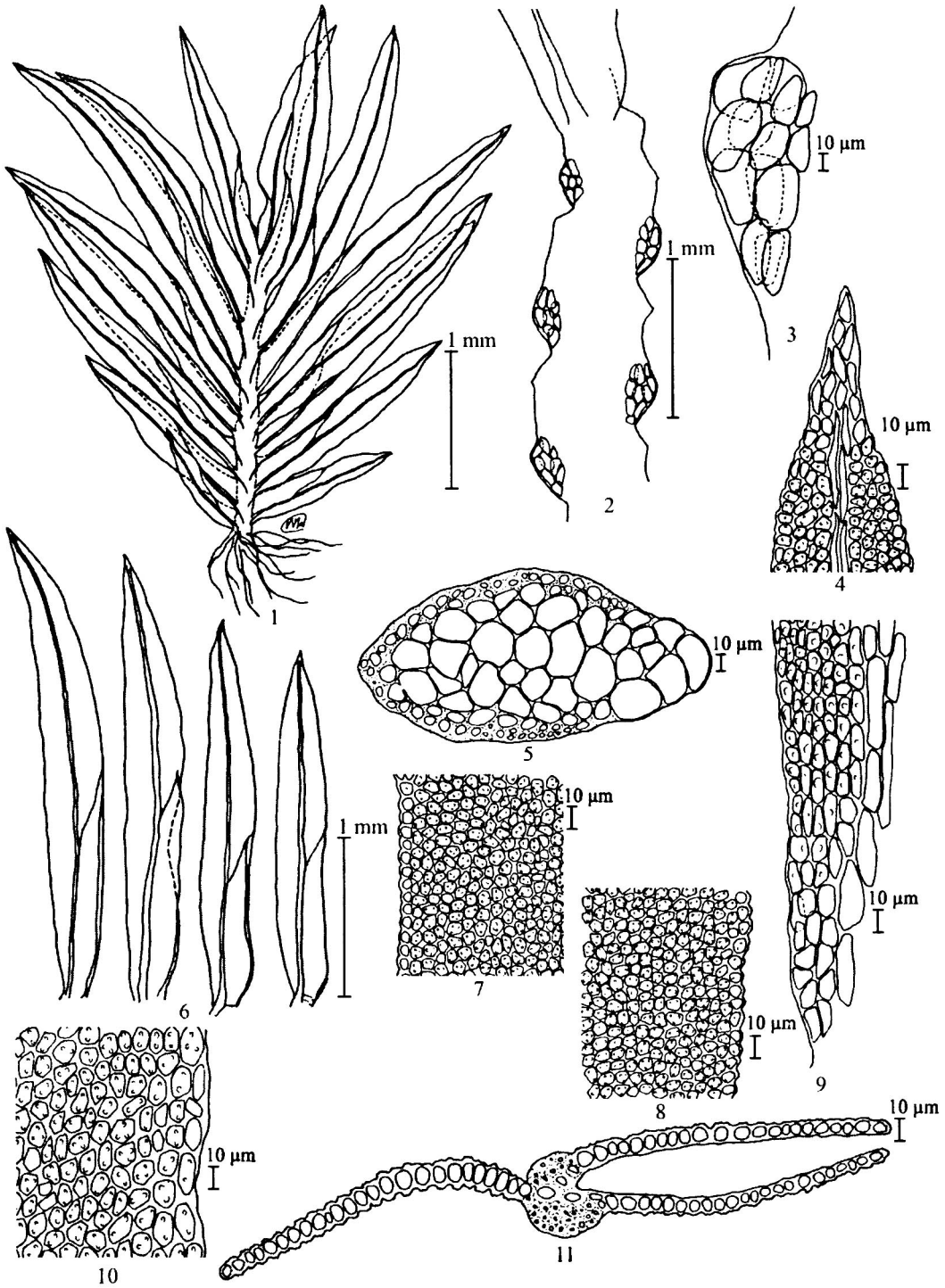


Figure 58. *Fissidens subangustus* Fleisch.
1: plant habit. 2: hyaline nodules on stem. 3: hyaline nodules. 4: leaf apex. 5: cross-section of stem. 6: leaves. 7: apical lamina cells. 8: dorsal lamina cells. 9: leaf base cells. 10: vaginant lamina cells. 11: cross-section of leaf. Drawn from Wongkuna 792.

42. ***Fissidens subbryoides*** Gangulee, Nova Hedwigia. 8 (1964) 141.
Gangulee (1971) 468 (map), 469.
Li and Iwatsuki (2001) 61 (map).

Plants 3.5-4 mm tall, 2-2.5 mm wide, light green; stem simple; hyaline nodules slightly to well-differentiated; central strand slightly differentiated; leaves 16-20, narrowly lanceolate, 1.6-2 mm long, 0.2-0.3 mm wide, apex narrowly acuminate (about 20°), base slightly decurrent, margins entire, limbate all around with 1-2 rows of cells, 1-2 cells thick; costa percurrent to excurrent; lamina cells thin-walled or slightly incrassate, rhomboidal to hexagonal, thin-walled, smooth, about 10-15 μm wide, cells at base longer than apical and dorsal laminar cells, vaginant lamina about 1/2 leaf length, cells of vaginant lamina similar to those of other leaves, but longer. Sporophyte not seen.

Illustrations: Figures 59 and 138B
Habitat: on bare soil in shaded areas
Ecology: deciduous dipterocarp-oak seasonal hardwood forest, 30-250 m elevation, mixed evergreen+deciduous seasonal hardwood forest, 850-1000 m elevation, and primary evergreen seasonal hardwood forest 1000-2565 m granitic, sandstone, and limestone bedrocks
Phenology—gametophytes: March-December
Distribution– (Figure 101) China, India, Nepal, Fiji Islands.
Distribution in Thailand—(Figure 80B) Chiang Mai: Doi Inthanon National Park, Doi Suthep-Pui National Park, Chiang Dao Wildlife Sanctuary. Phitsanulok: Phu Hin Rong Kla National Park. Loei: Phu Luang Wildlife Sanctuary. Chaiyaphum: Tat Ton National Park. Rayong: Khao Cha Mao- Khao Wong National Park, Khao Khitchakut National Park. Chanthaburi: Nam Tok Phlieo National Park. Nakhon Nayok: Khao Yai National Park. Phetchaburi: Kaeng Krachan National Park. Ranong: Nam Tok Ngao National Park. Nakhon Sri Thammarat: Khao Nan National Park. Krabi: Phanom Bencha National Park.
Specimens studied—(CMU, gametophyte) Wongkuna 845, 855, 1483; (CMU, gametophyte and sporophyte) Wongkuna 246, 997, 1009, 1062, 1069, 1166, 1270, 1280, 1509, 1523

This species is closely related to *F. biformis* Mitt. and *F. zollingeri* Mont. in which are hyaline nodules differentiated, lamina cells smooth, but the apex is narrowly acuminate in both species.

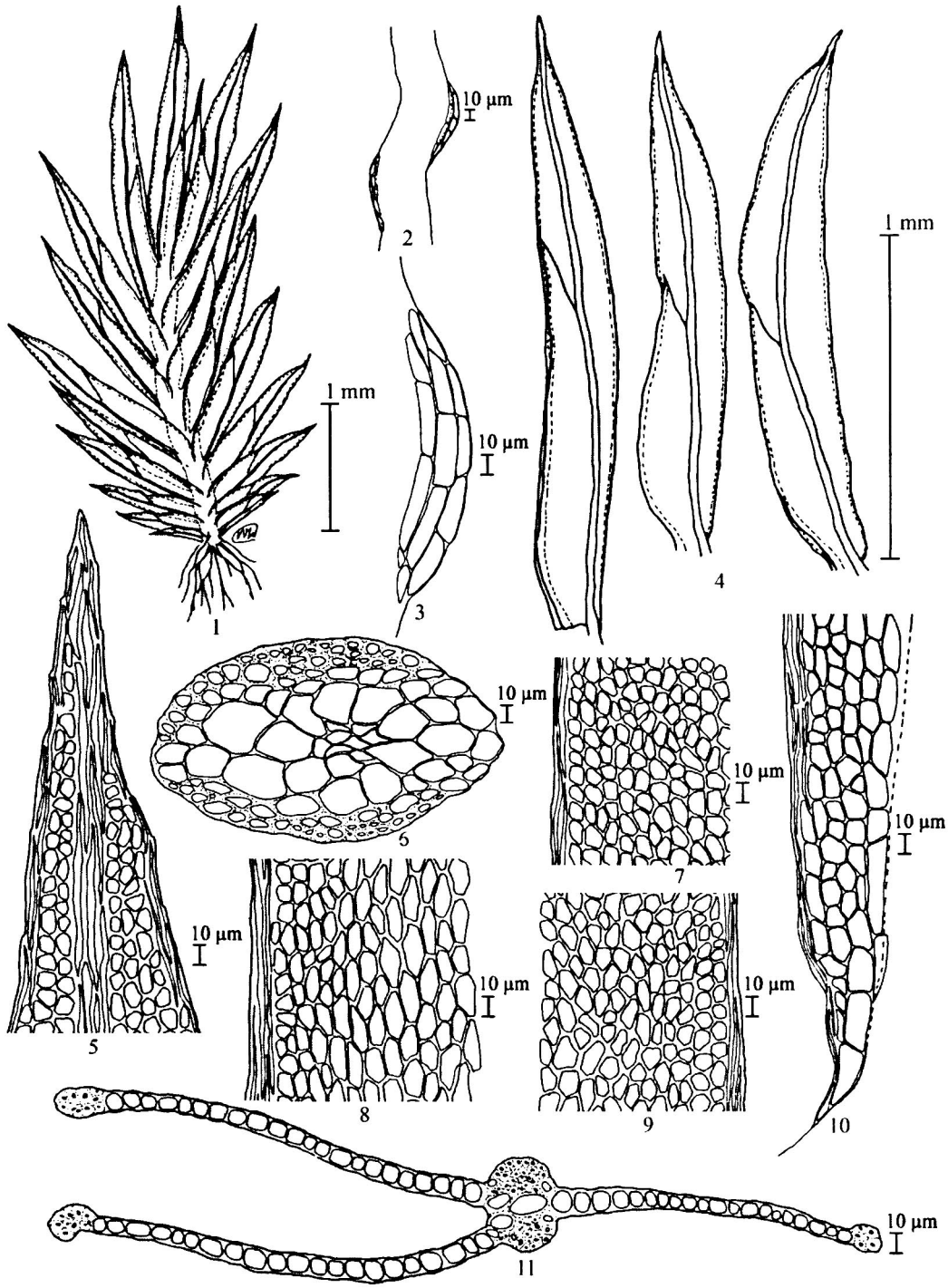


Figure 59. *Fissidens subbryoides* Gangulee
1: plant habit. 2: hyaline nodules on stem. 3: hyaline nodules. 4: leaves. 5: leaf apex. 6: cross section of stem. 6: leaves. 7: apical lamina cells. 8: vaginant lamina cells. 9: dorsal lamina cells. 10: leaf base cells. 11: cross section of leaf. Drawn from Wongkuna 339.

43. ***Fissidens taxifolius*** Hedw., Spec. Musc. Frond. (1801) 155 and Plate 39, 1-5.
Gangulee (1971) 544, 545 (fig.) 546, 547 (map).
Li and Iwatsuki (2001) 62 (map).
Fissidens sylvaticus Griff., Li & Iwatsuki (2001) 62, *pro syn.*.
Fissdens excedens Broth. Wongkuna *et al.* (2009) 307, *pro syn.*.

Plants 5.5-10 mm long, 1.6-3.5 mm wide; densely greagarous; green to dark green, rarely brownish when old; stems simple, axillary hyaline nodules not differentiated; central strand differentiated; leaves 14-24, densely arranged; middle to upper leaves lanceolate, 1.4-2.2 mm long, 0.4-0.8 mm wide, apex acute (45-55°); base usually rounded, not decurrent; margin serrulate throughout; costa stout, shortly excurrent; vaginant lamina 1/2 to 2/3 the leaf length, upper part slightly asymmetric to almost equal; cells of apical lamina orbicular to orbicular quadrate with thickened corners, 6-9 μm diameter, obscurely mammillose; vaginant laminae cells quadrate to hexagonal, larger than those of the apical lamina. Dioicous; female inflorescences at base of stems; perichaetial leaves narrowly lanceolate and much smaller than other leaves; upper portion of vaginant lamina of inner perichaetial leaves often emarginate; archegonia 3.5-4 μm long; Sporophyte not seen.

Illustrations: Figures 60 and 138C
Habitat: on soil in shaded areas
Ecology: primary, evergreen, seasonal, hardwood forest; granite bedrock, 1250-2565 m elevation
Phenology—gametophytes: March-November
Distribution—(Figure 126) India, Nepal, China, Taiwan, Japan, Borneo, Philippines, Sumatra, Java, New Guinea, United States, Bermuda, Chile, Cuba, Macronesia, Hawaiian, Mascarene Islands, Europe
Distribution in Thailand—(Figure 80C) Chiang Mai: Doi Inthanon National Park, Doi Suthep-Pui National Park.
Specimens studied—(CMU, gametophyte) Wongkuna 170B, 171, 227, 270, 435, 436, 437, 443, 450, 505, 506, 507, 509, 514, 962, 964A.

This species is recognised by lacking hylaline nodules. The leaf apex is acute to mucronate and the margins are distinctly serrate, without limbate. The sporophytes are lateral or basal.

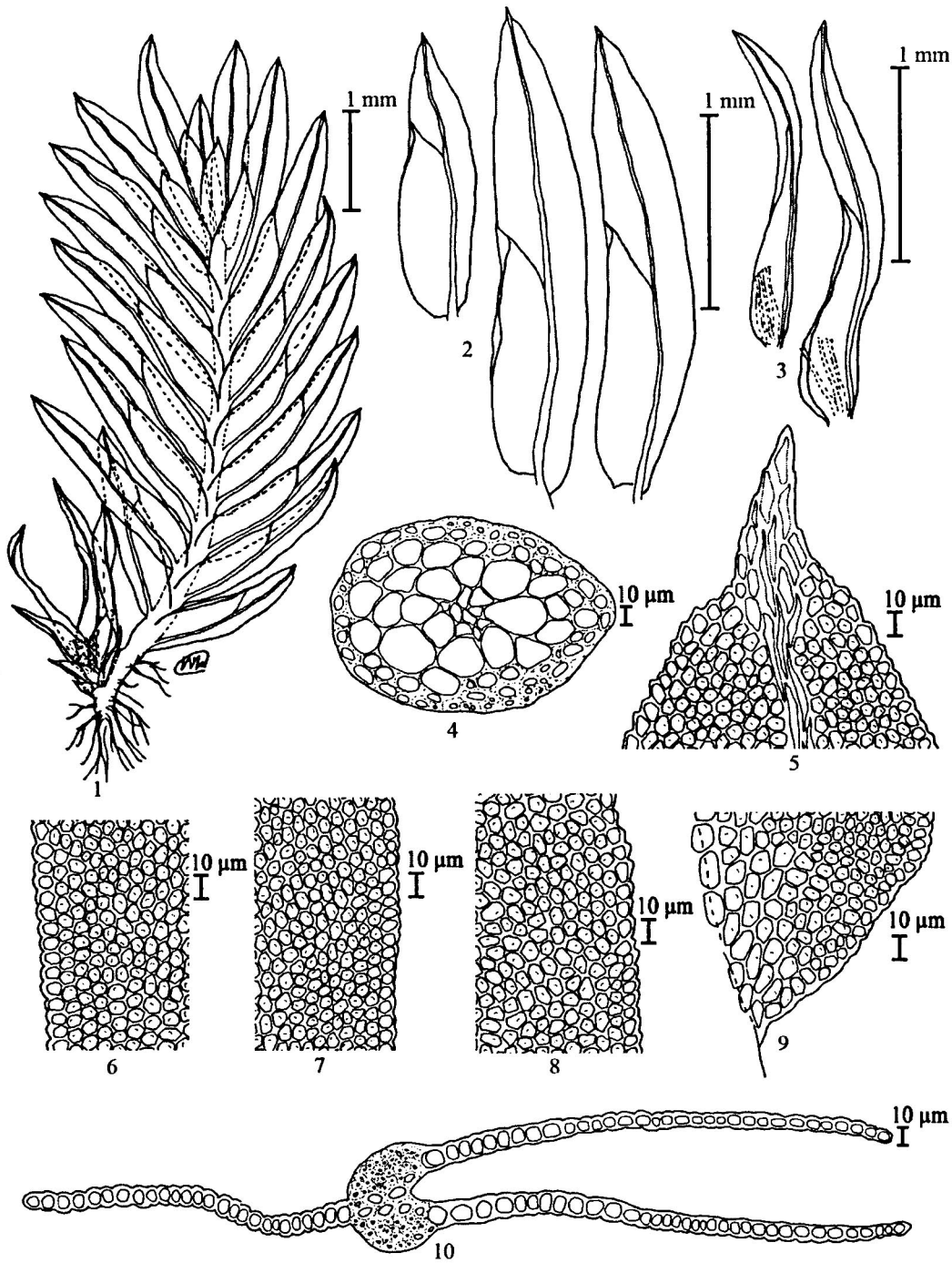


Figure 60. *Fissidens taxifolius* Hedw.
1: plant habit and perichaetial leaf with archegonia on base of stem. 2: leaves. 3: perichaetial leaf with archegonia. 4: cross section of stem. 5: leaf apex. 6: apical lamina cells. 7: dorsal lamina cells. 8: vaginant lamina cells. 7: leaf base cells. 10: cross section of leaf. Drawn from Wongkuna 509.

44. ***Fissidens tenellus*** Hook. f. & Wils., New Zealand J. Bot. 37 (1999) var. ***australiensis*** (A. Jaeger) Beever & Stone, New Zealand J. Bot. 37 (1999).

Fissidens papillosus Lac., Natuurk. Verh. K. Akad. Wet. Amsterdam 13 (1872) 1; Eddy (1988) 70, 72 (fig.); Beever & Stone (1999), *pro syn.*; Wongkuna *et al.* (2009) 304 (note *sub F. serratus*).

Plants 0.8-1.5 mm long, 0.5-1.9 mm wide; green to yellowish-brown; stems simple, axillary hyaline nodules not developed, central strand lacking; densely foliated with 12-20 leaves; upper stem leaves lanceolate to oblong-lanceolate, 0.4-1 mm long, 0.2-0.3 mm wide; apex broadly acute (60-70°); base usually rounded, not decurrent; margin serrulate; costa ending 3-4 cells below apex; vaginant laminae about 1/2 leaf length, slightly unequal at apex; cells of apical and dorsal lamina quadrate to hexagonal, thin-walled, 8-10 μm long, distinctly unipapillous at center, cells of upper of vaginant lamina similar to those of apical lamina. Autoicous. Sporophyte terminal; seta 3.0-3.5 mm long, capsule ovoid, erect, symmetrical, about 0.5 mm long.

Illustrations: Figures 61 and 139A

Habitat: on tree bark in shaded places

Ecology: primary, evergreen, seasonal, hardwood forest *c.* 1600 m elevation, granite bedrock

Phenology—gametophytes: February-November
sporophytes: February-March

Distribution—(Figure 114) Taiwan, Japan, Myanmar, Malaysia, Borneo, Philippines, Java, Papua New Guinea, Australia, New Zealand

Distribution in Thailand—(Figure 80D) Chiang Mai: Doi Suthep-Pui National Park. Loei: Phu Kradung National Park. Ranong: Nam Tok Ngao National Park. Nakhon Sri Thammarat: Khao Nan National Park.

Specimens studied—(CMU, gametophyte and sporophyte) Wongkuna 964B, 1074, 1089, 1094, 1095, 1432.

This species is closely related to *F. serratus* by also being a very small plant, with hyaline nodules not differentiated, leaf margins slightly serrulate, and not limbate. The cells of the apical and dorsal laminae are quadrate to polygonal, thin-walled, and unipapilose. The distinctions between *F. serratus* and this species are listed below (Wongkuna *et al.* (2009) 307).

Character	*Fissidens serratus*	*Fissidens tenellus* var. *australiensis*
Leaf shape	narrowly lanceolate	oblong- lanceolate
Leaf apex	narrowly acute	broadly acute to acute
Leaf costa	percurrent to shortly excurrent	ending below apex
Leaf margin	very strongly serrate	serrate to spinose-serrate

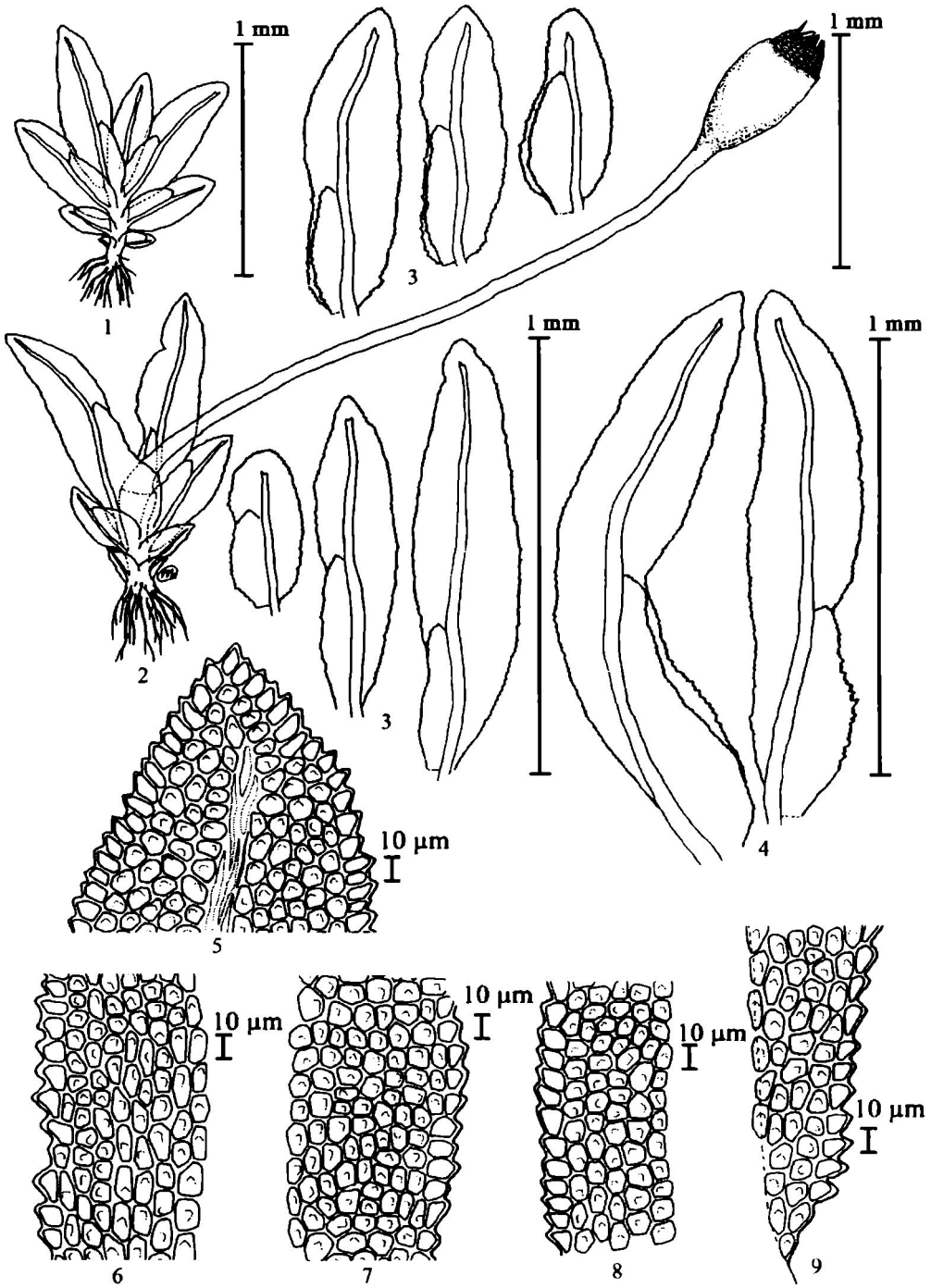


Figure 61. *Fissidens tenellus* Hook. f. & Wils. var. *australiensis* (A. Jaeger) Beever & Stone

1: plant habit. 2: plant with sporophyte. 3: leaves. 4: perichaetial leaves. 5: leaf apex. 6: vaginant lamina cells. 7: dorsal lamina cells. 8: apical lamina cells. 9: leaf base cells. Drawn from Wongkuna 1074.

45. ***Fissidens wichurae*** Broth. & Fleisch., Hedwigia 38 (Beibl.) (1899) 127.
Eddy (1988) 80 (fig.), 81.
Li and Iwatsuki (2001) 65 (map), 66 (fig.).

Plants up to 8 mm long, stem simple; leaves densely arranged; vaginant lamina about half of leaf length, unequal at apex; costa distince, yellowish, pellucid, percurrent or ending 1-2 cells below leaf tip; limbidium confined to vaginant lamina, 1-3 cells wide, bounded on the outside by a single series of much shorter, rectangular, usually chlorophyllose and papillose cells; dorsal lamina narrow, 3-4 cells wide, often suddenly reduced to a single cell row at costa base; lamina cells 6-10 μm diameter, pluripapillose, the papillae mainly adjacent to the cell corners. Autoicous? Seta terminal, 2-3 mm long. (Eddy, 1988). Capsule not seen.

Illustrations: Eddy (1988) 80 (fig. 74) 81.
Habitat: on bark or rocks in shaded places
Ecology: deciduous dipterocarp-ock forest 30-850 m elevation
Phenology—gametophytes: July
Distribution—(Figure 102) China, Taiwan, Hong Kong, Vietnam, Java, Malaysia, Philippines, New Guinea.
Distribution in Thailand—(Figure 81A)
Specimen studied—none

This species is small with linear leaves of 2-3 mm long. It is closely related to *F. kinabaluense* Z. Iwats., but has costa ending below the apex.

46. ***Fissidens zollingeri*** Mont., Ann. Sci. Nat. Bot. 3: 4 (1845) 114.
Bartram (1939) 16 (Plate+Fig.).
Gangulee (1971) 478, 479 (fig.), 480 (map).
Iwatsuki and Suzuki (1982) 367-369, 459 (fig.), 503 (map).
Iwatsuki and Mohamed (1987) 342.
Eddy (1988) 90, 91(fig.).
Li and Iwatsuki (2001) 66, 67 (map).
Fissidens xiphioides Fleisch., Hedwigia 38 (1999) 125; S. He (1996), *pro syn.*

Plants 2.8-3.4 mm long, 1.4-2.8 mm wide, stems simple; axillary hyaline nodules well-developed; central strand lacking; densely foliate with 8-20 leaves, lower leaves small, upper and perichaetial leaves much larger, 1.3-1.7 mm long, 0.2-0.4 mm wide, ovate-lanceolate to lanceolate, apex acute (45-55°); base usually rounded, not decurrent; margins entire, costa strongly excurrent; vaginant laminae about half of leaf length; limbidia differentiated all around the leaves, with 1-3 rows of cells in apical laminae, 3-7 rows in vaginant laminae, lamina cells quadrate irregularly hexagonal, 10-20 μm long, thin-walled, smooth, cells at base of vaginant laminae rectangular and very large toward costa, to 30 μm long, 20 μm wide. Synoicous. Sporophyte terminal, seta 3.5-4 mm long; smooth, capsule cylindric, symmetric, erect, 0.4-0.9 mm long.

Illustrations: Figures 62 and 139B
Habitat: on soil in shaded places
Ecology: deciduous dipterocarp-ock forest 30-850 m elevation; mixed evergreen+deciduous, seasonal, hardwood forest 850-1200 m elevation; and primary, evergreen, seasonal, hardwood forest 1200-2565 m elevation; granite, sandstone and limestone bedrocks, sometimes in disturbed sites.
Phenology—gametophytes: June-November
sporophytes: June-September
Distribution—(Figure 127) India, Nepal, Sri Lanka, Bangladesh, Taiwan, Hong Kong, Japan, Cambodia, Vietnam, Myanmar, Malaysia, Singapore, Philippines, Borneo, Java, Sumatra, New Guinea, Fiji Islands, Australia, New Zealand, Central African Repubic, Guinea, Gabon, Nigeria, Ocenia Islands, Paraguay, Rodrigues, Seychelles, Solomon Islands, Tanzania, Cameroon, Trinidad, Tobago, Kenya, Comoros, Madagascar, Uruguay, Angola, Argentina Venezuela, West Indies, Zaire, Bolivia, United State, Central America, Haiti, French Guiana, Colombia, Brazil, Peru.
Distribution in Thailand—(Figure 81B) Chiang Mai: Doi Inthanon National Park, Doi Suthep-Pui National Park, Pha Daeng National Park, Chiang Dao Wildlife Sanctuary. Phitsanulok: Phu Hin Rong Kla National Park. Sakon Nakhon: Phu Phan National Park. Rayong: Khao Cha Mao- Khao Wong National Park, Khao Khitchakut National Park. Suphanburi: Phu-Toei National Park. Nakhon Nayok: Khao Yai National Park. Phetchaburi: Kaeng Krachan National Park. Ranong: Nam Tok Ngao National Park. Krabi: Phanom Bencha National Park.
Specimens studied—(CMU, gametophyte) Wongkuna 164, 165, 332, 364, 374, 390, 416, 451, 602, 611, 624, 856, 1010, 1465, 1485, 1487, 1595B, 1703, 1729, 1765, 1770, 1812; (CMU, gametophyte and sporophyte) Wongkuna 165, 192, 226,

281, 319, 340B, 341, 365, 366, 525, 528, 531, 542, 591, 592, 595, 603, 608, 609, 614, 615, 627, 649, 686, 1761.

This species is recognized by having hyaline nodules, lanceolate to ovate-lanceolate leaves, and strongly excurrent costa.

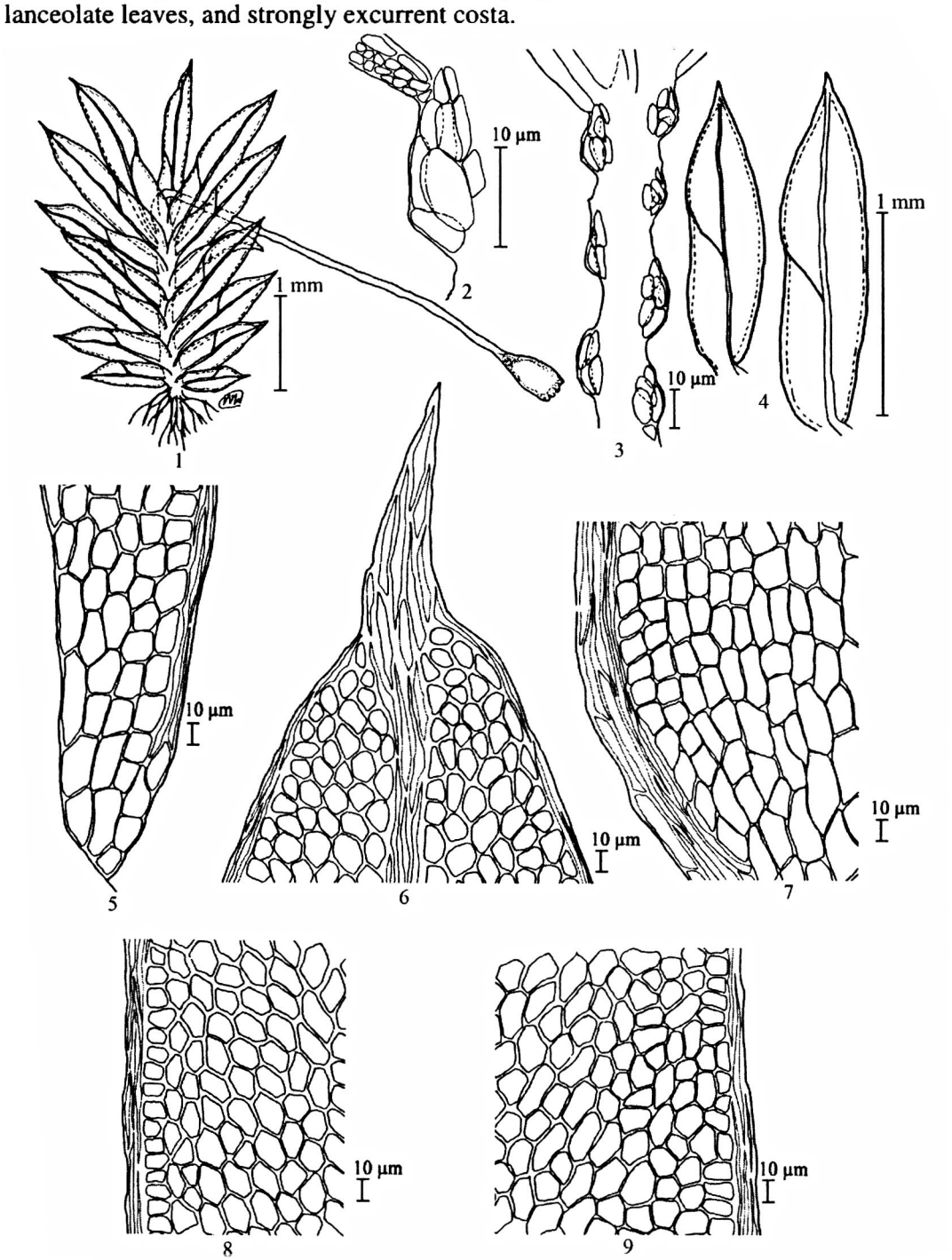


Figure 62. *Fissidens zollingeri* Mont.
1: plant habit with sporophyte. 2: hyaline nodules. 3: hyaline nodules on stem. 4: leaves. 5: leaf base cells. 6: leaf apex. 7: vaginant lamina cells. 8: apical lamina cells. 9: dorsal lamina cells. Drawn from Wongkuna 591.

Alpha, Beta, and Gamma Diversity of Thai *Fissidens*

Beta diversity of Thai *Fissidens* is determined to indicate habitats requiring conservation. Lists of *Fissidens* found in each national park (Table 4) and beta diversity are shown (Table 5).

Table 4. Lists of *Fissidens* found in each national park.

Location	alpha diversity (α)	Taxa	
Doi Inthanon National Park	23	*F. angustifolius* *F. anomalus* *F. bryoides* var. *schmidii* *F. ceylonensis* *F. crenulatus* var. *elmeri* *F. crispulus* var. *crispulus* *F. flabellulus* *F. gardneri* *F. geppii* *F. guangdongensis* *F. gymnogynus*	*F. hollianus* *F. hyalinus* *F. laxitextus* *F. nobilis* *F. oblongifolius* *F. pellucidus* *F. polypodioides* *F. semperfalcatus* *F. subangustus* *F. subbryoides* *F. taxifolius* *F. zollingeri*
Doi Suthep-Pui National Park	23	*F. angustifolius* *F. anomalus* *F. beckettii* *F. biformis* *F. ceylonensis* *F. crenulatus* var. *elmeri* *F. crispulus* var. *crispulus* *F. crispulus* var. *robinsonii* *F. flaccidus* var. *flaccidus* *F. geminiflorus* *F. geppii*	*F. guangdongensis* *F. gymnogynus* *F. hollianus* *F. incognitus* *F. irregulomarginatulus* *F. pellucidus* *F. semperfalcatus* *F. serratus* *F. subangustus* *F. subbryoides* *F. taxifolius* *F. zollingeri*
Pha Daeng National Park	8	*F. ceylonensis* *F. crenulatus* var. *crenulutus* *F. crispulus* var. *crispulus* *F. crispulus* var. *robinsonii*	*F. involutus* *F. gardneri* *F. semperfalcatus* *F. subbryoides*
Chiang Dao Wildlife Sanctuary	14	*F. biformis* *F. ceylonensis* *F. crenulatus* var. *crenulatus* *F. crenulatus* var. *elmeri* *F. crispulus* var. *crispulus*	*F. flaccidus* var. *flaccidus* *F. gardneri* *F. gymnogynus* *F. hollianus*

Table 4. (continued)

Location	alpha diversity (α)	Taxa	
(continued)	14	*F. crispulus* var. *robinsonii*	*F. pellucidus* *F. subangustus* *F. subbryoides* *F. zollingeri*
Phu Hin Rong Kla National Park	13	*F. crenulatus* var. *elmeri* *F. ceylonensis* *F. crispulus* var. *crispulus* *F. guangdongensis* *F. incognitus* *F. jungermannioides*	*F. gardneri* *F. pellucidus* *F. polypodioides* *F. semperfalcatus* *F. serratus* *F. subbryoides* *F. zollingeri*
Phu Kradung National Park	7	*F. crispulus* var. *crispulus* *F. filiformis* *F. firmus*	*F. hollianus* *F. pellucidus* *F. polypodioides* *F. sedgwickii*
Phu Luang Wildlife Sanctuary	12	*F. anomalus* *F. ceylonensis* *F. crenulutus* var. *crenulatus* *F. crispulus* var. *crispulus* *F. firmus* *F. jungermannioides*	*F. nobilis* *F. pellucidus* *F. polypodioides* *F. sedgwickii* *F. subbryoides* *F. tenellus* var. *australiensis*
Phu Kao-Phu Phan Kham National Park	3	*F. ceylonensis* *F. crispulus* var. *crispulus* *F. firmus*	
Phu Phan National Park	9	*F. ceylonensis* *F. crispulus* var. *crispulus* *F. crispulus* var. *robinsonii* *F. firmus* *F. flaccidus* var. *flaccidus*	*F. gardneri* *F. pellucidus* *F. semperfalcatus* *F. zollingeri*
Tat Ton National Park	5	*F. ceylonensis* *F. crispulus* var. *crispulus*	*F. firmus* *F. semperfalcatus* *F. subbryoides*
Pha Taem National Park	7	*F. ceylonensis* *F. crenulatus* var. *crenulutus* *F. crispulus* var. *robibsonii*	*F. gardneri* *F. incognitus* *F. pellucidus* *F. semperfalcatus*

Table 4. (continued)

Location	alpha diversity (α)	Taxa	
Khao Cha Mao-Khao Wong National Park	14	*F. ceylonensis* *F. crassinervis* *F. crenulatus* var. *crenulatus* *F. crispulus* var. *crispulus* *F. crispulus* var. *robinsonii* *F. firmus* *F. flaccidus* var. *flaccidus*	*F. gardneri* *F. hollianus* *F. javanicus* *F. pellucidus* *F. semperfalcatus* *F. subbryoides* *F. zollingeri*
Khao Khitchakut National Park	11	*F. bryoides* var. *schmidii* *F. ceylonensis* *F. crassinervis* *F. crenulatus* var. *crenulatus* *F. crispulus* var. *crispulus* *F. crispulus* var. *robinsonii*	*F. flaccidus* var. *flaccidus* *F. hollianus* *F. pellucidus* *F. subbryoides* *F. zollingeri*
Nam Tok Phlieo National Park	13	*F. ceylonensis* *F. crassinervis* *F. crenulatus* var. *crenulatus* *F crispulus* var. *crispulus* *F. crispulus* var. *robinsonii* *F. firmus* *F. flaccidus* var. *flaccidus*	*F. flaccidus* var. *percurrens* *F. gardneri* *F. hollianus* *F. pellucidus* *F. semperfalcatus* *F. subbryoides*
Phu-Toei National Park	9	*F. angustifolius* *F. bryoides* var. *esquirolii* *F. ceylonensis* *F. crispulus* var. *crispulus* *F. crispulus* var. *robinsonii*	*F. gymnogynus* *F. involutus* *F. semperfalcatus* *F. zollingeri*
Khao Yai National Park	18	*F. biformis* *F. ceylonensis* *F. crassinervis* *F. crenulatus* var. *crenulatus* *F. crispulus* var. *crispulus* *F. crispulus* var. *robinsonii* *F. firmus* *F. flaccidus* var. *flaccidus*	*F. guangdongensis* *F. hollianus* *F. incognitus* *F. javanicus* *F. nobilis* *F. pellucidus* *F. semperfalcatus* *F. subbryoides* *F. zollingeri*
Kaeng Krachan National Park	13	*F. angustifolius* *F. biformis* *F. ceylonensis* *F. crassinervis* *F. crenulatus* var. *crenulatus*	*F. crispulus* var. *robinsonii* *F. flaccidus* var. *flaccidus* *F. gardneri*

Table 4. (continued)

Location	alpha diversity (α)	Taxa	
(continued)	13	*F. crispulus* var. *crispulus*	*F. hollianus* *F. pellucidus* *F. pseudokinabaluensis* *F. subbryoides*
Thong Pha Phum National Park	6	*F. crenulatus* var. *crenulatus* *F. crispulus* var. *crispulus* *F. flaccidus* var. *percurrens*	*F. gardneri* *F. incognitus* *F. zollingeri*
Hui Yang Waterfall National Park	4	*F. biformis* *F. flaccidus* var. *flaccidus*	*F. hollianus* *F. javanicus*
Nam Tok Ngao National Park	9	*F. ceylonensis* *F. crassinervis* *F. crenulatus* var. *crenulatus* *F. crispulus* var. *crispulus* *F. crispulus* var. *robinsonii*	*F. firmus* *F. pellucidus* *F. subbryoides* *F. zollingeri*
Khao Nan National Park	13	*F. ceylonensis* *F. crassinervis* *F. crenulatus* var. *crenulatus* *F. crenulatus* var. *elmeri* *F. crispulus* var. *crispulus* *F. crispulus* var. *robinsonii* *F. hollianus*	*F. javanicus* *F. pellucidus* *F. polypodioides* *F. semperfalcatus* *F. tenellus* var. *australiensis* *F. zollingeri*
Phanom Bencha National Park	9	*F. ceylonensis* *F. crenulatus* var. *crenulatus* *F. crispulus* var. *crispulus* *F. crispulus* var. *robinsonii* *F. flaccidus* var. *flaccidus*	*F. hollianus* *F. semperfalcatus* *F. subbryoides* *F. zollingeri*
Sri Phang-nga National Park	2	*F. crassinervis* *F. javanicus*	
Khao Luang National Park	1	*F. kinabaluense*	

Table 5. Beta diversity between 24 locations (22 national parks and 2 wildlife sanctuaries).
red = critical zone, green = vulnerable zone

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1		18	21	17	16	**22**	21	**22**	20	20	**22**	21	20	21	20	**23**	**22**	**23**	**25**	**22**	20	20	**25**	**24**
2			19	13	20	**24**	**23**	**22**	18	20	18	17	16	17	18	15	16	19	21	18	20	14	**25**	**24**
3				**10**	**11**	13	12	**7**	**7**	**5**	**5**	**8**	**9**	**6**	**7**	14	**9**	**8**	12	**7**	**11**	**5**	**10**	**9**
4					13	15	16	13	**9**	13	**11**	**8**	**7**	**8**	13	12	**7**	**10**	12	**9**	**11**	**7**	16	15
5						14	13	12	**6**	**10**	**10**	13	14	13	14	15	16	**11**	17	12	12	12	15	14
6							**9**	**6**	**10**	**8**	12	13	12	**11**	14	17	14	**11**	**9**	**10**	12	**12**	**9**	**8**
7								**9**	13	**9**	13	14	13	12	17	18	15	14	16	**9**	20	13	14	13
8									**6**	**2**	**8**	**11**	**10**	**9**	**8**	15	12	**7**	**7**	**6**	12	**8**	**5**	**4**
9										**6**	**6**	**5**	**8**	**5**	**8**	**11**	**10**	**7**	**11**	**6**	**10**	**6**	**11**	**10**
10											**8**	**9**	**10**	**7**	**8**	13	12	**9**	**9**	**6**	12	**6**	**7**	**6**
11												**9**	**10**	**7**	**10**	13	**10**	7	**11**	**8**	**10**	**8**	**9**	**8**
12													**5**	**2**	13	**6**	**7**	**10**	12	**5**	**7**	**5**	12	15
13														**5**	12	**9**	**6**	**9**	**11**	**4**	**8**	**4**	**11**	**12**
14															14	**8**	**8**	**11**	13	**6**	**10**	**6**	13	14
15																17	14	**11**	13	**10**	12	**8**	**11**	**10**
16																	**11**	14	14	**9**	**11**	**9**	16	19
17																		**11**	**11**	**8**	12	**8**	13	14
18																			**8**	**9**	13	**9**	**8**	**7**
19																				13	13	**9**	**4**	**5**
20																					**8**	**6**	**9**	**10**
21																						**8**	**11**	14
22																							**11**	**10**
23																								**3**
24																								

1=Doi Inthanon National Park, 2=Doi Suthep-Pui National Park, 3=Pha Daeng National Park, 4=Chiang Dao Wildlife Sanctuary, 5= Phu Hin Rong Kla National Park, 6.=Phu Kradung National Park, 7=Phu Luang Wildlife Sanctuary, 8=Phu Kao-Phu Phan Kham National Park, 9=Phu Phan National Park, 10. Tat Ton National Park, 11=Pha Taem National Park, 12= Khao Cha Mao- Khao Wong National Park, 13=Khao Khitchakut National Park, 14= Nam Tok Phlieo National Park, 15=Phu-Toei National Park, 16= Khao Yai National Park, 17=Kaeng Krachan National Park, 18=Thong Pha Phum National Park, 19=Hui Yang Waterfall National Park, 20=Nam Tok Ngao National Park, 21=Khao Nan National Park, 22=Phanom Bencha National Park, 23=Sri Phang-nga National Park, 24= Khao Luang National Park.

