Two Moonworts of the Rocky Mountains; Botrychium hesperium and a New Species Formerly Confused with It

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The taxonomy of western North American botrychiums still needs much research. Interpretations of the past were based largely upon scanty and poorly prepared collections. For over 30 years only two *B. matricariifolium*-like moonworts have usually been accepted for this region—*B. boreale* subsp. *obtusilobum* (Rupr.) Clausen and *B. matricariifolium* subsp. *hesperium* Maxon and Clausen (Clausen, 1938). As to the former, we conclude that the western North American plant is not closely related to *B. boreale,* as will be discussed in a monograph of this genus currently in preparation. The correct name for taxon *obtusilobum* is *B. pinnatum* St. John (*Fig. 1,* a–g). Taxon *hesperium* also proves to be a distinct species, readily distinguished from *B. matricariifolium* A. Br. subsp. *matricariifolium,* which occurs in North America only east of the Great Plains (*Fig. 2,* h–n). With our recent opportunity to investigate large populations of these plants in the field in numerous localities, we are now confident of the distinctness of not only *B. pinnatum* and *B. hesperium,* but of a third element as well, which is described here for the first time.

It is no surprise to discover a new species related to *B. hesperium* in western North America, where the rate of endemism among moonworts is the highest in the world. With some ten out of 14 of the described and undescribed species known only there, western North America is clearly the metropolis for this subgenus (*Botrychium* subg. *Botrychium*). Using primarily the sterile lamina as a basis, we provide the following key to its major groups.

KEY TO THE GROUPS OF BOTRYCHIUM SUBG. BOTRYCHIUM IN NORTH AMERICA

1. Sterile lamina absent; frond composed of two sporophores.....*B. paradoxum* group
1. Sterile lamina present; frond with a single sporophore.
   2. Larger pinnae mostly fan-shaped or wedge-shaped, not pinnatifid; costa absent or poorly developed.
      3. Pinnae and lobes, especially the distal ones, commonly irregularly confluent; basal pinnae often strongly exaggerated.....*B. simplex* group
      3. Pinnae and lobes regularly separated; basal pinnae conform or only slightly exaggerated. *B. lunaria* group
   2. Larger pinnae mostly oblong to lanceolate, pinnatifid; costa usually present, at least in basal half of pinna.....*B. lanceolatum* group

Early in our studies we did not notice that the original collections of *B. hesperium* were mixtures of two species. Although certain specimens were different in a number of respects, we simply believed that some specimens had narrow, pointed segments and resembled *B. lanceolatum* and others had rounded segments and resembled *B. simplex*. We therefore assumed that *B. hesperium* was of hybrid origin,

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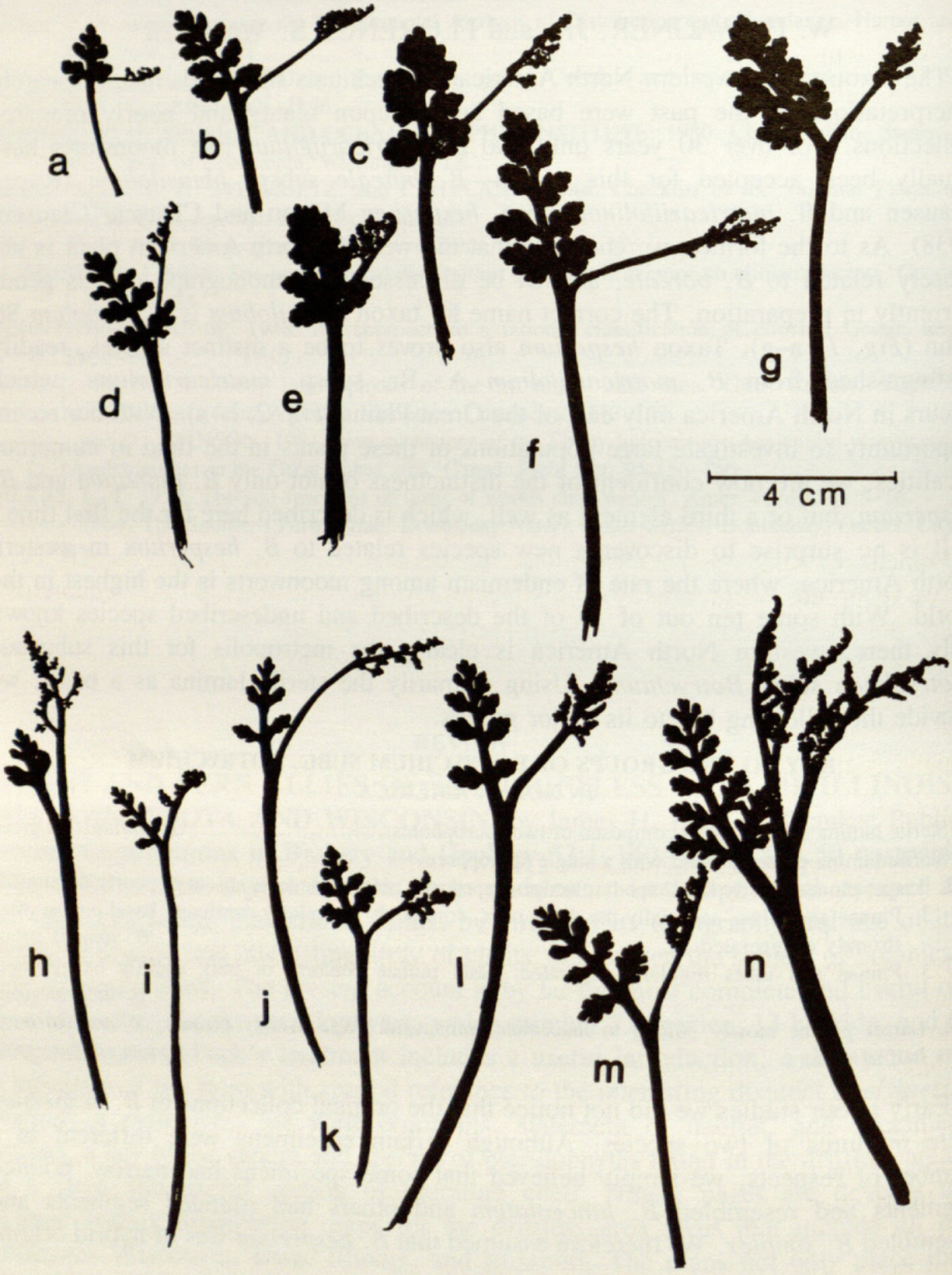

