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Morphological Variability in *Endarachne binghamiae* J. Agardh (Phaeophyta) from the East Coast of Korea

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갈조식물 *Endarachne binghamiae* J. Agardh의 동해안에서의 형태적 변이

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ABSTRACT

Morphological variability was quantified for *Endarachne binghamiae* J. Agardh from five local populations collected in December, 1989 and in March, 1990. The sampling sites were chosen at intervals of 50'N along the east coast of Korea. Fifty individuals were haphazardly collected for the relationship between the blade length and reproduction, among which twenty five individuals were randomly selected for morphological variation. The Korean plants of *E. binghamiae* had the capacity of reproduction at an early stage of growth. The holdfast diameter and the plurangial length showed clinal variation of increment from the north to the south whereas the cryptostomata from the south to the north. The holdfast diameter, the blade thickness, the number of plurangial blades and the cryptostomata increased from December to March, when the blade length decreased. *Endarachne* is distinguished by the densely interwoven hyphal cells in the medulla, four to eighteen rows of the plurangial compartments, and absence of paraphyses between plurangia. Therefore *E. binghamiae* should not be combined into *Petalonia*, but rather the Soviet plants of *P. zosterifolia* may be renamed as a taxon belonging to the genus *Endarachne*.

INTRODUCTION

Different phenotypes of marine plants have frequently been observed in different habitats, which have led some authors to describe subspecies, forms or ecotypes. Such a phenotypic mosaic has been reported to have a scale as small as 10 m to 10 km (Kilar and Hanisak, 1989; Rice and Kenchington, 1990) and morphological differentiation over short distances is of ecological, evolutionary and taxonomic significance (See Hamrick, 1982). The foregoing facts indicate that traditional conception of species or infraspecific taxa should be reappraised with a complete appreciation of the morphological variability in local and regional scales.

Endarachne is a monotypic genus represented as *E. binghamiae*, which is typified as a specimen collected by Mrs. Bingham in the vicinity of Santa Barbara, California and housed in the Agardh Herbarium (no. 47849) of Lund University (Agardh, 1896; Nizamuddin and Farooqi, 1968). It has been circumscribed in having the densely intertwined hyphal cells in the inner tissue of the blades (Agardh, 1896; Saunders, 1898) and the absence of paraphyses between plurangia (Abbott and Hollenberg, 1976), but it also cast a taxonomic problem because of its resemblance with a form of *Petalonia fascia* (Setchell and Gardner, 1925). Vinogradova (1973) merged it into *Petalonia* because the hyphal cells are often observed in *P. zostericola* and *P. fascia*; *P. binghamiae* (J. Agardh) Vinog-

radova.

Although the genus concept is uncertain and in dispute, *Endarachne binghamiae* has been known in the recent species account of Japan (Yoshida *et al.*, 1985) and Taiwan (Lewis and Norris, 1987). The species has been studied on the life history in culture (Nakamura and Tatewaki, 1975), seasonal variability at a local area (Brophy, 1985) and the strategy of life history in field and culture (Brophy and Murray, 1989). The chromosome number is known ca. 20-22 in haploid unilocular sporangia (Nakamura and Tatewaki, 1975). The plants of *E. binghamiae* usually grow in the upper to mid-tidal zone of the warm to the temperate coasts of the world; North America (Abbott and Hollenberg, 1976), Japan (Okamura, 1936), Korea (Kang, 1966), Taiwan (Lewis and Norris, 1987), and Parkistan (Nizamuddin and Farooqi, 1968). Here we investigated the morphological variability of *Endarachne binghamiae* during an algal season in five local sites along the east coast of Korea and discussed the taxonomic position of the species.

MATERIALS AND METHODS

Sample collections were carried out along the east coast of Korea in December 26 to 29, 1989 and March 9, 1990 because the preliminary survey said that *Endarachne binghamiae* became mature and produced reproductive organs during winter. The coast line is rather monotonous and consists of a series of rock beds parallel to the coast. Its tidal zone is narrow because of small fluctuation of diurnal tide (mean=40 cm, extreme=60 cm) and receives moderate wave activity. Five sampling sites were selected at intervals of 50′N; Anin (37°70′N, 128° 8′E), Sinnam (37°20′N, 129°3′E), Hupo (36°70′N, 129° 3′E), Ganggu (36°3′N, 129°3′E) and Daebon (35°70′N, 129°4′E).