The critical zone, vulnerable zone, and not vulnerable zone

The account of beta diversity value is 276 data. This was calculated by using combination formula of 24 national parks with two random selections

$$N = \frac{n!}{r!(n-r)!}$$

$$N = \frac{24!}{2!(24-2)!}$$

$$N = \frac{24 \times 23 \times 22!}{2 \times 1\ (22)!}$$

$$N = \frac{24 \times 23}{2}$$

$$N = 276$$

Two hundred and seventy-six beta diversity numbers can be grouped in 10 classes of frequency by using formula (Table 6)

$$\text{Range (R)} = X_{max} - X_{min}$$

$$= 25 - 2$$

$$= 23$$

$$\text{Class (K)} = 1 + 3.322 \log (N)$$

$$= 1 + 3.322 \log (276)$$

$$= 9.1086$$

$$\approx 10 \text{ classes}$$

$$\text{Range of each class (I)} = \frac{R}{K}$$

$$= \frac{23}{9.1086}$$

$$= 2.5$$

Table 6. classes of frequency of beta diversity

Beta Diversity	f_i	cf_i	x_i	$f_i x_i$	$(x_i - \bar{x})^2$	$f_i (x_i - \bar{x})^2$
2.0 - 4.4	7	7	3.2	22.4	76.39	534.73
4.5 - 6.9	28	35	5.7	159.6	38.94	1090.32
7.0 - 9.4	67	102	8.2	549.4	13.99	937.33
9.5 - 11.9	47	149	10.7	502.9	1.54	72.38
12.0 - 14.4	66	215	13.2	871.2	1.59	104.94
14.5 - 16.9	15	230	15.7	235.5	14.14	212.1
17.0 - 19.4	16	246	18.2	291.2	39.19	627.04
19.5 - 21.9	16	262	20.7	331.2	76.74	1227.84
22.0 - 24.4	11	273	23.2	255.2	126.79	1394.69
24.5 - 26.9	3	276	25.7	77.1	189.34	568.02
		N = 276		**$\Sigma f_i x_i$ = 3295.7**		**$\Sigma f_i (x_i - \bar{x})^2$ = 6769.39**

Calculating the average beta diversity ($\bar{x}$) and standard deviation (SD) at a statistically significant 95% by using below formula

$$\bar{x} = \frac{\Sigma f_i x_i}{N}$$

$$\bar{x} = \frac{3295.7}{276}$$

$$\bar{x} = 11.94$$

$$SD = \sqrt{\frac{\Sigma f_i (x_i - \bar{x})^2}{N-1}}$$

$$SD = \sqrt{\frac{6769.39}{275}}$$

$$SD = 4.9614$$
$$SD \approx 4.96$$

In this study, the average beta diversity was 11.94 with the minimum and maximum of 2 and 25 species respectively. As the average beta diversity is rather high, it means low critical conditions for most Thai *Fissidens* taxa occurring in different habitats in the 24 national parks (Figure 63).

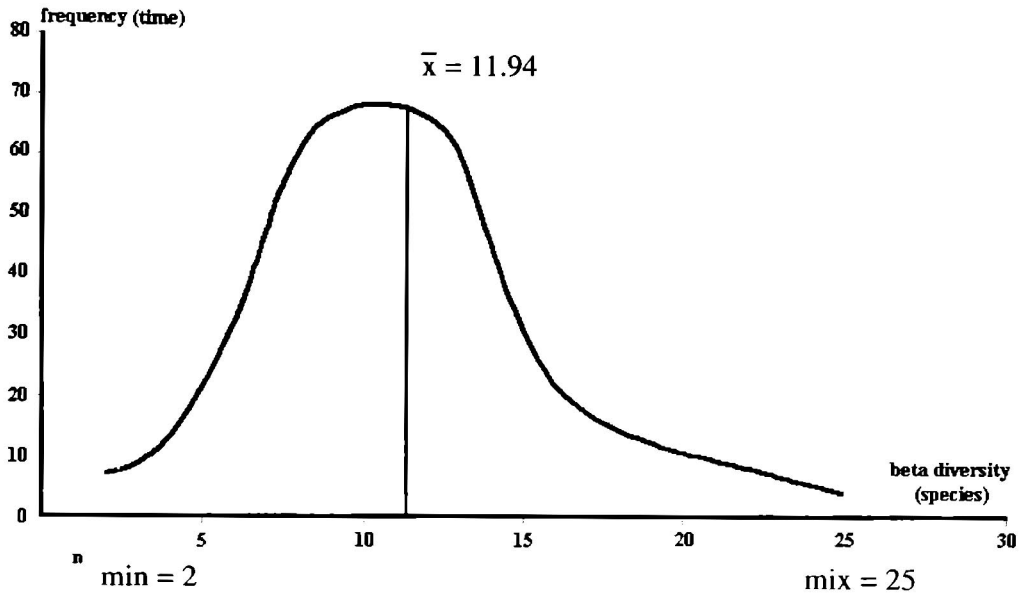


Figure 63. Beta diversity of 24 Thai national parks showing the minimum beta diversity = 2, maximum beta diversity, = 25, and the average = 11.94.

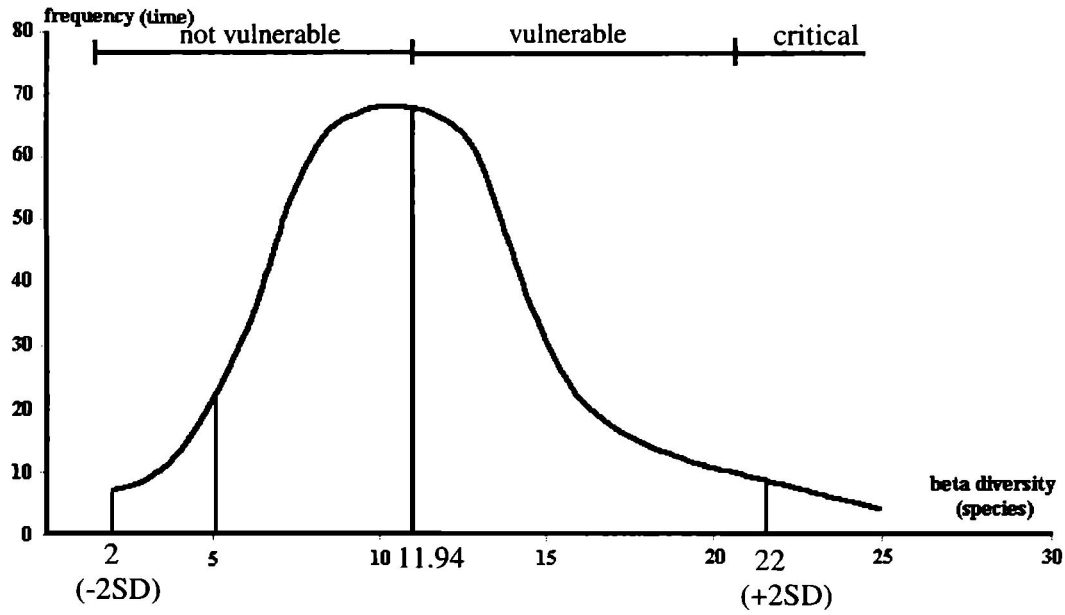


Figure 64. Beta diversity of 24 Thai national parks shows a critical point at a statistically significant 95% confidence level of 2 and 22 species. Three status levels of Thai *Fissidens* measured by beta diversity: critical, vulnerable, and not vulnerable are also indicated.

The three major zones of beta diversity can be divided (Figure 64), *i.e.* the critical zone (more than 22 species of beta diversity, the vulnerable zone (11.94-22 species of beta diversity, and not vulnerable zone (less than 11.94 species of beta diversity).

In the critical zone, 15 pairs (5%) of national parks are significant (Table 5). Conditions of significance can be grouped into two patterns (Table 7), *viz.* 1) significant by both being high in diversity and 2) significant by one area with high diversity and the other with low diversity. For both with high diversity, both areas should be conserved. The other should be conserved only the one with high diversity and also low diversity habitat in case of endangered or rare species occurring there. Some national parks are considered to be conserved due to high in diversity of Thai *Fissidens*, *i.e.* Doi Inthanon National Park, Doi Suthep-Pui National Park, Kaeng Krachan National Park, Khao Yai National Park, and Phu Luang Wildlife Sanctuary. Some national parks have uncommon species, *i.e.* Phu Kradung National Park, Phu Phan National Park, Thong Pha Phum National Park, and Khao Luang National Park.

Table 7. Grouping with two conditions of significance,1) significant by both being high in diversity and 2) significant by one area being high in diversity and the other in low diversity.

Both with high diversity habitats	High + low diversity habitats
(Doi Inthanon, Kaeng Krachan), (Doi Inthanon, Khao Yai), (Doi Suthep-Pui, Phu Luang),	(Doi Inthanon, Hui Yang Waterfall), (Doi Inthanon, Khao Luang), (Doi Inthanon, Nam Tok Ngao), (Doi Inthanon, Pha Taem), (Doi Inthanon, Phu Kao-Phu Phan Kham),(Doi Inthanon, Phu Kradung), (Doi Inthanon, Thong Pha Phum), (Doi Inthanon, Sri Phang-nga), (Doi Suthep-Pui, Khao Luang), (Doi Suthep-Pui, Phu Kao-Phu Phan Kham), (Doi Suthep-Pui, Phu Kradung), (Doi Suthep-Pui, Sri Phang-nga),

For vulnerable zone, about 40% of beta information from 24 Thai national parks, beta diversity shows the number of Thai *Fissidens* species that are unique to their national park habitat in a range of 11.94-22 taxa. They are 13 national park, *viz.* Doi Inthanon National Park, Doi Suthep-Pui National Park, Pha Daeng National Park, Phu Hin Rong Kla National Park, Phu Kradung National Park, Phu Luang Wildlife Sanctuary, Nam Tok Phlieo National Park, Khao Yai National Park, Kaeng Krachan National Park, Thong Pha Phum National Park, Hui Yang Waterfall National Park, Khao Nan National Park, Khao Luang National Park.

CHAPTER 5
DISCUSSION

Taxonomic notes on *Fissidens* in Thailand

I have included forty-two species and nine varieties of *Fissidens* for Thailand. In comparison with the most recent study of *Fissidens* in Thailand by He (1996), 61% of the taxa are similar. The 39% difference includes two new species, 15 new records, and two excluded species.

1. New species, a new variety, and new records

Eighteen taxa were found as new species, a new variety and new records (39%) of the total number of taxa in Thailand as more research has been on *Fissidens*. The trend has been an increasing number of species in the country. Other areas in Thailand not surveyed by bryologists could also have more species.

Two new species, *viz. F. irregulomarginatulus* K. Wongkuna & B. C. Tan and *F. pseudokinabaluensis* K. Wongkuna & B. C. Tan, were found. Both species are less than 5 mm long and grow as scattered individuals on soil. They are difficult to spot and impossible to identify by the naked eye in the field. They have been overlooked because of this. In addition, each species was found only one place in Thailand. *F. irregulomarginatulus* is known from evergreen, seasonal, hardwood and pine deciduous forest, *c.* 1100 m elevation at Doi Mawn Lawng, Chiang Mai in Doi Suthep-Pui National Park, while *F. pseudokinabaluensis* was found only at Pala-U waterfall, *c.* 1100 m elevation in evergreen, seasonal, hardwood forest at Kaeng Krachan National Park, Phetchaburi. Both areas apparently have never been surveyed by bryologists.

The habitat of both species is being rapidly destroyed. Doi Mawn Long is threatened by uncontrolled agricultural expansion and Pala-U Waterfalls by rampant tourism "development". Habitat conservation is urgently needed where both species are found.

Fissidens flaccidus Mitt. var. *percurrens* K. Wongkuna is a new variety. It occurs on soil at three places, *viz.* Khao Yai Natonal Park, Nakorn Nayok (primary, evergreen, seasonal, hardwood forest), Thong Pha Phum National Park, Kanchanaburi (primary, deciduous, seasonal, hardwood with bamboo forest), and Nam Tok Phlieo National Park, Chanthaburi (primary, evergreen, seasonal, hardwood forest).

Fifteen taxa are new records for Thailand (Table 8) and include 11 taxa new records for the Indo-Chinese moss flora (Tan *et al.*, 2006; Wongkuna *et al.*, 2009). The diversity of these species is discussed below.

1. *Fissidens angustifolius* Sull.

This species is found in China, Fiji, New Caledonia, Samoa, tropical America (Li and Iwatsuki, 2001), Central Africa Republic, Nigeria, and Togo (O' Shea, 2003). It occurs on soil and is found small colonies in mixed evergreen+deciduous, seasonal, forest at 600- 1200 m elevation. New for Indochina.

2. *Fissidens beckettii* Mitt.

This species is distributed from China, India, Nepal, Sri Lanka Japan, Myanmar, peninsular Malaysia, (Li and Iwatsuki, 2001) and Africa (Cape of Good Hope, Central Africa Republic, Natal, Tanzania, Transvaal, and Zimbabwe) (O' Shea, 1999). It occurs on soil in shaded to open, sometimes disturbed, sites in primary, evergreen, seasonal, hardwood forest at 1000-1300 m elevation.

3. *Fissidens bryoides* Hedw. var. ***esquirolii*** (Thér.) Z. Iwats. & T. Suzuki

This variety is known from China, Taiwan, and Japan (Li & Iwatsuki, 2001). It occurs on tree trunks and rocks, in deciduous dipterocarp-oak forest at *c.* 400 m and evergreen forest at 1100 m elevation. New for Indochina.

4. *Fissidens bryoides* Hedw. var. ***schmidii*** (C. Muell.) Chopra & Kumar

This variety is distributed from Australia (Queensland) (Ramsay & Cairns, 2004), China, Taiwan, Japan, India, Pakistan, Nepal, Sri Lanka, peninsular Malaysia, Philippines, Java, Celebes, and New Guinea (Shang and Lin, 1992, Eddy, 1971, and Li and Iwatsuki, 2001). It is found in Africa (Cameroons, Central Africa Republic, Gabon, Guinea, Nigeria, and Uganda) (O' Shea, 1999). It is common on soil in northern Thailand and less common in the southeast. New for Indochina.

5. *Fissidens flabellulus* Thwait. & Mitt.

This species is known from Australia (Queensland) (Ramsay & Cairns, 2004), China, Taiwan Japan, Sri Lanka, and Papua New Guinea (Shang and Lin, 1992; Li and Iwatsuki, 2001). It occurs on soil and was found only at Doi Inthanon National Park in primary, evergreen, seasonal hardwood forest, at 2295 m elevation and only in a small population. New for Indochina.

6. *Fissidens flaccidus* Mitt. var. ***flaccidus***

This species is widely distributed in India, Nepal, Sri Lanka, Bangladesh, China, Hong Kong, Japan, Philippines, Borneo, Vietnam, peninsular Malaysia, Myanmar, Java, Celebes, and New Guinea. (Shang and Lin, 1992; Li and Iwatsuki, 2001; Tan and Meng-Shyan; 2002; But, 2007), central and south America (Pursell, 2007) and Africa (Cape Verde, Central Africa Republic, Nigeria, Rodrigues, Sierra Leone, Zimbabwe, and Seychelles,) (O' Shea, 2003). It is commonly associated with

human settlements, on soil, 100-1600 m elevation in many places in Thailand (Figure 73D)

7. *Fissidens geminiflorus* Dozy & Molk.

This species is found in Bangladesh, China, Taiwan, Hong Kong, Japan, Philippines, Vietnam, peninsular Malaysia, Sumatra, Java, Borneo, Sulawesi, and Papua New Guinea (Shang and Lin, 1992; Li and Iwatsuki, 2001; Tan and Meng-Shyan; 2002; But, 2007). It grows on wet rocks in waterfall areas in mixed evergreen+deciduous, seasonal, hardwood forest in Doi Suthep-Pui National Park at 700 m elevation.

8. *Fissidens geppii* Fleisch.

This species has been found in China, Taiwan Korea, Japan, India, Borneo, peninsular Malaysia, Sumatra and Java (Gangulee, 1971; Iwatsuki and Suzuki, 1982; and Li and Iwatsuki, 2001). It grows on wet rocks in waterfall areas in evergreen, seasonal, hardwood forest at 1200-1700 m elevation in northern in Thailand. New for Indochina.

9. *Fissidens guangdongensis* Z. Iwats. & Z. H. Li

This species is known from China, Taiwan, Hong Kong, Japan, peninsular Malaysia, and Singapore (Shang and Lin; 1992 Li and Iwatsuki, 2001; Tan and Meng-Shyan, 2002; But, 2007). It grows on soil and tree trunks in primary, evergreen, seasonal, hardwood forest at 1000-2565 m elevation. It is found in northern and south-eastern in Thailand. New for Indochina.

10. *Fissidens hyalinus* Hook. & Wils.

This species is only one species of *Fissidens* that without costa. It is found in Australia (Queensland) (Ramsay & Cairns, 2004), China, Taiwan, Japan, India, Nepal, Malaysia, Borneo, Philippines, New Guinea, North and South America (Iwatsuki and Suzuki, 1982, Tan & Iwatsuki, 1991, Shang & Lin, 1992 Li & Iwatsuki, 2001). It is found on soil in shaded areas in primary, evergreen, seasonal, hardwood forest at 1200-2500 m elevation in Doi Suthep-Pui and Doi Inthanon National Parks. New for Indochina.

11. *Fissidens incognitus* Gangulee

This species is known from India, Bangladesh, China, and Hong Kong (Gangulee, 1971; Li & Iwatsuki, 2001; But, 2007). It grows on soil in open areas in deciduous, seasonal forest at 250 and primary, evergreen, seasonal, hardwood forest at 1200 m elevation. New for Indochina.

12. *Fissidens involutus* Wils. *ex* Mitt.

Fissidens involutus is known from India, Nepal, Pakistan, China, Taiwan, Japan, Myanmar, Vietnam, Philippines, and (Gangulee, 1971; Li and Iwatsuki, 2001). It grows on soil near waterfalls and is found in northern and central Thailand in deciduous seasonal forest at 400-600 m elevation.

13. *Fissidens jungermannioides* Griff.

Fissidens jungermannioides is recorded from China and India (Li and Iwatsuki, 2001). This species occurs on wet rocks along streams in primary, evergreen, seasonal, hardwood forest at about 1200 m elevation. It is known from Phu Hin Rong Kla National Park (Phitsanulok) and Phu Luang Wildlife and Sanctuary (Loei). The collecting locale of this species in Phu Hin Rong Kla was recently destroyed due to dam construction. New for Indochina.

14. *Fissidens obscurus* Mitt.

This species is known from India, Nepal, China, and Japan (Gangulee, 1971; Li and Iwatsuki, 2001). It occurs on rocks in streams. It was only found in Khao Nan National Park (Nakhon Sri Thammarat) in a few populations. New for Indochina.

15. *Fissidens serratus* Muell. Hal.

Fissidens serratus is found in China, Taiwan, Hong Kong, India, Sri Lanka, Japan, peninsular Malaysia, Singapore, Philippines, New Guinea, North America (Iwatsuki and Suzuki, 1982; Tan and Iwatsuki, 1991; Shang & Lin, 1992; Li & Iwatsuki, 2001) and Africa (Cape of Good Hope, Ivory Coast, Kenya, Madagascar, Mascarene Islands, Tanzania, Transvaal, Zimbabwe, Socotra Islands, and Seychelles) (O' Shea, 1999). It grows on soil, in shaded and moist sites in primary, evergreen, seasonal, hardwood forest at 900-1200 m elevation. It was found in Phu Hin Rong Kla (Phitsanulok) and Doi Suthep-Pui National Park (Chiang Mai).

2. Excluded species

1. ***Fissidens subspathulatus*** Dix.

This Papua New Guinea endemic (Dixon, 1943; Eddy, 1988) was reported new to Thailand by He (1996) based on a Thai specimens (Larsen, Santisuk, and Warncke 1976) at MO. I examined this specimen and it is *Fissidens crenulatus* Mitt. var. *crenulatus*.

2. ***Fissidens aspledioides*** Hedw.

Fissidens aspledioides Hedw. is from North America (Crum and Anderson, 1983). Two specimens identified as *Fissidens aspledioides* by He (1996) at MO (Touw 8974 and Touw 9248) were new for Thailand. One specimen was *F. involutus* (Touw 8974) and the other *F. gymnogynus* (Touw 9248).

Table 8. List recent new records of *Fissidens* for Thailand.

Name	Publication
1. *F. angustifolius* Sull.	Present work
2. *F. beckettii* Mitt.	Tan *et al.* (2006)
3. *F. bryoides* Hedw. var. *esquirolii* (Thér.) Z. Iwats. & T. Suzuki	Tan *et al.*, (2006)
4. *F. bryoides* Hedw. var. *schmidii* (C. Muell.) Chopra & Kumar	Tan *et al.* (2006)
5. *F. flabellulus* Thwait. & Mitt.	Wongkuna *et al.* (2009)
6. *F. flaccidus* Mitt. var. *flaccidus*	Wongkuna *et al.* (2009)
7. *F. geminiflorus* Dozy & Molk.	Wongkuna *et al.* (2009)
8. *F. geppii* Fleisch.	Present work
9. *F. guangdongensis* Z. Iwats & Z. H. Li	Tan *et. al.* (2006)
10. *F. hyalinus* Hook. & Wils.	Present work
11. *F. incognitus* Gangulee	Wongkuna *et al.* (2009)
12. *F. involutus* Wils. *ex* Mitt.	Wongkuna *et al.* (2009)
13. *F. jungermannioides* Griff.	Wongkuna *et al.* (2009)
14. *F. obscurus* Mitt.	Present work
15. *F. serratus* Muell. Hal.	Tan *et al.* (2006)

Distribution of *Fissidens* in Thailand

The distribution of Thai *Fissidens* can be grouped according to vegetation type, climate, and topography of the different floristic regions of Thailand (Figure 65).

The taxa of *Fissidens* founding floristic regions of Thailand include common and uncommon species. The east only has common species (Table 9). This might be due to this region being drier with, sandstone bedrock, and the forest are mostly deciduous dipterocarp-oak forest. This area has the lowest number of taxa. The highest number of uncommon species was found in the North (18 species) and 76% of all taxa (Table 9, Figure 65). Fourteen taxa which are specific to particular floristic areas (Table 11).

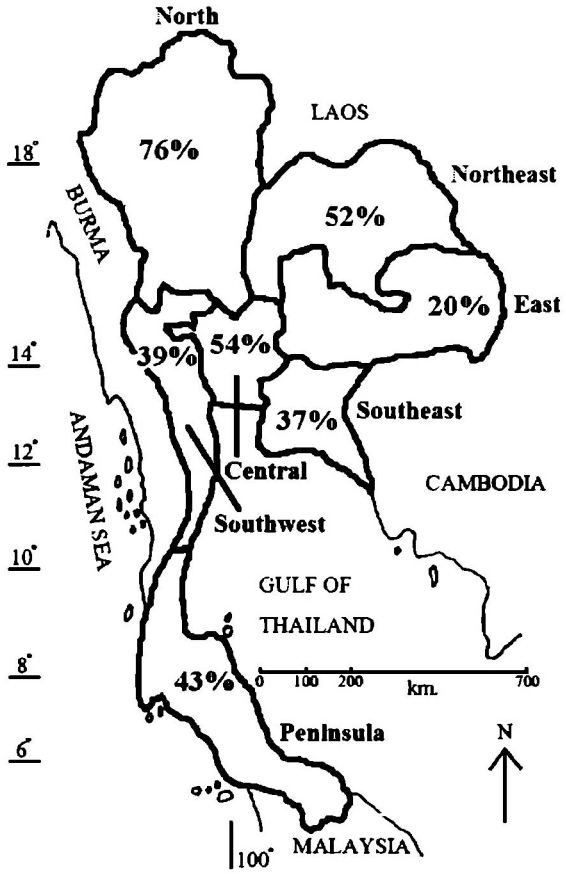


Figure 65. Percentages of *Fissidens* taxa in the seven floristic regions of Thailand (redraw, from Flora of Thailand 7:4 (2002) and CMU Herbarium label).

Table 9. *Fissidens* taxa found in each of the seven floristic regions of Thailand.

Floristic regions	Common taxa	Uncommon taxa
Northern (N) 35 taxa (76%)	*F. bryoides* var. *esquirolii*, *F. bryoides* var. *schmidii*, *F. ceylonensis*, *F. crenulatus* var. *crenulatus*, *F. crispulus* var. *crispulus*, *F. crispulus* var. *robinsonii*, *F. flaccidus* var. *flaccidus*, *F. gardneri*, *F. hollianus*, *F. incognitus*, *F. nobilis*, *F. pellucidus*, *F. polypodioides*, *F. semperfalcatus*, *F. serratus*, *F. subbryoides*, *F. zollingeri* (17 taxa, 49%)	*F. angustifolius*, *F. anomalus*, *F. beckettii*, *F. biformis*, *F. crenulatus* var. *elmeri*, *F. flabellulus*, *F. geminiflorus*, *F. geppii*, *F. guangdongensis*, *F. gymnogynus*, *F. hyalinus*, *F. involutus*, *F. irregulomarginatulus*, *F. laxitextus*, *F. oblongifolius*, *F. subangustus*, *F. taxifolius*, *F. tenellus* var. *australiensis* (18 taxa, 51%)

Table 9. (continued)

Floristic regions	Common taxa	Uncommon taxa
Northeastern (NE) 24 species (52%)	*F. ceylonensis*, *F. crassinervis*, *F. crenulatus* var. *crenulatus*, *F. crispulus* var. *crispulus*, *F. firmus*, *F. flaccidus* var. *flaccidus*, *F. gardneri*, *F. hollianus*, *F. incognitus*, *F. javanicus*, *F. nobilis*, *F. pellucidus*, *F. polypodioides*, *F. semperfalcatus*, *F. serratus*, *F. subbryoides*, *F. zollingeri* (17 taxa, 71%)	*F. anomalus*, *F. beckettii*, *F. crenulatus* var. *elmeri*, *F. filiformis*, *F. jungermannioides*, *F. sedgwickii*, *F. tenellus* var. *australiensis* (7 taxa, 29%)
Eastern (E) 9 species (20%)	*F. ceylonensis* , *F. crenulatus* var. *crenulatus*, *F. crispulus* var. *crispulus*, *F. firmus*, *F. gardneri*, *F. incognitus*, *F. pellucidus*, *F. semperfalcatus*, *F. subbryoides* (9 taxa, 100%)	
Central (C) 25 species (54%)	*F. bryoides* var. *esquirolii*, *F. ceylonensis*, *F. crassinervis*, *F. crenulatus* var. *crenulatus*, *F. crispulus* var. *crispulus*, *F. crispulus* var. *robinsonii*, *F. firmus*, *F. flaccidus* var. *flaccidus*, *F. gardneri*, *F. hollianus*, *F. incognitus*, *F. javanicus*, *F. nobilis*, *F. pellucidus*, *F. polypodioides*, *F. semperfalcatus*, *F. subbryoides*, *F. zollingeri* (18 taxa, 72%)	*F. angustifolius*, *F. biformis*, *F. geminiflorus*, *F. guangdongensis*, *F. gymnogynus*, *F. involutus*, *F. flaccidus* var. *percurrens*, (7 taxa, 28%)
Southeastern (SE) 17 species (37%)	*F. bryoides* var. *schmidii*, *F. crassinervis*, *F. ceylonensis*, *F. crenulatus* var. *crenulatus*, *F. crispulus* var. *crispulus*, *F. crispulus* var. *robinsonii*, *F. firmus*, *F. flaccidus* var. *flaccidus*, *F. gardneri*, *F. hollianus*, *F. javanicus*, *F. pellucidus*, *F. semperfalcatus*, *F. subbryoides*, *F. zollingeri* (15 taxa, 88%)	*F. oblongifolius*, *F. flaccidus* var. *percurrens* (2 taxa, 12%)

Table 9. (continued)

Floristic regions	Common taxa	Uncommon taxa
Southwestern (SW) 18 species (39%)	*F. ceylonensis*, *F. crassinervis*, *F. crenulatus* var. *crenulatus*, *F. crispulus* var. *crispulus*, *F. crispulus* var. *robinsonii*, *F. flaccidus* var. *flaccidus*, *F. gardneri*, *F. hollianus*, *F. incognitus*, *F. javanicus*, *F. nobilis*, *F. pellucidus*, *F. subbryoides*, *F. zollingeri* (14 taxa, 78%)	*F. angustifolius*, *F. biformis*, *F. pseudokinabaluensis*, *F. flaccidus* var. *percurrens* (4 taxa, 22%)
Peninsula (PEN) 20 species (43%)	*F. crassinervis*, *F. ceylonensis*, *F. crenulatus* var. *crenulatus*, *F. crispulus* var. *crispulus*, *F. crispulus* var. *robinsonii*, *F. firmus*, *F. flaccidus* var. *flaccidus*, *F. hollianus*, *F. javanicus*, *F. nobilis*, *F pellucidus*, *F. polypodioides*, *F. semperfalcatus*, *F. subbryoides*, *F. zollingeri* (15 taxa, 75%)	*F. crenulatus* var. *elmeri*, *F. kinabaluense*, *F. obscurus*, *F. tenellus* var. *australiensis*, *F. wichurae* (5 taxa, 25%)

Five (24%) common species were found widely spread in all 7 floristic regions *viz*. *F. ceylonensis* (Figure 71C), *F. crenulatus* var. *crenulatus*, (Figure 72A), *F. crispulus* var. *crispulus* (Figure 72C), *F. pellucidus* (Figure 78C), and *F. subbryoides* (Figure 80B). In addition, five (24%) common species were found widely spread in 6 floristic regions of Thailand (Table 10).

Table 10. Five common species of *Fissidens* found widely spread in 6 floristic regions.

Common species	Six floristic be found
1. *F. flaccidus* var. *flaccidus*	N, NE, C, SE, SW, PEN
2. *F. hollianus*	N, NE, C, SE, SW, PEN
3. *F. gardneri*	N, NE, C, E, SE, SW
4. *F. semperfalcatus*	N, NE, C, E, SE, PEN
5. *F. zollingeri*	N, NE, C, SE, SW, PEN

The highest number of rare species are found in the North (8 species, 57.14%), followed by Northeastern (3 species, 21.43%), Peninsular (2 species, 14.29%), and Southwest (1 species, 7.14%) (Table 11).

Table 11. Ecology of rare *Fissidens* species only found in particular locations in Thailand.

Floristic region	Species	Substrate	Location	Forest type
Northern (57.14%)	*F. flabellulus*	soil	Doi Inthanon National Park	primary, evergreen, seasonal, hardwood
	F. geminiflorus	wet rocks	Doi Suthep-Pui National Park	primary, evergreen, seasonal, hardwood
	F. geppii	wet rocks	Doi Inthanon National Park	primary, evergreen, seasonal, hardwood
			Doi Suthep-Pui National Park	mixed evergreen+deciduous, seasonal, hardwood
	F. hyalinus	soil	Doi Inthanon National Park	primary, evergreen, seasonal, hardwood
			Doi Suthep-Pui National Park	
	F. irregulomarginatulus	soil	Doi Suthep-Pui National Park	deciduous dipterocarp-oak
	F. laxitextus	bark	Doi Inthanon National Park	primary, evergreen, seasonal, hardwood
	F. oblongifolius	soil	Doi Inthanon National Park	primary, evergreen, seasonal, hardwood
	F. wichurae	soil	Chiang Dao Wildlife Sanctuary, Omkoi District	mixed evergreen+deciduous, seasonal, hardwood
Northeast (21.43%)	*F. filiformis*	soil	Phu Kradung National Park	primary, evergreen, seasonal, hardwood with pine
	F. jungermannioides	wet rocks	Phu Luang Wildlife Sanctuary	primary, evergreen, seasonal, hardwood with pine
	F. sedgwickii	wet rocks (aquatic)	Phu Luang Wildlife Sanctuary Phu Kradung National Park	primary, evergreen, seasonal, hardwood with pine
Southwest (7.14%)	*F. pseudokinabaluensis*	soil	Kaeng Krachan National Park	deciduous, seasonal, hardwood with bamboo
Peninsular (14.29%)	*F. kinabaluense*	soil	Khao Luang National Park	primary, evergreen, seasonal, hardwood
	F. obscurus	wet rocks	Khao Nan National Park	primary, evergreen, seasonal, hardwood

Most Thai *Fissidens* (76%) occur in the North with the most uncommon taxa (18). Twenty percentages of Thai *Fissidens* occurred in the Eastern with no uncommon species.

Distribution of *Fissidens* in various countries and regions

Previous revisions were complied (Table 12) and grouped under two criteria of distribution patterns, *viz.* major and minor pattern (Tan and Pócs, 2000) and *Index Muscorum* (van der Wijk *et al.*, 1959). Five regional groups are discussed here (Figure 134).

Table 12. Number of *Fissidens* taxa in the Asia-Pacific region various countries and the percentage of species common to Thailand and comparison of *Fissidens* taxa in Thailand with other countries and regions.

Country and Region (Figure 134)	Number of taxa listed	Publication	Number and percentages of taxa in common with this study
China (AS2)	58	Li and Iwatsuki, 2001	34 (73.9%)
Taiwan (AS2)	50	Yang and Lin, 1992	28 (60.9%)
Thailand(AS3+ AS4)	37	He, 1996	28 (60.9%)
Philippines (AS4)	35	Tan and Iwatsuki, 1991	24 (52.2%)
Nepal (AS3)	49	Pradhan and Joshi, 2006	22 (47.8%)
India (Eastern India) (AS3)	49	Gangulee, 1971	23 (50%)
India (Kerala) (AS3)	25	Manju *et al.*, 2008	15 (32.6%)
India (southern India) (AS3)	2	Dixon, 1910	2 (4.3%)
Japan (AS2)	47	Iwatsuki and Suzuki, 1982	23 (50%)
peninsular Malaysia (AS4)	39	Iwatsuki and Mohamed, 1987; Eddy, 1988	23 (50%)
Hong Kong (AS2)	27	But, 2007	22 (47.8%)
Borneo (AS4)	35	Suleiman *et al.*, 2006	22 (47.8%)
Papua New Guinea (AS4)	25	Norris and Koponen,1987	16 (47.8%)
Laos (AS3)	4	Tan and Iwatsuki, 1993	3 (6.5%)
Myanmar (AS3)	28	Tan and Iwatsuki, 1993	14 (30.4%)
Vietnam (AS3)	32	Tan and Iwatsuki, 1993	14 (30.4%)
Pakistan (AS3)	13	Higuchi and Nishimaru, 2003	4 (8.7%)
Bangladesh (AS3)	29	O' Shea, 2003	12 (26.1%)
Sri Lanka (AS3)	13	O' Shea, 2003	10 (21.7%)

Table 12. (continued)

Country and Region (Figure 134)	Number of taxa listed	Publication	Number and percentages of taxa in common with this study
Mindoro Island (Philippines) (AS4)	9	Linis, 2009	9 (19.6%)
Cambodia (AS3)	7	Tan & Iwatsuki, 1993	6 (13%)
Turkey (AS5)	5	Özdemir, 2009	1 (2.2%)
Sub-Saharan Africa (AF2)	144	O' Shea, 1999	12 (26%)
South America, (tropical Andean countries) (AM4+ AM6)	65	Churchill, 2000	9 (19.6%)
Chile (AM6)	17	He, 1998 and Müller, 2009	3 (6.5%)
Costa Rica (AM2)	8	Dauphin, 1999	3 (6.5%)
North America (AM1)	37	Pursell, 2007	6 (13%)
Interior highlands of North America (AM1)	15	Redfearn, 2009	2 (4.3%)
North Carolina (AM1)	16	Anderson & Shaw, 1997	1 (2.2%)
USA (Wisconsin) (AM1)	10	Anderson *et al.*, 1990	2 (4.3%)
Canada (AM1)	17	Bird, 1973	1(2.2%)
Europe and Macaronesia (EUR+AF1)	38	Hill *et al.*, 2006	2 (4.3%)
British & Irish (EUR)	25	Hill *et al.*, 2008	1 (2.2%)
Sweden (EUR)	15	Hallingbäck, 2006	1(2.2%)
Australia (AU1)	55	Scott & Stone,1976	2 (4.3%)
Hawaiian Islands (OC)	12	Staples *et al.*, 2004	1 (2.2%)

Major distribution of Thai *Fissidens*

Bryophytes can be grouped into five major global regions, *viz.* 1. Arctic-alpine, 2. boreal, 3. north and south temperate, 4. tropical and 5. subantarctic and antarctic. *Fissidens* in Thailand are tropical and temperate distributions (Appendix B).

1. Tropical distribution

Eighty seven percentages of Thai *Fissidens* taxa are found in both tropical and temperate regions (Table 14). This result also correlates with the work of Gradstein and Pócs (1989), where many tropical bryophyte families, *e.g.* Calymperaceae, Meteoriaceae, Neckeraceae, Sematophyllaceae, and Fissidentaceae are best represented in the tropics but are also fairly widespread in temperate zones.

Thirteen percentages of Thai *Fissidens* taxa are found only in tropical Asia, *viz. F. firmus* (Figure 104), *F. flaccidus* var. *percurrens* (Figure 105), and *F. sedgwickii* (Figure 97). Among these, some species are found only in Thailand, *viz. F. filiformis* (Figure 103), *F. irregulomarginatulus* (Figure 106), and *F. pseudokinabaluensis* (Figure 107).

Eight species (17%) of Thai *Fissidens* taxa are distributed worldwide, *viz. F. angustifolius* (Figure 120), *F. flaccidus* var. *flaccidus* (Figure 121), *F. gardneri* (Figure 122), *F. oblongifolius* (Figure 123), *F. pellucidus* (Figure 124), *F. serratus* (Figure 125), *F. taxifolius* (Figure 126), and *F. zollingeri* (Figure 127).

The worldwide distributed species may be due to dispersal over great distances by air currents with diaspores (spores and gemmae). Most species of *Fissidens* have spores 8-15 (30) µm diameter (Iwasuki and Suzuki, 1982). Spore sizes of less than 25 µm diameter are best suited for air transport over long distances (Tan and Pócs, 2000). The spore sizes of Thai *Fissidens* in this study range from 15 to 25 µm diameter. For example, *F. angustifolius* has the spore size of 15 to 20 µm with rough surface while *F. serratus* has sticky spores ranging from 7.5 to 9 µm. Vegetative propagation by gemmae, which are capable developing new plants, *i.e. F. flaccidus* var. *flaccidus* which produces axillary gemmae.

A problem which has occurred when plotting the distribution of many pantropical species, *i.e. F. serratus*, is some are treated under different names by various authors (Table 13). To solve this problem all species need to be revised.

Table 13. Comparison of names given to *F. serratus* and related taxa, *F. tenellus* var. *australiensis* and *F. papillosus*.

Churchill, 2000 Li and Iwatsuki, 2001 Hill *et al.*, 2006	Iwatsuki and Suzuki, 1982; Eddy, 1988; Beever and Stone, 1999	Beever and Stone, 1999; Wongkuna *et al.*, 2009
F. serratus (syn=*F. papillosus*)	*F. serratus* *F. papillosus*	*F. serratus* *F. tenellus* var. *australiensis* (syn.=*F. papillosus*)

Less than 10 percentages of Thai *Fissidens* are paleotropic (Asia-Africa) with some parts of Australia, *viz. F. beckettii* (Figure 109), *F. bryoides* var. *schimidii* (Figure 115), *F. ceylonensis* (Figure 116), and *F. crispulus* var. *crispulus* (Figure 117). *F. beckettii* is paleotropic, while *F. bryoides* var. *schimidii*, *F. ceylonensis* and *F. crispulus* var. *crispulus* are paleotropic to Australia (Ramsay and Cairns, 2004). The checklist of 144 African *Fissidens* taxa has sub-saharan *Fissidens* species treated under different names compared to other works in tropical Asia, including Thailand (O' Shea, 1999). A detailed of comparison study of *Fissidens* taxa from different regions is necessary before an accurate phytogeographical analysis can be made.

2. Temperate distribution

Many temperate *Fissidens* species have a continuous distribution from the northern to southern hemispheres reaching the tropics at high elevation. For example,

F. taxifolius (Figure 126) has a wide range of distribution in both hemispheres to tropical southeast Asia (Li and Iwatsuki, 2001; Hill *et al.*, 2006; Pursell, 2007; Redfearn, 2009); and *F. bryoides* var. *esquirolii* found in Japan, China, and Taiwan as well as in east Asia (Iwatsuki and Suzuki, 1982; Li and Iwatsuki, 2001). These taxa are also in the mountains of Thailand and Indochina (Tan *et al.*, 2006).

Table 14. Thai *Fissidens* taxa distributed in temperate and tropical regions.

Temperate and Tropical species (40 species = 87%)		**Tropical species (6 species = 13%)**
F. angustifolius	*F. hyalinus*	*F. filiformis*
F. anomalus	*F. incognitus*	*F. firmus*
F. beckettii	*F. involutus*	*F. flaccidus* var. *percurrens*
F. biformis	*F. javanicus*	*F. irregulomarginatulus*
F. bryoides var. *esquirolii*	*F. jungermannioides*	*F. pseudokinabaluensis*
F. bryoides var. *schmidii*	*F. kinabaluense*	*F. sedgwickii*
F. ceylonensis	*F. laxitextus*	
F. crassinervis	*F. nobilis*	
F. crenulatus var. *crenulatus*	*F. oblongifolius*	
F. crenulatus var. *elmeri*	*F. obscurus*	
F. crispulus var. *crispulus*	*F. pellucidus*	
F. crispulus var. *robinsonii*	*F. polypodioides*	
F. gardneri	*F. semperfalcatus*	
F. flaccidus var. *flaccidus*	*F. serratus*	
F. flabellulus	*F. subangustus*	
F. geminiflorus	*F. subbryoides*	
F. geppii	*F. taxifolius*	
F. guangdongensis	*F. tenellus* var. *australiensis*	
F. gymnogynus	*F. wichurae*	
F. hollianus	*F. zollingeri*	

Minor patterns, Australasia-America disjunctive distribution

This is an interesting pattern of distributions of *Fissidens*, because of distance dispersal in long across the oceans and continents. For two Thai *Fissidens* species, *F. hyalinus* (Figure 118) and *F. polypodioides* (Figure 119) are examples for is disjunctive Australasia-America pattern. There are many well-known transcontinental or transoceanic distributions of the other moss genera such as bipolar disjunction of the moss genus *Timmia* from the southern hemisphere in New Zealand to northern hemisphere population (Horton and Barlett, 1983). Eastern Asia and North America disjunction of the moss genus *Ulota* from Japan to Alaska (Iwatsuki and Sharp, 1968).

Distribution of Thai *Fissidens* following *Index Muscorum* (Wijk *et al.*, 1959).