FIG. 1. Silhouettes of moonworts similar to *B. echo* and *B. hesperium*. FIGS. a–g. *B. pinnatum (Wagner 81113*, MICH). FIGS. h–n. *B. matricariifolium* (h, j, n, *Wagner 81003*, MICH; others *Wagner 81028*, MICH).

and that its apparent variability resulted from this. Our field studies, however, soon dispelled this interpretation. The type specimen of *B. hesperium* includes only individuals with rounded segments. It was taken at Glacier Lake in Rocky Mountain National Park by a high school teacher, E. Bethel, in 1914. Bethel and others took numerous specimens there during the period 1911 to 1921. Bethel was aware that there were actually two elements involved, and he and Ira Clokey separated their 1921 collection at Glacier Lake into two groups—*Bethel & Clokey 3987*, typical, and *3987a*, with "segments narrow, more acute." W. R. Maxon was also aware of these distinctive plants as shown by his annotations of one of the herbarium sheets (US984959).

Our new interpretation is based upon over 200 specimens of *B. hesperium* studied in the field in seven localities, and over 300 of the new species, *B. echo*, in ten localities. The two species grow in such similar habitats that one description of the habitat will suffice for both. They tend to occur together, often side-by-side. Also associated in genus communities with them in the southern Rockies are *B. lanceolatum*, *B. lunaria*, and *B. minganense*. In Montana and Alberta, where *B. echo* is not known, *B. hesperium* occurs also with *B. paradoxum* and *B. pinnatum*. Most of the localities that we studied had only a few plants. To illustrate, for *B. echo*, ten localities yielded respectively 1, 2, 2, 2, 3, 9, 11, 25, 97, and 150+ plants. The two most productive localities were in Arizona at Mount Baldy and at San Francisco Peaks. In the former locality, *B. hesperium* was absent, but at the latter we recorded 88 individuals of this species. At only one locality in the southern Rockies did we find only *B. hesperium* (*Wagner 81158*, 3 individuals in company with *B. lanceolatum*), but in the northern Rockies it apparently regularly occurs alone.

The two species grow on grassy slopes, roadsides, and at edges of lakes. The soil is usually rocky, the substrate including decomposed granite as well as other rock types. In the southern Rockies the plants grow at elevations between 8,500 and 11,500 ft. The easiest way to find them is to drive along roads at proper altitudes and to seek flat roadside ditches with gravelly soil and scattered shrubby vegetation, *Picea* saplings and *Salix* shrubs dominating. Plants are sometimes found growing even in the gravel of the road shoulder! In addition to spruces and willows, other woody associates encountered are *Lonicera involucrata*, *Potentilla fruticosa*, and species of *Abies*, *Juniperus*, and *Ribes*. The herbaceous associates include weeds and involve such genera as *Achillaea*, *Antennaria*, *Arenaria*, *Carex*, *Cerastium*, *Epilobium*, *Festuca*, *Fragaria*, *Frasera*, *Mertensia*, *Penstemon*, *Potentilla*, *Saxifraga*, *Sedum*, *Selaginella*, *Setaria*, *Solidago*, *Trifolium*, *Valeriana*, and *Zygadenus*. Seekers of these plants should be warned that only one out of ten or twenty seemingly appropriate habitats yield these botrychiums. It is therefore necessary to sample many likely sites.