Fifty individuals of *Endarachne binghamiae* were collected haphazardly from each sampling sites for relationship between reproduction and size class, among which twenty-five individuals were randomly chosen and examined for the morphological variability. As an individual of *E. binghamiae* grows in tuft with many blades orginating from a discoid rhizoid, the quantitative data were taken from the individuals and the blades respectively. The number of blades, the diameter of the rhizoid, and the presence or absence of plurangia were measured and examined in the individual level. The largest blade was measured for length (± 1 mm), width (± 1 mm), and thickness (± 1 μm). The number of cryptostomata was counted in a slice of 25 mm^2 of the upper blade and the undulation was quantified the number of bends of the blade put on a white board. The fertile blade was measured for number of darkened plurangial sori, blade length, blade width and blade thickness. The plurangial sori were measured for length and row.

Representative specimens of *Endarachne binghamiae* were collected throughout our study and mounted on herbarium sheets. These voucher specimens have been deposited in the herbarium of Department of Biology at the Chungnam National University.

RESULTS

Reproduction and size class. A total of 4,246 blades (n=250) in December and 4,520 blades (n=250) in March were examined to determine the relationship between blade length and plurangia formation. The plurangial sori began to occur on the blades in the 21-40 mm range. Fifty percent of the blades was reproductive in the 61-80 mm range during December while in the 41-60 mm range during March. All blades longer than 121 mm bore the plurangial sori during December and March (Fig. 2). In the blade above 20 mm, proportion of the plurangial blades was just 49% during December whereas 71% during March. The blade thickness decreased with the blade length increasing (Fig. 3).

Vegetative morphology. The plants of *Endarachne binghamiae* grow in tufts on rocks, barnacles or other algae during fall and spring in Korean coast (Fig. 1a). They are very simple with a holdfast and many blades. The holdfast is discoid and the variability of its diameter ranged 3.7± 1.1 mm at Anin to 5.8± 1.4 mm at Ganggu in December while 5.2± 0.9 mm to 6.4± 1.4 mm at the same sites in March. In total the holdfast diameter increased from December to March and from the north to the south (Fig. 4a).

The erect blades originate from a holdfast. They are narrow in base and seem broad, linear to broadly spatulate in outline. The variability of blade length ranged 99.8± 23.7 mm at Sinnam to 122.8± 43.7 mm at Gampo in December while 75.8± 23.0 mm at Anin to 116.2± 30.0 mm at Ganggu in March. In total it decreased from December (mean=107.7 mm) to March (mean=97.3). It is interesting that the blade length increased from December to March in Sinnam, Hupo and Ganggu whereas decreased in Anin and Daebon (Fig. 4c). The blade width determines the blade shape. Its morphological variability ranged 7.9± 2.1 mm at Sinnam to 11.0± 3.6 mm at Ganggu