By following *Index Muscorum*, Thailand is located in section AS3 (except peninsular Thailand which is in AS4). Fifty-nine percentages of Thai *Fissidens* (27

taxa) occur in Asia (AS2, AS3, AS4) (Table 11). The highest number of taxa are found in region AS3 (89%) (Figure 66) followed by, AS2 (80%), AS4 (76%), AU1 (35%), AF2 (22%), AM1, and AM4 (17%) (Table 15).

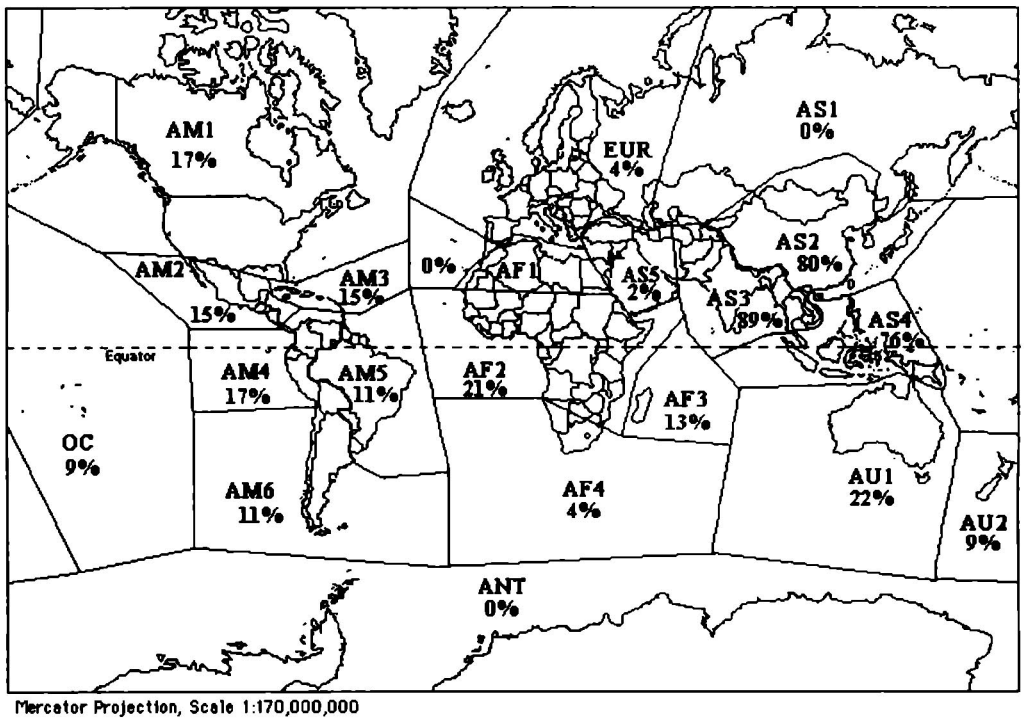


Figure 66. Number of Thai *Fissidens* species found in 20 world biogeographic regions as defined by Wijk *et al.* (1959).

Table 15. Comparison of the number of Thai *Fissidens* taxa distributed in each floristic region of *Index Muscorum* (Wijk *et al.*, 1959).

Floristic Region	Number of Thai *Fissidens* taxa
1. AS3 = southern Asia	41 (89%)
2. AS2 = central Asia	37 (80%)
3. AS4 = southwestern Asia	35 (76%)
4. AU1 = Australia	16 (35%)
5. AF2 = continental sub-Saharan Africa	10 (22%)
6. AM1 = North America	8 (17%)
7. AM4 = northern South America	8 (17%)
8. AM2 = Central America	7 (15%)
9. AM3 = Carribean islands	7 (15%)
10. AF3 = Mascarene Islands	6 (13%)
11. AM5 = Brazil	5 (11%)
12. AM6 = southern South America	5 (11%)
13. AU2 = New Zealand	4 (9%)

Table 15. (continued)

Floristic Region	Number of Thai *Fissidens* taxa
14. OC = Oceania	4 (9%)
15. EUR = Europe	2 (4%)
16. AF4 = southern Africa	2 (4%)
17. AS5 = western Asia	1 (2%)
18. AF1 = northern Africa	0 (0%)
19. AS1 = northern Asia	0 (0%)
20. ANT = Antarctica	0 (0%)

The inter-related dispersal among Asian subfloristic regions (AS2, AS3, and AS4), includes temperate species *e.g. F. bryoides* var. *esquirolii* (Figure 84) from China to become a new record for Thailand. This is an example of regional dispersal from Central Asia (AS2) to Southern Asia (AS3). *Fissidens kinabaluense* (Figure 95) and *F. guangdongensis* (Figure 89), which are distributed in AS2 and AS4, are also new records for Thailand.

For regional dispersal in AS3, 4 species of Thai *Fissidens* are also found in the Indian subcontinent, *viz. F. firmus* (Figure 104), *F. laxitextus* (Figure 96), *F. sedgwickii* (Figure 108), and *F. semperfalcatus* (Figure 99).

A lack of bryophytes from Indochina is apparent since the number of *Fissidens* taxa increased from 23 (Tan and Iwatsuki, 1993; He, 1996) to 37 taxa (61% increase) (Table 16). There is a need to study bryophytes in Indochina.

Table 16. Thai *Fissidens* taxa also known from Indochina (Tan and Iwatsuki, 1993; He, 1996.)

Taxon	Southeast Asian Countries found
1. *F. anomalus*	Myanmar, Thailand, Vietnam
2. *F. biformis*	Indonesia, Malaysia, Philippines, Thailand
3. *F. ceylonensis*	Cambodia, Laos, Myanmar, Thailand, Vietnam
4. *F. crassinervis*	Thailand
5. *F. crenulatus* var. *crenulatus*	Indonesia, Thailand
6. *F. crenulatus* var. *elmeri*	Malaysia, Philippines, Singapore, Thailand,
7. *F. crispulus* var. *crispulus*	Vietnam
8. *F. gardneri*	Cambodia, Myanmar, Thailand, Vietnam
9. *F. geminiflorus*	Laos, Myanmar, Thailand
10. *F. gymnogynus*	Indonesia, Malaysia, Philippines, Singapore, Thailand, Vietnam
11. *F. hollianus*	Thailand
12. *F. javanicus*	Cambodia, Myanmar, Thailand, Vietnam
13. *F. kinabaluense*	Myanmar, Thailand, Vietnam
14. *F. pellucidus*	Indonesia, Malaysia, Thailand
15. *F. nobilis*	Cambodia, Myanmar, Thailand, Vietnam
16. *F. oblongifolius*	Indonesia, Thailand
17. *F. polypodioides*	Myanmar, Thailand, Vietnam

Table 16. (continued)

Taxon	Southeast Asian Countries found
18. *F. semperfalcatus*	Myanmar, Thailand
19. *F. subangustus*	Indonesia, Thailand
20. *F. taxifolius*	Indonesia, Thailand
21. *F. tenellus* var. *australiensis*	Myanmar, Thailand
22. *F. wichurae*	Thailand, Vietnam
23. *F. zollingeri*	Cambodia, Myanmar, Thailand, Vietnam

Eleven new records, two new species, and one new variety of Thai *Fissidens* were found in this study, *viz. F. angustifolius, F. bryoides* var. *esquirolii, F. bryoides* var. *schmidii, F. flabellulus, F. geppii, F. guangdongensis, F. hyalinus, F. incognitus, F. jungermannioides, F. obscurus*, and *F. serratus*; *F. flaccidus* var. *percurrens, F. irregulomarginatulus,* and *F. pseudokinabaluensis.*

A total of 46 Thai *Fissidens* taxa now are known in Thailand (Table 17). Among these *F. angustifolius, F. bryoides* var. *equirolii, F. filiformis, F. flabellulus, F. flaccidus* var. *percurrens, F. incognitus, F. irregulomarginatulus, F. jungermanioides, F. laxitextus, F. obscurus, F. pseudokinabaluensis, F. sedgwickii,* and *F. subbryoides* are only found in Thailand. *Fissidens filiformis* was reported to be an endemic species for Thailand (He, 1996). The specimen was collected from Phu Kradung National Park, Loei province (Iwatsuki, 1987). I did not find *Fissidens filiformis*, but studied the holotype. Before making any conclusions about the endemism of this species, collecting in Laos and Cambodia needs to be done more wider and broader ranges. This species is endangered since the type habitat is risky to be destroyed by tourism.

Fissidens irregulomarginatulus (collected from Doi Suthep-Pui National Park, Chiang Mai, northern Thailand) and *F. pseudokinabaluensis* (collected from Khao Nan National Park, Nakhorn Sri Thammarat, southern Thailand) were also mixed with other specimens of *Fissidens*. *F. flaccidus* var. *percurrens* is known from central and southern Thailand. *Fissidens irregulomarginatulus, F. pseudokinabaluensis,* and *F. flaccidus* var. *percurrens* are rare and endangered species.

Table 17. New checklist of Thai *Fissidens* in Southeast Asia.

No.	Taxon	Countries found
1.	*F. angustifolius* *	Thailand
2.	*F. anomalus*	Indonesia, Malaysia, Myanmar, Philippines, Thailand, Vietnam
3.	*F. beckettii*	Malaysia, Thailand
4.	*F. biformis*	Malaysia, Philippines, Thailand
5.	*F. bryoides* var. *equirolii* *	Thailand
6.	*F. bryoides* var. *schmidii*	Indonesia, Malaysia, Philippines, Thailand
7.	*F. ceylonensis*	Cambodia, Indonesia, Laos, Malaysia, Philippines, Singapore, Thailand, Vietnam
8.	*F. crassinervis*	Indonesia, Malaysia, Philippines, Singapore, Thailand

Table 17. (continued)

No.	Taxon	Countries found
9.	*F. crenulatus* var. *crenulatus*	Indonesia, Malaysia, Myanmar, Philippines, Thailand, Vietnam
10.	*F. crenulatus* var. *elmeri*	Malaysia, Philippines, Singapore, Thailand, Vietnam
11.	*F. crispulus* var. *crispulus*	Cambodia, Indonesia, Malaysia, Myanmar, Philippines, Singapore, Thailand, Vietnam
12.	*F. crispulus* var. *robinsonii*	Indonesia, Malaysia, Philippines, Singapore, Thailand
13.	*F. filiformis*	Thailand
14.	*F. firmus*	Malaysia, Thailand
15.	*F. flabellulus* *	Thailand
16.	*F. flaccidus* var. *flaccidus*	Indonesia, Malaysia, Myanmar, Philippines, Singapore, Thailand, Vietnam
17.	*F. flaccidus* var. *percurrens* **	Thailand
18.	*F. gardneri*	Indonesia, Laos, Malaysia, Myanmar, Philippines, Thailand, Vietnam
19.	*F. geminiflorus*	Indonesia, Malaysia, Philippines, Thailand, Vietnam
20.	*F. geppii*	Indonesia, Malaysia, Thailand
21.	*F. guangdongensis*	Malaysia, Singapore, Thailand
22.	*F. gymnogynus*	Malaysia, Philippines, Singapore, Thailand
23.	*F. hollianus*	Cambodia, Indonesia, Malaysia, Myanmar, Philippines, Thailand, Vietnam
24.	*F. hyalinus*	Malaysia, Philippines, Thailand
25.	*F. incognitus* *	Thailand
26.	*F. involutus*	Myanmar, Philippines, Thailand, Vietnam
27.	*F. irregulomarginatulus* **	Thailand
28.	*F. javanicus*	Indonesia, Laos, Malaysia, Myanmar, Philippines, Thailand, Vietnam
29.	*F. jungurmannioides* *	Thailand
30.	*F. kinabaluense*	Indonesia, Malaysia, Thailand
31.	*F. laxitextus*	Thailand
32.	*F. nobilis*	Cambodia, Indonesia, Malaysia, Myanmar, Philippines, Thailand, Vietnam
33.	*F. oblongifolius*	Indonesia, Malaysia, Philippines, Singapore, Thailand
34.	*F. obscurus* *	Thailand
35.	*F. pellucidus*	Indonesia, Malaysia, Myanmar, Philippines, Singapore, Thailand, Vietnam
36.	*F. polypodioides*	Malaysia, Myanmar, Philippines, Singapore, Thailand, Vietnam
37.	*F. pseudokinabaluensis* **	Thailand
38.	*F. sedgwickii*	Thailand

Table 17. (continued)

No.	Taxon	Country found
39.	*F. semperfalcatus*	Myanmar, Thailand
40.	*F. serratus*	Malaysia, Philippines, Singapore, Thailand
41.	*F. subangustus*	Indonesia, Malaysia, Philippines, Thailand
42.	*F. subbryoides**	Thailand
43.	*F. taxifolius*	Indonesia, Thailand
44.	*F. tenellus*. var. *australiensis*	Indonesia, Malaysia, Myanmar, Philippines, Thailand
45.	*F. wichurae*	Indonesia, Malaysia, Philippines, Thailand, Vietnam
46.	*F. zollingeri*	Cambodia, Indonesia, Malaysia, Myanmar, Philippines, Singapore, Thailand, Vietnam

Notes: * new record, and ** new species / new variety

A total of 46 *Fissidens* taxa were found in this study (Table 17). Three new species, seven new records of Thai *Fissidens* are also new to Southeast Asia.

Australasian tropical group distribution

Fissidens crassinervis (Figure 110), *F. crenulatus* var. *crenulatus* (Figure 111), *F. flabellulus* (Figure 112), *F. hollianus* (Figure 113), and *F. tenellus* var. *australiensis* (Figure 114), which are present Asia (AS2, AS3, AS4), are also found in northern Queensland (Ramsay and Cairns, 2004).

There are three possible ways of how *Fissidens* is found in Thailand 1) long-distance distribution of *F. obscurus* 2) Expansion of temperate species ranges especially from AS2 and tropical species from AS3 and AS4. 3) Thailand species origin. Thai *Fissidens* can be classified into five regional groups: 1) Asian group, 2) more likely Pantropic (Asia Africa America) and temperate group, 3) Australasian group, 4) Paleotropic and Paleotropic with some parts of Australia, and 5) Disjunctive Australasian and American group (Table 18).

Table 18. Distribution of Thai *Fissidens* in five regional groups.

Group	**Species**
Asian (27 species =59%)	*F. anomalus, F. biformis, F. bryoides* var. *esquirolii, F. crenulatus* var. *elmeri, F. crispulus* var. *robinsonii, F. filiformis, F. firmus , F. flaccidus* var. *percurrens, F. geminiflorus, F. geppii, F. guangdongensis, F. gymnogynus, F. incognitus, F. involutus, F. irregulomarginatulus, F. javanicus, F. jungermannioides, F. kinabaluense, F. laxitextus, F. nobilis, F. obscurus, F. pseudokinabaluensis, F. sedgwickii, F. semperfalcatus, F. subangustus, F. subbryoides, F. wichurae*

Table 18. (continued)

Group	Species
More likely Pantropic and Temperate (8 species = 17%)	*F. angustifolius*, *F. flaccidus* var. *flaccidus*, *F. gardneri*, *F. oblongifolius*, *F. pellucidus*, *F. serratus*, *F. taxifolius*, *F. zollingeri*
Australasian (5 species = 11%)	*F. crenulatus* var. *crenulatus*, *F. crassinervis*, *F. flabellulus*, *F. hollianus*, *F. tenellus* var. *australiensis*
Paleotropic and Paleotropic with some parts of Australia (4 species = 9%)	*F. beckettii*, *F. bryoides* var. *schmidii*, *F. ceylonensis*, *F. crispulus* var. *crispulus*
Disjunctive of Australasian and America (2 species = 4%)	*F. hyalinus*, *F. polypodioides*

Morphology and Ecology of Thai *Fissidens*

Thai *Fissidens* can be discussed in 4 categories, *viz.* 1. plant length, 2. habitat, 3. forest type, and 4. beta diversity conservation.

1. Plant length

Based on the stem length, Thai *Fissidens* can be grouped into three categories, *viz.*, small (less than 0.5 cm), medium (0.5-2.0 cm), and large (more than 2.0 cm). More than half of Thai *Fissidens* taxa (65%), belong to the small-sized category. Of these, 14 taxa are common in Thailand and are found in evergreen and deciduous forests and distributed habitats under a wide range of elevations (30-2565 m) (Table 15). Sixteen taxa are uncommon and are found in moist to very wet primary and secondary forests without excessive human disturbance except *Fissidens gardneri* that grows on tree bark in human settlements. For the medium sized category, 9 species or 20% of the total, belong to this group and are found in moist to very wet conditions in evergreen seasonal forest at 1000-2565 m elevation. In the large sized category 7 species or 15% of all species grow in waterfall areas and streams. *Fissidens filiformis*, only known from the type material, was collected in evergreen, seasonal, hardwood with pine forest at 1200 m elevation (Iwatsuki, 1987).

Two of these species, *viz. F. nobilis* and *F. polypodioides*, are common in Thailand and occur in primary, evergreen, seasonal, hardwood forest on rocks along waterfalls and streams at 1200-2565 m elevation.

Table 19. Groups of *Fissidens* based on stem length and abundance.

abundance / stem length	common	uncommon/rare
Small (less than 0.5 cm)	*F. bryoides* var. *esquirolii* *F. ceylonensis*	*F. angustifolius* *F. beckettii*

Table 15. (continued)

abundance / stem length	common	uncommon/rare
(continued)	*F. crenulatus* var. *crenulatus* *F. crispulus* var. *crispulus* *F. crispulus* var. *robinsonii* *F. flaccidus* var. *flaccidus* *F. gardneri* *F. hollianus* *F. incognitus* *F. pellucidus* *F. semperfalcatus* *F. serratus* *F. subbryoides* *F. zollingeri*	*F. biformis* *F. crenulatus* var. *elmeri* *F. flabellulus* *F. guangdongensis* *F. hyalinus* *F. irregulomarginatulus* *F. jungermannioides* *F. kinabaluense* *F. laxitextus* *F. pseudokinabaluensis* *F. subangustus* *F. tenellus* var. *australiensis* *F. wichurae*
Medium (0.5-2.0 cm)	*F. bryoides* var. *schmidii* *F. crassinervis* *F. firmus* *F. javanicus*	*F. geppii* *F. gymnogynus* *F. oblongifolius* *F. sedgwickii* *F. taxifolius*
Large (more than 2.0 cm)	*F. nobilis* *F. polypodioides*	*F. anomalus* *F. filiformis* *F. geminiflorus* *F. involutus* *F. obscurus*

2. Habitat

Sixty-seven percentages of Thai *Fissidens* are terrestrial. Eleven taxa (24%) are both terrestial and epiphytic. Only three taxa (9%) are epiphytic found on tree bark, base of tree trunks, and buttresses, *viz. F. anomalus*, *F. crenulatus* var. *elmeri*, *F. semperfalcatus*, and *F. tenellus* var. *australiensis* (Table 20).

Twenty-six taxa of Thai *Fissidens* grow on soil and 6 species occur on rocks. *F. sedgwickii* occurs on wet rocks and is the only aquatic species of *Fissidens* in Thailand. Until now, it is only found Loei province. It is rare in Thailand due to having small populations and a specific habitat on rocks in the streams at 1200 m elevation. This species needs urgent conservation. Several species are specific to their habitats such as *Fissidens involutus*, found on soil along limestone waterfalls at Pha Daeng National Park at about 600 m elevation. *Fissidens geminiflorus*, *F. nobilis*, *F. geppii*, *F. javanicus*, and *F. obscurus* occur on wet granite near waterfalls, 1000-1600 m elevation. *Fissidens polypodioides* grows up to 5 cm long in wet soil and rocks along waterfalls and streams, 1200-2565 m elevation. This species is effective in controlling soil bank erosion.

Fissidens anomalus is epiphytic on tree bark and branches. It is found in northern to northeastern Thailand above 1200 m elevation.

Some species of *Fissidens* are pioneer species, *viz. F. ceylonensis* and *F. pellucidus* growing on soil in open areas at 30-2565 m elevation. They help to reduce water evaporation from soil and help other plants to develop.

Table 20. Habitats of Thai *Fissidens*.

Habitat	Species
Aquatic	*F. sedgwickii*
Terrestrial (on soil)	*F. angustifolius, F. beckettii, F. biformis, F. filiformis, F. flabellulus F. flaccidus* var. *flaccidus, F. flaccidus* var. *percurrens, F. gymnogynus, F. hyalinus, F. incognitus, F. involutus F. irregulomarginatulus, F. kinabaluense, F. laxitextus, F. nobilis, F. obscurus, F. pellucidus, F. polypodioides, F. pseudokinabaluensis, F. semperfalcatus, F. serratus, F. subangustus, F. subbryoides, F. taxifolius, F. wichurae, F. zollingeri*
Epilithic	*F. firmus, F. geminiflorus, F. geppii, F. javanicus, F. jungermannioides*
Epiphytic	*F. anomalus, F. crenulatus* var. *elmeri, F. tenellus* var. *australiensis*
Terrestrial and Epiphytic	*F. bryoides* var. *esquirolii, F. bryoides* var. *schmidii, F. ceylonensis F. crassinervis, F. crenulatus* var. *crenulatus, F. crispulus* var. *crispulus, F. crispulus* var. *robinsonii, F. gardneri, F. guangdongensis, F. hollianus, F. oblongifolius*

3. Forest types and abundance of Thai *Fissidens*

The vegetation of Thailand (Maxwell, 2001, 2004) has been classified and simplified (Table 2).

Primary, evergreen, seasonal, hardwood forest has the highest number of *Fissidens* species (38), followed by deciduous, seasonal, hardwood with bamboo (22), deciduous dipterocarp-oak (19), mixed evergreen+deciduous, seasonal, hardwood (16), and primary, evergreen, seasonal, hardwood with pine (13) (Table 21, Figure 67).

Primary, evergreen, seasonal, hardwood forest also has more uncommon taxa than other forest types (Table 21 and Figure 67). Nineteen uncommon taxa are found in primary, evergreen, seasonal, hardwood forest followed by deciduous seasonal hardwood with bamboo (7); primary evergreen seasonal hardwood with pine (5); mixed evergreen+deciduous (5); and deciduous dipterocarp-oak (5). Primary, evergreen, seasonal, hardwood forest also has higher diversity in common species than other forest types. Nineteen common species are found in primary, evergreen, seasonal, hardwood forest, followed by deciduous, seasonal, hardwood with bamboo (15); deciduous dipterocarp-oak (14); mixed evergreen+deciduous (11); and primary, evergreen, seasonal, hardwood with pine (8).

From the result, moisture in the forest affects abundances of Thai *Fissidens*. Primary, evergreen, seasonal, hardwood forest which is more humid than other forests, occupied higher numbers of *Fissidens* species. While primary, evergreen,

seasonal, hardwood with pine drier, occupied fewer species of *Fissidens*. Moreover, the occurrences of *Fissidens* in drier forest are mainly colonized near waterfalls and streams.

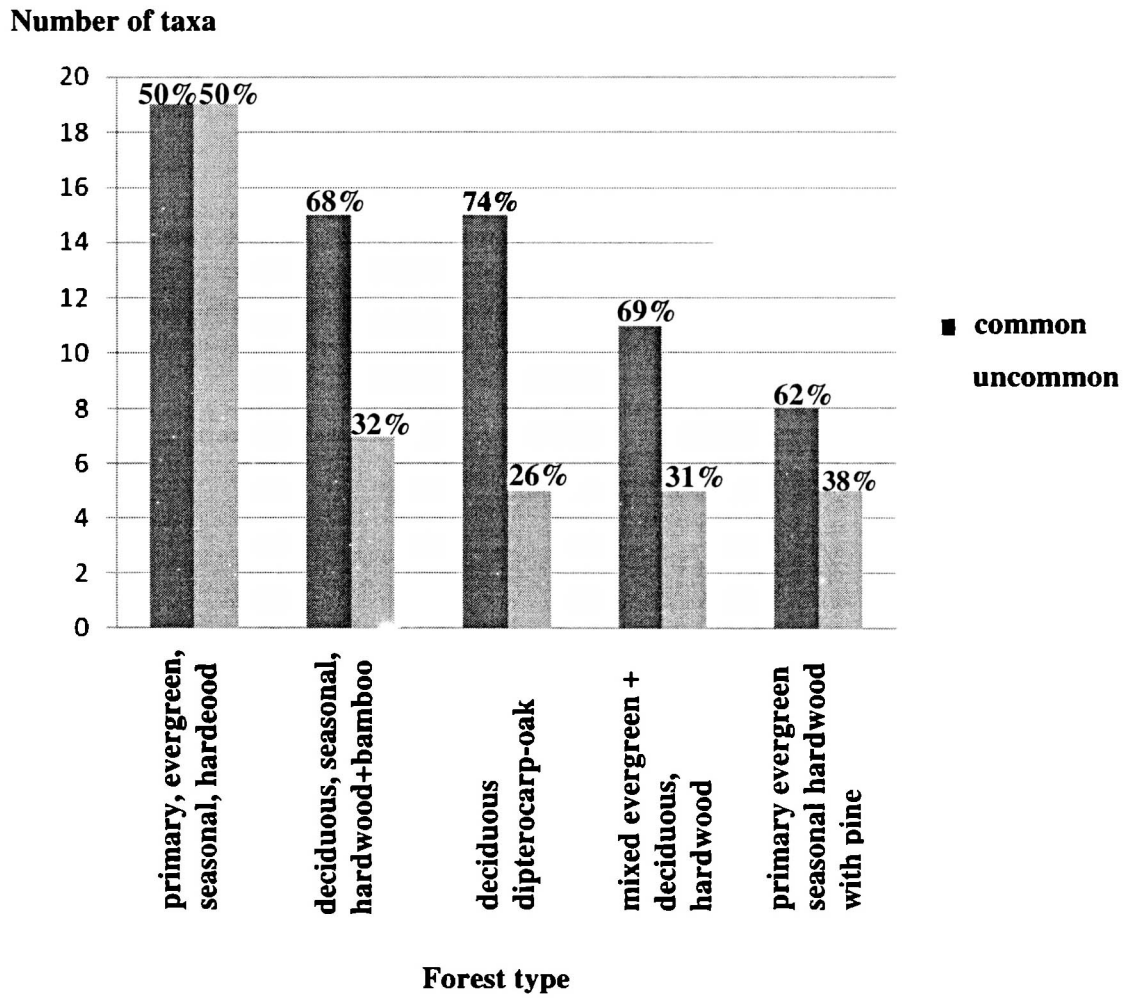


Figure 67. Forest types and abundance of Thai *Fissidens*.

In conclusion, primary, evergreen, seasonal, hardwood forest is the most important habitat for both common and uncommon Thai *Fissidens* taxa. This habitat found scattered in every floristic part of Thailand and should be conserved habitat for *Fissidens*.

Table 21. Forest types and abundance of Thai *Fissidens*.

Forest type	Location	Taxon	
		Common	**Uncommon**
Primary evergreen seasonal hardwood 38 species	Doi Inthanon Doi Suthep-Pui Phu Hin Rong Kla Khao Khitchkut Khao Yai Nam Tok Ngao Khao Nan Phanom Bencha Sri Phang-nga	*F. bryoides* var. *schmidii*, *F. ceylonensis*, *F. crenulatus* var. *crenulatus*, *F. crassinervis*, *F. crispulus* var. *crispulus*, *F. crispulus* var. *robinsonii*, *F. flaccidus* var. *flaccidus*, *F. gardneri*, *F. hollianus*, *F. incognitus*, *F. javanicus*, *F. jungermannioides*, *F. nobilis*, *F. pellucidus*, *F. polypodioides*, *F. semperfalcatus*, *F. subbryoides*, *F. taxifolius*, *F. zollingeri* 19 species	*F. angustifolius*, *F. anomalus*, *F. beckettii*, *F. biformis*, *F. crenulatus* var. *elmeri*, *F. flabellulus*, *F. flaccidus* var. *percurrens*, *F. firmus*, *F. guangdongensis*, *F. geminiflorus*, *F. gymnogynus*, *F. hyalinus*, *F. kinabaluense*, *F. obscurus*, *F. laxitextus*, *F. oblongifolius*, *F. serratus*, *F. subangustus*, *F. tenellus* var. *australiensis* 19 species
Primary evergreen seasonal hardwood with pine 13 species	Phu Luang Wildlife Sanctuary Phu Kradung	*F. ceylonensis*, *F. crispulus* var. *crispulus*, *F. crenulutus*, *F. hollianus*, *F. nobilis*, *F. pellucidus*, *F. polypodioides*, *F. subbryoides*, 8 species	*F. anomalus*, *F. firmus*, *F. jungermannioides*, *F. sedgwickii*, *F. tenellus* var. *australiensis* 5 species
Mixed evergreen + deciduous seasonal hardwood 16 species	Chiang Dao Wildlife Sanctuary Doi Inthanon	*F. ceylonensis*, *F. crenulatus* var. *crenulatus*, *F. crispulus* var. *crispulus*, *F. crispulus* var. *robinsonii*, *F. flaccidus* var. *flaccidus*, *F. hollianus*, *F. gardneri*, *F. pellucidus*, *F. subbryoides*, *F. semperfalcatus*, *F. zollingeri* 11 species	*F. biformis*, *F. gymnogynus*, *F. geppii*, *F. subangustus*, *F. wichurea* 5 species

Table 21. (continued)

Forest type	Location	Taxon	
		Common	**Uncommon**
Decidudous diptercarp-oak 19 species	Khao Cha Mao-Kha Wong Phu Kao-Phu Phan Kham Phu Phan Tat Ton Pha Taem Doi Suthep-Pui Pha Daeng Nam Tok Phlieo	*F. ceylonensis, F. crassinervis,* *F. crenulatus* var. *crenulatus,* *F. crispulus* var. *crispulus,* *F. crispulus* var. *robinsonii,* *F. flaccidus* var. *flaccidus,* *F. gardneri, F. hollianus,* *F. incognitus, F. javanicus,* *F. pellucidus, F. semperfalcatus,* *F. subbryoides, F. zollingeri* 14 species	*F. bryoides* var. *esquirolii,* *F. firmus,* *F. guangdongensis,* *F. irregulomarginatulus,* *F. involutus,* 5 species
Deciduous seasonal hardwood +bamboo 22 species	Phu-Toei Kaeng Krachan Thong Pha Phum Hui Yang	*F. bryoides* var. *schmidii,* *F. ceylonensis, F. crassinervis,* *F. crenulatus* var. *crenulatus,* *F. crispulus* var. *crispulus,* *F. crispulus* var. *robinsonii,* *F. flaccidus* var. *flaccidus,* *F. gardneri,* *F. hollianus, F. incognitus,* *F. javanicus, F. pellucidus,* *F. semperfalcatus, F. subbryoides,* *F. zollingeri* 15 species	*F. angustifolius, F. biformis,* *F. bryoides* var. *esquirolii,* *F. gymnogynus, F. filiformis,* *F. involutus,* *F. pseudokinabaluensis,* 7 species

Alpha, Beta, and Gamma Diversity of Thai *Fissidens*

Whittaker (1972) described three terms for measuring biodiversity over spatial scales, *viz.* alpha, beta, and gamma diversity. Alpha diversity refers to the diversity within a particular area or ecosystem and is usually expressed by the number of species (*i.e.* species richness) in that ecosystem. Beta diversity refers to a comparison of diversity between ecosystems, usually measured as the amount of species change between the ecosystems. Gamma diversity is a measure of the overall diversity for the different ecosystems within a large region (the combination of alpha and beta diversities).

Beta diversity and conservation

Thai *Fissidens*, beta diversity is determined to indicate habitats requiring conservation. Lists of *Fissidens* found in each national park (Table 4).and beta diversity are shown (Table 5).

To interpret the low and high for beta diversity, the two examples are presented.

1. Low beta diversity:

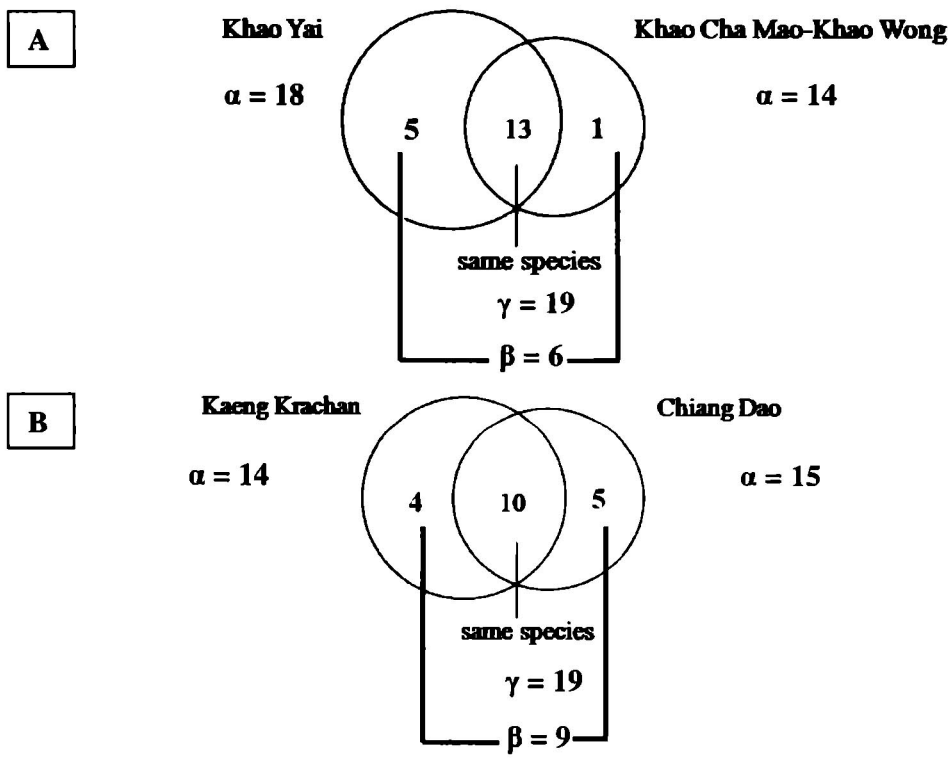


Figure 68. A: Comparison of alpha, beta, and gamma diversity between Khao Yai National Park and Khao Cha Mao-Khao Wong National Park. B: comparison of alpha, beta, and gamma diversity between Chiang Dao & Wildlife Sanctuary and Kaeng Krachan National Park.

Both models A and B show a high number of the same (overlapped) species, 13 and 10, respectively. In contrast, both show low of the beta diversity (changed species between habitats), *i.e.* 6 and 9 respectively. These areas/habitats represent good conditions for most species in these two national parks. The species found in these national parks are considered to be the generalists.

2. High beta diversity:

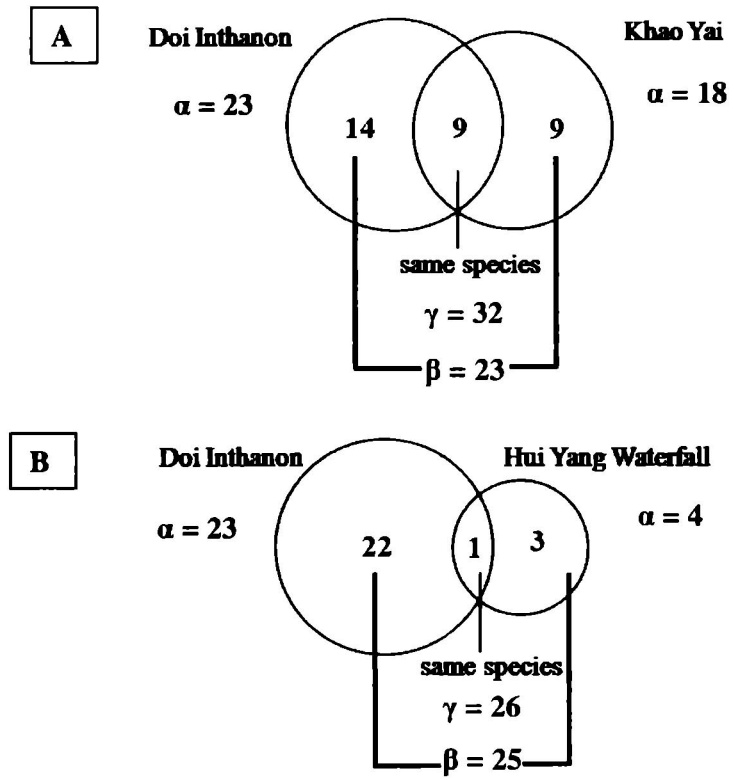


Figure 69. A: Comparison of alpha, beta, and gamma diversities between Doi Inthanon National Park and Hui Yang Waterfall National Park. B: Comparison of alpha, beta, and gamma diversity between Doi Inthanon and Khao Yai National Park.

These two models show a low number of the same species between national parks, *viz.* 1 and 9 species, respectively. In contrast, both show high beta diversity of 23 and 25 species, respectively. If there is the loss of habitats of either Doi Inthanon National Park or Khao Yai National Park, *Fissidens* occurring in both areas may be extirpated. These areas/habitats should become conserved areas. Thai *Fissidens* occurring there are called specialists.

Some National Parks have high *Fissidens* diversity, *viz.* Doi Inthanon, Doi Suthep-Pui, Kaeng Krachan, Khao Yai, and Phu Luang Wildlife Sanctuary. Some have uncommon species, *viz.* Phu Kradung, Phu Phan, Pha Taem, Thong Pha Phum, and Khao Luang, that need to have the conservation habitats. Because there is high differences in species diversity between national parks and few with the same species diversity, these habitats are the most needed to be conserved.

The critical zone, vulnerable zone, and not vulnerable zone

Beta diversity can be used for finding "hot spot areas" of *Fissidens* in Thailand. The results show a statistically significant confidence level at 95% of beta diversity at 2 and 22 species, respectively (Figure 64).

Eight national parks in the critical zone, *viz.* Doi Inthanon National Park, Doi Suthep-Pui National Park, Kaeng Krachan National Park, Khao Yai National Park, Phu Kradung National Park, Thong Pha Phum National Park, Khao Luang National Park and Phu Luang Wildlife Sanctuary should be conserved.

For vulnerable zone, 13 national parks, *viz.* Doi Inthanon National Park, Doi Suthep-Pui National Park, Pha Daeng National Park, Phu Hin Rong Kla National Park, Phu Kradung National Park, Phu Luang Wildlife Sanctuary, Nam Tok Phlieo National Park, Khao Yai National Park, Kaeng Krachan National Park, Thong Pha Phum National Park, Hui Yang Waterfall National Park, Khao Nan National Park, Khao Luang National Park show the number of Thai *Fissidens* species that are unique to their national park habitat in a range of 11.96-22 taxa and not vulnerable zone (50%) have the most *c.* 10 species about 67 frequency (Figure 64). This means most Thai national parks have high similarities in generalist species, but these zones still have specialists within the different habitats of different national parks. Therefore, vulnerable and not vulnerable zone of Thai *Fissidens* measuring by beta diversity are also conserved to be natural resources habitat for Thai *Fissidens.*

CHAPTER 6
CONCLUSIONS

Taxonomic study

Taxonomic revision of *Fissdens* in Thailand resulted in 42 species and 9 varieties. These include 2 new species and 1 new variety, *viz. F. irregulomarginatulus* K. Wongkuna & B. C. Tan, *F. pseudokinabaluensis* K. Wongkuna & B. C. Tan, and *F. flaccidus* Mitt. var. *percurrens* K. Wongkuna, and 15 new records. Two species are excluded from Thailand, *viz. F. aspledioides* Hedw. and *F. subspathuulatus* Dix.. Specimens were collected from the 7 different floristic regions and 5 types of forests in Thailand during 2005-2009. Several specimens (holotype, lectotype, and isotypes) were borrowed from the Royal Forest Department Herbarium, Bangkok (BKF); National Herbarium Netherlands, Leiden, Netherlands (L); Missouri Botanical Garden (MO); Finnish Museum of Natural History, Botanical Museum (H); Prince of Songkla University (PSU), and Herbarium, National Museum of Nature and Science, Japan (TNS) were borrowed. I also visited the Department of Botany, Chulalongkorn University, Bangkok (BCU) and the Singapore Botanic Gardens (SING) to study specimens and consult the bryophyte literature there.

Since new species, a new variety, and new records were found, more new taxonomic and ecological information on Thai *Fissidens* can still be done. More collecting in other areas in Thailand is needed to determine if more species are in the country as well as much ecological information required for conservation of several endangered taxa.

Distribution of *Fissidens* in Thailand

Most taxa of Thai *Fissidens* (76%) occur in the north which also has the most uncommon species (18 species). The least (20%) are found in the east.

Primary, evergreen, seasonal, hardwood forest has the highest number of *Fissidens* taxa (38). Fourteen species are uncommon and habitat specific. *Fissidens* has been found in deciduous, seasonal, hardwood with bamboo forest (22 taxa), deciduous dipterocarp-oak (19 taxa), mixed evergreen+deciduous seasonal, hardwood forest (16 taxa), primary, evergreen, seasonal, hardwood forest with pine (13 taxa).

Most Thai *Fissidens* are distributed in tropical and temperate regions and also occurred in other Asian countries. There are three possible ways of how *Fissidens* is found in Thailand 1) long-distance distribution of diaspores (spores and gemmae), 2) expansion of temperate species ranges to other tropical areas, and 3) ancient continental drift distributions are also considered.

Fissidens Ecology

More than half of Thai *Fissidens* taxa are terrestrial, including one aquatic species, *F. sedgwickii* Broth. & Dix.. The others are both terrestrial and epiphytic and a few species are epiphytic. More than half of Thai *Fissidens* (65%), belong to the small-sized category (less than 0.5 cm long), are common in evergreen and deciduous forests, and are distributed in habitats with a wide range of elevations (30-2565 m). Sixteen taxa are uncommon and are found in moist to very wet places in primary and secondary forests without excessive human disturbance. *Fissidens gardneri* Mitt., which grows on tree bark, is found in human settlements. The medium and large-sized categories are found in moist to very wet conditions in primary, evergreen, seasonal, hardwood forest at 1000-2565 m elevation.

Fissidens ceylonensis and *F. pellucidus* are pioneer species which grow on soil in open areas at 30-2565 m elevation.

Fourteen species of Thai *Fissidens*, *viz. Fissidens filiformis* Z. Iwats., *F. flabellulus* Thwait. & Mitt., *F. geminiflorus* Dozy & Molk., *F. geppii* Fleisch., *F. hyalinus* Hook. & Wils., *F. irregulomarginatulus* K. Wongkuna & B. C. Tan, *F. jungermannioides* Griff., *F. kinabaluense* Z. Iwats., *F. laxitextus* Broth. *ex* Gangulee, *F. oblongifolius* Hook. f. & Wils., *F. obscurus* Mitt., *F. pseudokinabaluensis* K. Wongkuna & B. C. Tan, *F. sedgwickii* Broth. & Dix., and *F. wichurae* Broth. & Fleisch. are rare in Thailand.