Rather than distinguish only *B. hesperium* and *B. echo*, all of the North American taxa of the *B. lanceolatum* group that might be confused with them are keyed. For more details of the differences between *B. hesperium* and *B. echo* themselves, the reader is referred to the descriptions and to *Figure 4*. This key is based upon medium and large individuals.

FIG. 2. Silhouettes of moonworts. FIGS. a–i. *B. echo (Wagner 82107b,* MICH). FIG. j. A much divided form of *B. echo* (*Bethel & Clokey 3987a,* US; see also *Fig.* 3, a–e). FIGS. k–o. *B. hesperium* (k–n, *Wagner 82107a,* MICH; o, *Bethel* in 1914, US—type).

KEY TO THE BOTRYCHIUM LANCEOLATUM GROUP IN NORTH AMERICA

1. Sterile lamina broadly deltate, sessile to subsessile; sporophores of full-sized plants usually composed of several major upright axes; plants of northern North America.....*B. lanceolatum*
1. Sterile lamina mostly oblong to oblong-deltate, subsessile to stalked; sporophores of full-sized plants usually with one major upright axis, sometimes with one or two upright laterals.
   2. Sterile segment mostly conspicuously stalked, the stalk 20–30% of the blade length; segment tips usually serrulate or crenulate; living lamina pale blue-green, dull; sporophore commonly twice as long as sterile lamina; plants of eastern North America.....*B. matricariifolium*
   2. Sterile segment short-stalked or subsessile, the stalk 5–20% of the blade length; segment tips usually entire, repand, or pointed; living lamina color various; sporophore usually only 1.5 times as long as sterile segment (except in *B. hesperium*); plants of western North America.
      3. Pinnae and lobes well separated, not approximate or overlapping, mostly more or less parallel-sided, linear to oblanceolate; pinna tips pointed; basal pinnae, except in the smallest and largest fronds, usually deeply cleft into a single lower projection and larger upper projection; lamina shiny green in life.....*B. echo*
      3. Pinnae and lobes usually approximate or overlapping, the large ones abruptly contracted at base, oblong-lanceolate to ovate to deltate; pinna tips blunted or rounded; basal pinnae not cleft into two projections; color and luster various.
         4. Pinnae with few lobes, these mainly on the basal side; lowest pinnae exaggerated, ascending and subclasping, strongly asymmetrical, the lower side with coarse basiscopic lobe; segments broadly adnate at base; lamina gray-green, dull in life.....*B. hesperium*
         4. Pinnae with numerous lobes, these roughly equal in number on the upper and basal sides; lowest pinnae mostly equal to or slightly larger or smaller than next distal pair, not ascending or clasping, nearly symmetrical, the lower side with small lobes subopposite to those on upper side; segments narrowly adnate at base; lamina bright green, shiny in life. *B. pinnatum*

The following descriptions have been condensed to emphasize the most important differences between the species.

Botrychium echo W. H. Wagner, sp. nov. **Figs. 2–5.**

Sporophorum segmento sterili plerumque sesquilongius; segmentum sterile vivum supra vivide viride nitidumque, fere sessile vel brevissime stipitatum, lamina late oblonga 2.2 (1–4.5) cm longa; pinnae bene separatae, non imbricatae, oblanceolatae, lanceolatae, vel lineares, apicibus acutis, basibus subzygomorphis; pinnarum par infimum longitudine par proximum aequans vel paulo superans, patens, non amplectens; sporae tenelle verrucatae.

Plants exclusive of their roots 9.5 (3–15) cm tall, the common stalk 6 (2–10) cm tall, sporophore relatively short, 3.5 (1.5–8) cm tall, only half again as long as the sterile segment and only 20% with 1 or more branches ⅓ or more as long as main axis of sporangial cluster; sterile segment bright green and shiny in life, nearly sessile to short-stalked, broadly oblong, 2.2 (1–4.5) cm long; pinnae narrowly attached to a relatively narrow rachis, remote to approximate, not overlapping, lanceolate to oblanceolate to linear with pointed apices, the pinna bases subsymmetrical, the laminar margins nearly entire; basal pinna pair not exaggerated in length, equal to or somewhat longer than the adjacent pair, spreading or only moderately ascending, not clasping; spores 37 (27–53) μm in maximum diameter, irregularly and finely verrucate, the warts small, low, and separated by narrow, shallow channels.