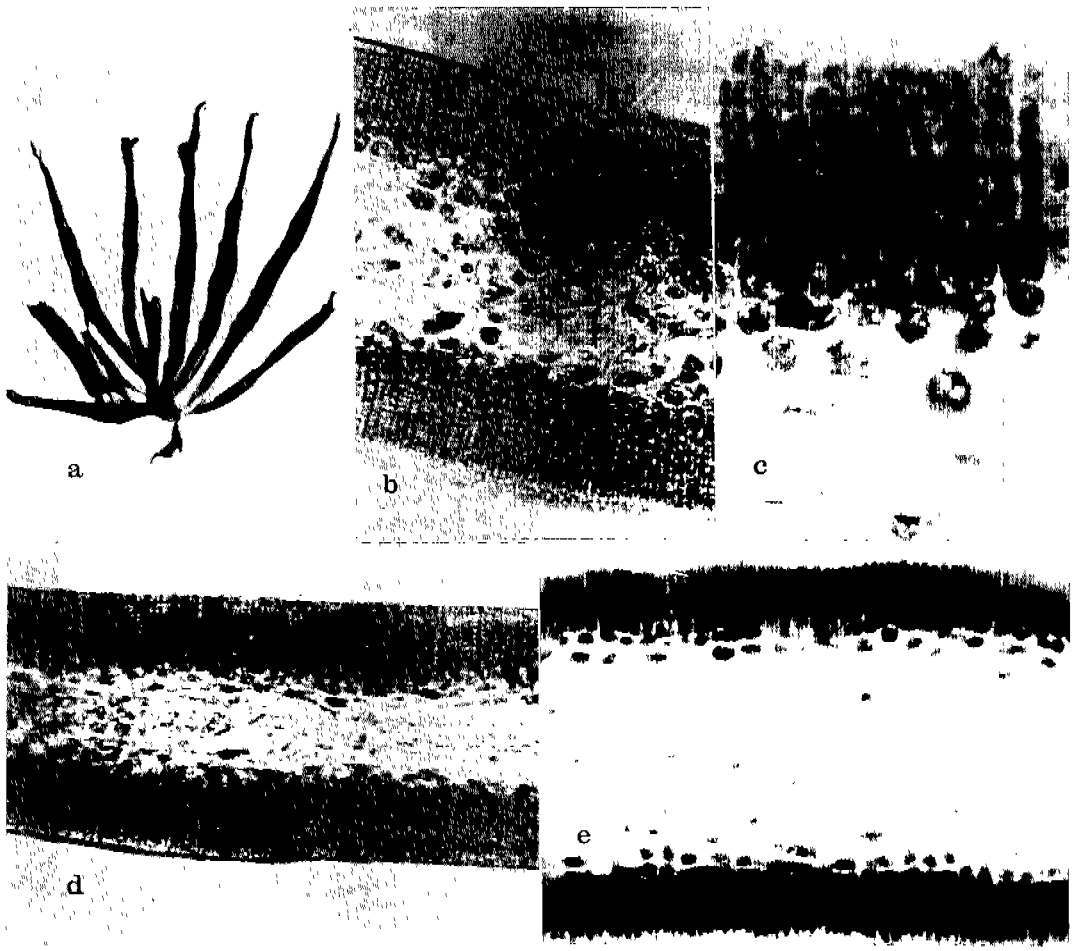

Fig. 1. The morphology of *Endarachne binghamiae* in (a) a mature plant (16 cm), (b) a transverse slice of blade with cryptostomata and plurangia (100 ×), (c) a transverse slice of blade with 12 layers of plurangial row arranged uniseriately to biseriately (400 ×), (d) a transverse slice of blade with 8 layers of plurangial row (100 ×), and (e) a transverse slice of blade showing the densely intertwined hyphal cells (100 ×).

in December while 8.0± 1.8 mm at Anin to 12.3± 3.2 mm at Ganggu in March. In total it increased a little from December (mean =9.7 mm) to March (mean=10.5 mm) but showed little significant difference among sites (Fig. 4b).

The blade thickness is also closely related to length and shows monthly difference (Fig. 4b). Its variability ranged 126.7± 26.7 μm at Hupo to 177.0± 35.5 μm at Ganggu in December while 191.3± 30.1 μm at Hupo to 240.4± 47.9 μm at Gampo in March. In total the blade thickness increased from December (mean=152 μm) to March (mean=210 μm). In a transverse section, the blades are composed of three tissues. The meristodermal cells in outer layer are radially elongated, arranged in a single row (Fig. 1b-c), and externally protected by a mucilage. Below the meristoderm lies the cortex which is composed of two to three layers of polygonal cells (Fig. 1c-d). The innermost tissue, the medulla, is densely full of the intertwined hyphal cells (Fig. 1d-e), that is one of the most important characters delimiting the genus *Endarachne* (Agardh, 1896).