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APPENDIX A
Index to Taxa

Index to Taxa

Fissidens
Taxa in bold type are accepted those in italics are synonyms

Taxon	Taxon no.	Page
F. angustifolius Sull.	1	31
F. anomalus Mont.	2	33
F. areolatus Griff.	36	105
F. aspledioides Hedw.	excluded	-
F. beckettii Mitt.	3	35
F. biformis Mitt.	4	37
F. bryoides Hedw. var. ***esquirolii*** (Thér.) Z. Iwats. & T. Suzuki	5	39
F. bryoides Hedw. var. ***schmidii*** (C. Muell.) Chopra & Kumar	6	41
F. ceylonensis Dozy & Molk.	7	43
F. crassinervis Sande Lac.	8	46
F. crassinervis Sande Lac. var. *laxus* (Sull. & Lesq.)	35	102
F. crenulatus Mitt. var. ***crenulatus***	9	48
F. crenulatus Mitt. var. ***elmeri*** (Broth.) Z. Iwats. & T. Suzuki	10	51
F. crispulus Brid. var. ***crispulus***	11	53
F. crispulus Brid. var. ***robinsonii*** (Broth.) Z. Iwats. & Z. H. Li	12	56
F. elmeri Broth.	10	51
F. excedens Broth.	46	125
F. filiformis Z. Iwats.	13	59
F. firmus Mitt.	14	60
F. flabellulus Thwait. & Mitt.	15	62
F. flaccidus Mitt. var. ***flaccidus***	16	64
F. flaccidus Mitt. var. ***percurrens*** K. Wongkuna, *var. nov.*	17	66
F. gardneri Mitt.	18	68
F. geminiflorus Dozy & Molk.	19	70
F. geppii Fleisch.	20	72
F. guangdongensis Z. Iwats & Z. H. Li	21	74
F. gymnogynus Besch.	22	76
F. hollianus Dozy & Molk.	23	78
F. hyalinus Hook. & Wils.	24	80
F. incognitus Gangulee	25	82
F. involutus Wils. *ex* Mitt.	26	84
F. irregulomarginatulus K. Wongkuna & B. C. Tan, *sp. nov.*	27	86
F. javanicus Dozy & Molk.	28	88
F. jungermannioides Griff.	29	90
F. kinabaluense Z. Iwats.	30	92
F. laxitextus Broth. *ex* Gangulee	31	94
F. laxus Sull. & Lesq. var. *laxus*	35	102
F. microcladus Thwaites & Mitt.	18	68
F. mittenii Par. var. *mittenii*	35	102

Taxon	Taxon no.	Page
F. nobilis Griff.	32	96
F. oblongifolius Hook. f. & Wils.	33	98
F. oblongifolius Hook. f. & Wils. var. *oblongifolius*	33	98
F. obscurus Mitt.	34	100
F. obtuso-apiculatus Dix.	26	84
F. papillosus Hornsch.	44	122
F. papillulosus Broth.	9	48
F. pellucidus Hornsch.	35	102
F. polypodioides Hedw.	36	105
F. polypodioides Hedw. var. *areolatus* (Griff.) Wils.	36	105
F. pseudokinabaluensis K. Wongkuna & B. C. Tan, *sp. nov.*	37	108
F. sedgwickii Broth. & Dix.	38	110
F. semperfalcatus Dix.	39	112
F. serratus Muell. Hal.	40	114
F. siamensis Broth.	7	43
F. subangustus Fleisch.	41	116
F. subbryoides Gangulee	42	118
F. subspathulatus Dix.	excluded	-
F. sylvaticus Griff. var. *zippelianus* (Dozy & Molk.) Gangulee	11	53
F. taxifolius Hedw.	43	120
F. tenellus Hook. f. & Wils. var. ***australiensis*** (A. Jaeger) Beever & Stone	44	122
F. virens Thwaites & Mitt.	9	48
F. wichurae Broth. & Fleisch.	45	124
F. xiphoioides Fleisch.	44	122
F. zippelianus Dozy & Molk.	11	53
F. zippelianus Dozy & Molk. var. *robinsonii* (Broth.) Z. Iwatsuki & Suzuki	12	56
F. zippelianus Dozy & Molk. var. *fontanus* Fleisch.	11	53
F. zollingeri Mont.	46	125

APPENDIX B

Distribution in Thailand and World Distribution of Thai *Fissidens*

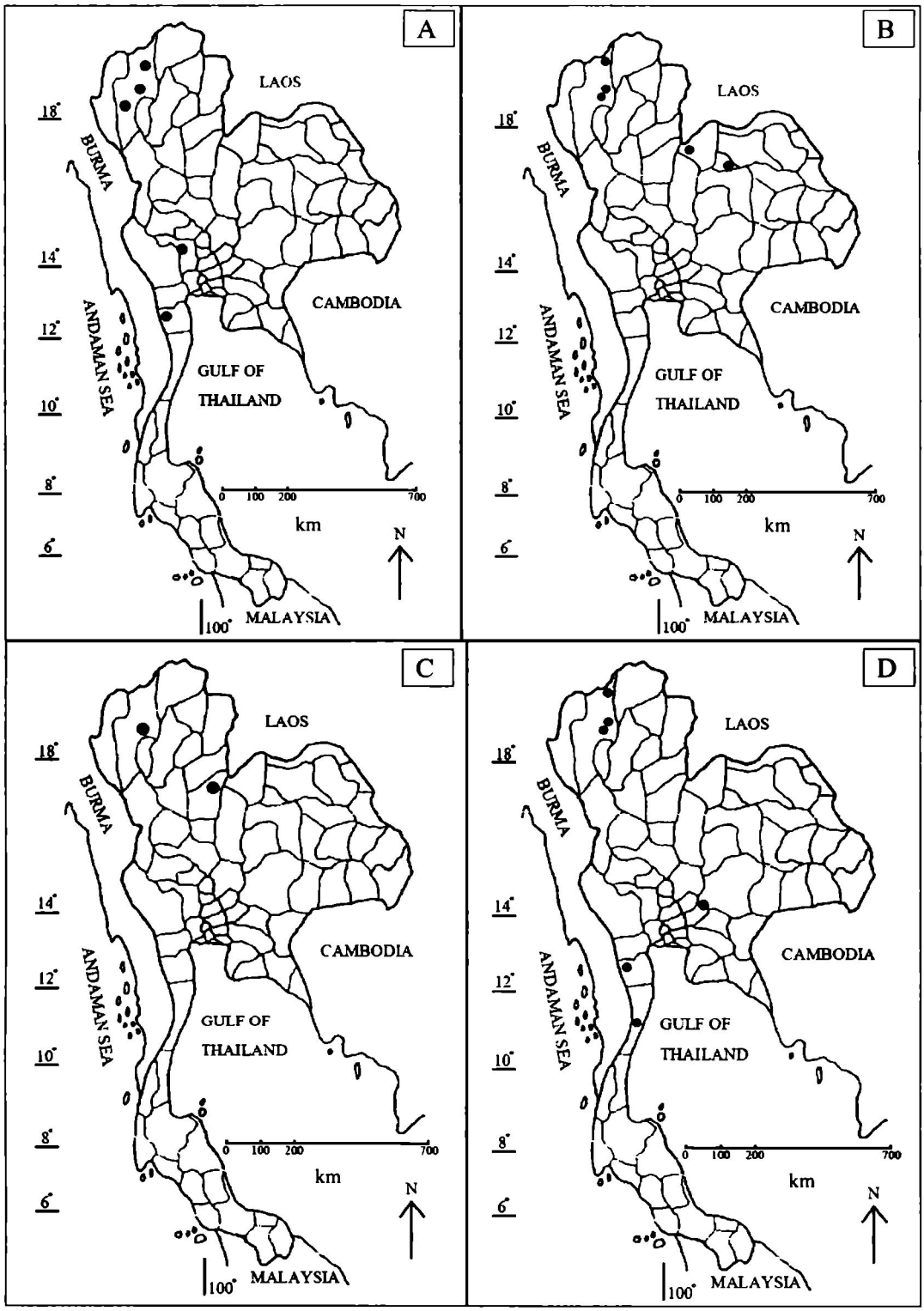

Figure 70. Distribution in Thailand A: *Fissidens angustifolius* Sull., B: *Fissidens anomalus* Mont., C: *Fissidens beckettii* Mitt., and D: *Fissidens biformis* Mitt.

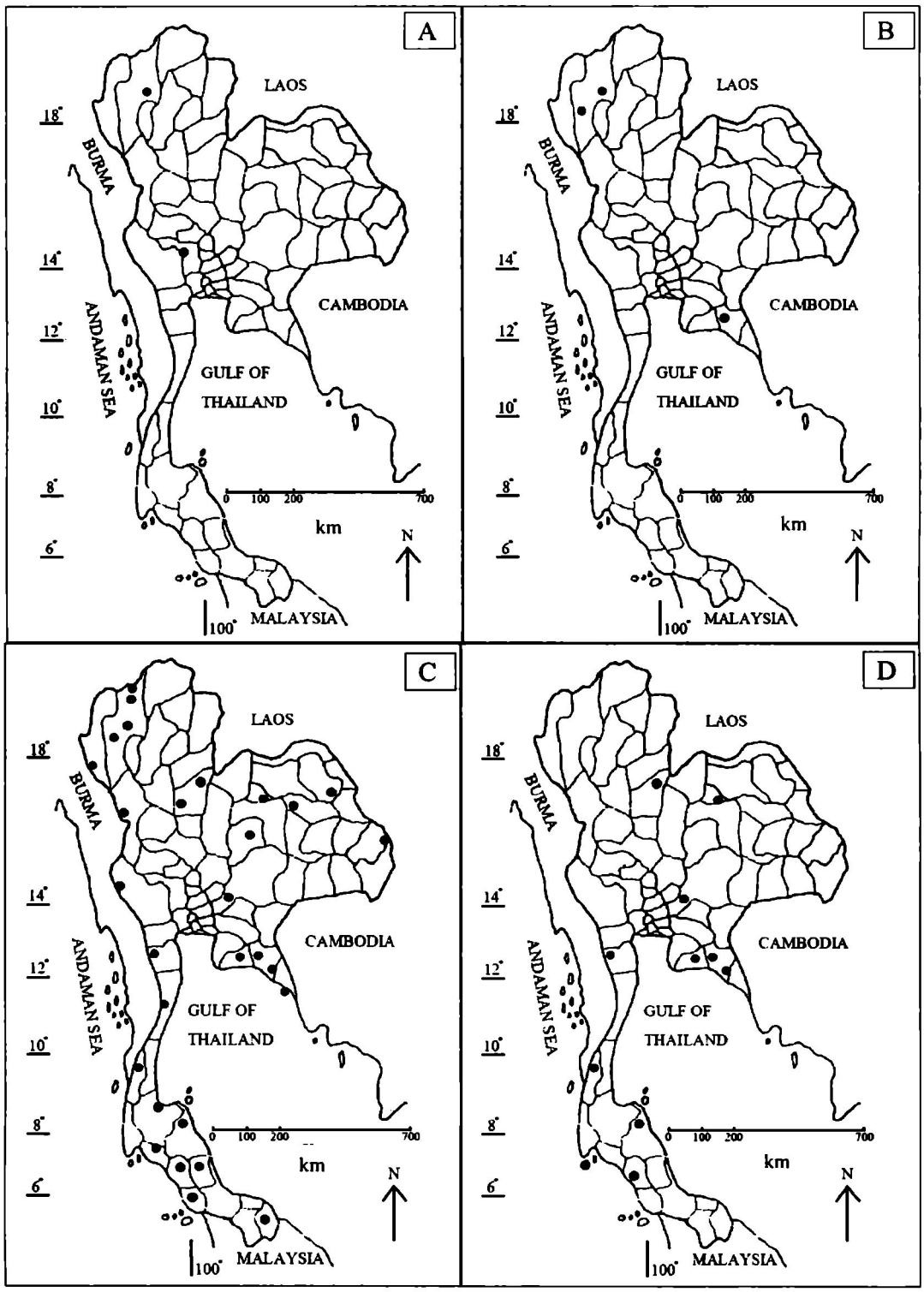

Figure 71. Distribution in Thailand A: *Fissidens bryoides* Hedw. var. *esquirolii* (Thér.) Z. Iwats. & T. Suzuki, B: *Fissidens bryoides* var. *schmidii* (C. Muell.) Chopra & Kumar, C: *Fissidens ceylonensis* Dozy & Molk., and D: *Fissidens crassinervis* Sande Lac.

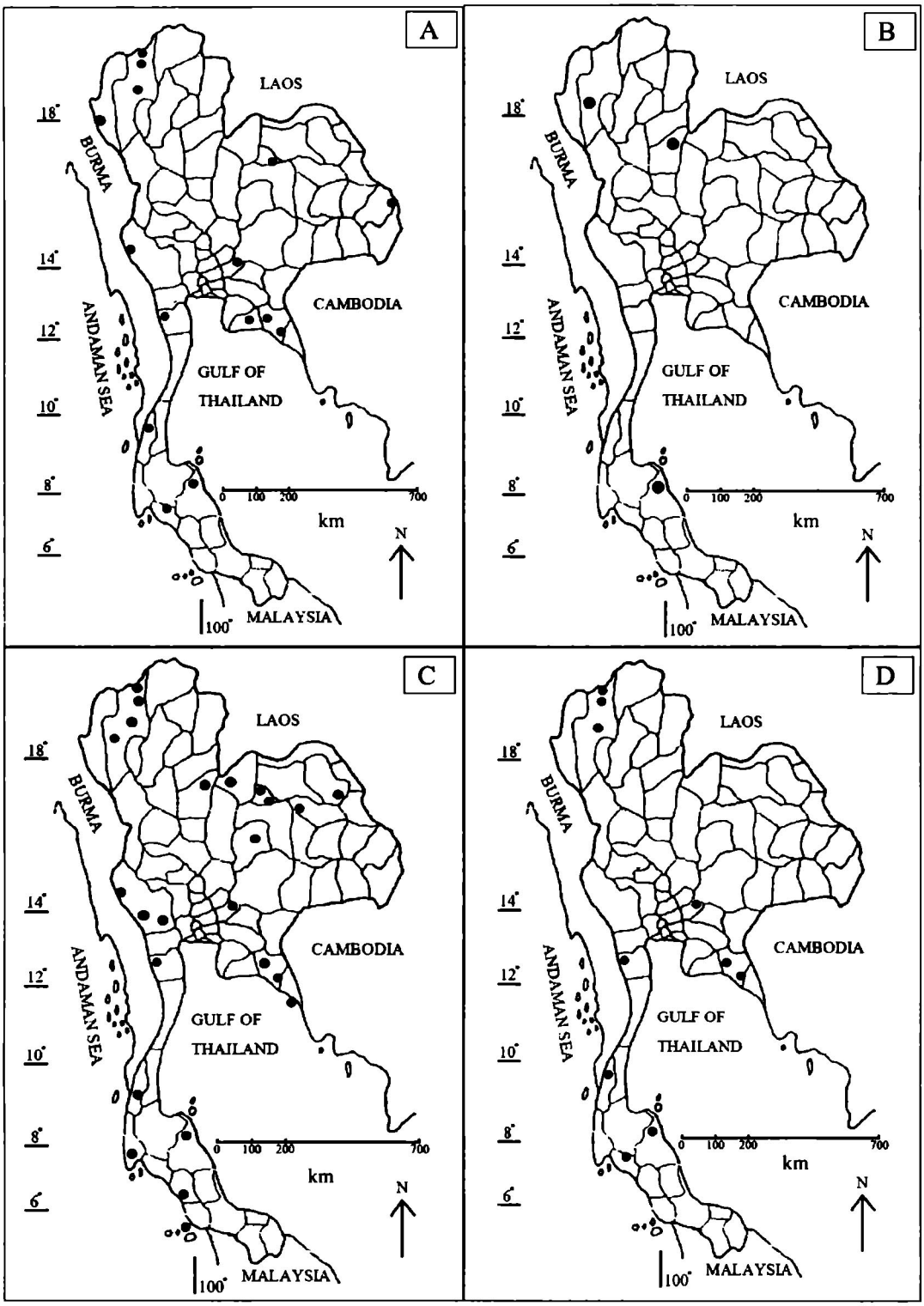

Figure 72. Distribution in Thailand A: *Fissidens crenulatus* Mitt. var. *crenulatus*, B: *Fissidens crenulatus* Mitt. var. *elmeri* (Broth.) Z. Iwats. & T. Suzuki, C: *Fissidens crispulus* Brid. var. *crispulus*, and D: *Fissidens crispulus* Brid. var. *robinsonii* (Broth.) Z. Iwats. & Z. H. Li

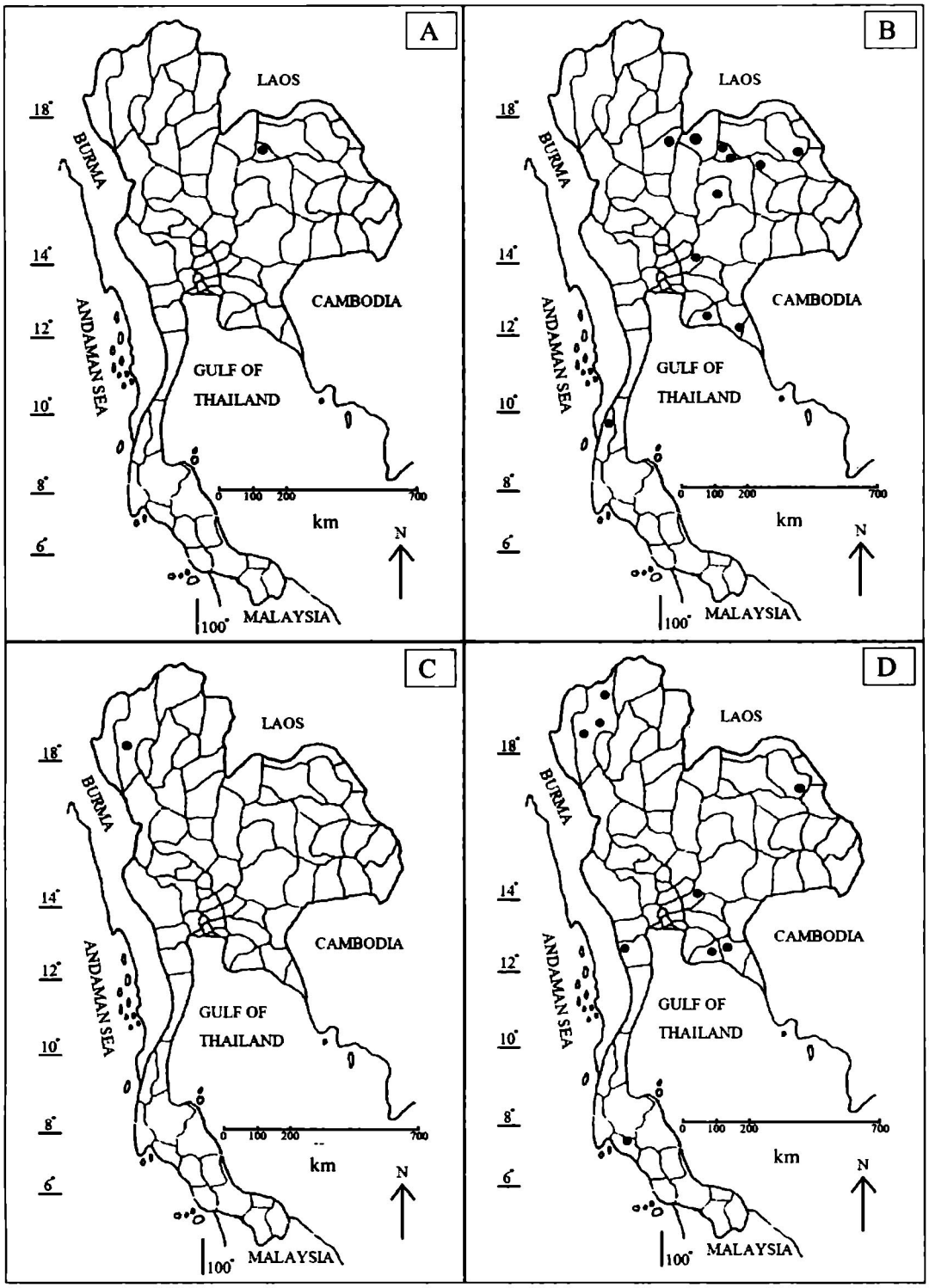

Figure 73. Distribution in Thailand A: *Fissidens filiformis* Z. Iwats., B: *Fissidens firmus* Mitt., C: *Fissidens flabellulus* Thwait. & Mitt., and D: *Fissidens flaccidus* Mitt. var. *flaccidus*

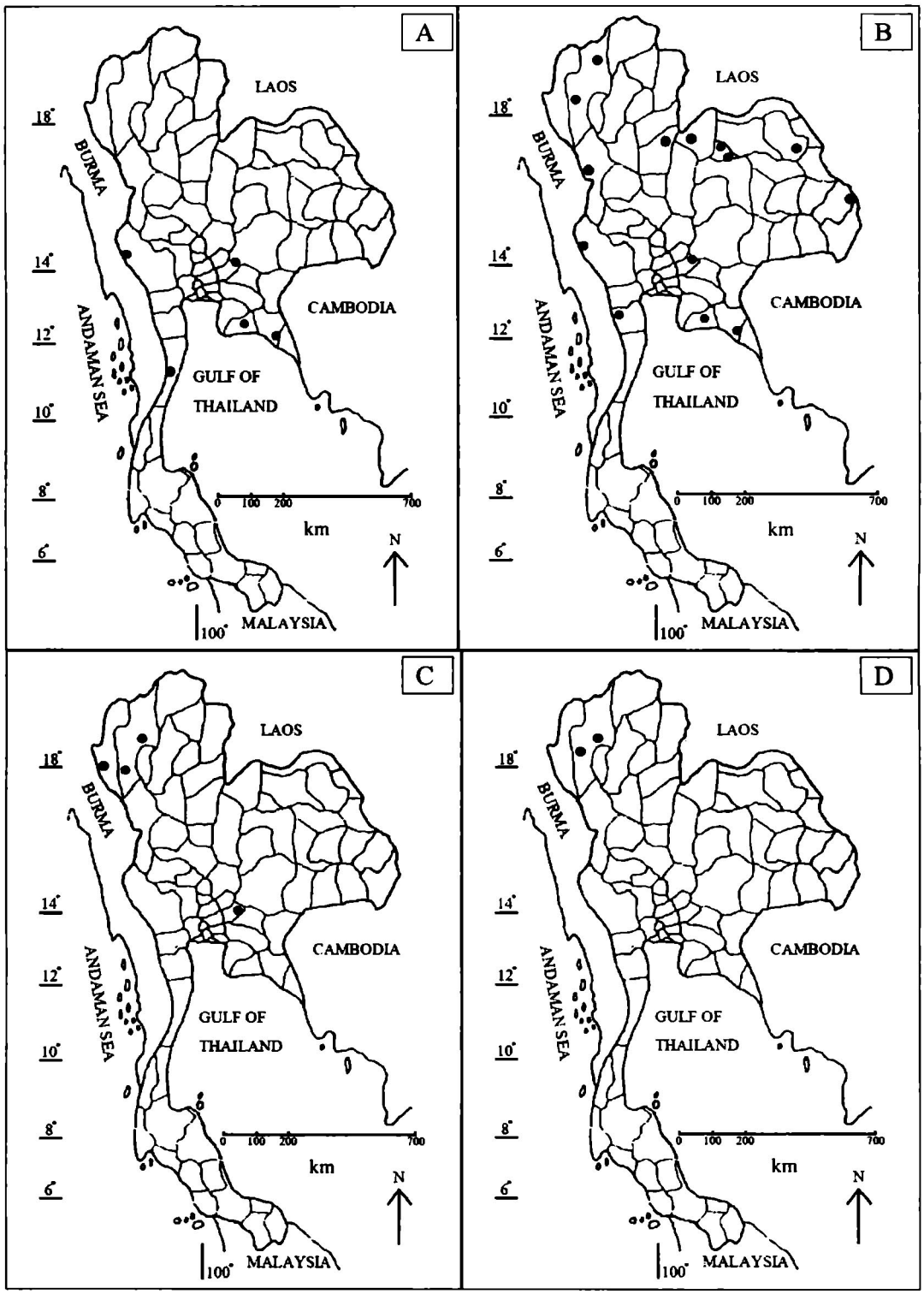

Figure 74. Distribution n Thailand A: *Fissidens flaccidus* Mitt. var. *percurrens* K. Wongkuna, B: *Fissidens gardneri* Mitt., C: *Fissidens geminiflorus* Dozy & Molk., and D: *Fissidens geppii* Fleisch.

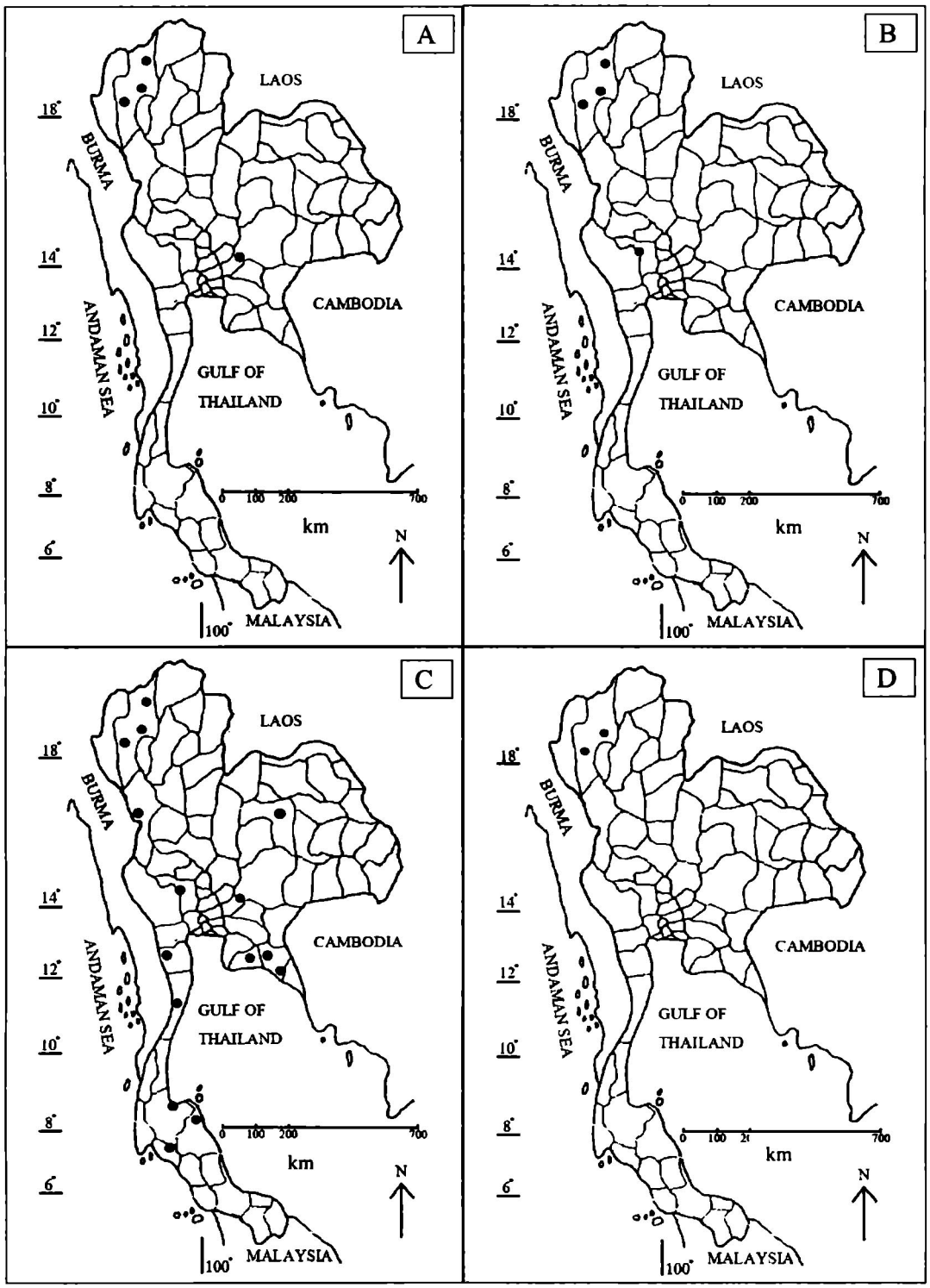

Figure 75. Distribution in Thailand A: *Fissidens guangdongensis* Z. Iwats. & Z. H. Li, B: *Fissidens gymnogynus* Besch., C: *Fissidens hollianus* Dozy & Molk., and D: *Fissidens hyalinus* Hook. & Wils.

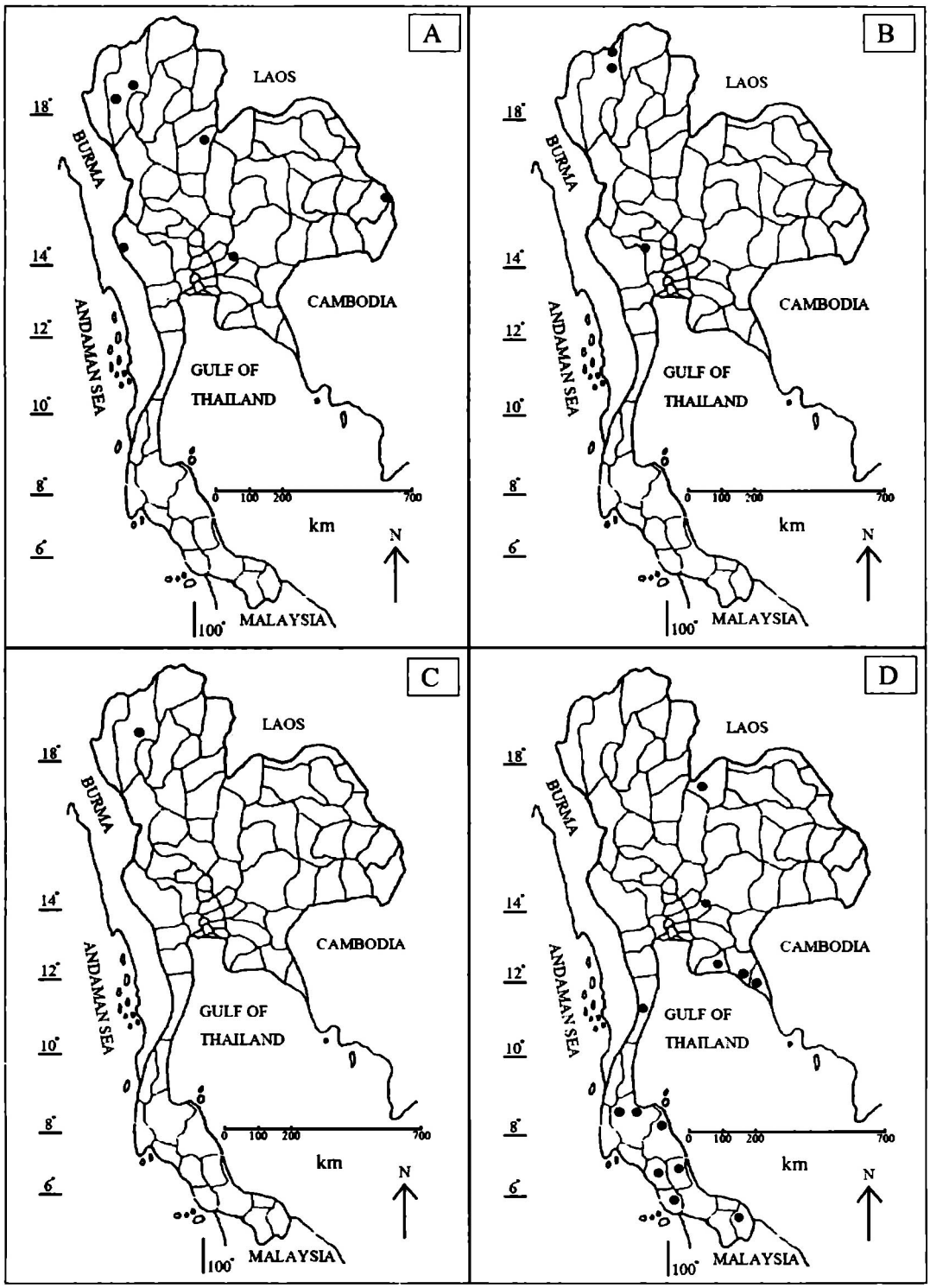

Figure 76. Distribution in Thailand A: *Fissidens incognitus* Gangulee, B: *Fissidens involutus* Wils. *ex* Mitt., C: *Fissidens irregulomarginatulus* K. Wongkuna & B. C. Tan, and D: *Fissidens javanicus* Dozy & Molk.

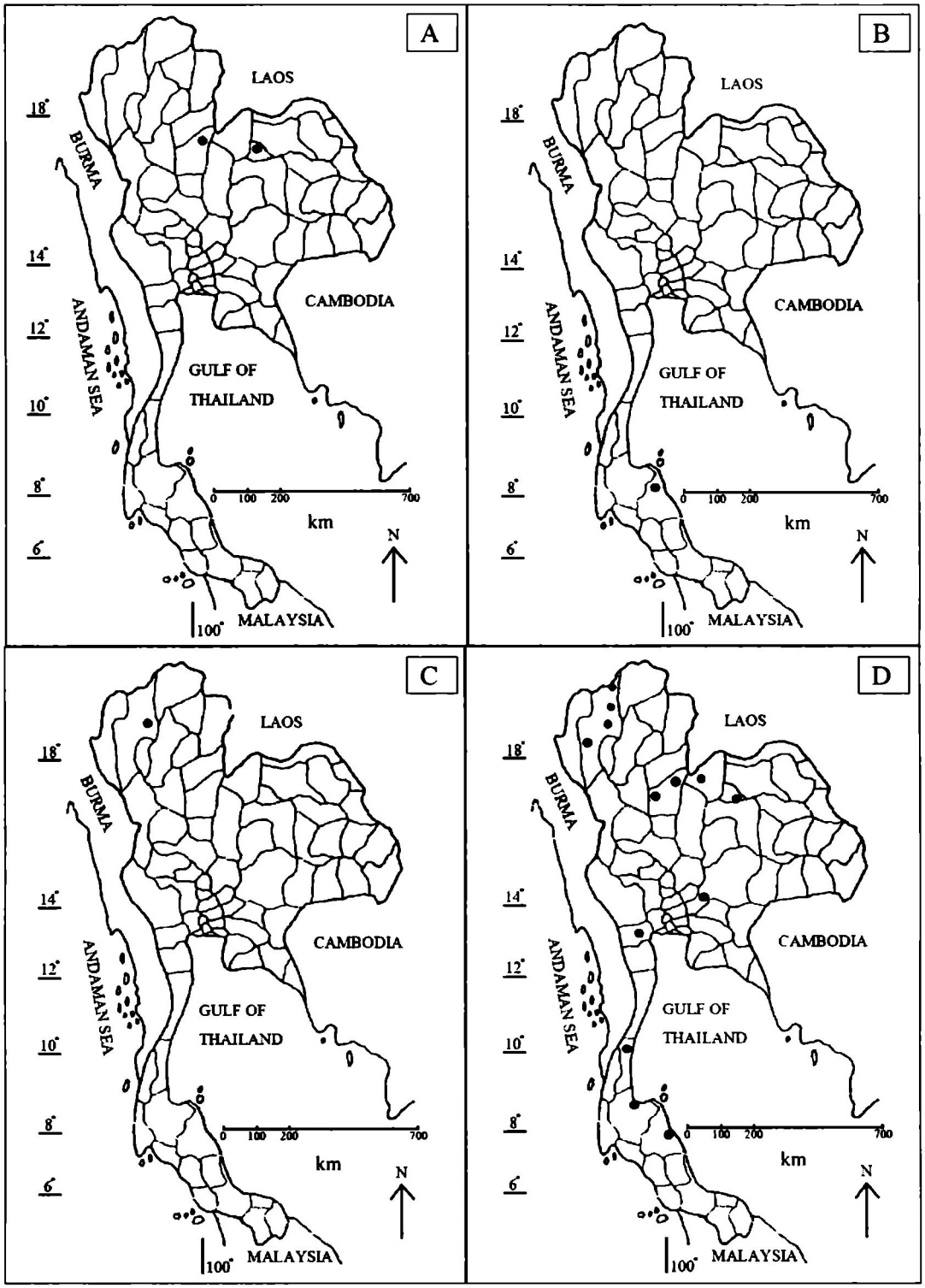

Figure 77. Distribution in Thailand A: *Fissidens jungermannioides* Griff., B: *Fissidens kinabaluense* Z. Iwats., C: *Fissidens laxitextus* Broth. *ex* Gangulee, and D: *Fissidens nobilis* Griff.

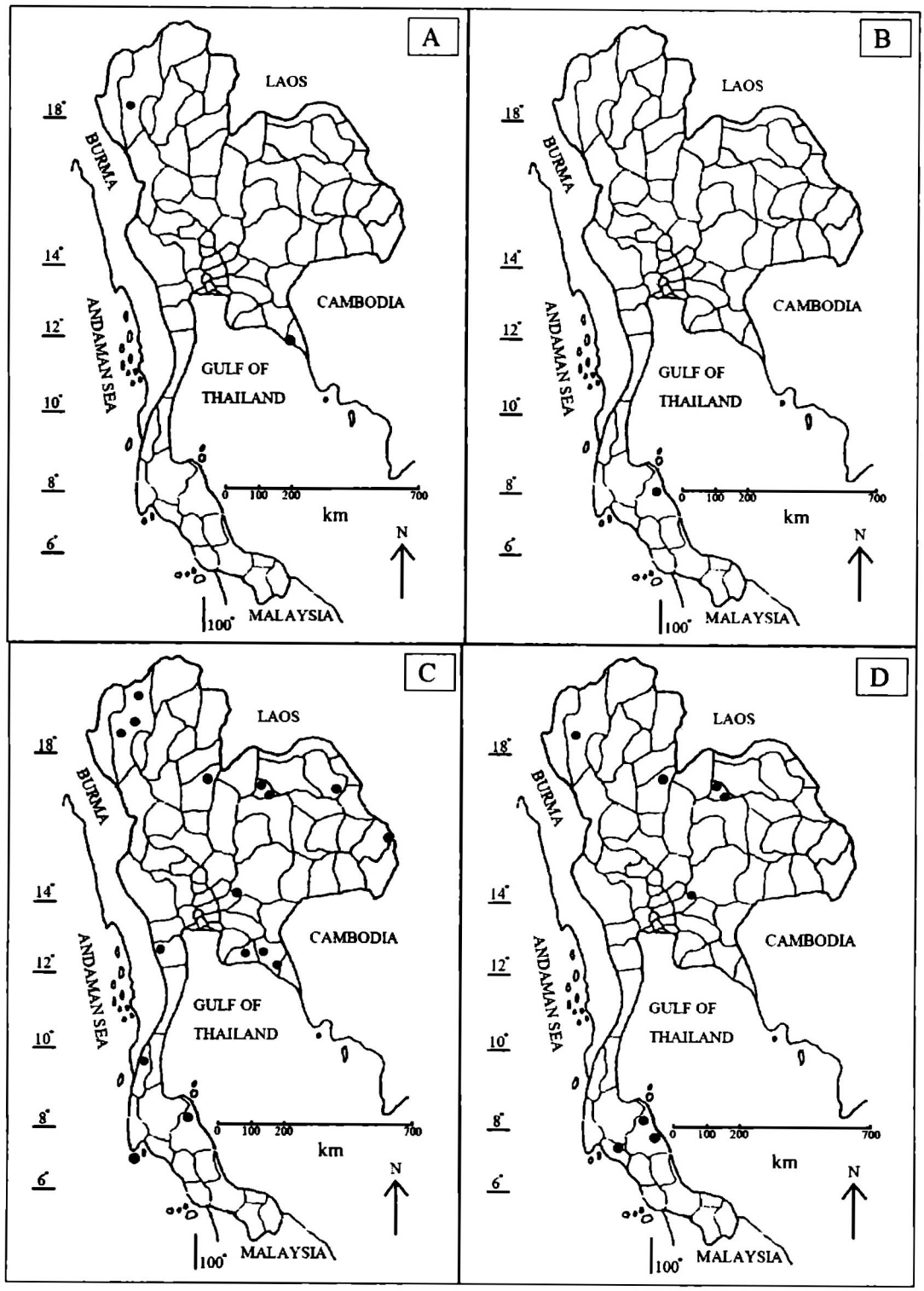

Figure 78. Distribution in Thailand A: *Fissidens oblongifolius* Hook. f. & Wils., B: *Fissidens obscurus* Mitt., C: *Fissidens pellucidus* Hornsch., and D: *Fissidens polypodioides* Hedw.

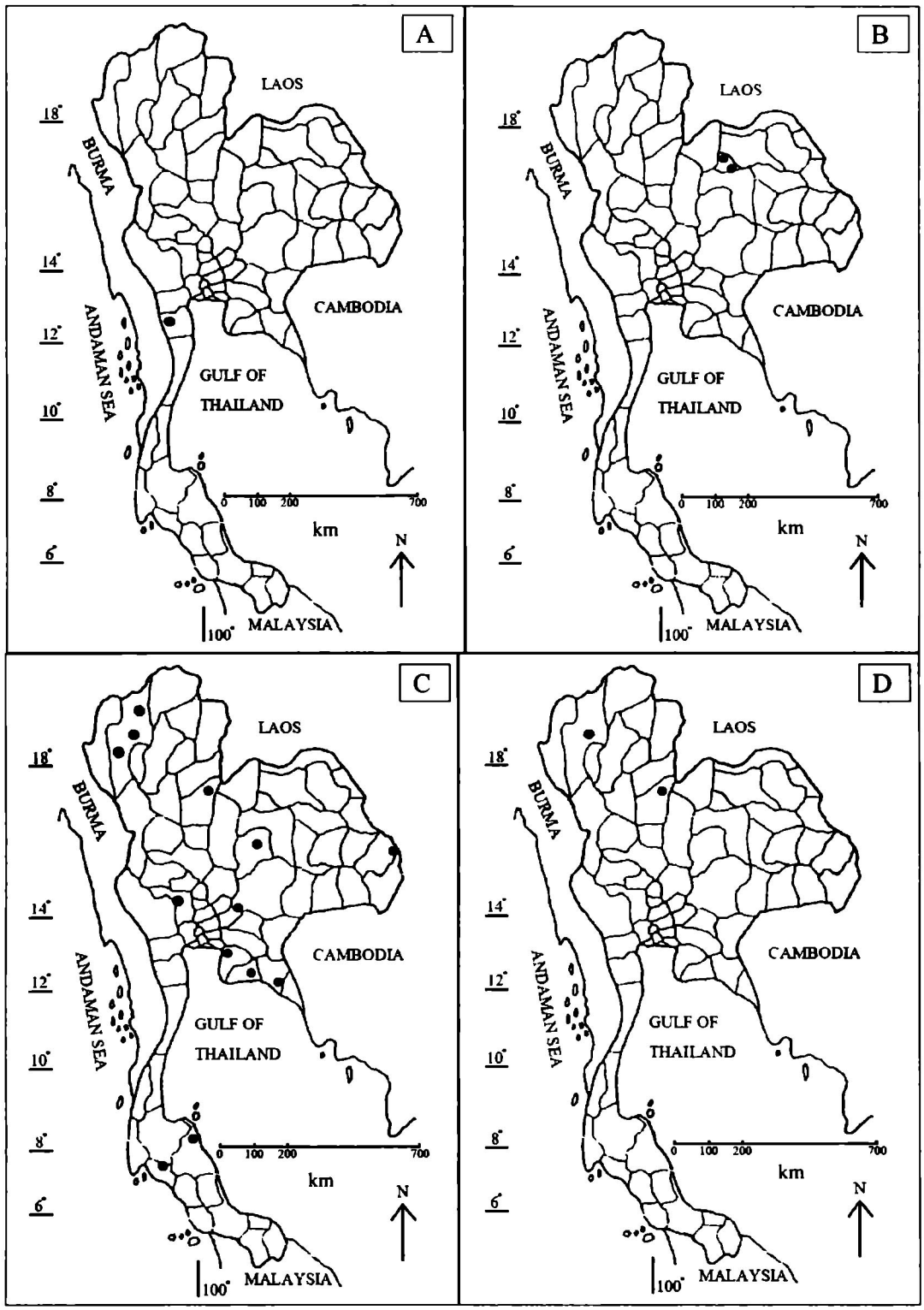

Figure 79. Distribution in Thailand A: *Fissidens pseudokinabaluensis* K. Wongkuna & B. C. Tan, B: *Fissidens sedgwickii* Broth. & Dix., C: *Fissidens semperfalcatus* Dix., and D: *Fissidens serratus* Muell. Hal.