TYPE: Glacier Lake, Boulder Co., Colorado, 2800 m. alt, *E. Bethel & I. W. Clokey 3937a* (US; isotypes CAS, WTU).

PARATYPES:

ARIZONA: Apache Co.: White Mts., Mt. Baldy, on open bald, *Wagner 82101* (MICH). **Coconino Co.:** San Francisco Mt., Inner Basin, *E. L. Little, Jr. 4741* (US—mixed with *B. lunaria*); NE slope of

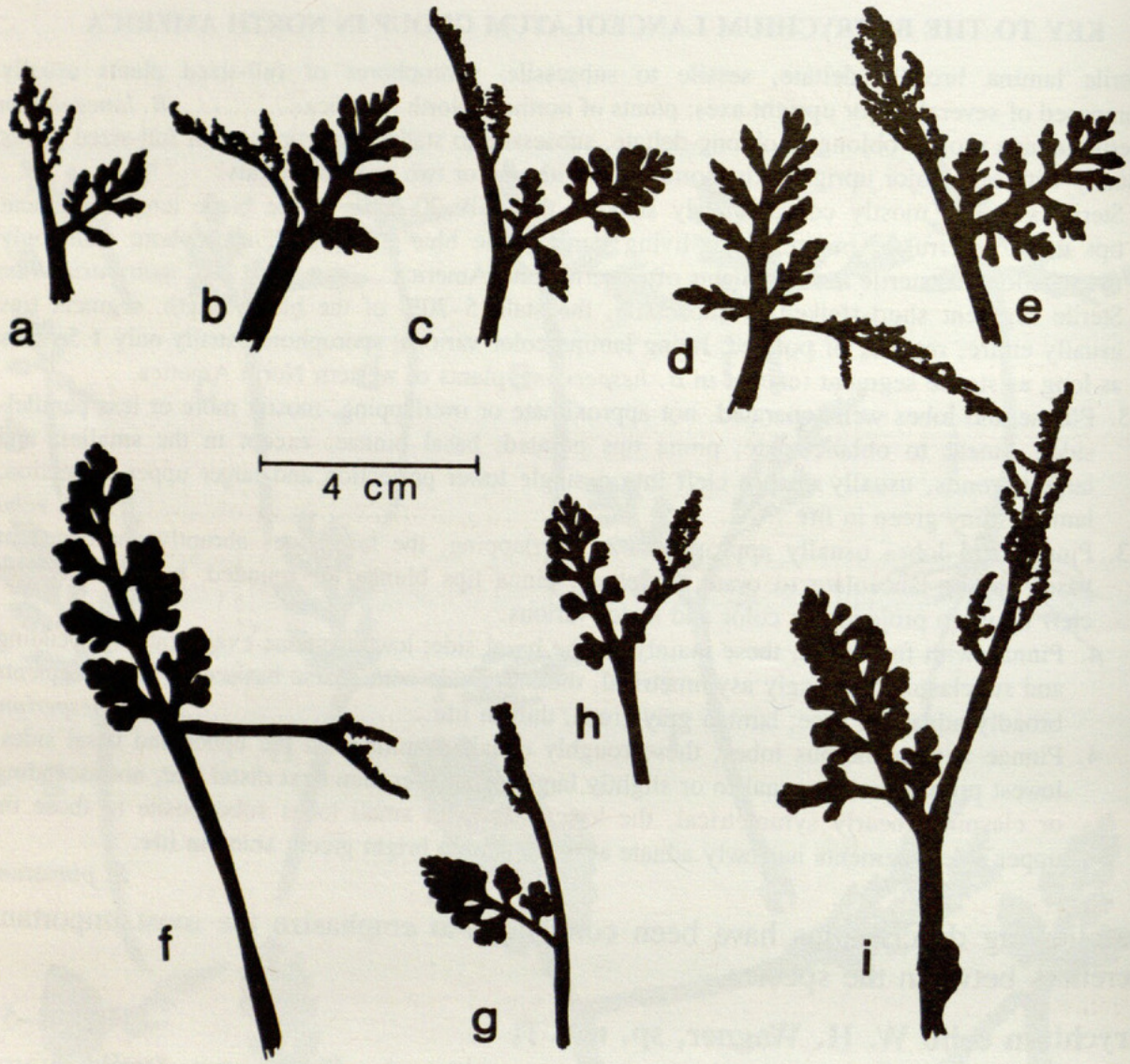

FIG. 3. Silhouettes of moonworts. FIGS. a–e. Unusually dissected forms of *B. echo* resembling *B. matricariifolium (Wagner 82101,* MICH—see also *Fig. 1,* j). FIG. f. Probable *B. lanceolatum* × *minganense* hybrid; note the few, long segments (*Wagner 82121,* MICH). FIGS. g–i. Probable *B. echo* × *minganense* hybrids; note the relatively more numerous, shorter segments (*Wagner 82104*, MICH).