The marginal undulation of the blades may be related to the environmental conditions. It was low (10.3± 6.8) at Anin and (12.9± 5.8) at Gampo while high (23.2± 9.7 to 35.1± 12.3) at other sites in March. The cryptostomata show local and monthly variation, of which the number increased from the south to the north (Fig. 5c). The number of cryptostomata per 25 mm^2 of the upper blade

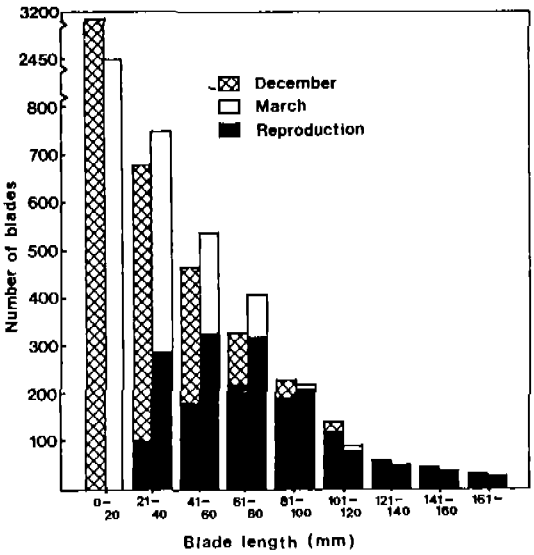

Fig. 2. Relationship between blade length and the proportion of reproductive blades in all local plants of *E. binghamiae*. Plotted are total number of blades examined per 20 mm size class.

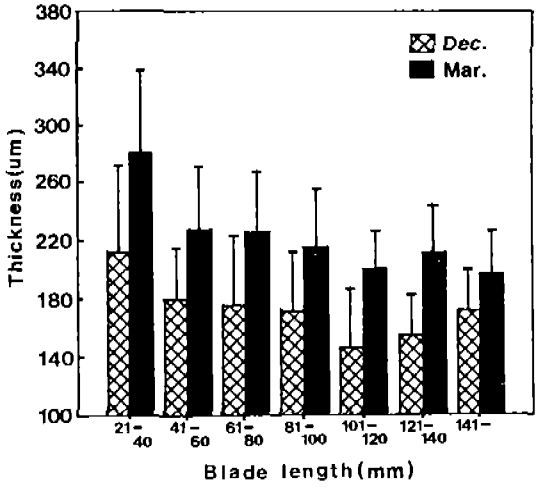

Fig. 3. Relationship between size class and thickness of all local plants in *E. binghamiae*. Plotted are total number of blades examined per 20 mm size class (mean± SD).

ranged 48.4± 19.6 at Ganggu to 112.5± 41.4 at Anin in December while 68.6± 29.7 at Sinnam to 139.7± 42.9 at Anin in March. In total the number of the cryptostomata increased from December (mean=69.4) to March (mean=96.5).

Reproductive morphology. *Endarachne binghamiae* shows heteromorphic life history in field and culture