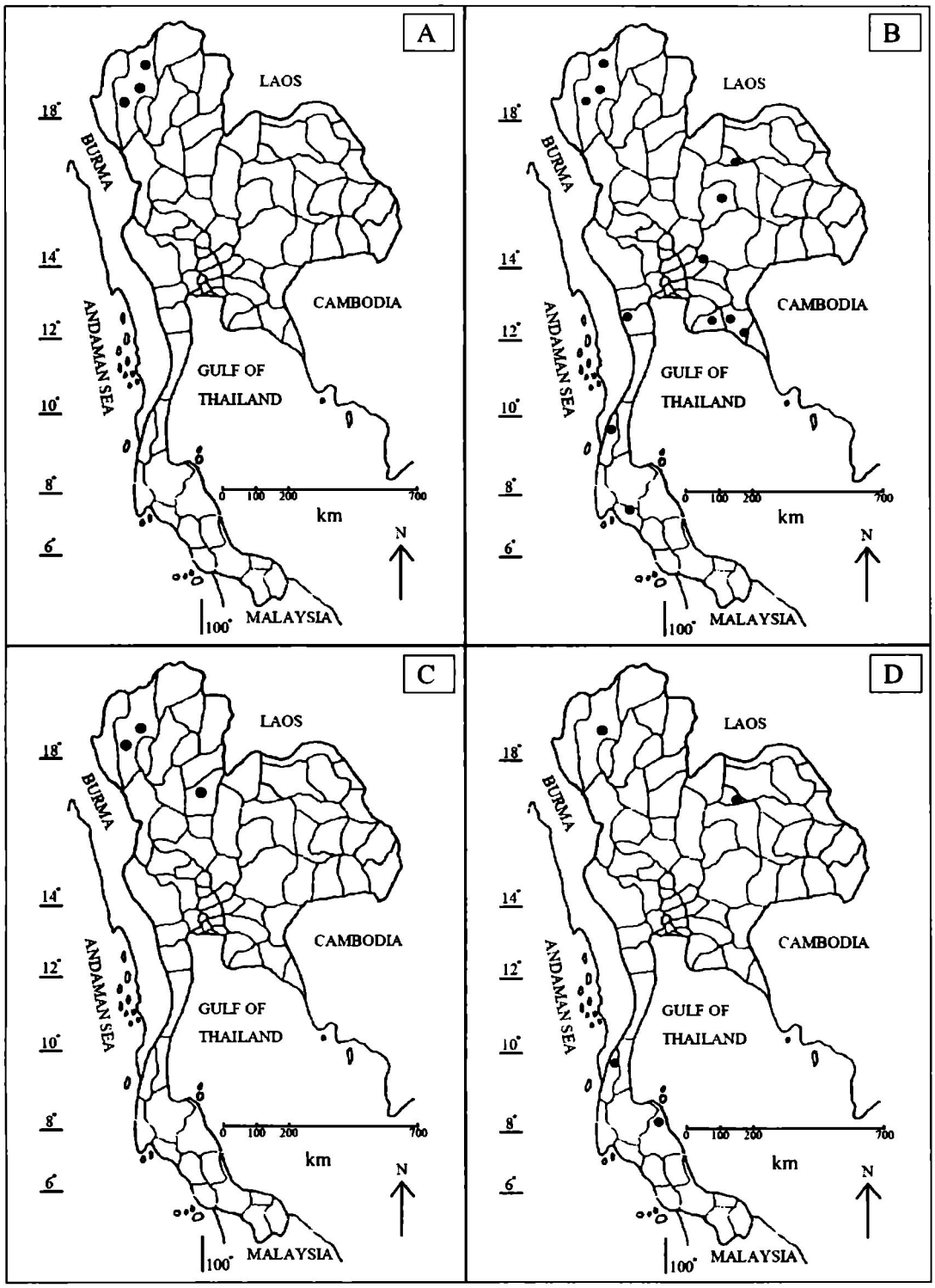

Figure 80. Distribution in Thailand A: *Fissidens subangustus* Fleisch., B: *Fissidens subbryoides* Gangulee, C: *Fissidens taxifolius* Hedw., and D: *Fissidens tenellus* Hook. f. & Wils. var. *australiensis* (A. Jaeger) Beever & Stone

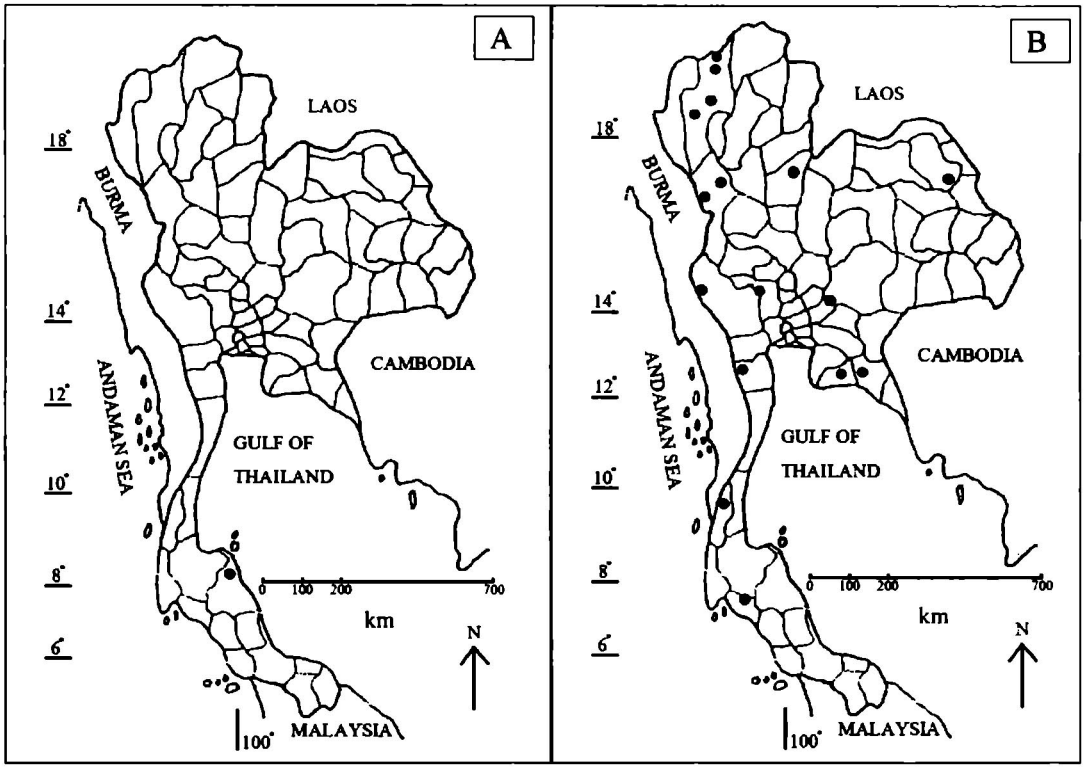

Figure 81. Distribution in Thailand A: *Fissidens wichurae* Broth. & Fleisch., and B: *Fissidens zollingeri* Mont.

Tropical and Temperate Asia distribution

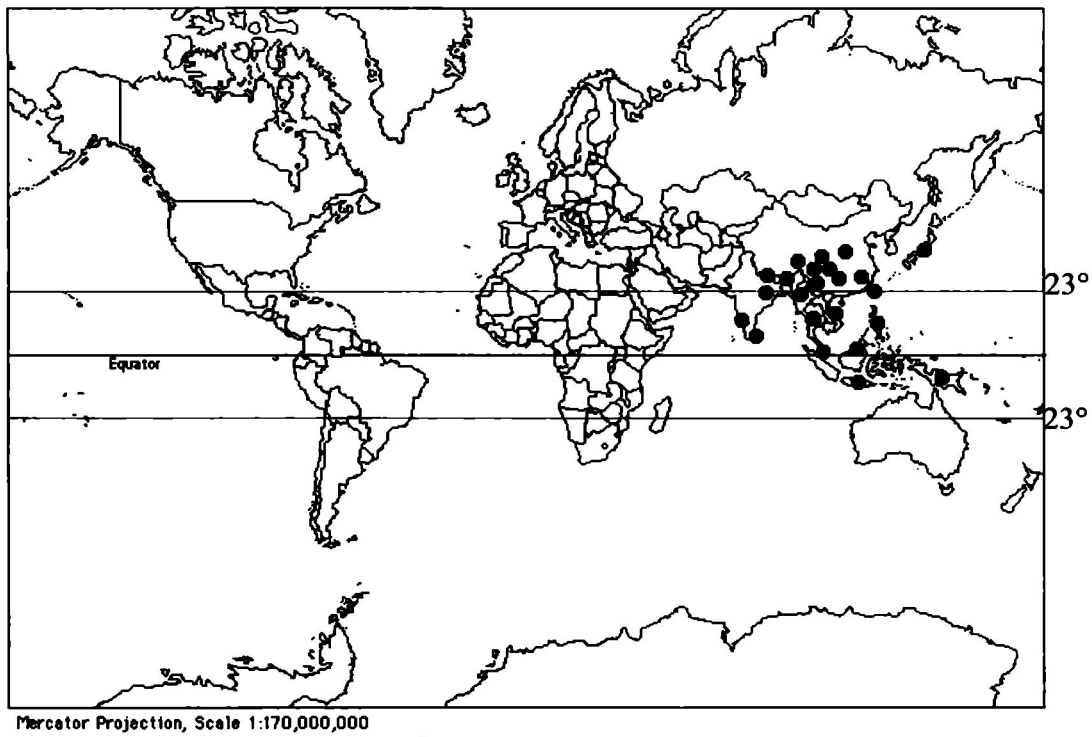

Figure 82. World distribution of *Fissidens anomalus* Mont.

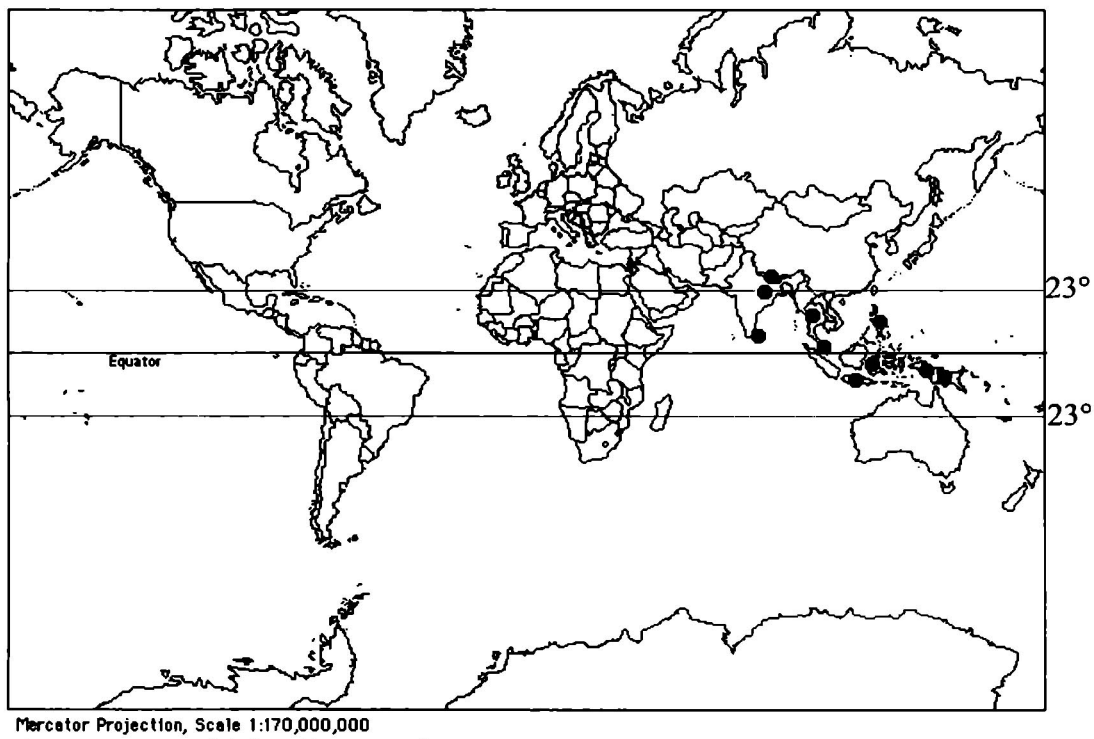

Figure 83. World distribution of *Fissidens biformis* Mitt.

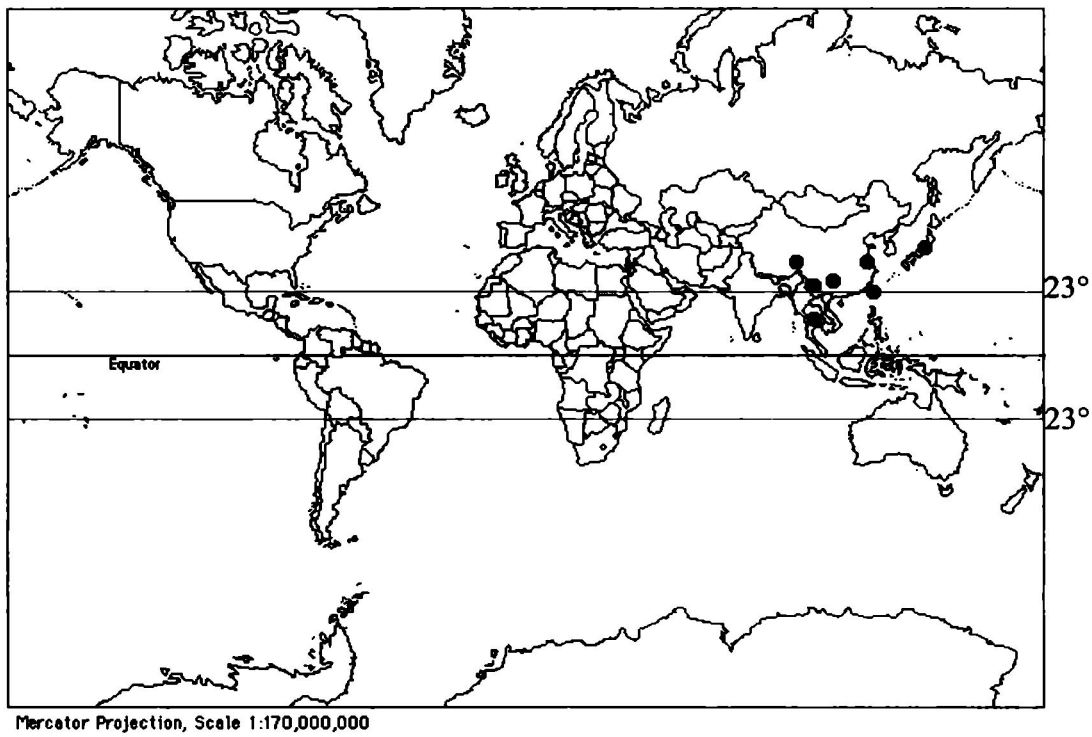

Figure 84. World distribution of *Fissidens bryoides* Hedw. var. *esquirolii* (Thér.) Z. Iwats. & T. Suzuki

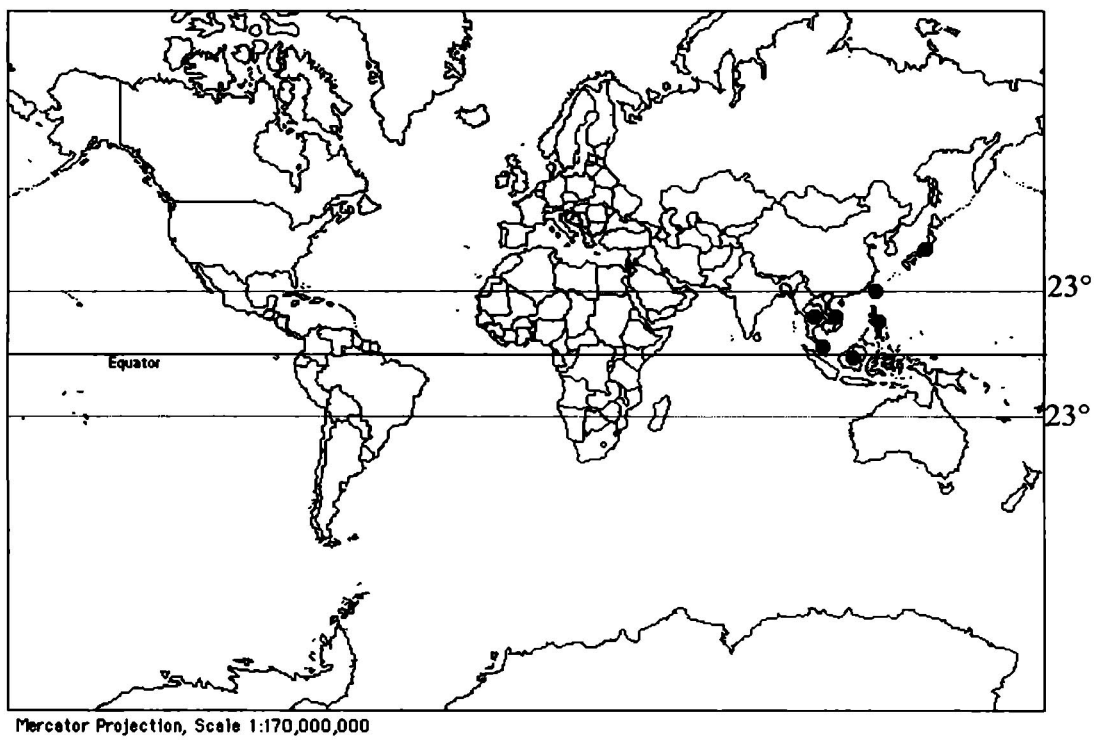

Figure 85. World distribution of *Fissidens crenulatus* Mitt. var. *elmeri* (Broth.) Z. Iwats. & T. Suzuki

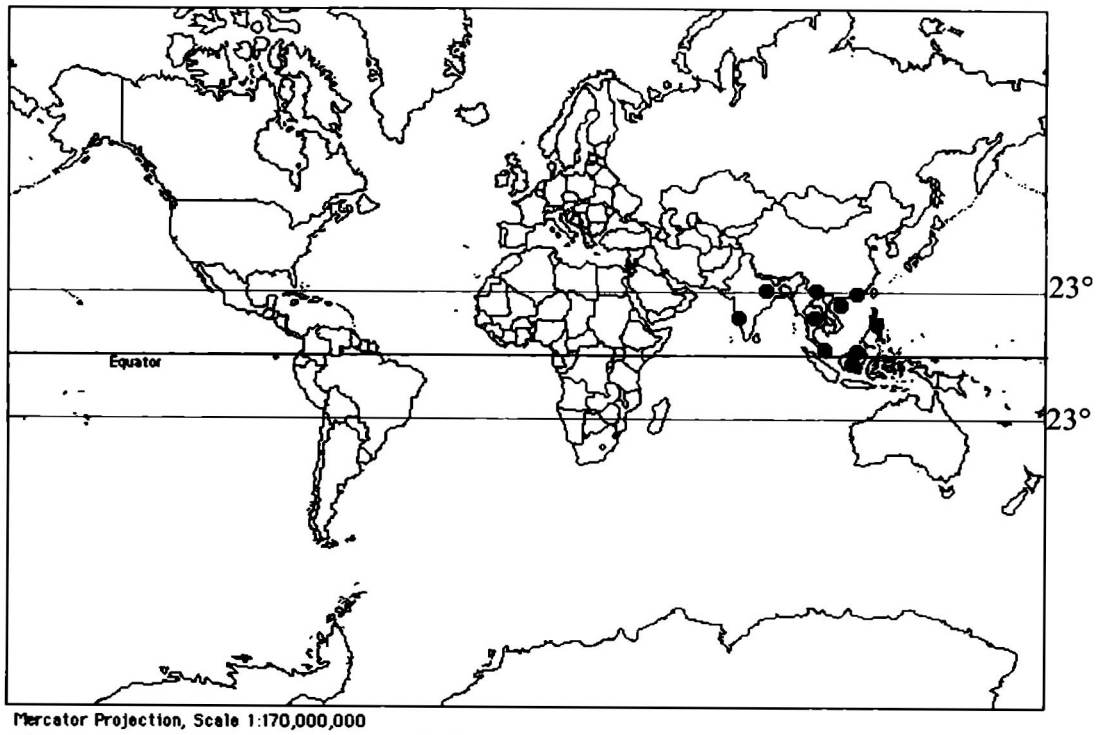

Figure 86. World distribution of *Fissidens crispulus* Brid. var. *robinsonii* (Broth.) Z. Iwats. & Z. H. Li

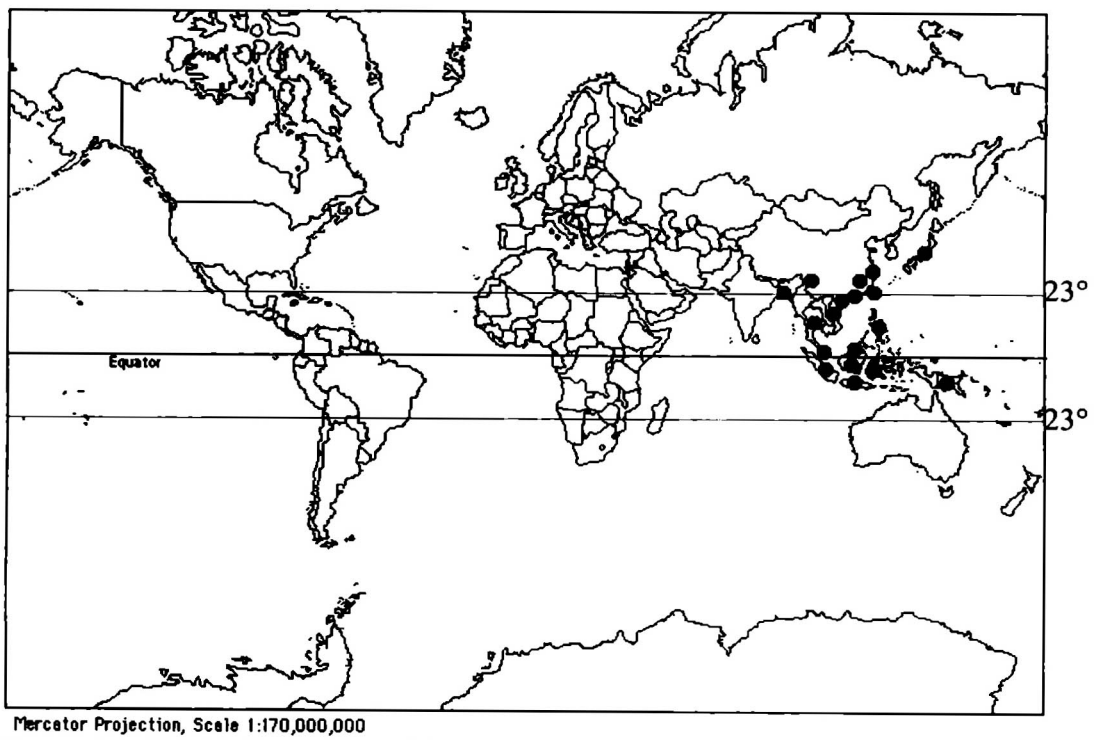

Figure 87. World distribution of *Fissidens geminiflorus* Dozy & Molk.

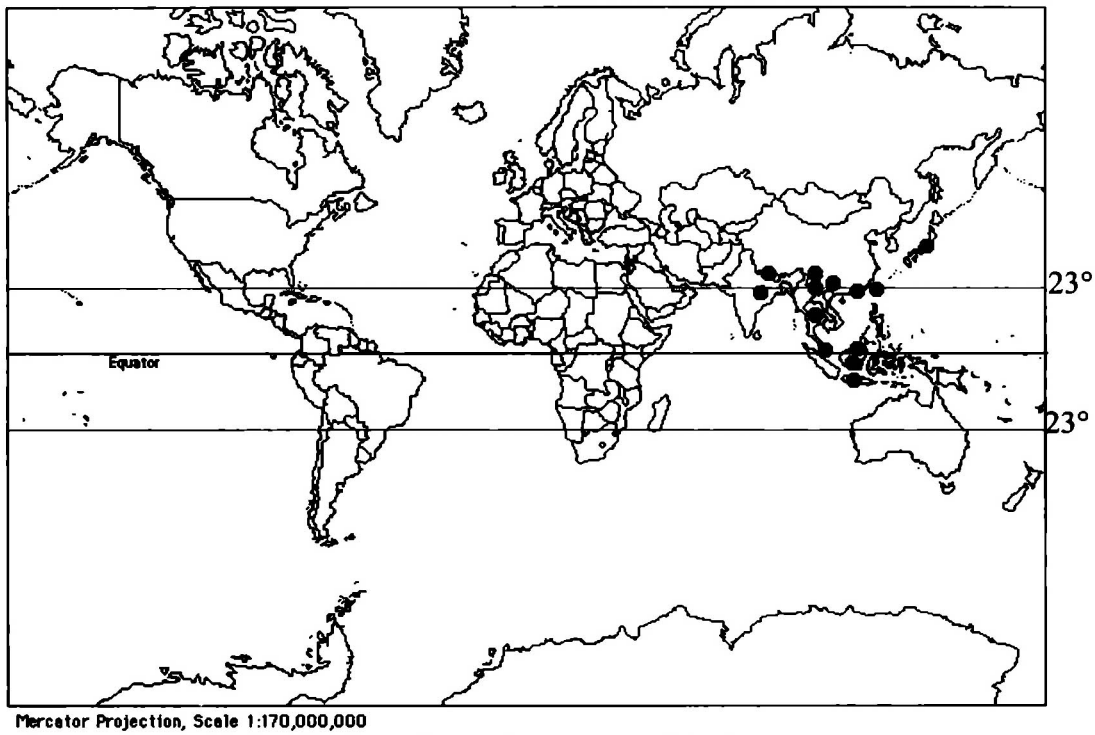

Figure 88. World distribution of *Fissidens geppii* Fleisch.

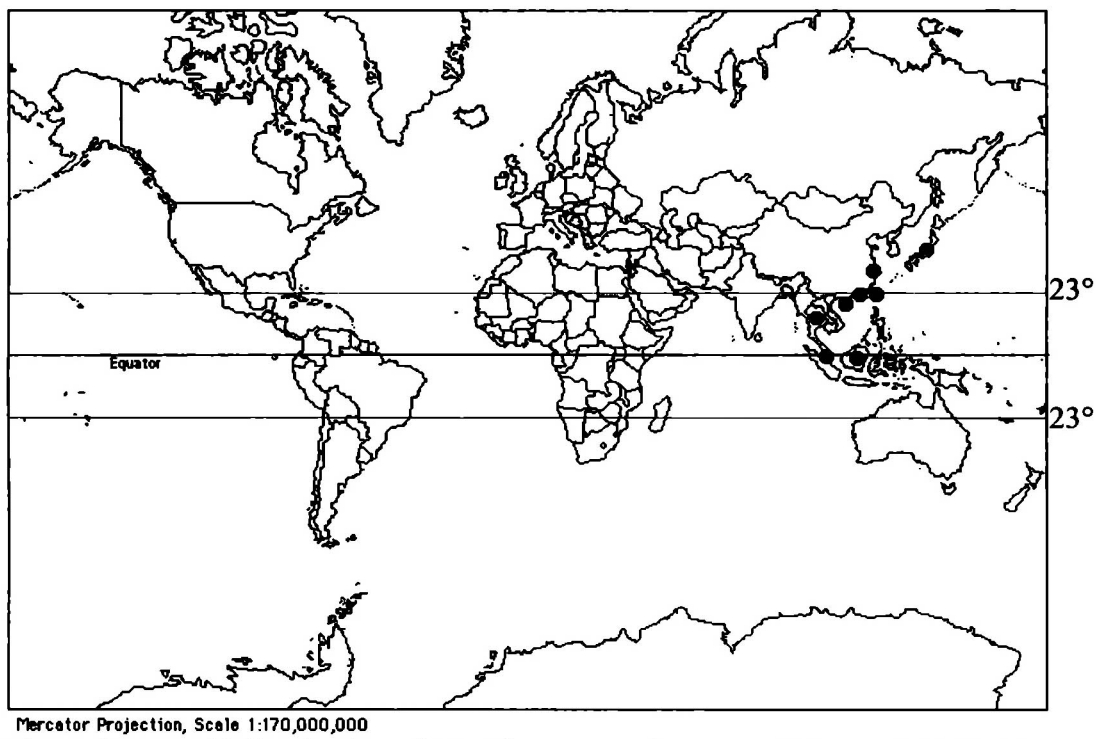

Figure 89. World distribution of *Fissidens guangdongensis* Z. Iwats & Z. H. Li

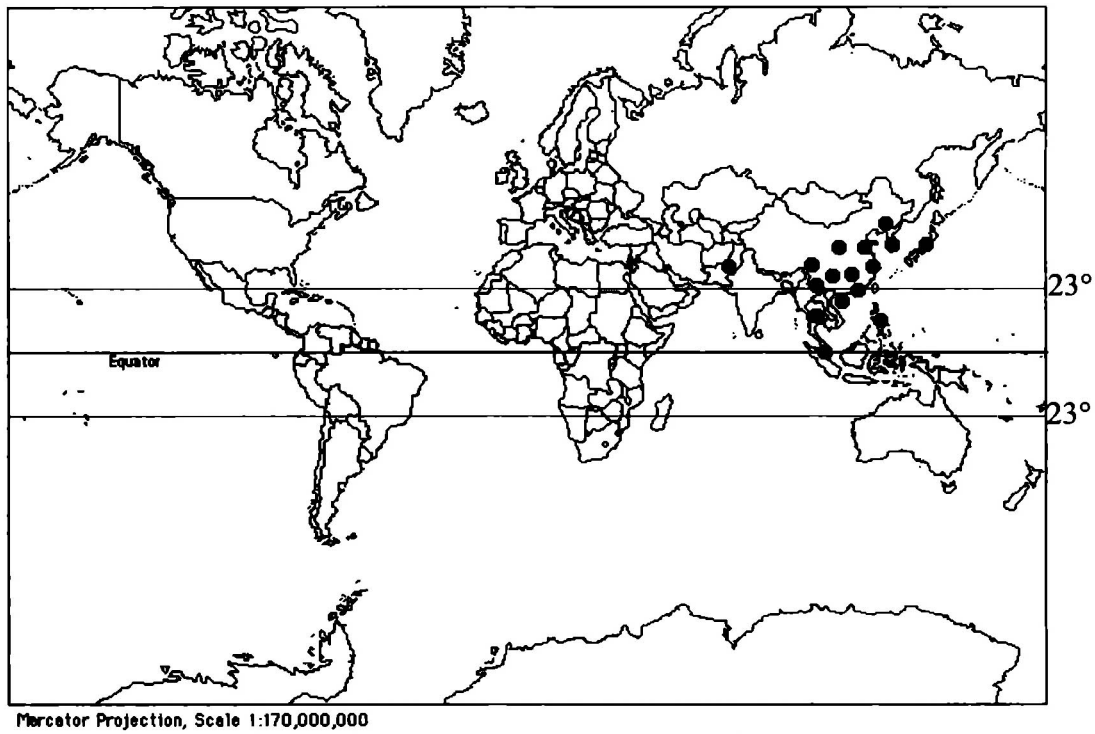

Figure 90. World distribution of *Fissidens gymnogynus* Besch.

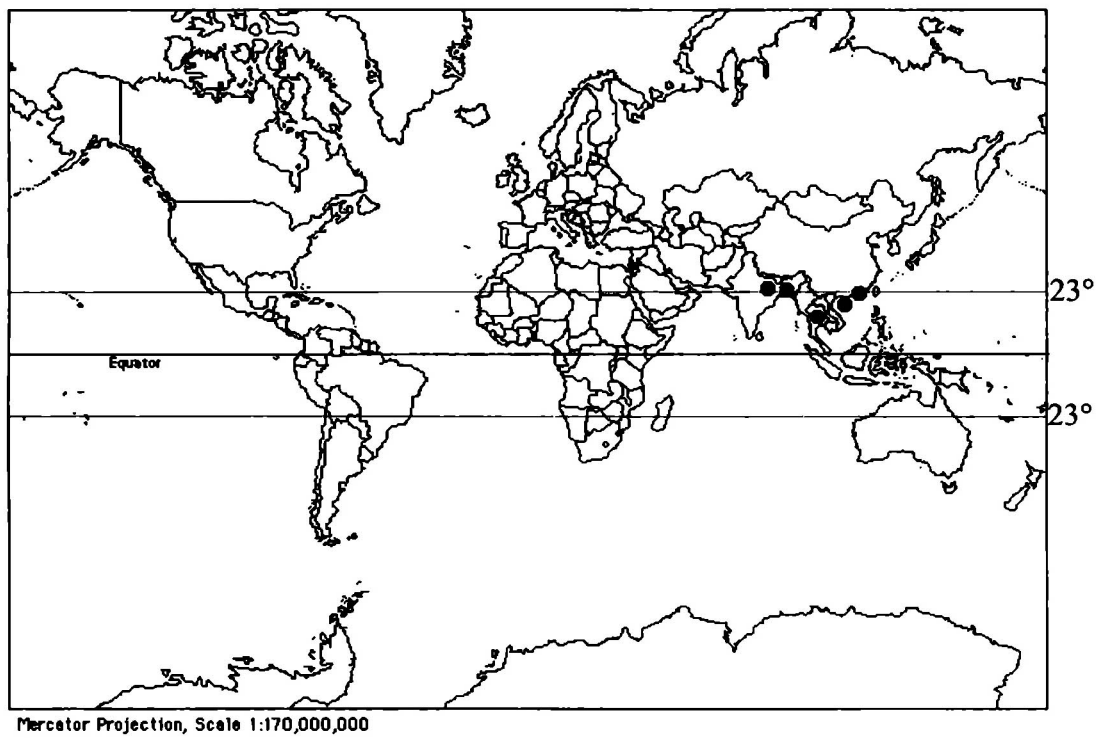

Figure 91. World distribution of *Fissidens incognitus* Gangulee

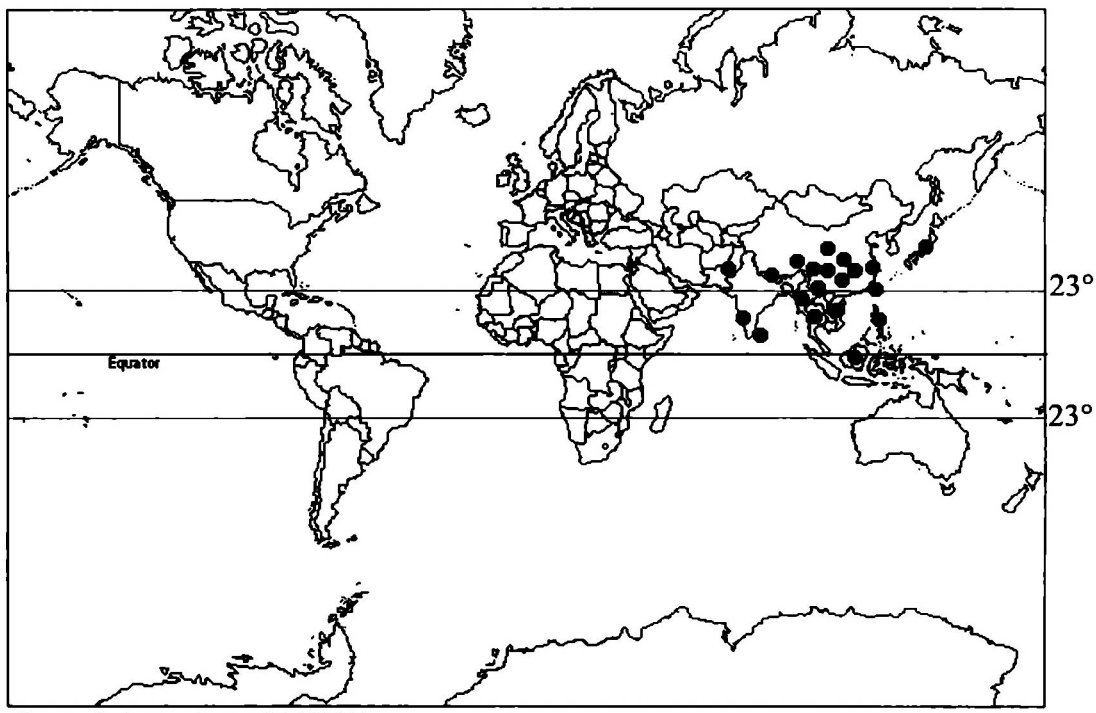

Figure 92. World distribution of *Fissidens involutus* Wils. *ex* Mitt.

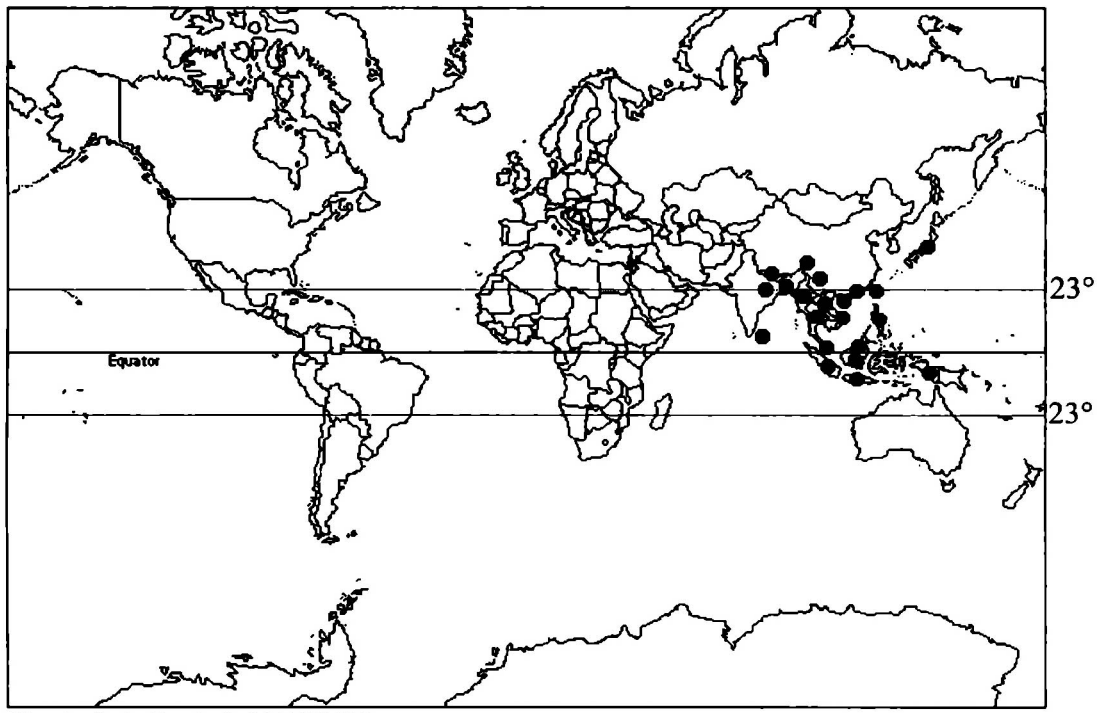

Figure 93. World distribution of *Fissidens javanicus* Dozy & Molk.

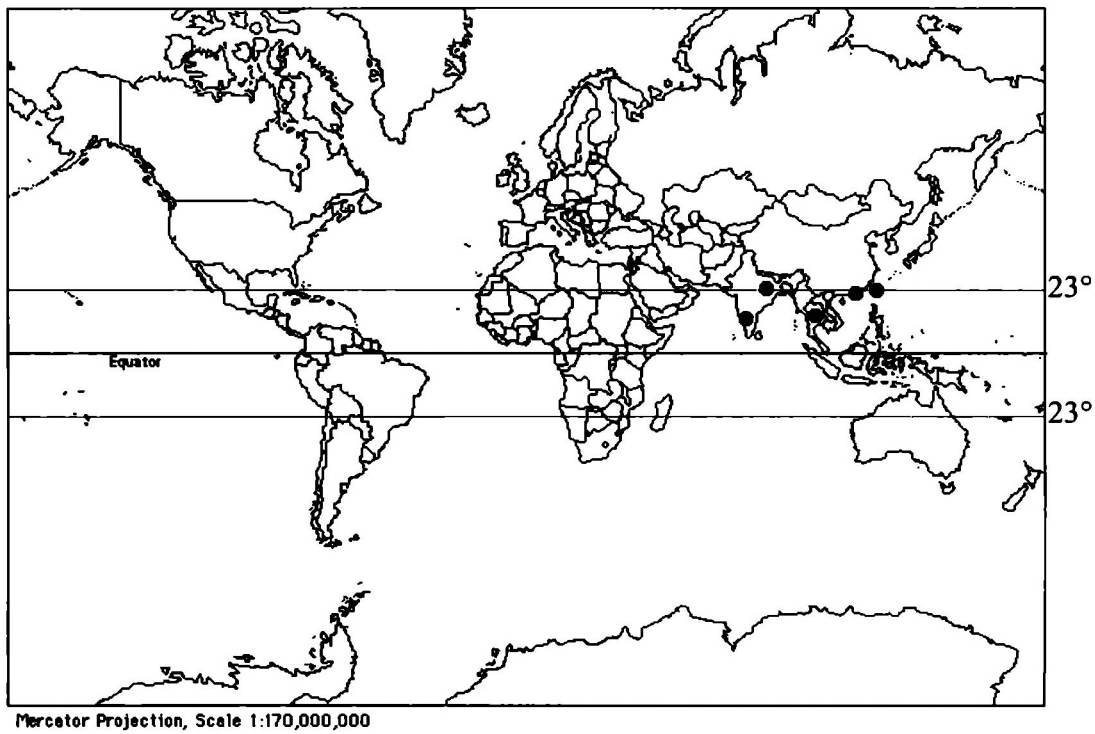

Figure 94. World distribution of *Fissidens jungermannioides* Griff.

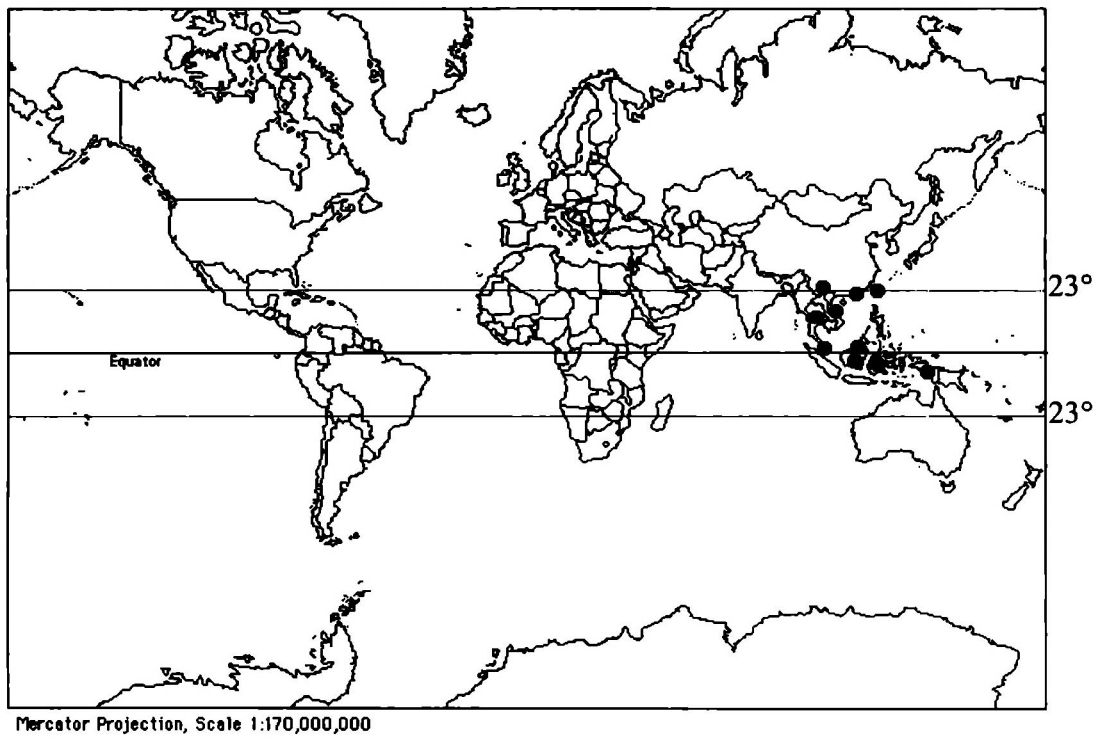

Figure 95. World distribution of *Fissidens kinabaluense* Z. Iwats.