Mt. Doyle, *Wagner 82107b* (MICH). **COLORADO: Boulder Co:** Glacier Lake, July 1914, *E. Bethel* (US), 13 July 1912, *E. R. Cross* (US), *Bethel & Clokey 3987* (UC—2 sheets, both mixed with *B. hesperium*); Arapahoe Moraine, E slope, 1 mi S of University Camp, *W. A. Weber 3431* (WTU). **Clear Creek Co.:** Roadside near Echo Lake, *Wagner 80136b* (MICH), *81153b* (MICH); Warren Mt. Picnic Ground, 2.8 mi E of CO-515, *Wagner 81158* (MICH); US-6, 0.8 mi S of I-70, *Wagner 81160* (MICH). **El Paso Co.:** Pikes Peak below moraine, *H. L. Shantz 52* (US). **Gunnison Co.:** Monarch Pass, *Wagner 82118* (MICH); 0.5 mi E of Monarch Pass on CO–50, *Wagner 82123* (MICH). **Lake Co.:** Road to Independence Pass, 3.1 mi E of Hairpin Turn, *Wagner 82127* (MICH). **Summit Co.:** Near Breckenridge, *K. K. Mackenzie 99* (NY—mixed with *B. lanceolatum*); CO-91, 2–3 mi S of I-70, *Wagner 81164* (MICH). **UTAH: Summit Co.:** 1.5 mi S of Spirit Lake, *A. H. Holmgren et al. 7130* (UC—mixed with *B. lunaria*).

The Greek specific epithet *echo* is used here in apposition. It was chosen to reflect the fact that this moonwort seems to repeat the characteristics of other, similar species. One of the best areas to study it is where we first recognized its distinctions from *B. hesperium,* namely Echo Lake on the slopes of Mount Evans, Colorado.