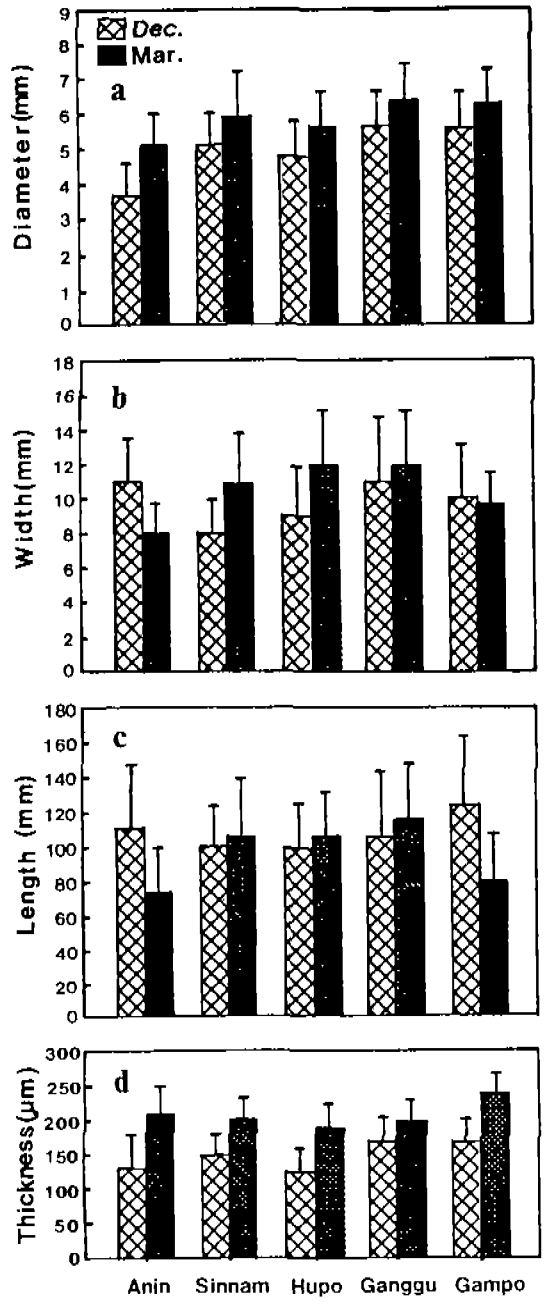

Fig. 4. Local variability of (a) the holdfast diameter, (b) the blade width, (c) the blade length, and (d) the blade thickness in *E. binghamiae* from the east coast of Korea (mean± SD).

(Nakamura and Tatewaki, 1975; Brophy and Murray, 1989). In summer the plants thrive a crust and in fall to spring live as an erect form. When fertile, the blades form plurangia spreading over the entire surface. The

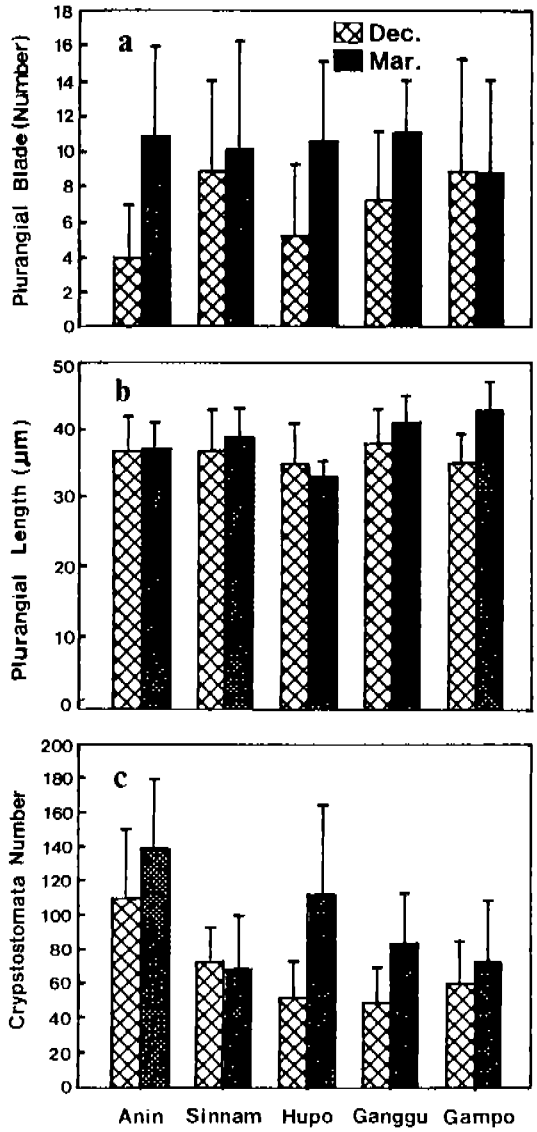

Fig. 5. Local variability of (a) the number of plurangial blades, (b) the length of plurangia, and (c) the number of cryptostomata in *E. binghamiae* from the east coast of Korea (mean± SD).

plurangial region appears a darkened band, which is a reliable indication of reproductive activity. The fertile blades usually had one to two darkened bands at all sites and sometimes three to six at Sinnam in March.