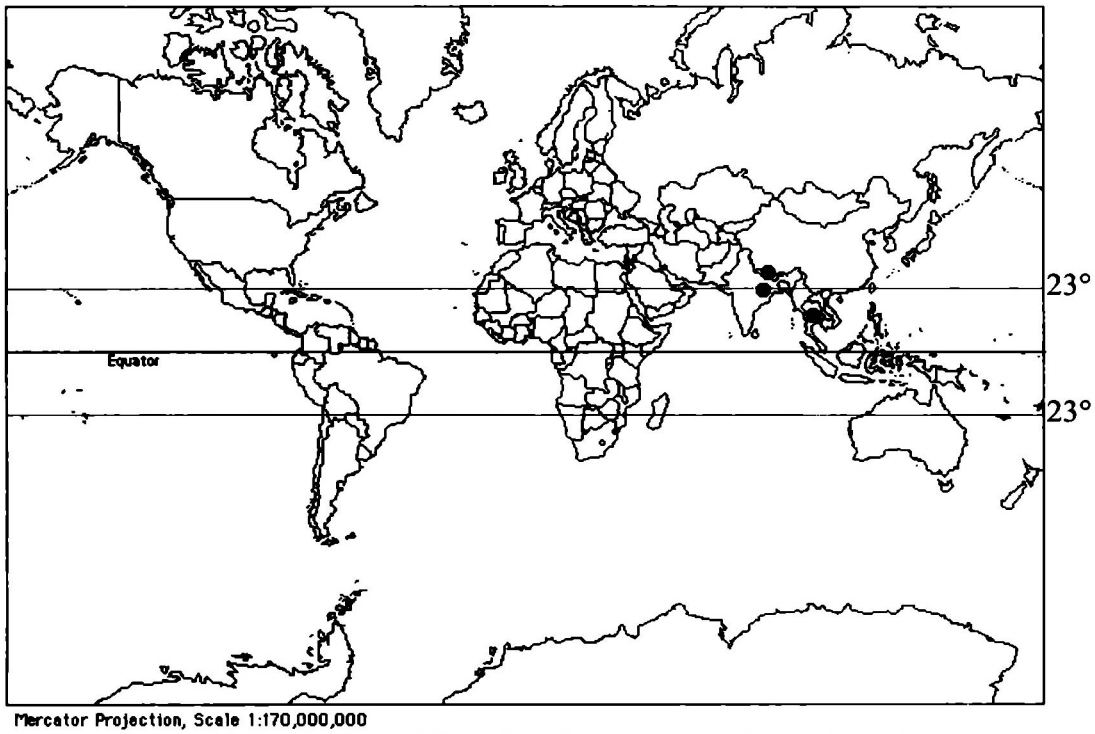

Figure 96. World distribution of *Fissidens laxitextus* Broth. *ex* Gangulee

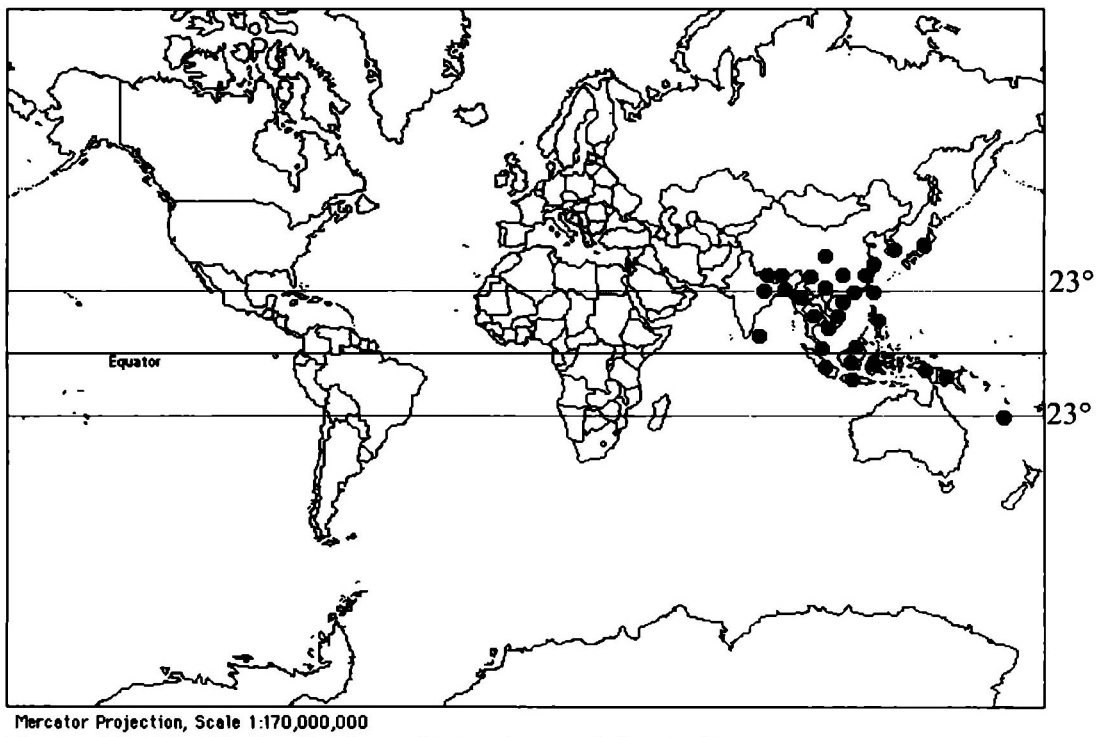

Figure 97. World distribution of *Fissidens nobilis* Griff.

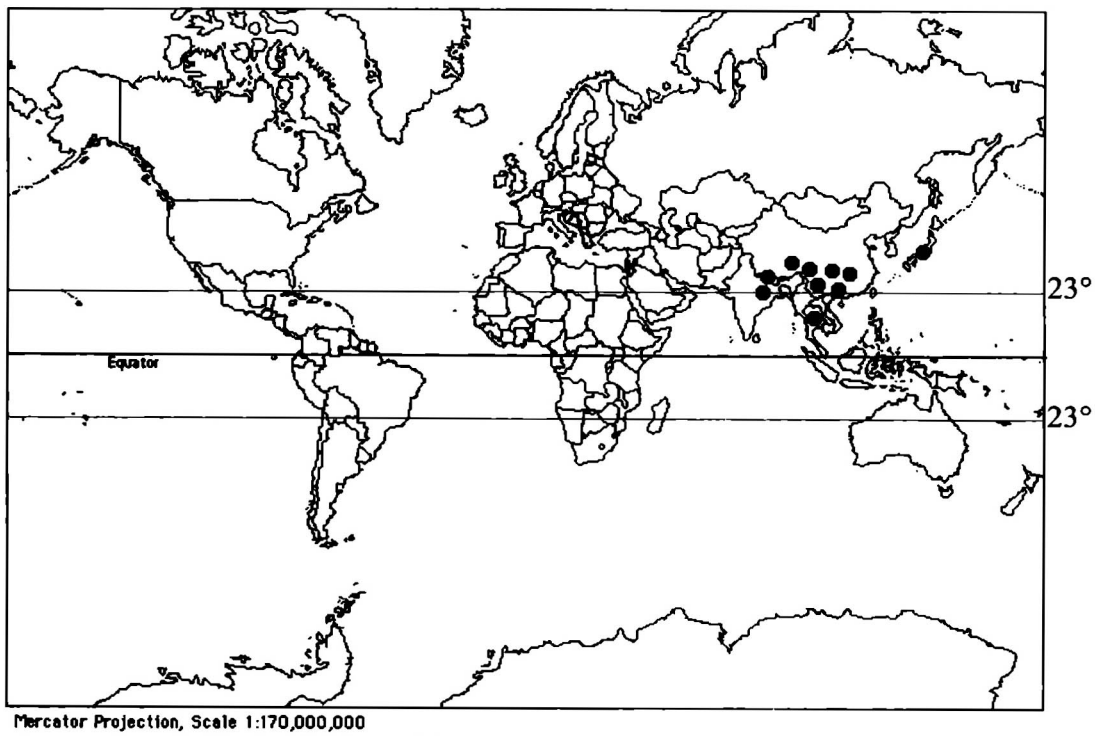

Figure 98. World distribution of *Fissidens obscurus* Mitt.

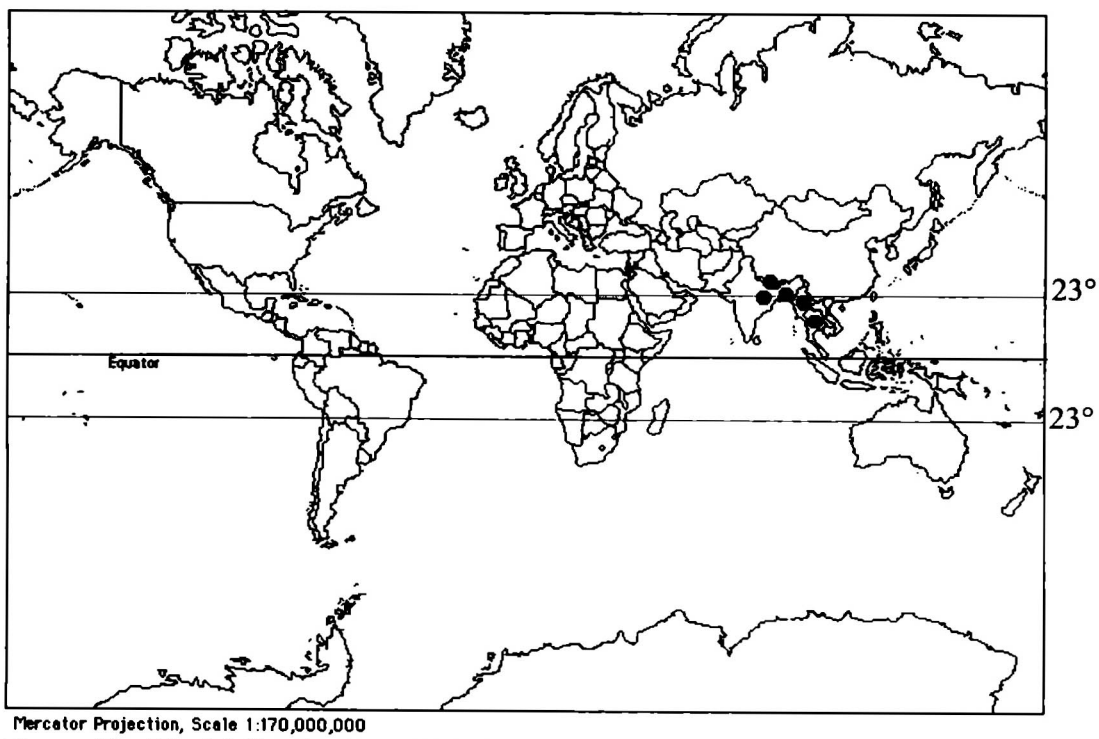

Figure 99. World distribution of *Fissidens semperfalcatus* Dix.

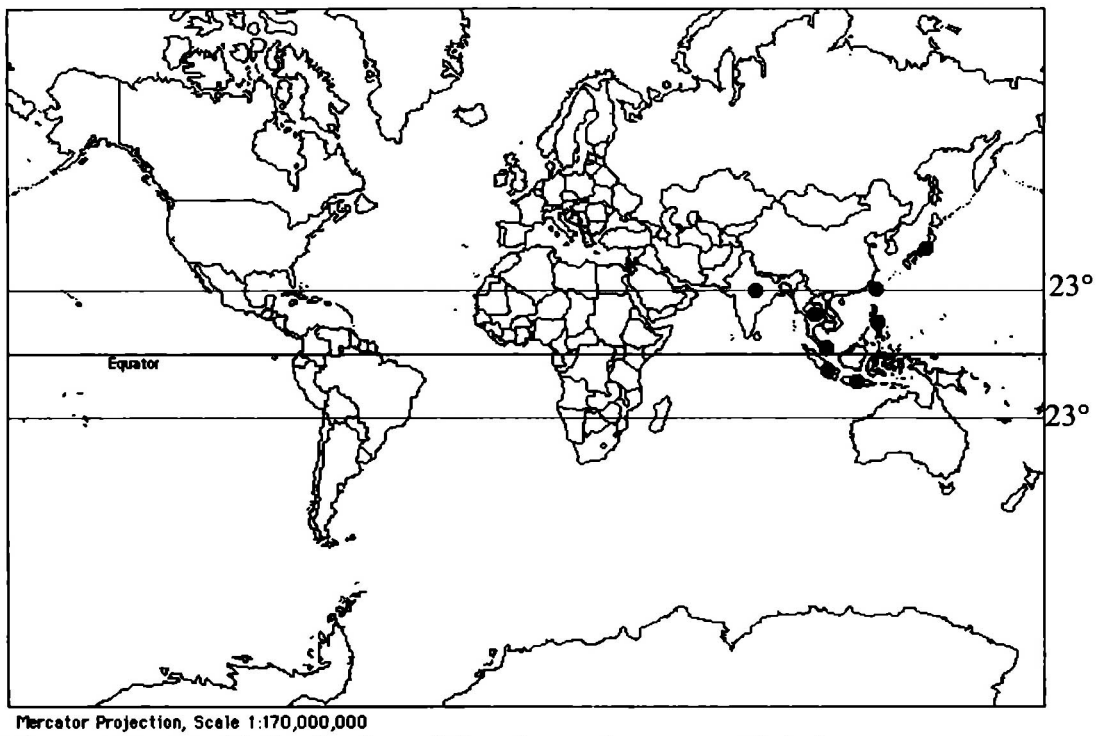

Figure 100. World distribution of *Fissidens subangustus* Fleisch.

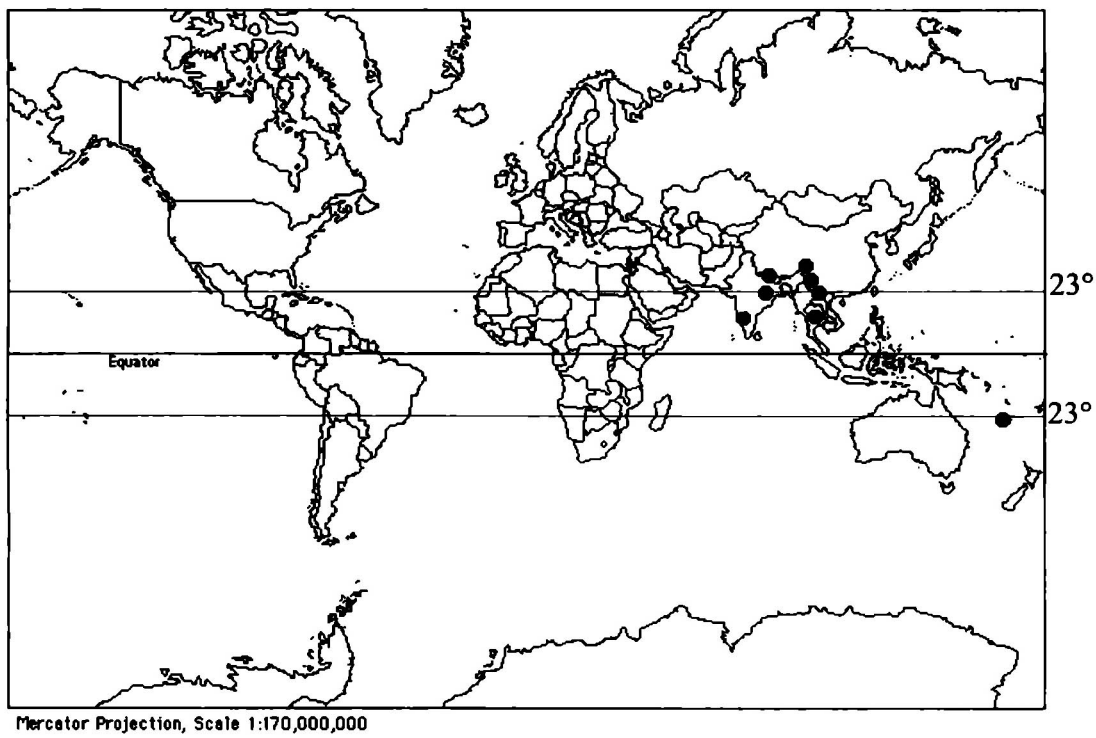

Figure 101. World distribution of *Fissidens subbryoides* Gangulee

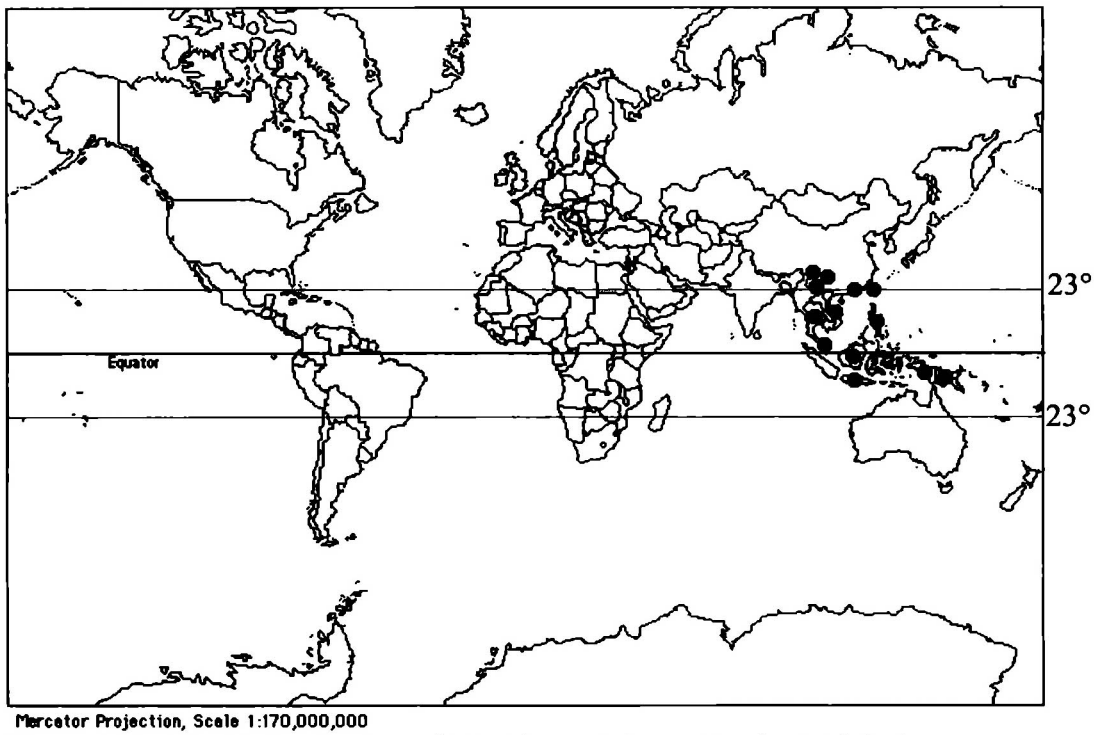

Figure 102. World distribution of *Fissidens wichurae* Broth. & Fleisch.

Tropical Asia distribution

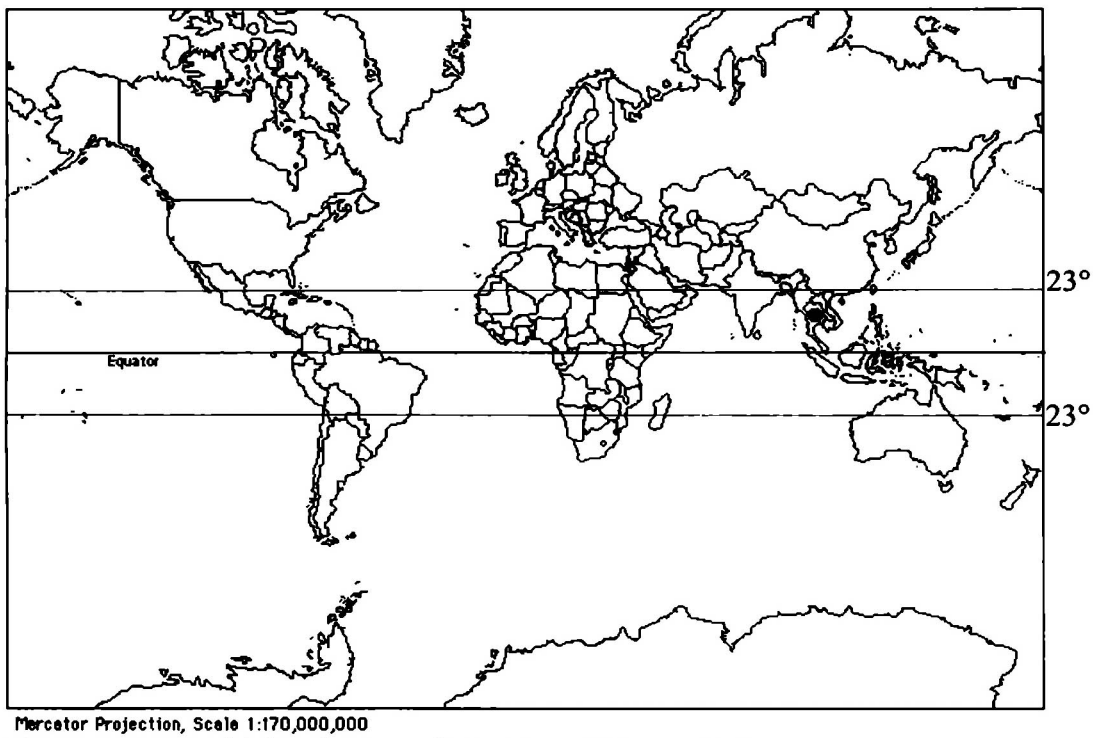

Figure 103. World distribution of *Fissidens filiformis* Z. Iwats.

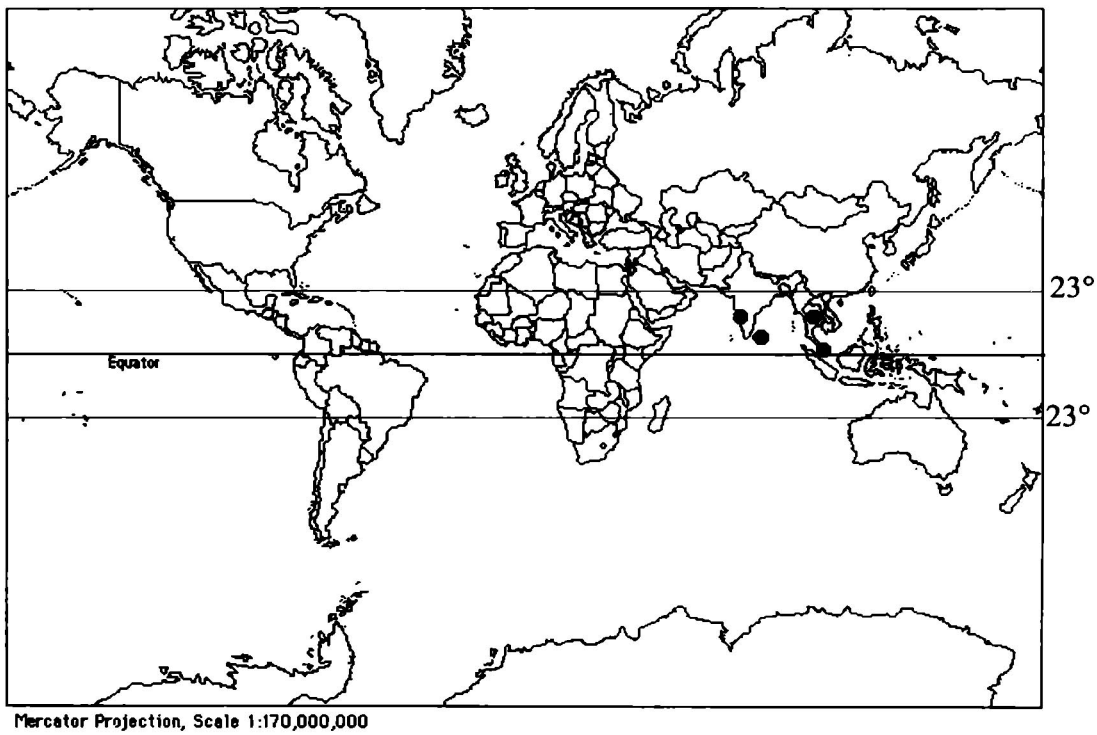

Figure 104. World distribution of *Fissidens firmus* Mitt.

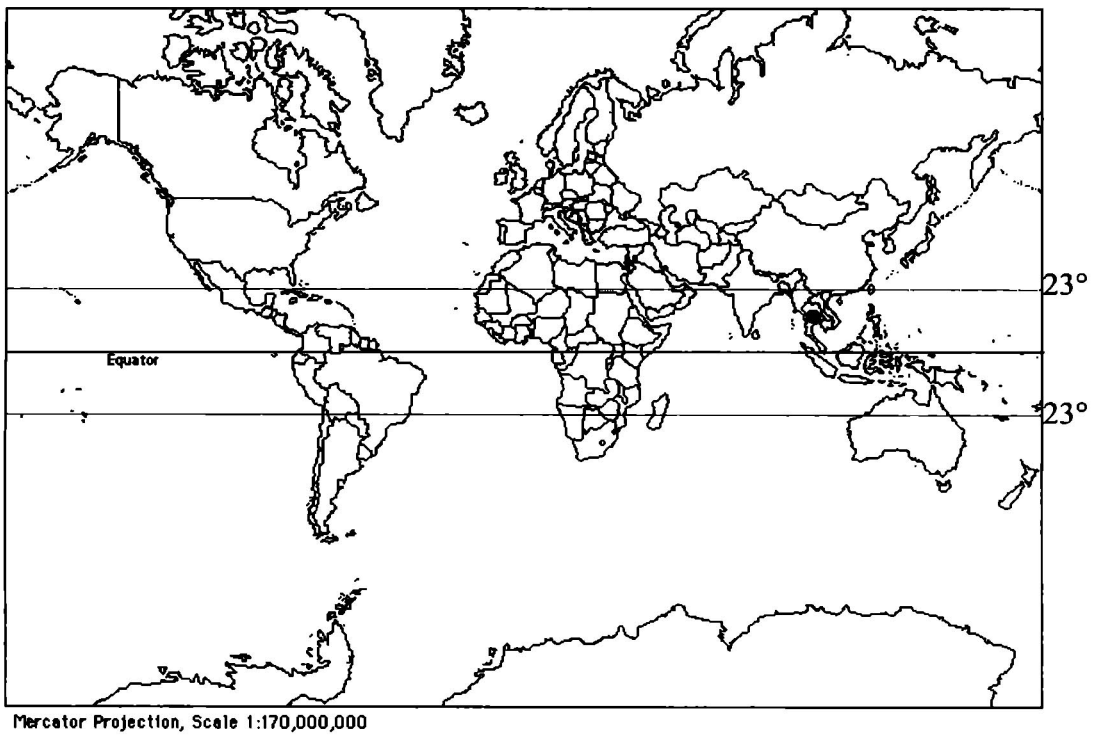

Figure 105. World distribution of *Fissidens flaccidus* Mitt. var. *percurrens* K. Wongkuna, *var. nov.*

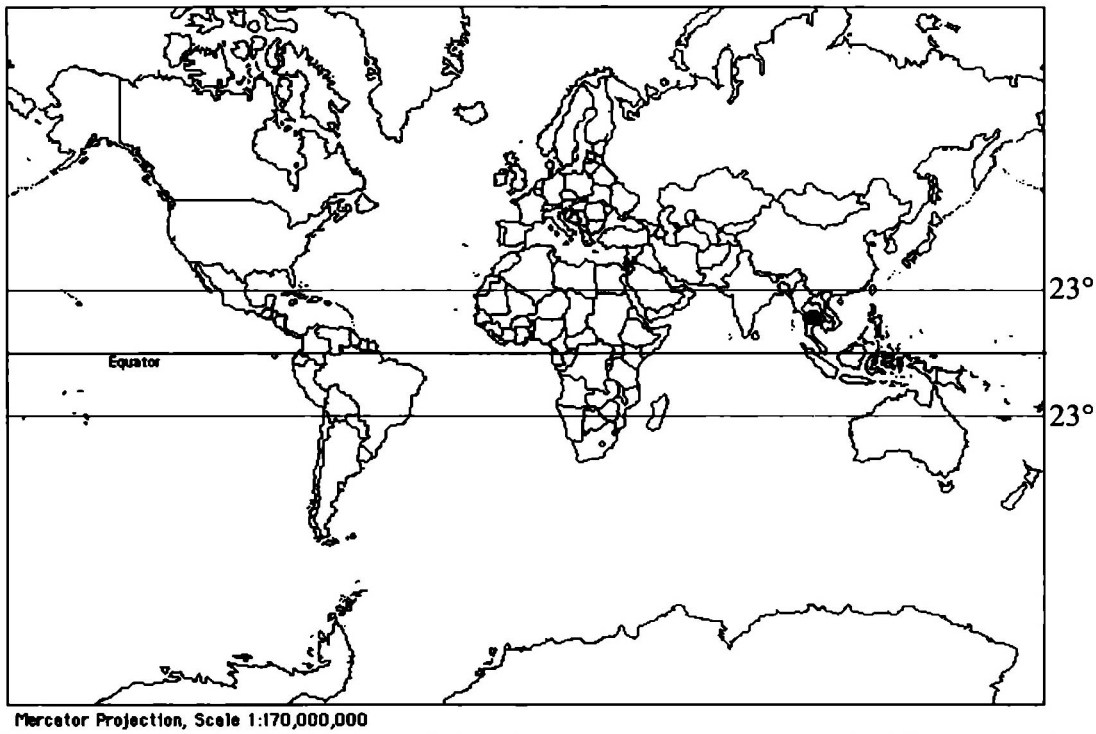

Figure 106. World distribution of *Fissidens irregulomarginatulus* K. Wongkuna & B. C. Tan, *sp. nov.*

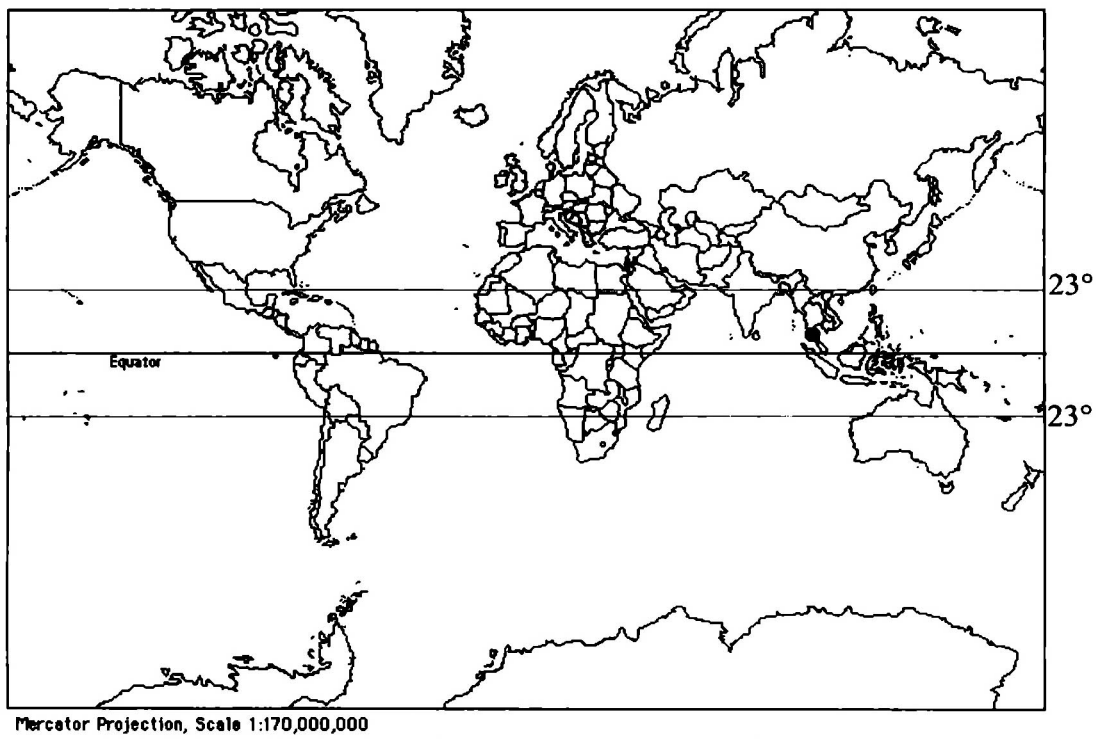

Figure 107. World distribution of *Fissidens pseudokinabaluensis* K. Wongkuna & B. C. Tan, *sp. nov.*

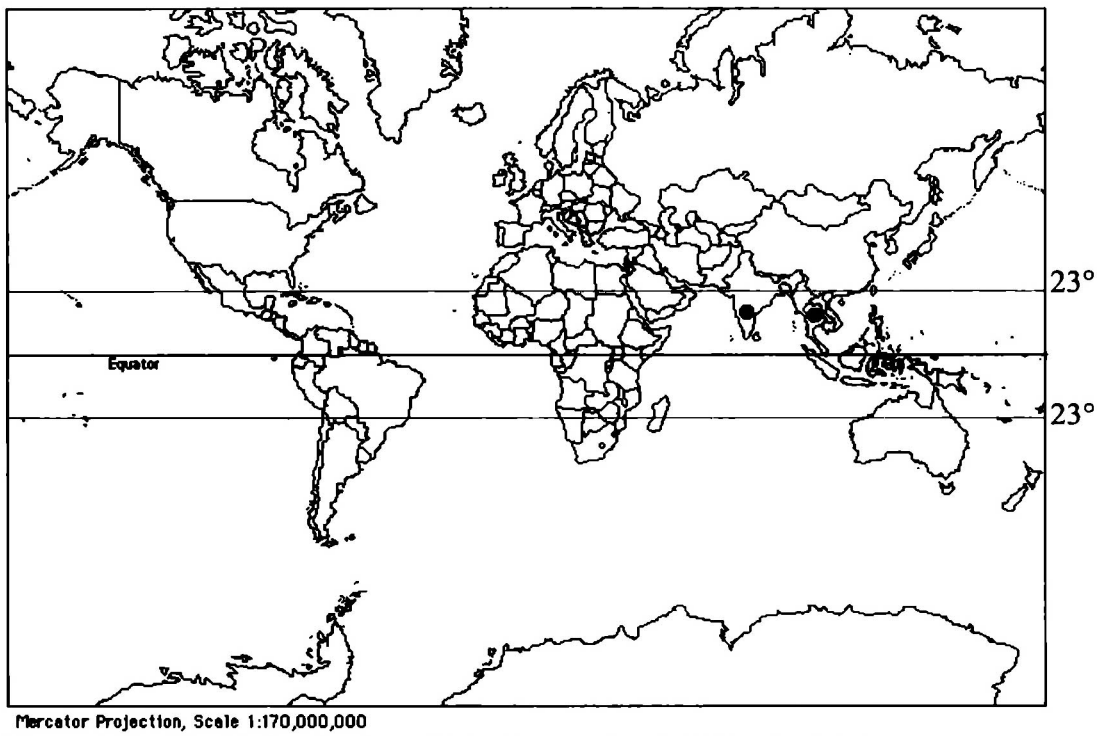

Figure 108. World distribution of *Fissidens sedgwickii* Broth. & Dix.

Asia-Africa and Temperate distribution

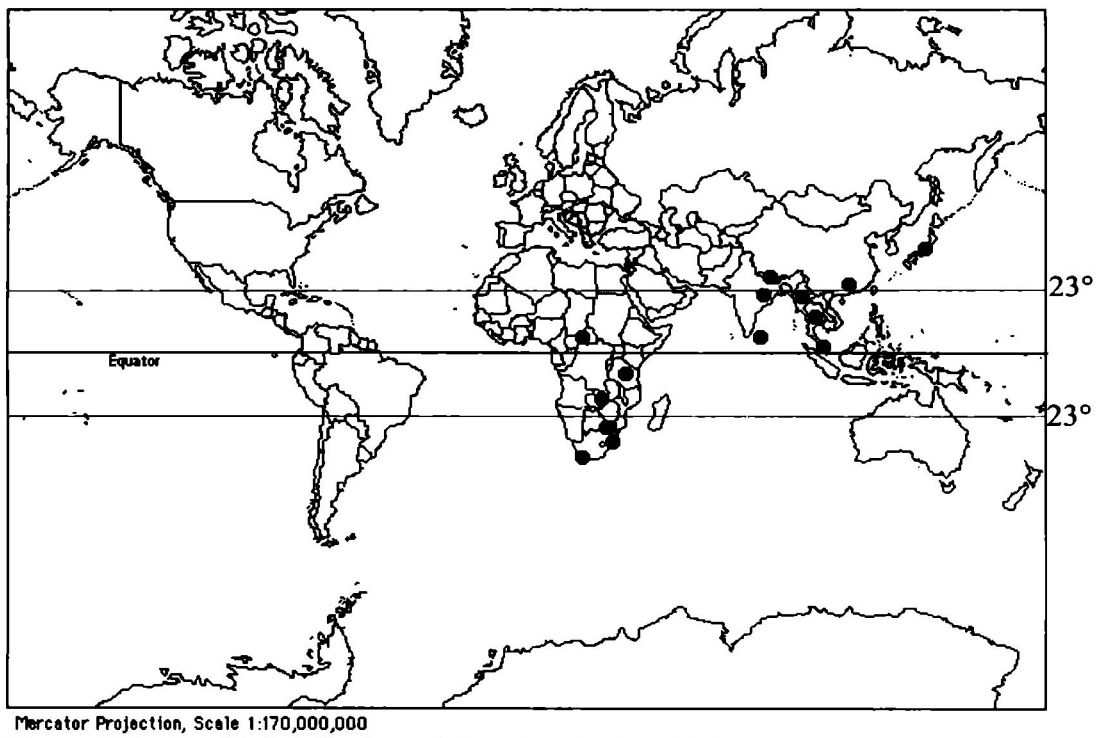

Figure 109. World distribution of *Fissidens beckettii* Mitt.

Australasia and Temperate distribution

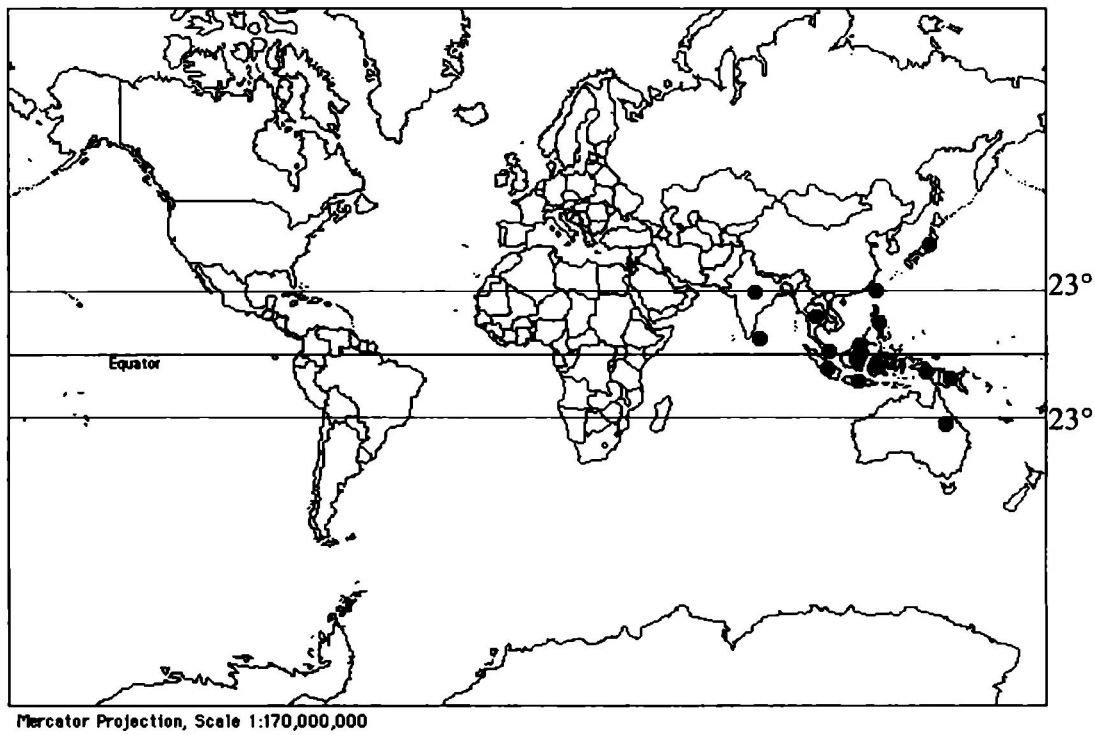

Figure 110. World distribution of *Fissidens crassinervis* Sande Lac.

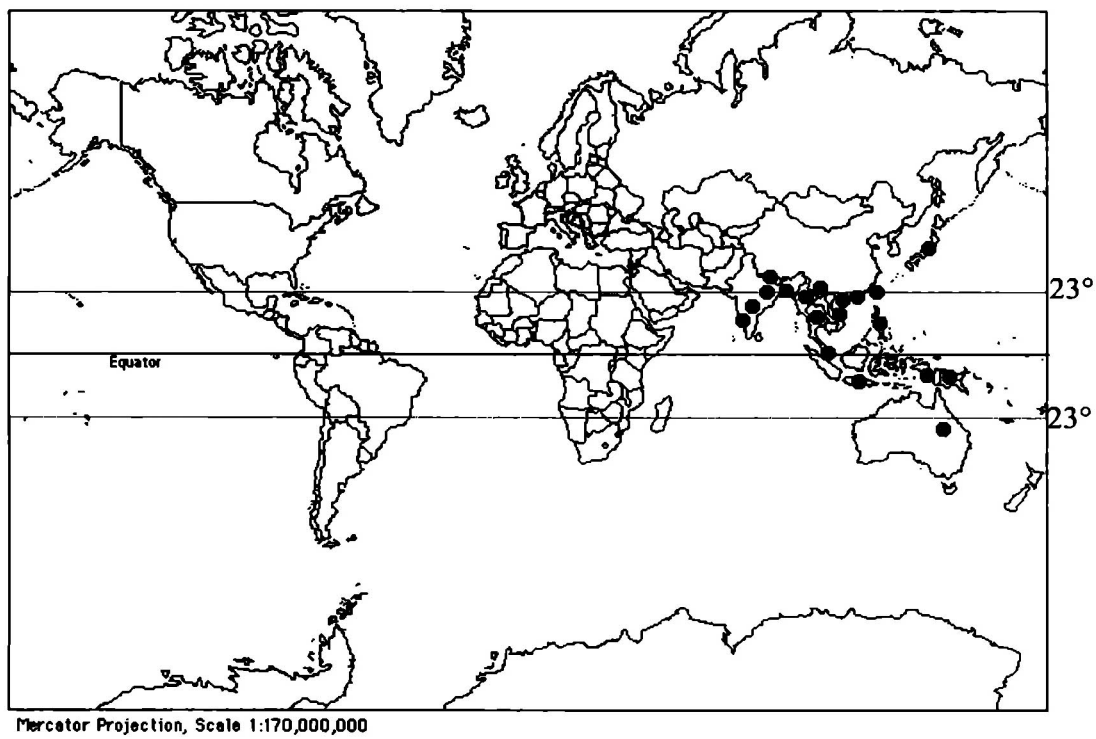

Figure 111. World distribution of *Fissidens crenulatus* Mitt. var. *crenulatus*

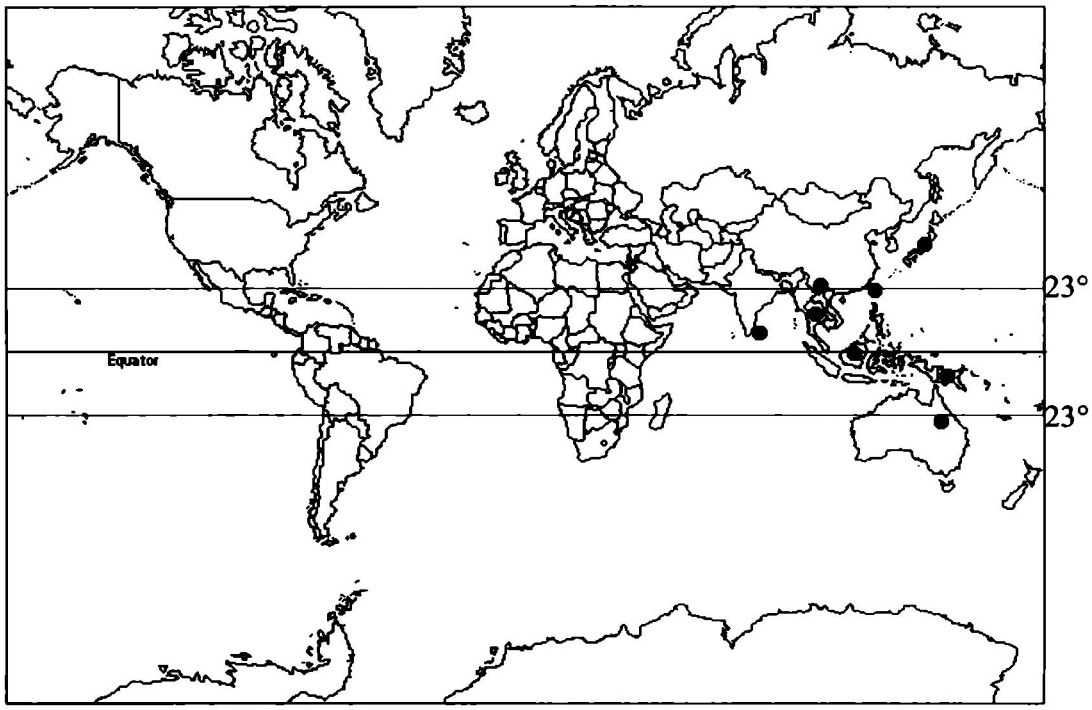

Figure 112. World distribution of *Fissidens flabellulus* Thwait. & Mitt.