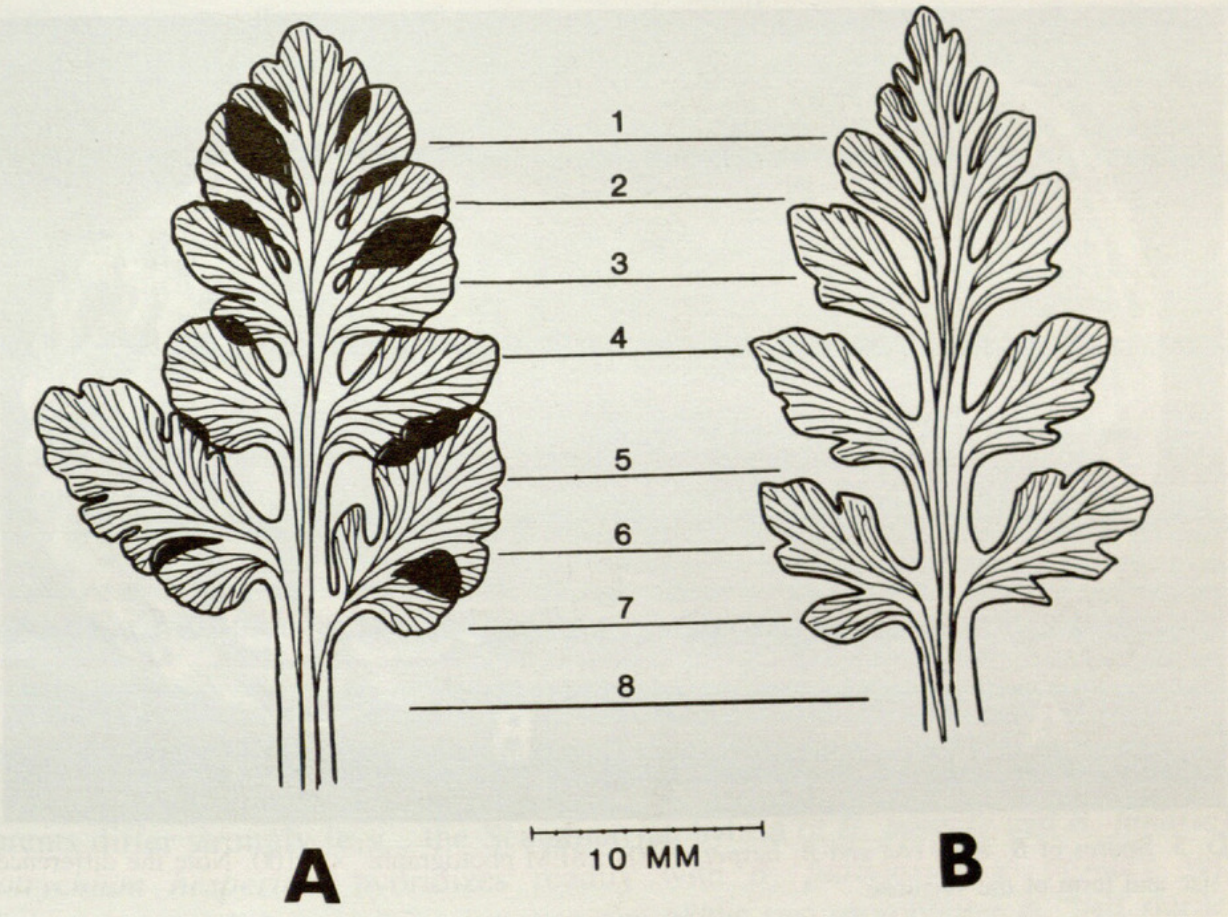

FIG. 4. Comparison of *B. hesperium* (A) and *B. echo* (B) from a mixed population at San Francisco Peaks, AZ. Tracings of cleared sterile blades. The characters are: 1 = ovate, broadly attached vs. linear-lanceolate, narrowly attached pinnae. 2 = Overlapping vs. separated pinnae. 3 = Repand vs. subentire margins. 4 = Rounded vs. pointed pinna tips. 5 = Basal pinnae much larger than vs. subequal to adjacent pinnae. 6 = Basal pinnae erect and subclasping vs. spreading and non-clasping. 7 = Basal pinnae with broad, overlapping basal lobe vs. with narrow separated basal lobe. 8 = Stalk long vs. short.

In certain respects, especially the shape of the pinnae and the glossy laminar surfaces, *B. echo* resembles *B. lanceolatum*. We have not yet detected any hybrids between the two species, but they might readily be confused with one or the other of the parents.

A distinctive but uncommon form of *B. echo* with more dissected pinnae than normal is known (*Fig. 1*, j; *Fig. 3*, a–e). The basal pinnae and sometimes the medial pinnae possess 3 or 4 lobes on the lower side and 2 or 3 lobes on the upper side. Comparison of the outline of these with *B. matricariifolium* (*Fig. 1*, h–n) shows considerable resemblance. Clausen (1938), who combined *B. echo* and *B. hesperium* as a single taxon, surely had such plants as these in mind when he wrote that some specimens "can be matched almost exactly by material of [typical *matricariifolium*]." The dissected form is especially well developed at Mount Baldy, White Mountains, Arizona. It is connected by intermediates to the normal form.

Botrychium hesperium (Maxon & Clausen) Wagner & Lellinger, Amer. Fern J. 71:92. 1981, pro hybr.

Botrychium matricariifolium subsp. *hesperium* Maxon & Clausen, Mem. Torrey Bot. Club 19:88. 1938.