The plurangial blades showed similar pattern of variability to the vegetative blades in length, width and thickness (data not seen). The blade number bearing plurangia increased from December to March but showed no local difference (Fig. 5a). The plurangia originate from the meristodermal cells and are arranged in palisade tiers at right angle to the surface. They were uniseriate to biseriate and had 4-8-18 rows of compartments (Fig. 1c-d). We couldn't observe any paraphyses associated with plurangia in many sectioned slices. The plurangial length showed no significant difference among sites or months (Fig. 5b).

DISCUSSION

Reproduction in many land plants depends on size or accumulation of stored reserves rather than on age. In the brown algal genus *Laminaria*, sorus formation and development have been related to growth period, seasonal factors, carbon: nitrogen ratio in tissue, tissue age, and blade thickness (Lee and Brinkhuis, 1986) while in *Glossophora kunthii*, temperature, daylength and photon dose affect the fertility as well as the growth (Hoffman and Malbran, 1990). The Korean population of *Endarachne binghamiae* is shown to have the reproductive capacity at a relatively early stage of growth and the aged population (in March) is much more reproductive, that agrees well with Brophy and Murray (1989). The more aged the blades the thicker the blades while the longer the blades the thinner the blades. The foregoing facts imply that reproduction in *E. binghamiae* depends on blade length, thickness, seasonal factors and tuft age.

Spatial and temporal phenotypic plasticities are a major source of taxonomic confusion (See Briggs and Walters, 1984). Local and temporal patterns of morphological characters in *Endarachne binghamiae* vary with the kind of characters in this study. The holdfast shows local and temporal variabilities in its diameter, which is related to blade length, width, thickness, and other growth patterns. The blade length shows no local but temporal difference. The shortening of length in March is ascribed to withering of the apical portion of the blades (Abbott and Hollenberg, 1976) and wave action. The Korean plants reach a maximal height of 24 cm at Gampo, that is similar to Japanese (Okamura, 1936) and American plants (Abbott and Hollenberg, 1976), whereas the Parkistan plants in a sheltered area 52 cm (Nizamuddin and Farooqi, 1968). The blade width is usually 1-3(5) cm and shows little geographical difference, as seen in Table 1.

The blade thickness is closely related to reproduction (see Fig. 3) and its increment in March is ascribed to the formation of reproductive organs originating from the meristodermal cells (Setchell and Gardner, 1925). The

Table 1. Taxonomic characters among geographical populations of *Endarachne binghamiae*

	Korea (East coast)	Japan (Hokkaido)	America (California)	Parkistan (Karachi)
Blade length	5-24 cm	20-25 cm	10-25 cm	10-52 cm
Blade width	1-2 cm	1-5 cm	1-3(5) cm	upto 2.5 cm
Blade shape	linear spatulate	linear spatulate	linear, broadly spatulate	linear, broadly lanceolate
Apex	acute, obtuse	acute, obtuse	obtuse	acute
Tissue layer	three	three	three	three
Plurangial sori				
row layer	4-18	1-12	-	4-18
arrangement	unseriate biseriate	uniseriate biseriate	uniseriate	uniseriate
length	33-43 μm	-	40-50 μm	43-46 μm
Unilocular sporangia	-	obovoid*	-	-
Growing season	winter-spring	winter-spring	fall-winter**	Sep.-Oct.
Reference	Our result	Okamura 1936	Abbott and Hollenberg, 1976	Nizamuddin and Farooqi, 1968

*Nakamura and Tatewaki, 1975 in culture.
**Brophy and Murray, 1989

intertwined hyphal cells in the medulla are present in all the local and temporal plants as well as a blade in whole, that supports the establishment of the genus as well as the species by Agardh (1896).

The marginal undulation of the blades may be related to wave action. It is very interesting that the cryptostomata shows clinal variation from the south to the north whereas the holdfast diameter and the plurangial length show the opposite direction of clinal variation. The size and distribution of cryptostomata have been considered to be of taxonomic value in the brown algal genus *Sargassum* (Kilar and Hanisak, 1989).