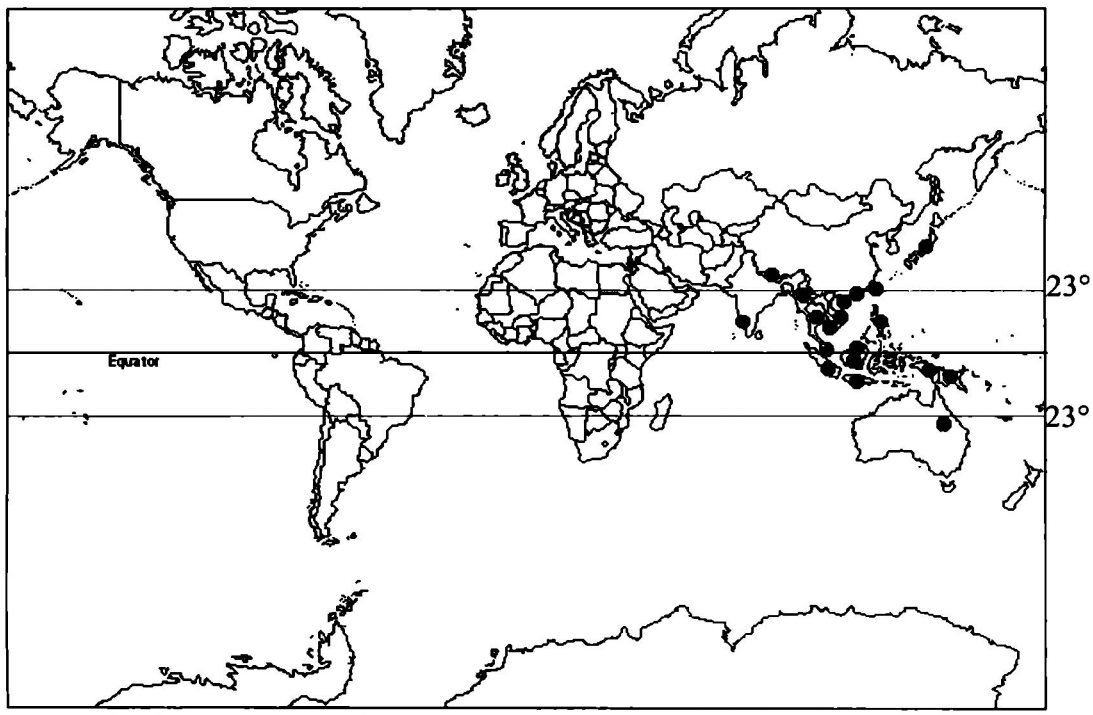

Figure 113. World distribution of *Fissidens hollianus* Dozy & Molk.

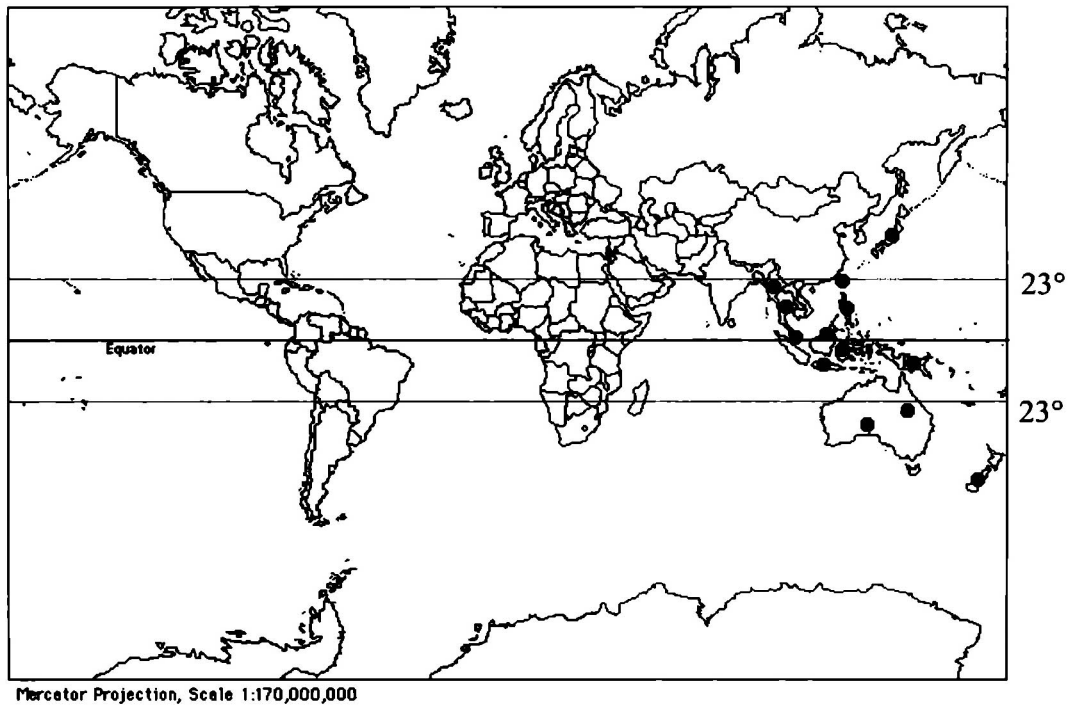

Figure 114. Distribution of *Fissidens tenellus* Hook. f. & Wils. var. *australiensis* (A. Jaeger) Beever & Stone

Australasia Africa and Temperate distribution

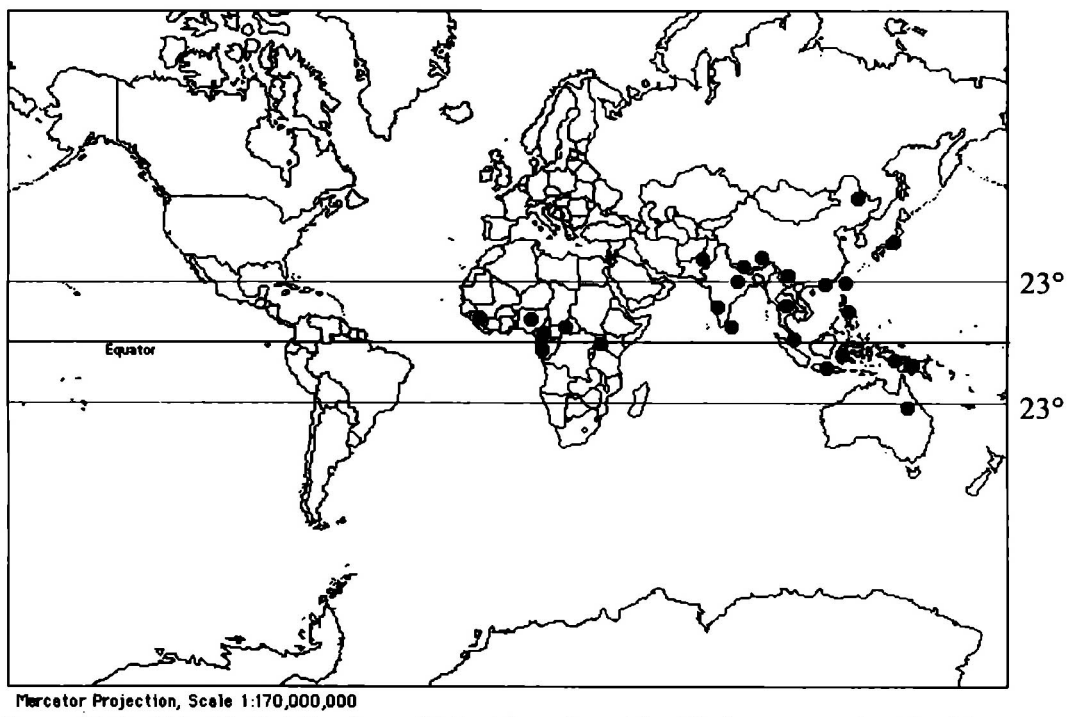

Figure 115. World distribution of *Fissidens bryoides* Hedw. var. *schmidii* (C. Muell.) Chopra & Kumar

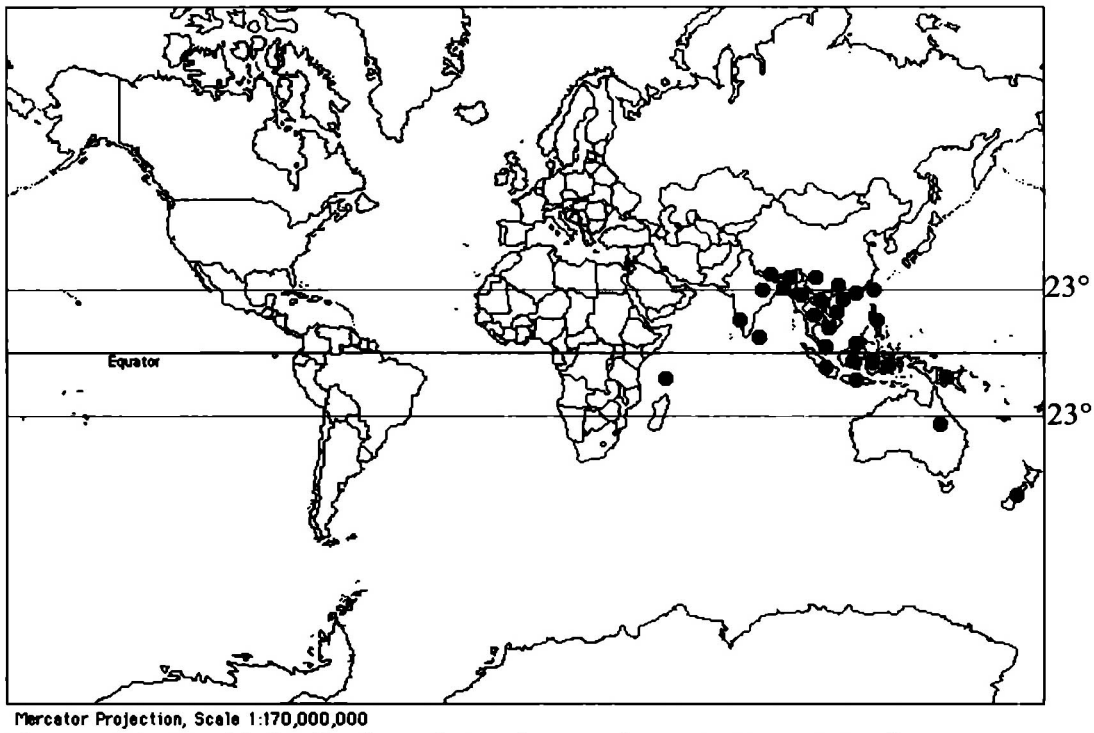

Figure 116. World distribution of *Fissidens ceylonensis* Dozy & Molk.

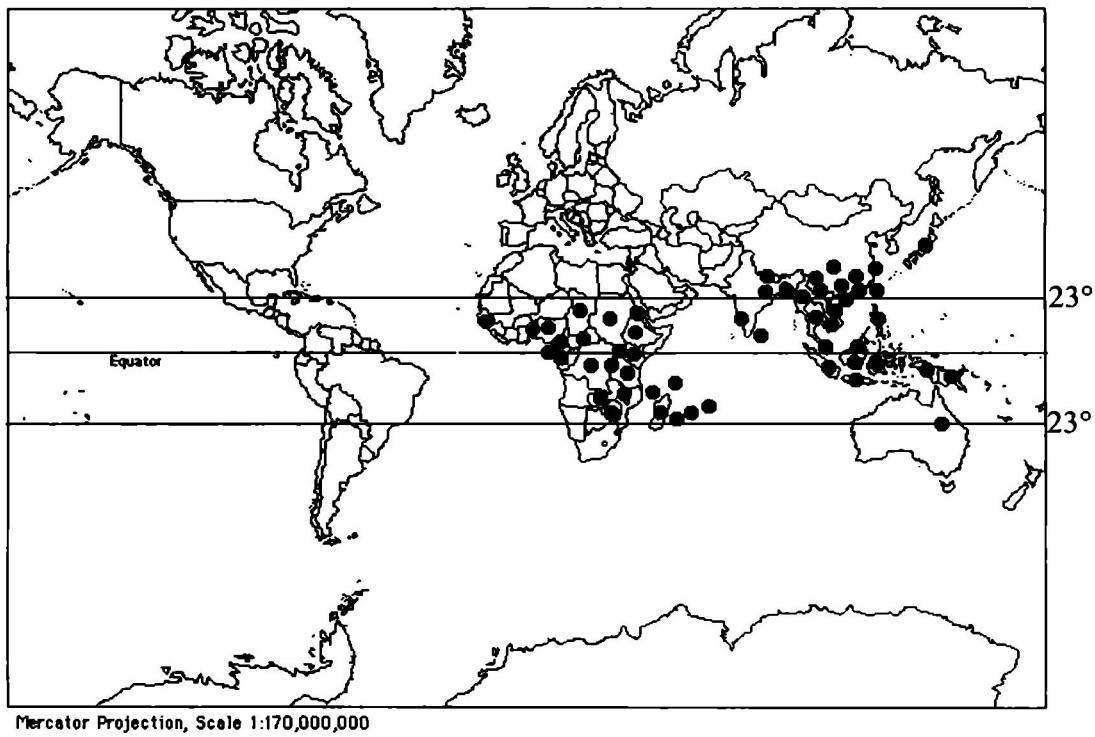

Figure 117. World distribution of *Fissidens crispulus* Brid. var. *crispulus*

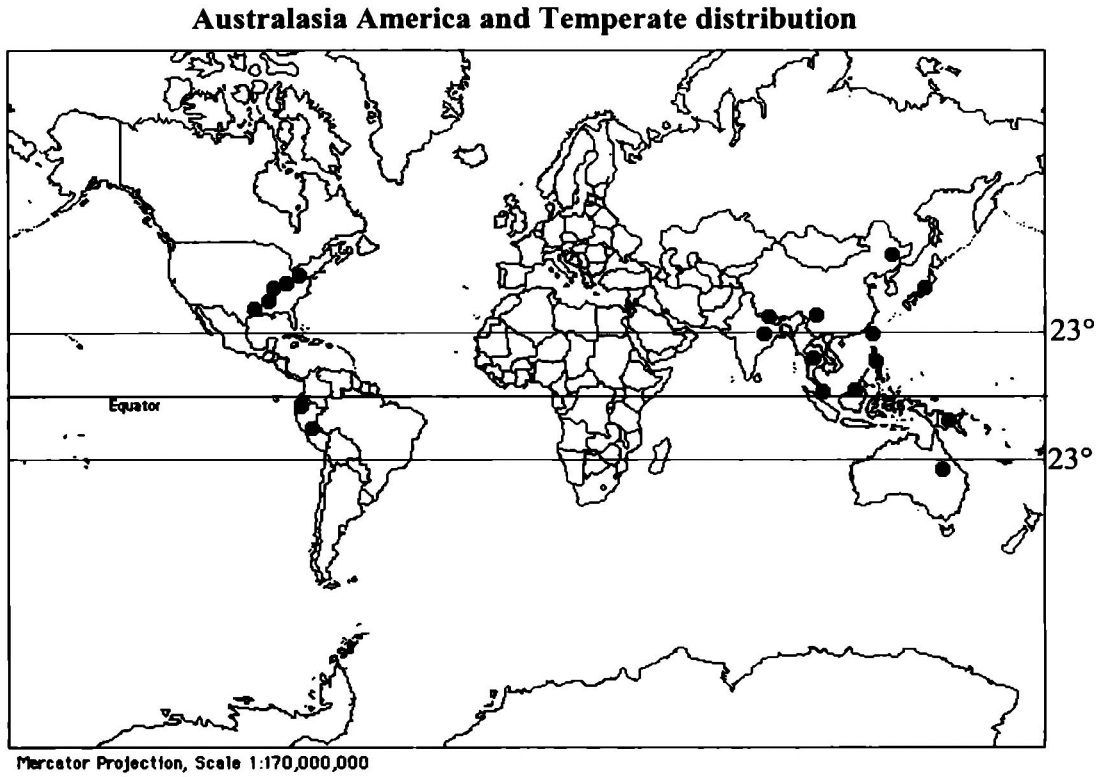

Figure 118. World distribution of *Fissidens hyalinus* Hook. & Wils.

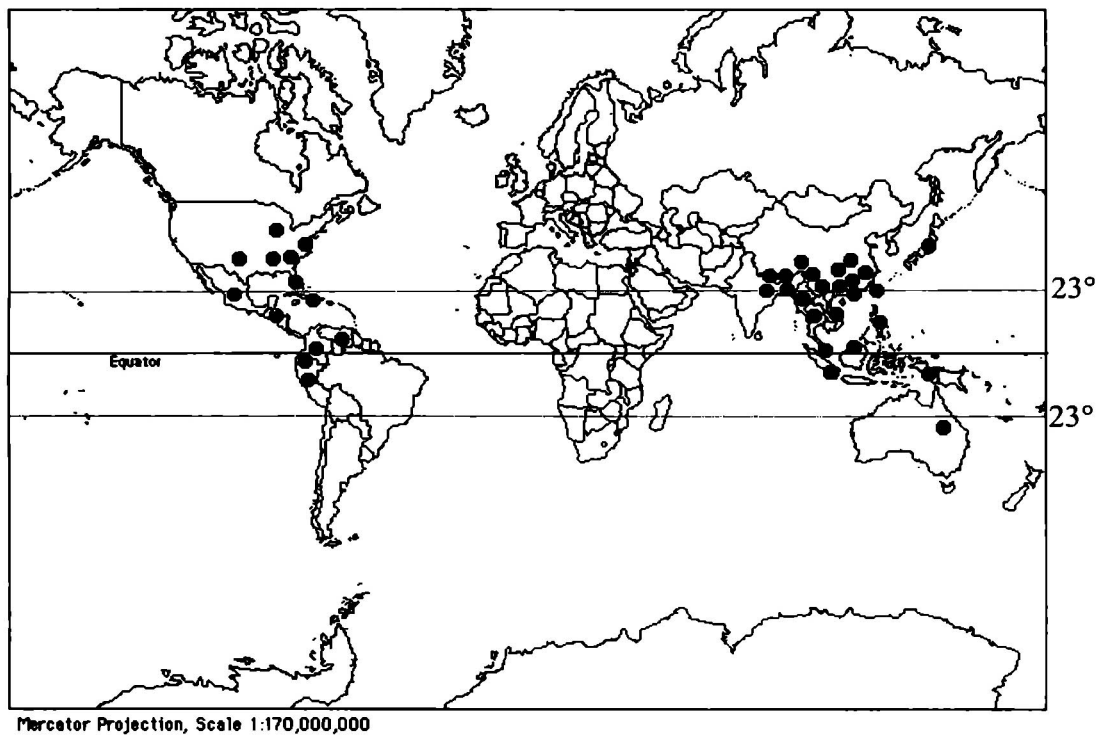

Figure 119. World distribution of *Fissidens polypodioides* Hedw.

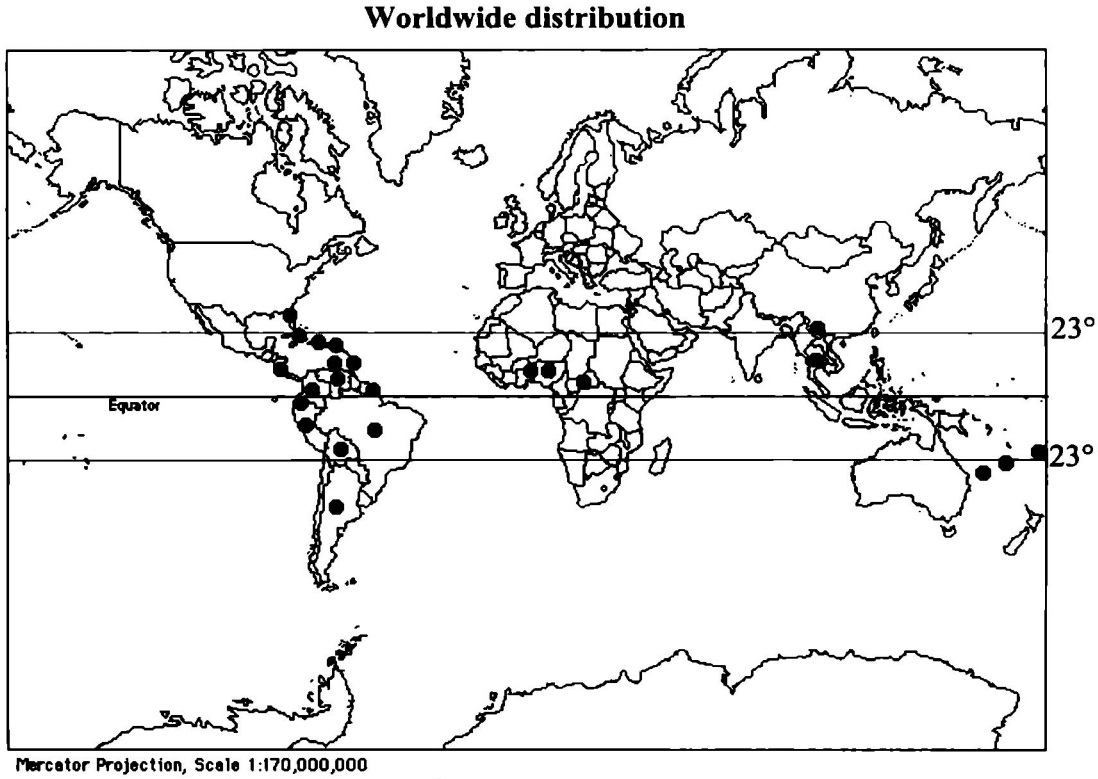

Figure 120. World distribution of *Fissidens angustifolius* Sull.

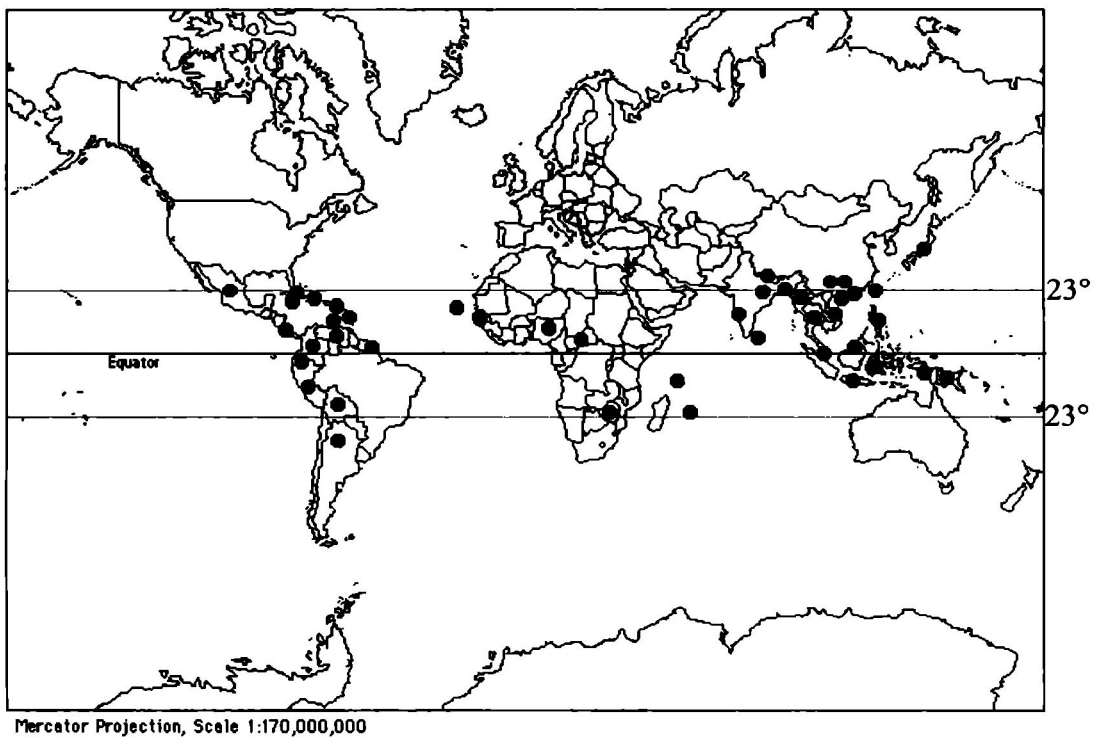

Figure 121. World distribution of *Fissidens flaccidus* Mitt. var. *flaccidus*

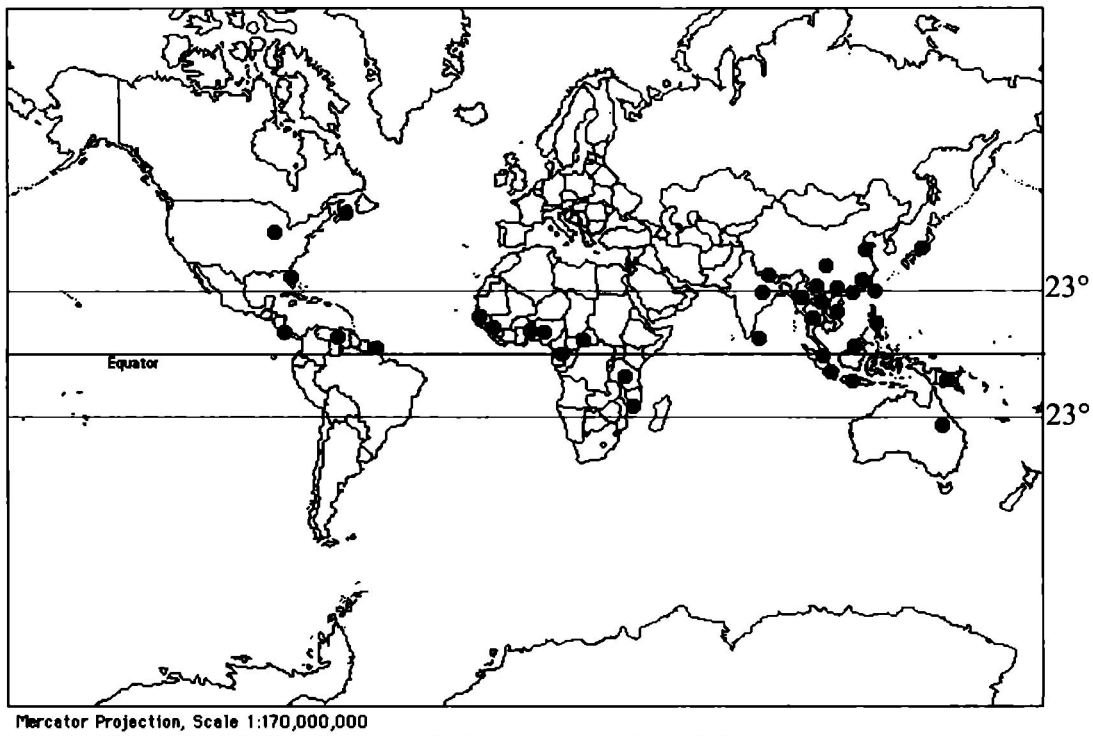

Figure 122. World distribution of *Fissidens gardneri* Mitt.

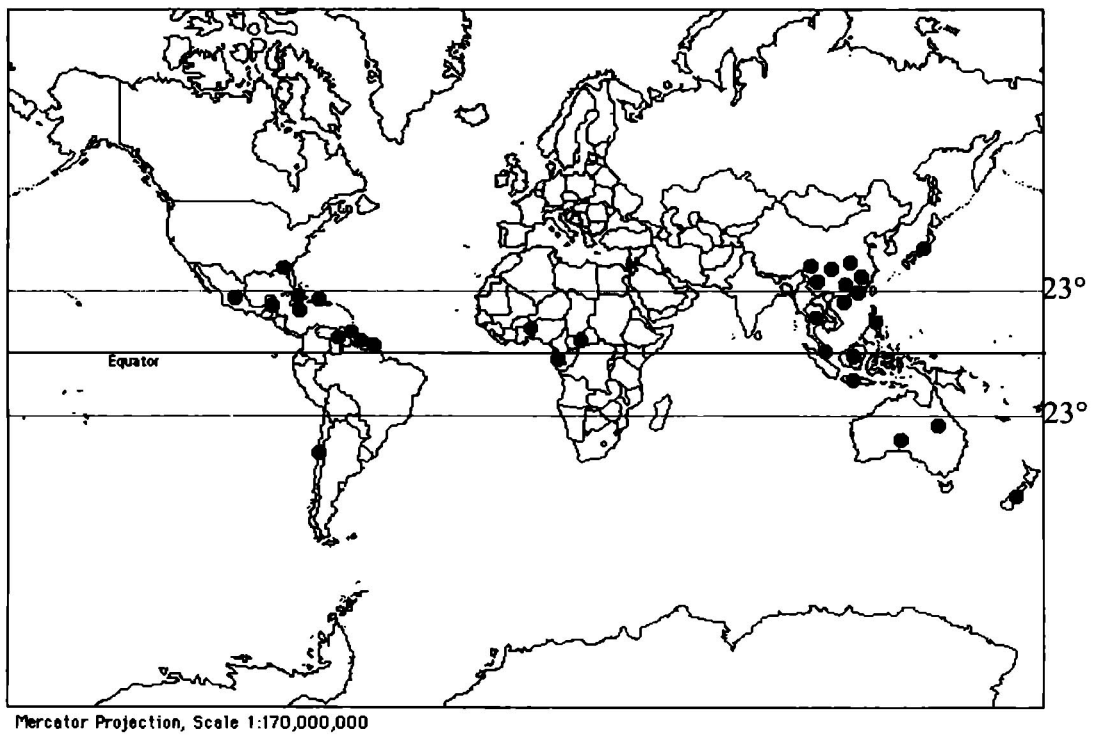

Figure 123. World distribution of *Fissidens oblongifolius* Hook. f. & Wils.

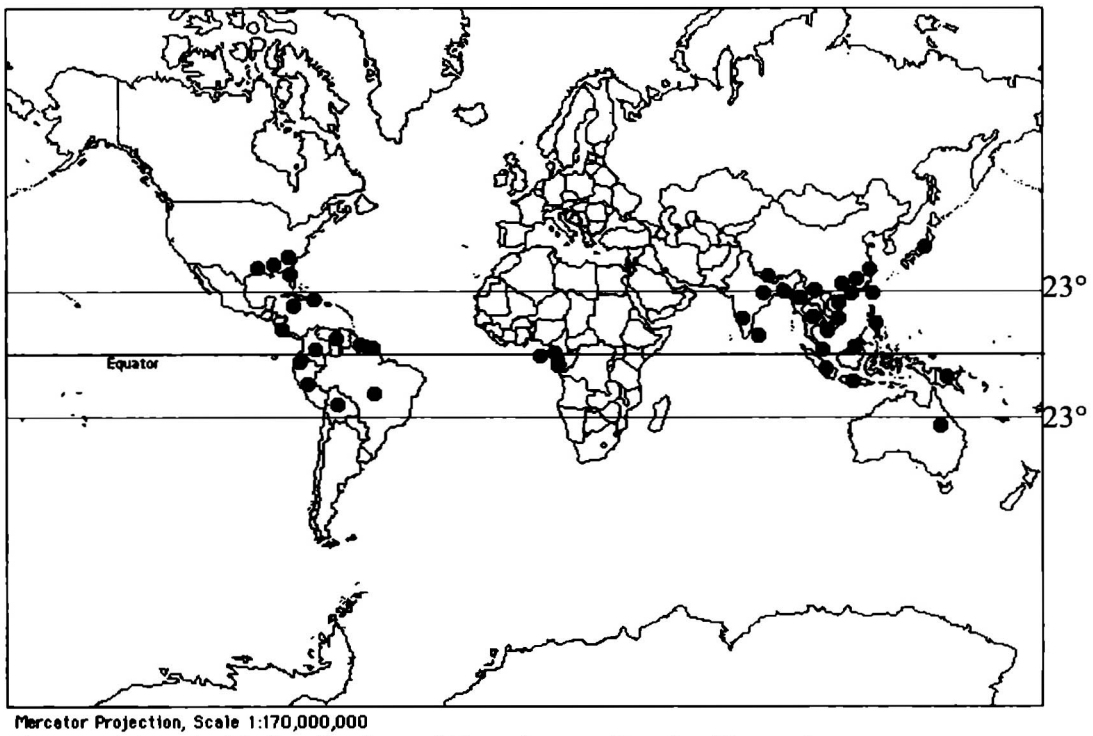

Figure 124. World distribution of *Fissidens pellucidus* Hornsch.

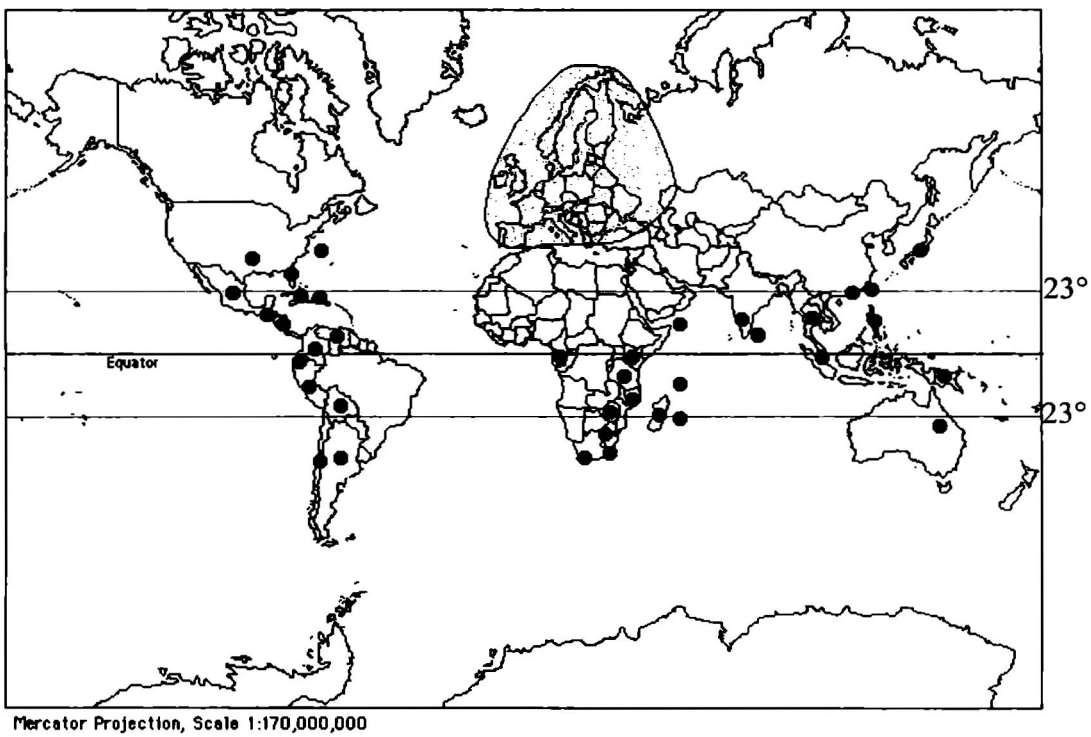

Figure 125. World distribution of *Fissidens serratus* Muell. Hal.

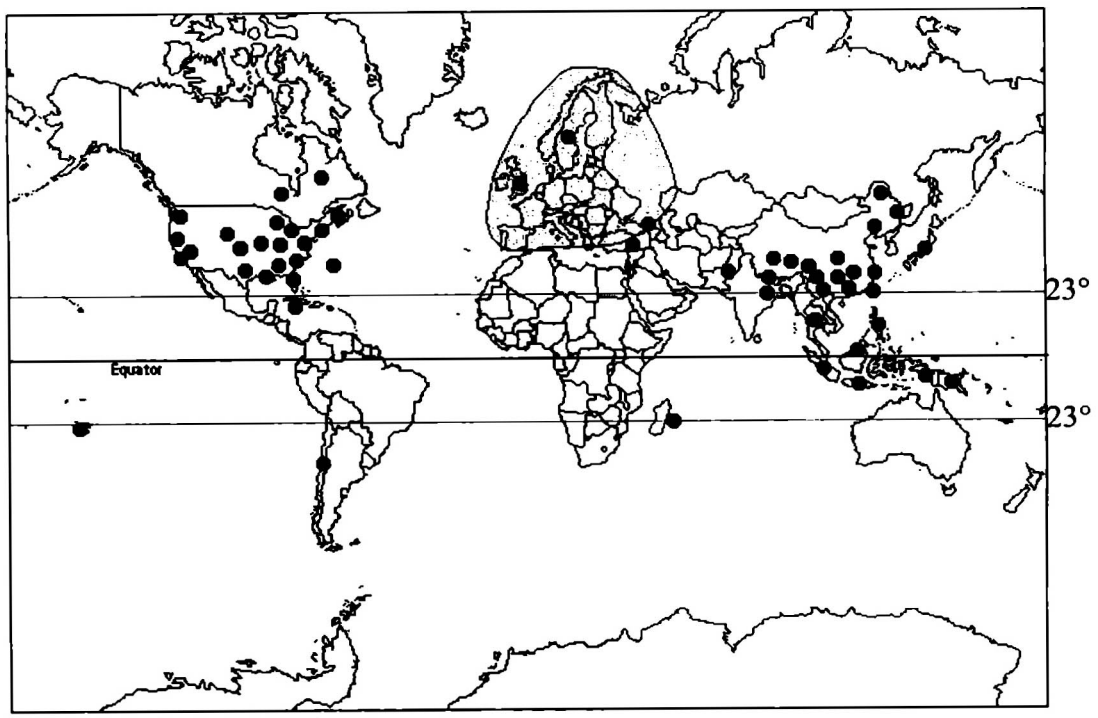

Figure 126. World distribution of *Fissidens taxifolius* Hedw.

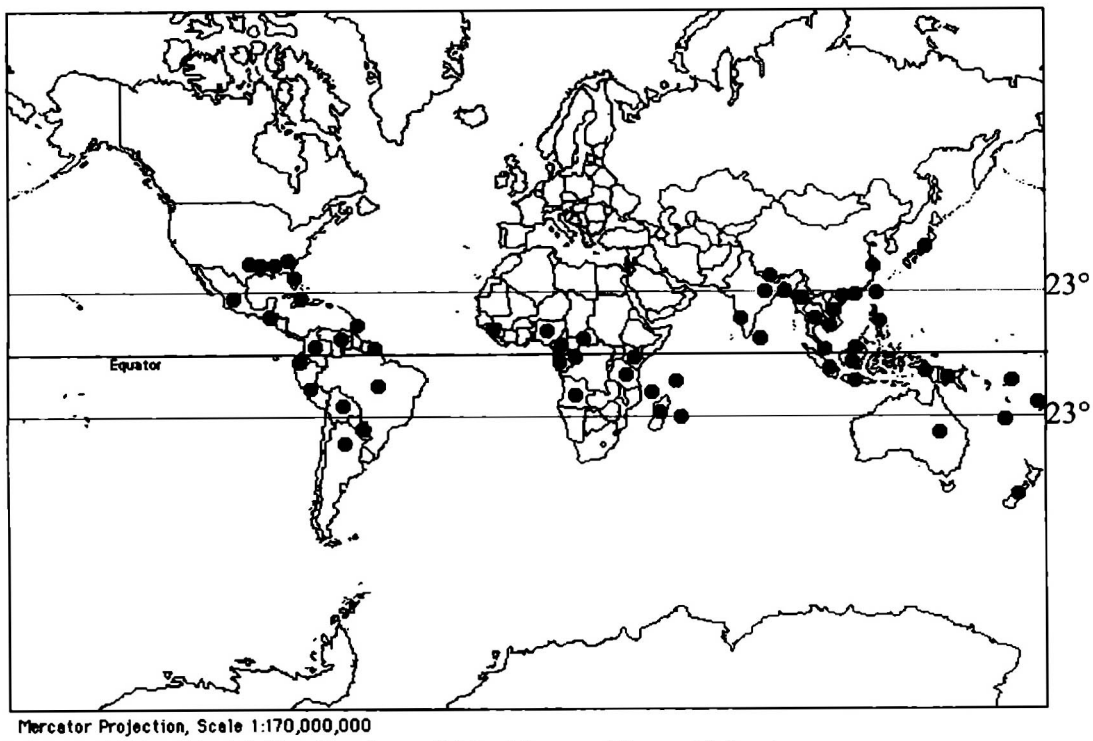

Figure 127. World distribution of *Fissidens zollingeri* Mont.

APPENDIX C

Photograph of Thai *Fissidens*

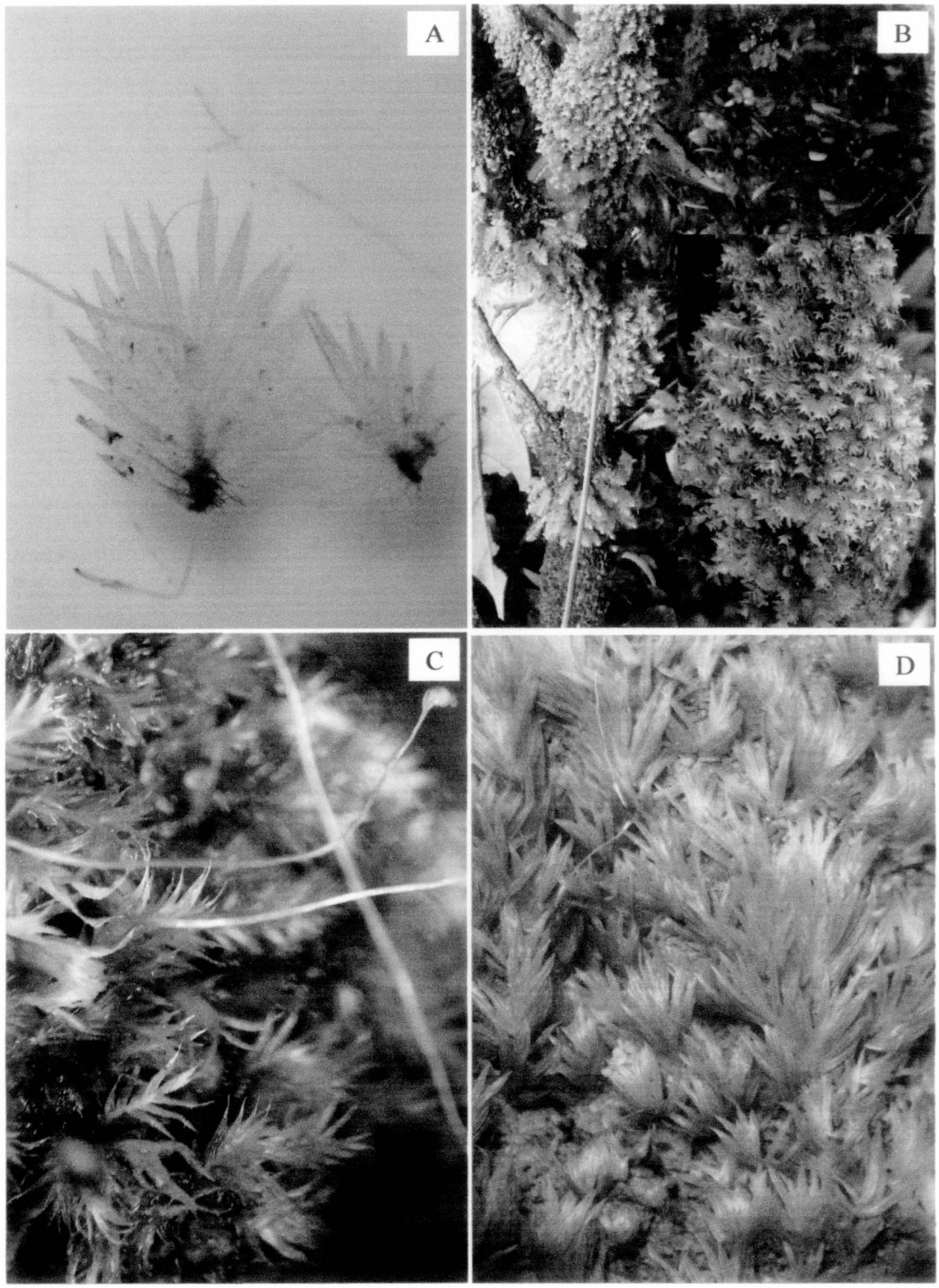

Figure 128. A: *Fissidens angustifolius* Sull., B: *Fissidens anomalus* Mont., C: *Fissidens beckettii* Mitt., and D: *Fissidens biformis* Mitt.