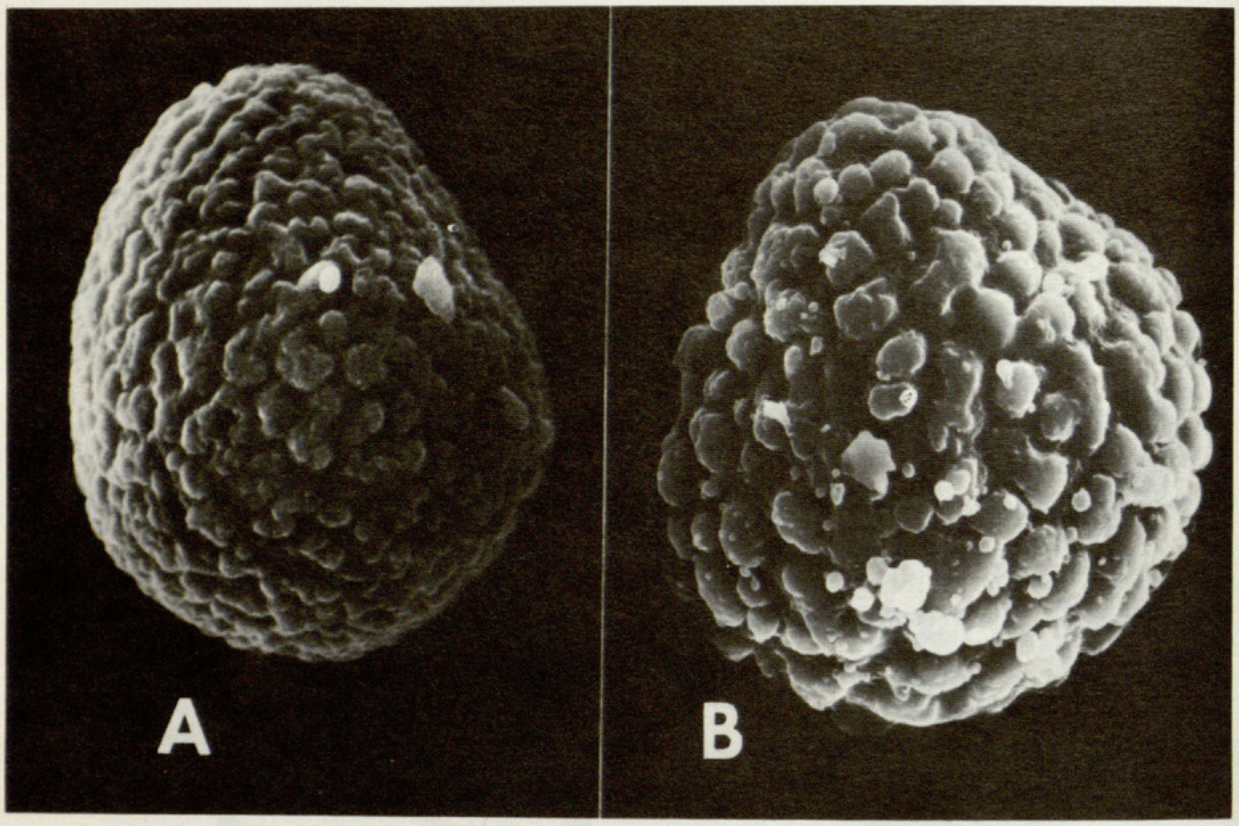

FIG. 5. Spores of *B. echo* (A) and *B. hesperium* (B). SEM photographs ×1,100. Note the differences in size and form of the verrucae.

Plants exclusive of their roots 12 (5–20) cm tall, the common stalk 7 (3–13) cm tall, sporophore relatively tall, 5 (3–10) cm tall, nearly twice as long as sterile segment, 80 percent with 1 or more basal branches ⅓ or more as long as main axis of sporangial cluster; sterile segment gray-green and dull in life, mostly short-stalked, subdeltate, 2.5 (1–5) cm long; pinnae broadly attached to a relatively wide rachis, crowded to commonly overlapping, ovate to lanceolate with rounded apices, the pinna bases asymmetrical, the lamina margins finely repand; basal pinnae commonly exaggerated, up to twice as long as the adjacent ones, often upright and commonly clasping; spores 37 (29–50) μm in maximum diameter, irregularly and coarsely verrucate, the warts large, prominent, and separated by wide, deep channels.

TYPE: Glacier Lake, Boulder Co., Colorado, 8500 ft, July 1914, *E. Bethel* (US—5 isotypes in addition).

OTHER COLLECTIONS EXAMINED:

CANADA: Alberta: Waterton Lakes National Park, W of Red Rock Canyon Parking Area, *Wagner 81103a-d* (MICH).

ARIZONA: Coconino Co.: San Francisco Peaks, Inner Basin, NE slope of Doyle Mt., *Wagner 82107a* (MICH). **COLORADO: Boulder Co.:** Glacier Lake, *Bethel & Clokey 3987* (CAN, CAS, US); Rocky Mt. National Park, Loch Vail Trail, Glacier Gorge, *A. E. Porsild & B. E. Willard 23102* (CAN). **Clear Creek Co.:** Roadside near Echo Lake, *Wagner 80136a* (MICH), *81153a* (MICH). **Lake Co.:** Road to Independence Pass, 3.1 mi E of Hairpin Turn, *Wagner 82128* (MICH). **MONTANA: Deer Lodge Co.:** Flint Ridge Mts., Storm Lake, S of Georgetown Lake, *Wagner 80129a* (MICH), *81116b* (MICH).

It is interesting to note that Maxon's original, unpublished interpretation of this taxon was as given here. On the type specimen he had written the label to read "Botrychium hesperium Maxon sp. nov." The occurrences that we have found so far

in Montana and Alberta contain plants much smaller on the average than those in Colorado and Arizona. The northern plants resemble young stages of the southern ones, and they may be dwarfed by the climate. The coarsely sculptured spores that we observed in *B. hesperium* (*Fig. 5*, B) are like those of *B. lanceolatum*.