Reproductive and the associated organs have been much useful in differentiating taxa because structural stability maintains the specific identity (See Stuessy, 1990). *Endarachne binghamiae* forms two kinds of reproductive organ in culture. The one is plurangia in an erect stage and the other unilocular sporangia in a crust stage (Nakamura and Tatewaki, 1975). The row of plurangial compartments ranges 4 to 18 in this study, as is the same in other geographical populations. Their arrangement is uniseriate to biseriate in Korean and Japanese plants whereas uniserate in American and Parkistan plants (Table 1). This difference may be of taxonomic importance because the different reproductive structures can express the different specific identity. The paraphyses between plurangia which separate the genus *Petalonia* from *Endarachne* (Abbott and Hollenberg, 1976) are not present in our plants.

The genus *Endarachne* has been placed between *Scytosiphon* and *Petalonia* (=*Phyllitis*) (Agardh, 1896) and has especially been confused with forms of *P.* (=*Ilea*) *fascia* (Saunders, 1898; Setchell and Gardner, 1925; Fletcher, 1987). Vinogradova (1973) treated *Endarachne* as a homonym of *Petalonia*, but we have a view that the genus *Endarachne* is correct. The Soviet plants of *P. zosterifolia* (Vinogradova, 1973, p. 29, Fig. 1) have densely interwoven hyphal cells, strikingly different from the Soviet *P. fascia* (Vinogradova, 1973, p. 31, Fig. 2). As the genus *Petalonia* is typified as *P. debilis* (C. Agardh) Derbes et Solier (=*P. fascia* (Müller) Kuntze) (Womersley, 1987; Greuter *et al.*, 1988), the fact that *P. zosterifolia* from Soviet and *E. binghamiae* share the hyphal cells in the medulla cannot reject the genus *Endarachne*. Furthermore the England plants of *P. zosterifolia* observed by Fletcher (1987, p. 238, Fig. 65d-g) have no hyphal cells but only the round cells. If the observation of Vinogradova (1973) is right, the Soviet plants of *P. zosterifolia* may be renamed as a species of *Endarachne* (See Jeffrey, 1982). The second circumscribing *Endarachne* is the row of plurangial compartments. They range 4-18 in *Endarache* (Table 1), but usually 4-8 or rarely 14 in *Petalonia* (Nakamura and Tatewaki, 1975; Fletcher, 1987). The third is that the paraphyses are absent in *Endarachne* while present

between plurangia in *Petalonia* (Fletcher, 1987). However, because the genus *Petalonia* is notoriously variable with numerous dubious species and varieties (Fletcher, 1987), the taxonomic relationship between *Endarachne* and *Petalonia* needs as further study.

摘 要

Endarachne binghamiae J. Agardh의 형태적 변이를 조사하여 분류학적으로 고찰하였다. 북위 50′ 간격으로 동해안의 안인, 신남, 후포, 강구, 대본을 채집 대상지로 선정하여, 1989년 12월과 1990년 3월에 각 장소에서 50개체씩 任意로 채집하고 체장 계급별 생식율을 조사한 후, 이중에서 25개체를 無作爲로 선택하여 형태적 특징을 정량화하였다. *E. binghamiae*의 한국산 식물들은 생장의 초기부터 생식기관을 형성한다. 가근의 직경과 複子囊의 길이는 북에서 남으로 境斜變移(clinal variation)을 보이는 반면 毛叢의 수는 남에서 북으로 경사변이를 보인다. 가근의 직경, 엽상체의 두께, 모총의 수 및 복자낭을 가진 엽상체의 수는 3월에 증가하나, 엽상체의 체장은 감소한다. *Endarachne* 속은 수층에 꼬여 있는 사상형의 가근세포가 밀집하여 있고, 복자낭의 층수가 4-18열이며, 측사가 없다는 점에서 近緣屬들과 분류학적으로 뚜렷이 구별된다. 따라서 *E. binghamiae*는 *Petalonia*屬 식물로 改名되기 보다는 오히려 소련산 *P. zosterifolia*가 *Endarachne*屬에 속하는 한 분류군으로 改稱되어야 할 것이다.

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