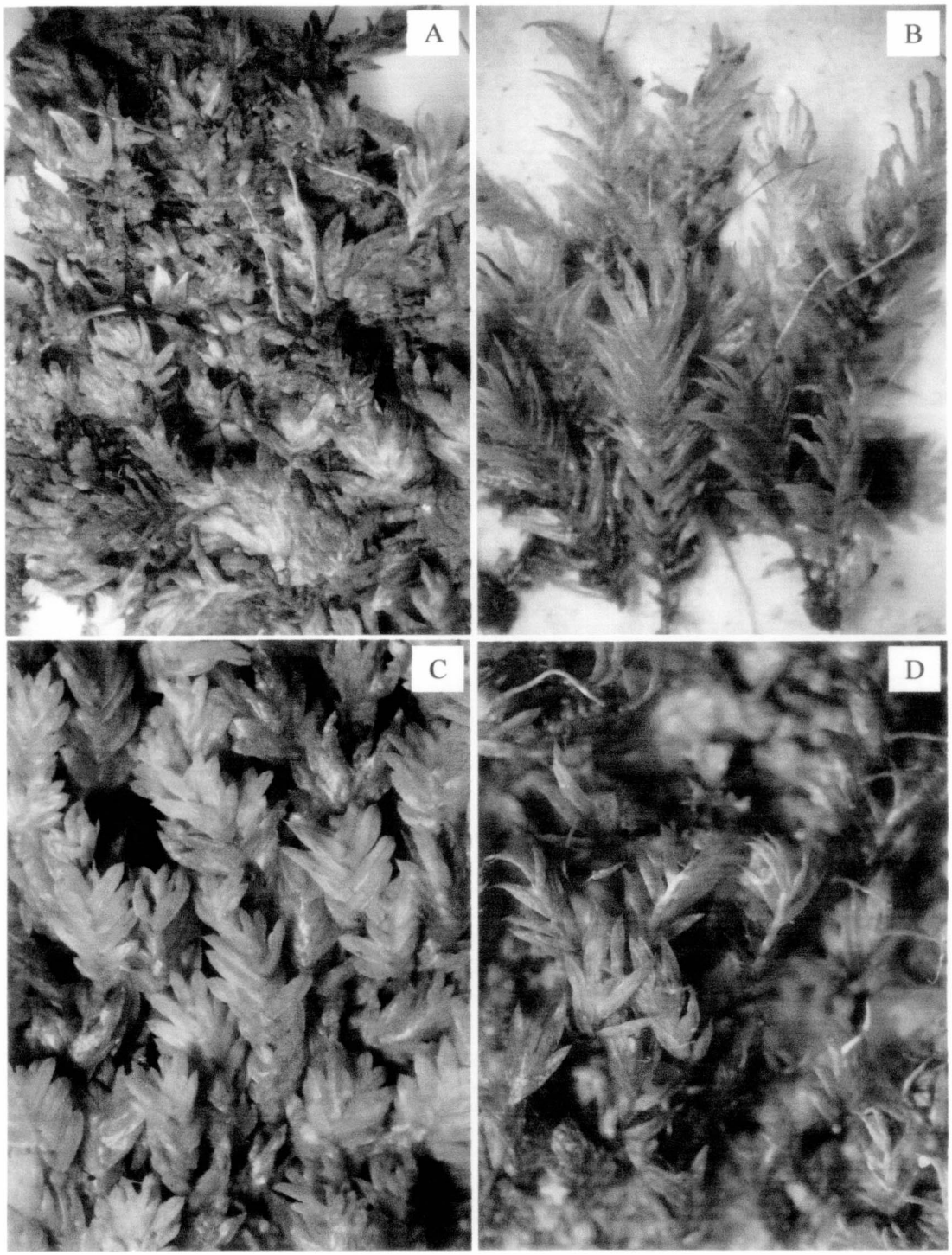

Figure 129. A: *Fissidens bryoides* Hedw. var. *esquirolii* (Thér.) Z. Iwats & T. Suzuki, B: *Fissidens bryoides* Hedw. var. *schmidii* (C. Muell.) Chopra & Kumar, C: *Fissidens ceylonensis* Dozy & Molk., and D: *Fissidens crassinervis* Sande Lac.

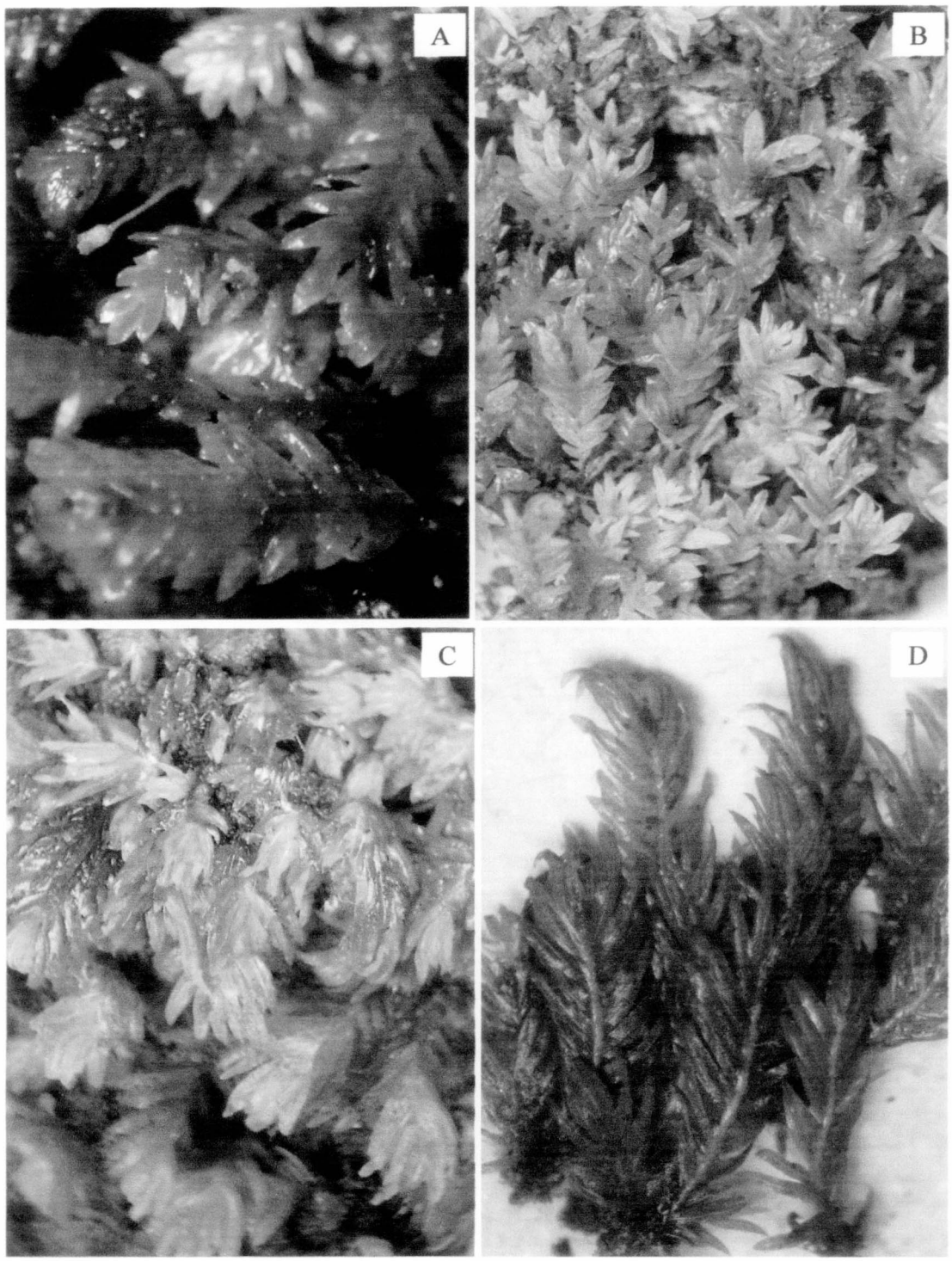

Figure 130. A: *Fissidens crenulatus* Mitt.var. *crenulatus*, B: *Fissidens crenulatus* Mitt. var. *elmeri* (Broth.) Z. Iwats. & Z. H. Li, C: *Fissidens crispulus* Brid. var. *crispulus*, and D: *Fissidens crispulus* Brid. var. *robinsonii* (Broth.) Z. Iwats. & Z. H. Li

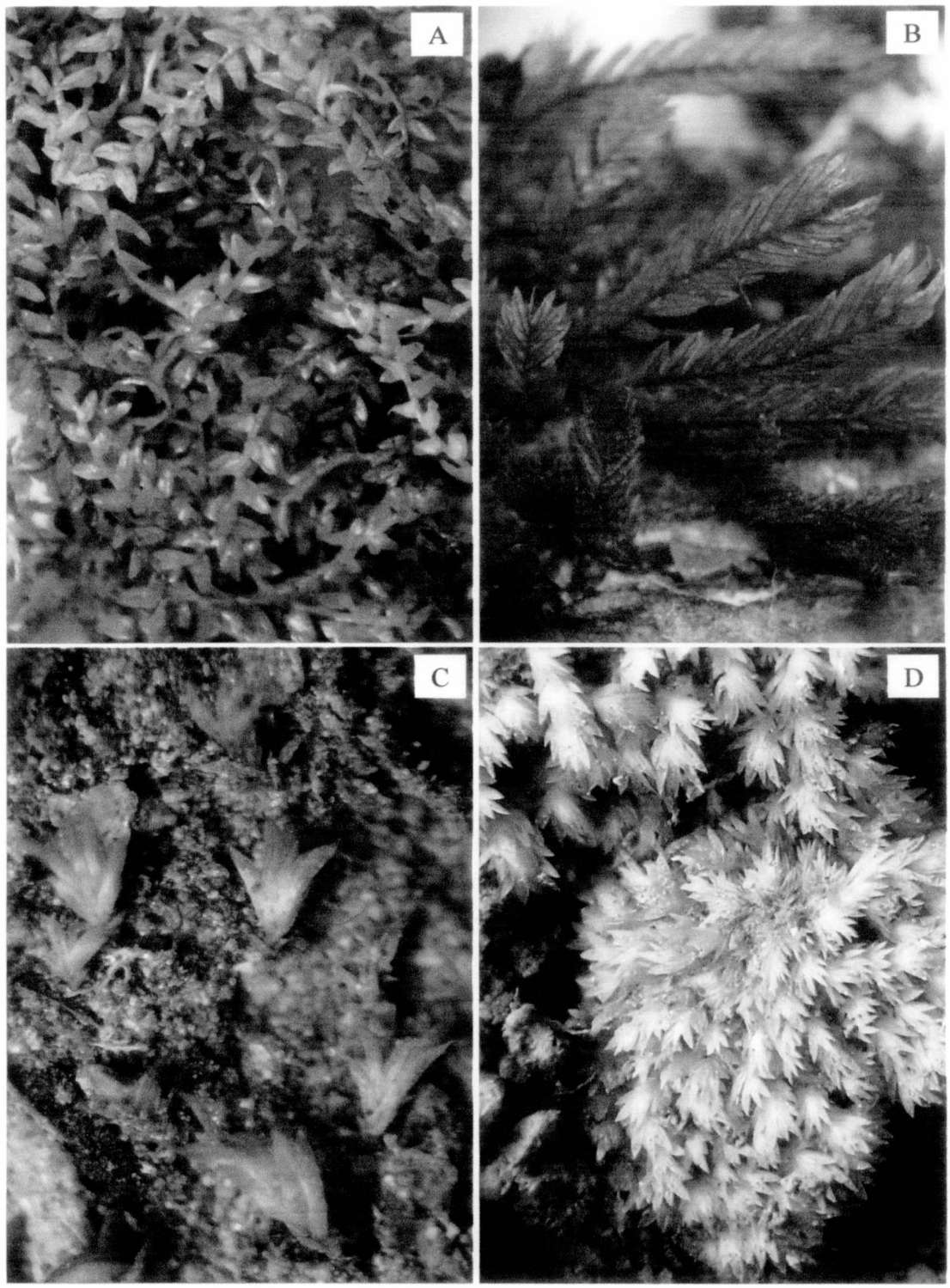

Figure 131. A: *Fissidens filiformis* Z. Iwats. B: *Fissidens firmus* Mitt., C: *Fissidens flabellulus* Thwait. & Mitt., and D: *Fissidens flaccidus* Mitt var. *flaccidus*

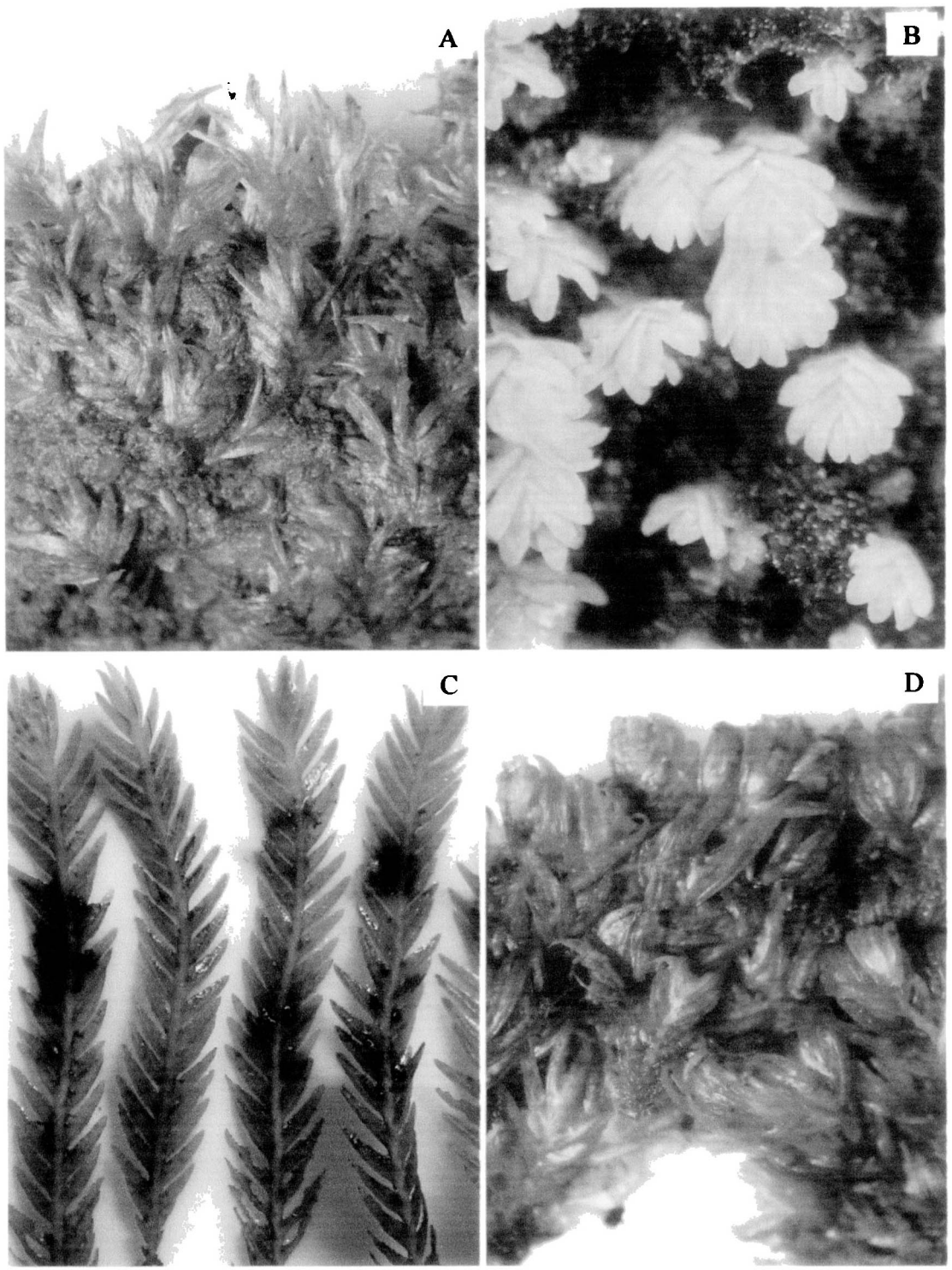

Figure 132. A: *Fissidens flaccidus* Mitt var. *percurrens* K. Wongkuna, B: *Fissidens gardneri* Mitt., C: *Fissidens geminiflorus* Dozy & Molk., and D: *Fissidens geppii* Fleisch.

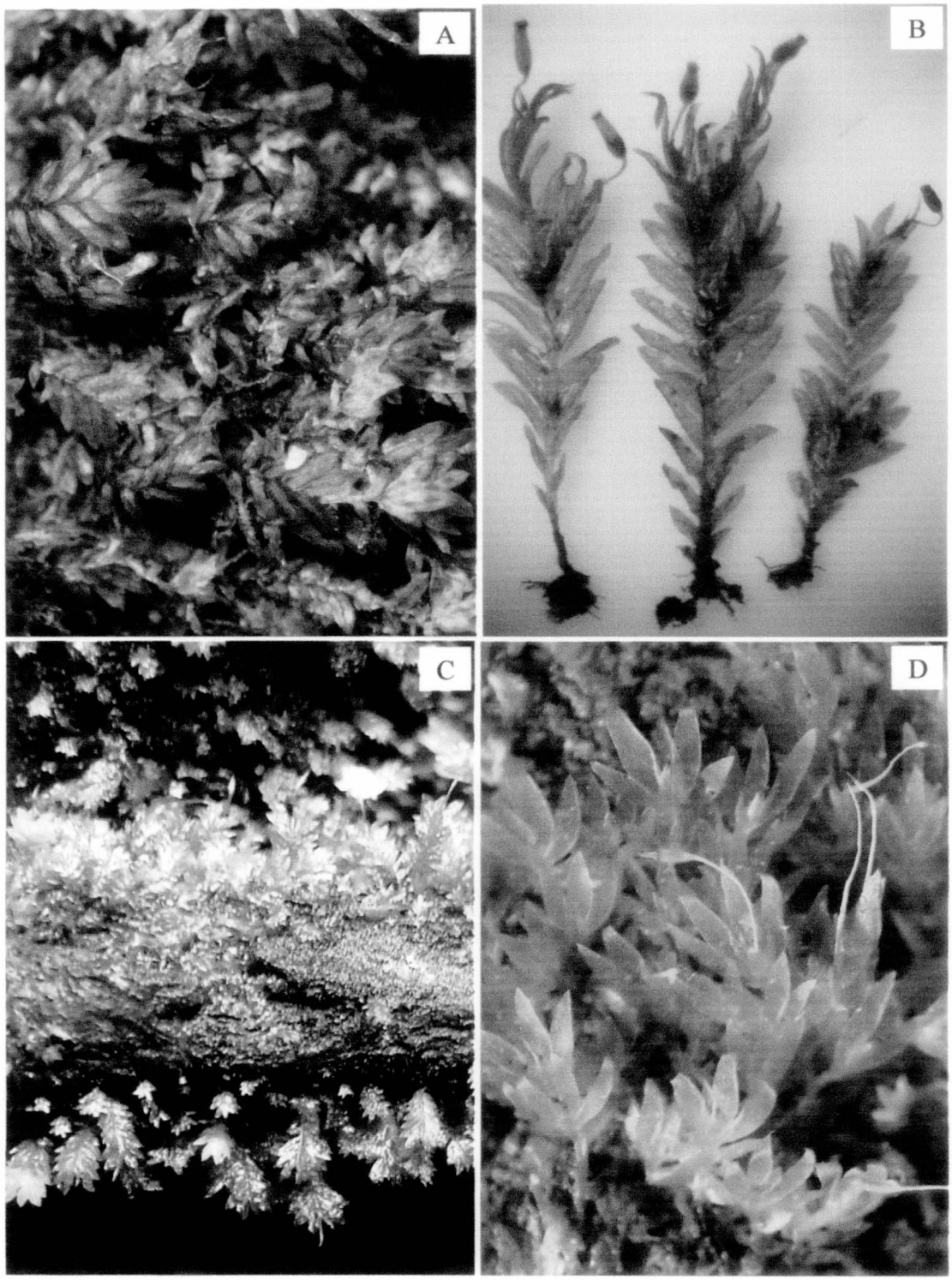

Figure 133. A: *Fissidens guangdongensis* Z. Iwats. & Z. H. Li, B: *Fissidens gymnogynus* Besch., C: *Fissidens hollianus* Dozy & Molk., and D: *Fissidens hyalinus* Hook. & Wils.



Figure 134. A: *Fissidens incognitus* Gangulee, B: *Fissidens involutus* Wils. *ex* Mitt., C: *Fissidens irregulomarginatulus* K. Wongkuna & B. C. Tan, and D: *Fissidens javanicus* Dozy & Molk.

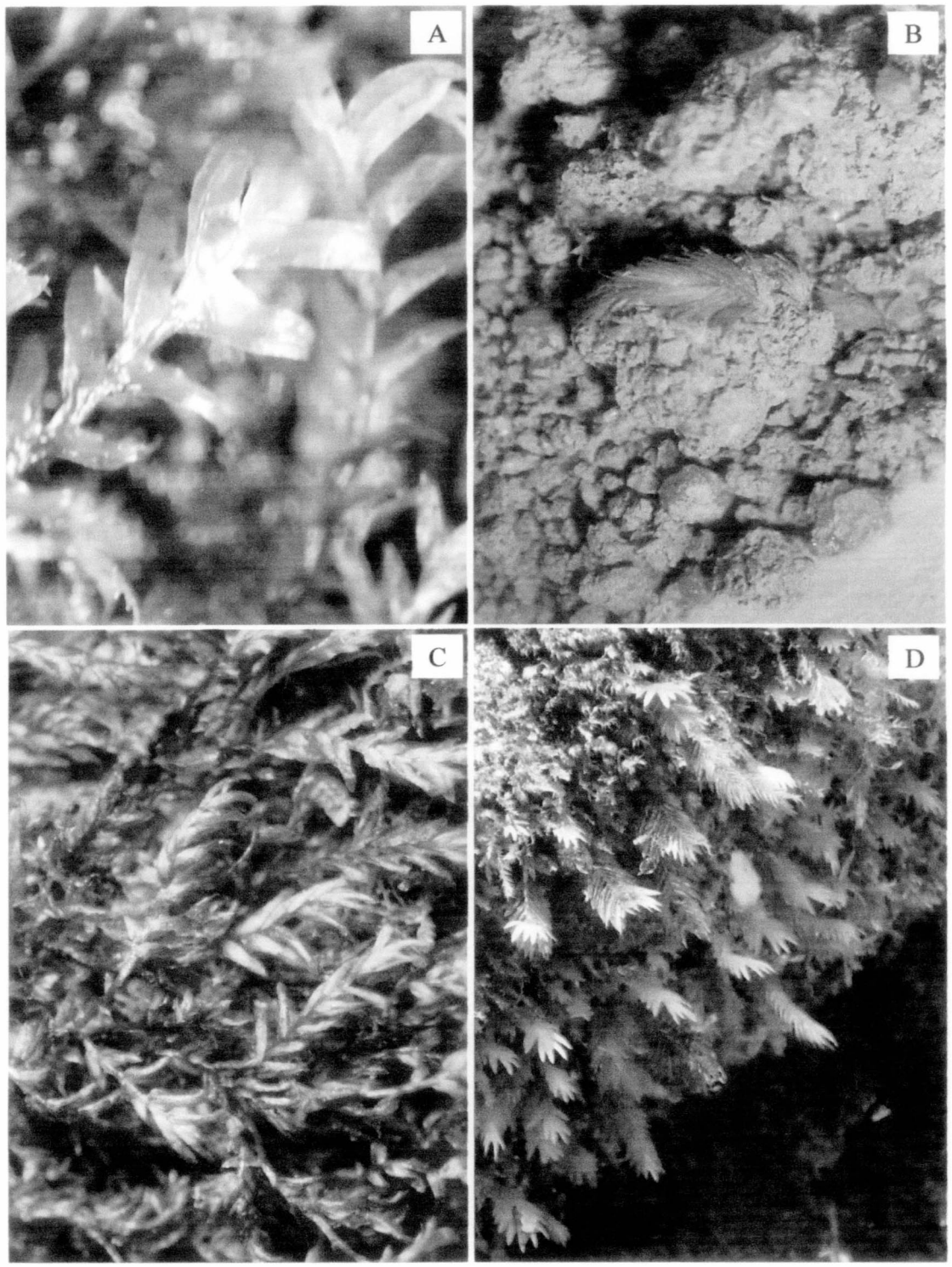

Figure 135. A: *Fissidens jungermannioides* Griff., B: *Fissidens kinabaluense* Z. Iwats., C: *Fissidens laxitextus* Broth. *ex* Gangulee, and D: *Fissidens nobilis* Griff.

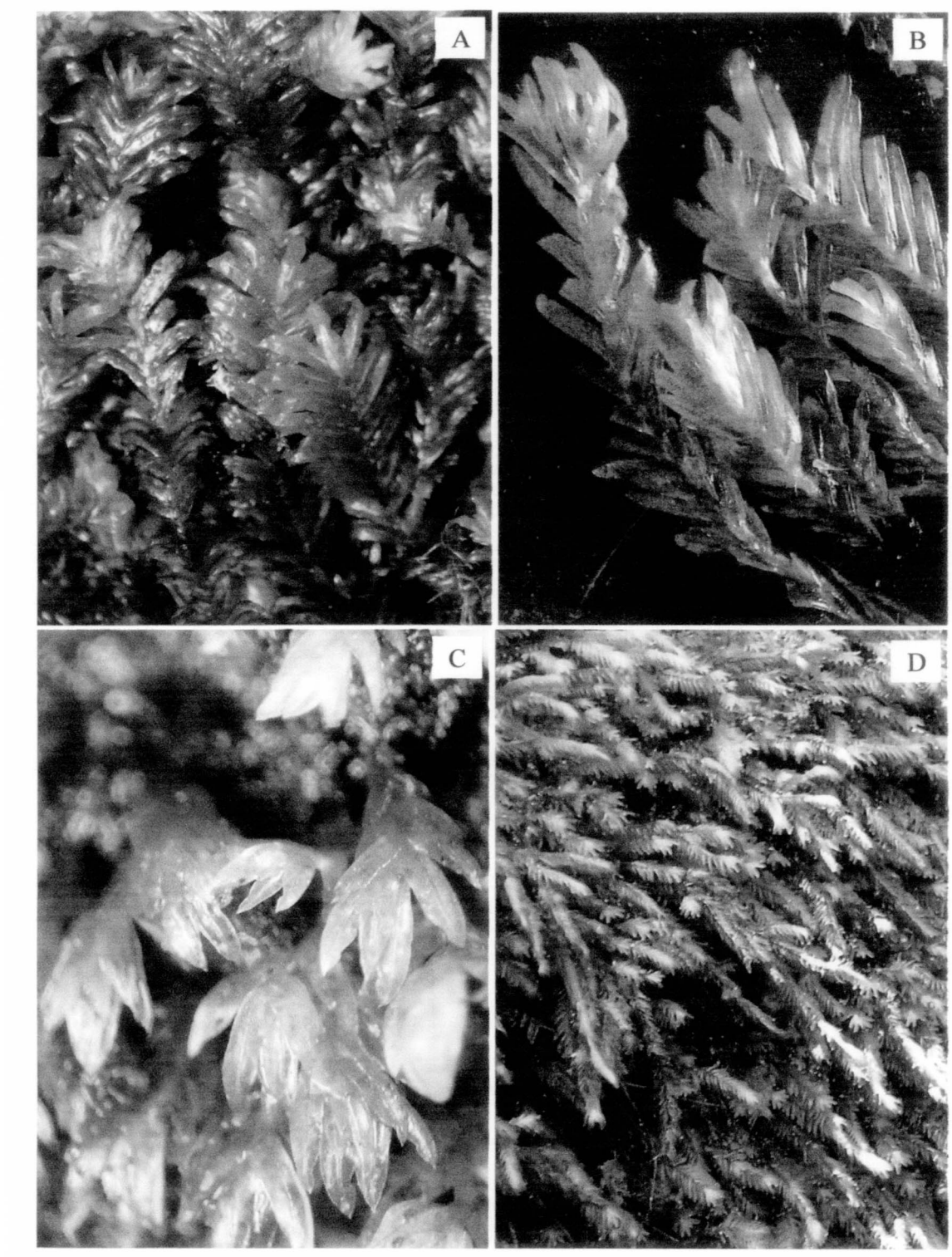

Figure 136. A: *Fissidens oblongifolius* Hook. f. & Wils., B: *Fissidens obscurus* Mitt., C: *Fissidens pellucidus* Hornsch., and D: *Fissidens polypodioides* Hedw.

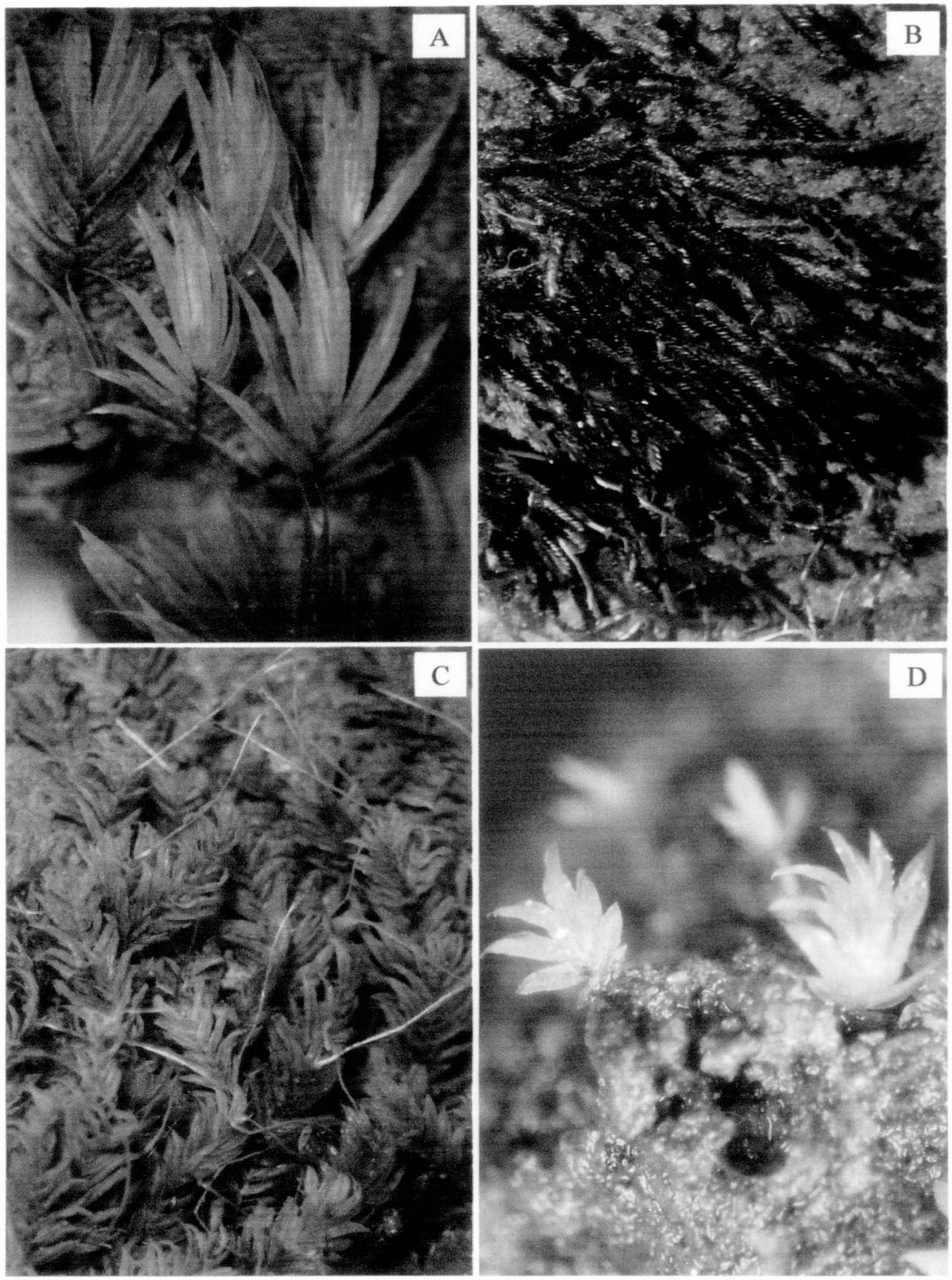

Figure 137. A: *Fissidens pseudokinabaluensis* K. Wongkuna & B. C. Tan, B: *Fissidens sedgwickii* Broth. & Dix., C: *Fissidens semperfalcatus* Dix., and D: *Fissidens serratus* Muell. Hal.



Figure 138. A: *Fissidens subangustus* Fleisch, B: *Fissidens subbryoides* Gangulee, and C: *Fissidens taxifolus* Hedw.

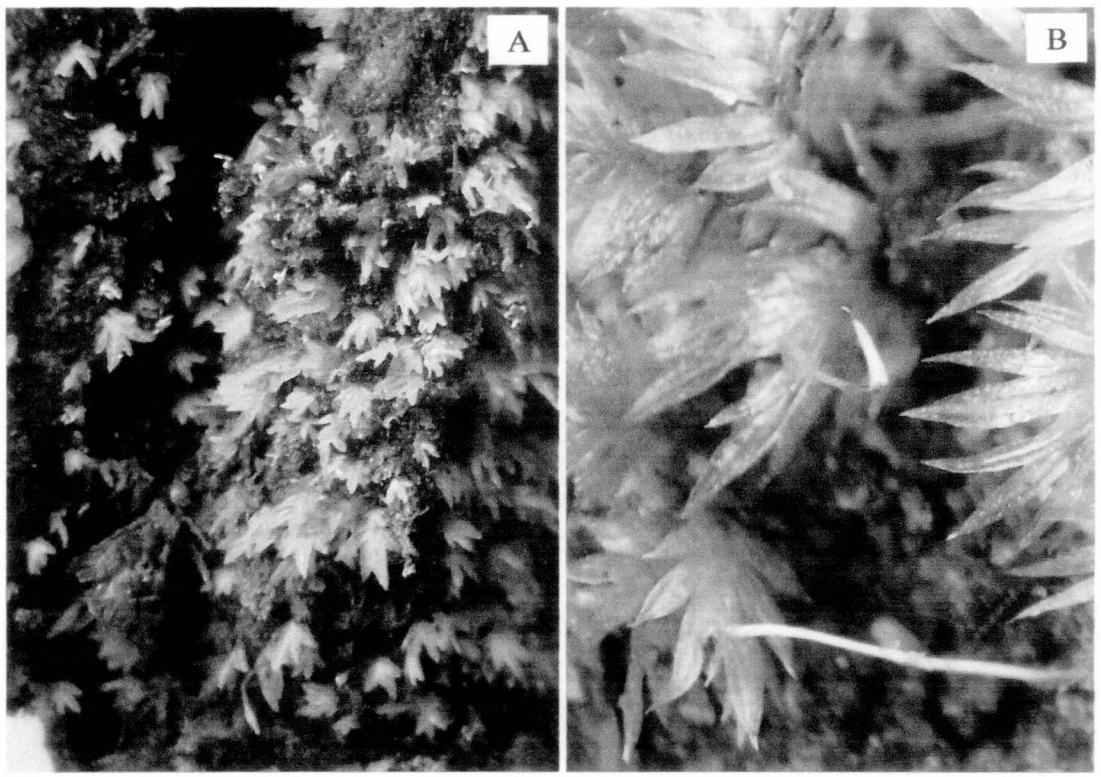

Figure 139. A: *Fissidens tenellus* Hook. f. & Wils. var. *australiensis* (A. Jaeger) Beever & Stone, and B: *Fissidens zollingeri* Mont.

APPENDIX D

Index of specimens

Index of Specimens

taxon number in brackets

Bartram 8 (39), Chantanaorrapint 611 (28), 886 (25), 1031 (9), 1092 (28), 1105 (9), 1126 (18), 2116 (8), Kurokawa 4176 (13), Kornochalert 585 (14), 1068 (23), Maxwell B-203 (32), B-204 (32), Narin 2576 (19), Nathi 1024 (34), Porompa 3 (19), Richards 28502 (11), 28503 (11), Robbins 3554 (7), 3556 (6), 3563 (11), 3584 (2), 3633 (7), Smitinand 1232 (23), 1296 (7), Suchit 37/2 (20), Suvarnasara 40 (7), 53 (39), 68 (39), Tan 05-106 (5), 02-201 (30), Tixier 658 (23), 1066 (7), Touw 3537 (11), 8022 (23), 8040 (9), 8045 (23), 8255 (9), 8309 (8), 8392 (11), 8729 (2), 8406 (7), 8867 (4), 8949 (22), 9015 (7), 9019 (23), 9187 (18), 9248 (22), 9275 (2), 9415 (9), 9547 (2), 9421 (23), 9461 (11), 9562 (18), 9663 (2), 9844 (2), 9902 (2), 10144 (22), 10176 (2), 10193 (7), 10212 (2), 10214 (31), 10248 (22), 10308 (39), 10380 (23), 10503 (2), 10788 (38), 10838 (28), 10852 (11), 11094 (14), 11101 (2) 11187 (8), 11193 (23), 11215 (23), 11219 (23), 11324 (28), 11549 (30), 12079 (35), 12210 (11), 12219 (19), 12220 (19), 12274 (23), 12289 (23), 12336 (14), 12351 (11), 12395 (9), 12415 (9), 12416 (11), 122275 (9), Wongkuna 150 (3), 151 (7), 152 (7), 154 (40), 155 (7), 162 (27), 163 (16), 164 (46), 165 (46), 166 (16), 167 (16), 168 (7), 169 (7), 170A (7), 170B (43), 171 (43), 172 (7), 173 (9), 174 (6), 175 (6), 176 (6), 177 (18), 178 (16), 179 (18), 180 (16), 181A (9), 183 (16), 184 (35), 185 (23), 186 (35), 187 (16), 188 (12), 189 (11), 190 (32), 192 (46), 197 (39), 199 (35), 200 (23), 202 (39), 204 (35), 205 (39), 206 (23), 207 (23), 208 (23), 209 (23), 212 (35), 213 (23), 214 (23), 216 (23), 217 (23), 218 (23), 219 (35), 220 (35), 221A (23), 222 (35), 224 (35), 226 (46), 227 (43), 230 (11), 231 (22), 232 (11), 233 (11), 234 (7), 235 (11), 236 (11), 237 (11), 238 (7), 239 (11), 240 (41), 241 (12), 242 (7), 243 (12), 244 (11), 245 (11), 246 (42), 247 (11), 248 (11), 249 (11), 250 (11), 251 (11), 252 (11), 254 (11), 255 (11), 253 (11), 256 (11), 257 (11), 259 (11), 260 (8), 261 (11), 262 (35), 263 (11), 264 (11), 265 (11), 266A (41), 267 (11), 268 (11), 269A (41), 270 (43), 270B (18), 271 (6), 272 (11), 273 (11), 273A (2), 275 (11), 276 (32), 277 (32), 278 (11), 279 (11), 280 (11), 281 (46), 282 (7), 283 (7), 284 (7), 285 (7), 286 (7), 287 (7), 288 (7), 289 (7), 290 (2), 291 (7), 292 (7), 293 (7), 294 (39), 295 (39), 297 (35), 297B (32), 299 (35), 300 (35), 301 (35), 303 (21), 304 (36), 305 (35), 306 (29), 307 (35), 309 (18), 310 (21), 311 (39), 312 (7), 313 (36), 314 (36), 315 (35), 316 (11), 317 (11), 318 (11), 319 (46), 320 (11), 321 (36), 322 (11), 323 (11), 324 (11), 325 (11), 326 (11), 327 (7), 328 (7), 331 (11), 331B (32), 332 (46), 334 (7), 335B (25), 336A (40), 337 (11), 338A(3), 338B (11), 338C (6), 339A (3), 340A (3), 340B (46), 341 (46), 341A (3), 342A (3), 343 (11), 344 (25), 345A (25), 346 (7), 347 (25), 349 (7), 350 (16), 352 (7), 353 (7), 358 (7), 359 (16), 360 (7), 361A (16), 362 (16), 363 (7), 364 (46), 364B (16), 365 (46), 366 (46), 367 (16), 370 (7), 371 (11), 374 (46), 375 (11), 376 (16), 377 (7), 379 (7), 382 (7), 383 (7), 384 (7), 385 (7), 386 (35), 387 (18), 390 (46), 391 (18), 393 (18), 398 (18), 399 (7), 400 (7), 401 (18), 405A (16), 405B (9), 409A (16), 410 (12), 411 (12), 416 (46), 417 (41), 418A (41), 419 (41), 435 (43), 436 (43), 436A (40), 437 (43), 437A (40), 438A (1), 438B (4), 438D (40), 439 (4), 441 (6), 442 (35), 443 (43), 444A (41), 444B (6), 444C (40), 446 (6), 447 (6), 448 (24), 450 (43), 451 (46), 452 (12), 453 (12), 454 (39), 455 (12), 456 (12), 457 (26), 458 (12), 459 (12), 460 (12), 461 (5), 462 (5), 463 (12), 464 (12), 465 (12), 466 (5), 467 (12), 468 (11), 471 (12),

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EDUCATION	1. B. Sc. Chiang Mai University, March 2002. Project: Taxonomy of some dicotyledonous plants in Sahnpakwahn, Hang Dong District, Chiang Mai 2. M. Sc. Chiang Mai University, May 2005. Thesis: Diversity of Epiphytic Mosses at Huay Kog-Ma, Doi Suthep-Pui National Park, Chiang Mai Province
PUBLICATION	1. B. C. Tan, **K. Wongkuna**, S. Manachit, and K. Santanachote. 2006. New records of Thailand mosses collected from Chiang Mai Province. Tropical Bryology 27: 95-100. 2. **Wongkuna, K.**, K. Santanachote, and B. C. Tan. 2009. Miscellaneous observations on *Fissidens* in Thailand with five new species records. Cryptogamie Bryologie 30(2): 301-309. 3. Printarakul N., **K. Wongkuna**, Soonthree Kornochalert, and Kanya Santanachote. 2009. Database of bryophytes and their ecological parameters in the CMU Herbarium. Maejo Int. J. Sci. Technol., 3(01), 99-129.
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