For *B. echo*, our collection records range from 13 July to 20 September, with most specimens taken in August. *Botrychium hesperium* may be similar, but there is some evidence that it may appear earlier and die down earlier. Judging from the condition of the large sample of plants taken at San Francisco Peaks, *B. hesperium* shows more effects of ageing. Seventy percent of the specimens of *B. hesperium* collected on 21 August 1982 showed evidence of damage—browned margins and broken, eaten, or otherwise tattered pinnae—compared to only 30% of *B. echo* collected at the same place and time. The leaves of *B. echo* appeared to be fresher.

As would be expected, sterile interspecific hybrids involving both *B. hesperium* and *B. echo* have been encountered. Their hybrid origin is deduced by their association with parents, occurrence as usually one or a few plants, morphological intermediacy, and abortion of spores.[1]

Because only a single leaf is produced per year, it is difficult to obtain cytological observations as a rule; however, Sahashi (1979) has documented irregular meiosis in a Japanese hybrid. The most obvious interspecific hybrids are those in which the parents differ strongly (e.g., the Scandinavian hybrid of *B. boreale* and *B. lunaria*). *Botrychium hesperium* hybridizes readily with *B. paradoxum* to produce very obvious intermediates, striking because one of the two sporophores is "half sterile" (Wagner & Wagner 1981; Wagner et al., 1982). We have encountered a few definite hybrids involving *B. echo*. These involve *B. minganense* Victorin. Some are from Mount Baldy, Arizona, where the parents occur together locally in abundance. At San Francisco Peaks, we found a number of sterile plants involving what appear to be combinations of *B. echo, hesperium,* and *lunaria*, but these will require more study to separate. Some hybrids involve yet other species, for instance, a specimen from Monarch Pass, Colorado, we first thought was *B. echo* × *minganense* (*Fig. 3*, f). However, the cutting is somewhat different; also *B. echo* is rare and sporadic at this locality, while both *B. lanceolatum* and *minganense* are abundant and the latter species probably are the parents.

This is part of an investigation of the evolution and systematics of *Botrychium* made possible by NSF grants DEB 800536 and DEB 8202768. We are indebted to a number of individuals who have helped us, especially W. R. Anderson, R. Eccleston, R. H. Hevly, J. Kuijt, J. D. Montgomery, A. Neas, W. A. Weber, M. D. Windham, and G. Yatskievych. The following herbaria have kindly supplied specimens of the species considered here: ASC, BRY, CAN, CAS, DAO, MO, NY, UC, US, and WTU.

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[1]Confirmation of spore abortion is accomplished in *Botrychium* using only a dissecting microscope at 30–60X magnification. The spores of specimens that were dried while the sporangia still had not completely discharged tend to be released and become attached (electrostatically?) to the sporophore axes and opened sporangial walls. If the spores are abortive, the sizes are extremely irregular—very small, normal, and very large. The largest spores tend to be more or less spherical and not tetrahedral.

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SHORTER NOTES

LYCOPODIUM COMPLANATUM AND L. ANNOTINUM FOUND IN THE BLACK HILLS.—*Lycopodium complanatum* L. and *L. annotinum* L. were found growing together in the Black Hills of Wyoming on July 27, 1982. The location is in Crook County, Upper Sand Creek at confluence with Spottedtail Gulch, T51N R60W Section line of 20–21, elevation 5600 feet. The plants were growing under White Spruce, *Picea glauca* (Moench) Voss, and Hazelnut, *Corylus cornuta* Marsh., along with Low Red Huckleberry, *Vaccinium scoparium* Leiberg. *Lycopodium complanatum* was found only at this location, but *L. annotinum* extended on down the canyon at several more localities. Specimens are deposited at the University of Wyoming (RM) and the New York Botanical Garden (NY) (*Dorn 3793, 3792*). The closest known locality for *L. complanatum* is about 450 miles to the northwest in Lewis and Clark County, Montana. The closest known locality for *L. annotinum* is about 270 miles to the west in Park County, Wyoming.

Several other pteridophytes were collected within two miles of the *Lycopodium* location along the same creek: *Equisetum sylvaticum* L. (*Dorn 3777*, collected for the first time in Wyoming one day earlier by E. F. Evert in the Big Horn Mountains), *Athyrium filix-femina* (L.) Roth (*Dorn 3778*), and *Equisetum scirpoides* Michx. (*Dorn 3809*, another first record for Wyoming).—*Robert D. Dorn, Box 1471, Cheyenne, WY 82003.*