



United States
Department of
Agriculture

Agricultural
Research
Service

Beltsville Area
Beltsville Agricultural
Research Center

Beltsville, Maryland
20705

May 25, 1995

SUBJECT: Research Proposal on a Taxonomic Revision of *Taxus*

TO: Thomas S. Elias, Director
National Arboretum

FROM: Richard Spjut, Botanist,
USDA ARS Systematic Botany & Mycology Laboratory (SBML)

As you requested, I enclose a two-page proposal and an attachment--one page of references--in follow-up to our meeting about four weeks ago. I also return your outline of items that was to be covered in the proposal. It should be noted that herbarium specimens were borrowed through the National Arboretum, and not BARC, and that my two publications on the subject were conducted on outside time.

I hope this will be of use to you.

Proposed Research on *Taxus*

Objectives. To define and classify the species of *Taxus*, and to be able to identify them based on their morphological and molecular characteristics; to produce a taxonomic key for species identification, accompanied by species descriptions and illustrations of key taxonomic characters.

Taxonomic Dilemma. The genus *Taxus*--native to temperate and subtropical forests of Eurasia and North America, south to Celebes and Central America--has been interpreted to include only one species (*T. baccata* L.) subdivided into five subspecies with many varieties and forms (Pilger, 1903, 1926), or perhaps nine species [*T. baccata*, *T. brevifolia* Nutt., *T. canadensis* Marshall, *T. cuspidata* Sieb. & Zucc., *T. floridana* Nutt. ex Chapm., *T. globosa* Schlecht., *T. sumatrana* (Miq.) de Laub., *T. wallichiana* Zucc., *T. yunnanensis* Cheng & L. K. Fu] by integrating data from other literature (see attachment--References). Most biologists accept multiple species; however, studies since Pilger (1926) have focused only on regional taxa (e.g., *Flora Republicae Popularis Sinicae* 1978), or cultivated taxa (e.g., Chadwick & Keen 1976; Rehder 1940). Moreover, relationships of cultivated species of *Taxus* to their wild relatives appear obscured by a long history of their cultivation in Europe and Asia.

It has not been possible to distinguish species of *Taxus* using the taxonomic characters applied by Rehder (1940) and others (see references). Consequently, species of *Taxus* have been generally adopted more on phytogeographic grounds. This can present problems to identifying cultivated yews. For example, at least three different cultivars have been commonly planted on the Beltsville Agricultural Research Center, and since their origin is not known, one may speculate whether they represent three cultivars derived from one species, or represent three species. Duncan & Duncan (1988, *Trees of the Southeastern United States*) present a color photograph of "*Taxus* sp.", the only plant in their book not identified to species. Furthermore, the anticancer drug taxol, which was originally isolated from *T. brevifolia*, has led to numerous introductions of *Taxus* spp. in search of better germplasm for obtaining taxol through tissue cultures, or from propagation of living plants. Geneticists and pharmacognosists frequently publish their phytochemical results employing Latin names that appear to have little taxonomic validity.

The following questions might be asked. Do species of *Taxus* appear morphologically indistinct because their differences cannot be correlated entirely with phytogeographic data? To what extent does molecular data correlate with phytogeographic and morphological data? Can molecular data be employed to guide selection of key morphological characters? How do yews in cultivation compare with those in the wild? These questions would best be answered by undertaking a taxonomic revision of the genus *Taxus*.

A Taxonomic Revision of *Taxus* is proposed to include study of herbarium specimens from Harvard (GH), Kew (K), London (BM) and other herbaria to identify taxonomic characters for evaluating old and new species concepts.

Historically, there has been a lack of systematic procedures with regard to naming species. Types for most species names have not been clearly designated, and this needs to be done. This will require tracking down the original publications, and finding specimens that best match the original authors' descriptions. Spjut has obtained types for most

species, but has not made an effort to locate all the potential isotypes or isolectotypes, and rare literature for some species needs to be consulted.

Spjut has already developed an experimental identification key to species of *Taxus* based on a morphological study of dried herbarium specimens of plants collected primarily in eastern Asia and North America--approx. 350 from India, Nepal, China, Taiwan, Japan, Korea, 50 from U.S. and Canada, 15 from Mexico and Central America, and 50 from Europe and North Africa. Fresh specimens have also been studied--approx. 30 from California, Oregon, Washington, British Columbia, Idaho, and Montana, 4 from Ohio, Michigan, New Hampshire, and New York, 20 from Taiwan, 5 from China, 5 from Korea, 1 from the Philippines, 1 from Viet Nam, 3 from Europe, and 5 from Mexico and Central America. More material needs to be studied from Europe, southwest Asia, Celebes, Philippines, and Sumatra, and if this study is to be supported by the National Arboretum, representation of the different cultivars that reportedly originated in Europe, Japan, and the United States might also be included.

Spjut's experimental key employs anatomical characters of the leaf as well as familiar gross morphological features. Anatomical characters include the nature of papillae on the lower leaf midrib, the thickness and shape of epidermal cells on the lower leaf surface, the development of sclerified resin cells in the leaf parenchyma, number of stomata rows, width of the lower leaf margin without stomata. While some of Spjut's characters (Spjut 1993) have been accepted for distinguishing North American species (Hils 1993), the Asian species appear more problematical because they are either more variable, or there are many more species that have yet to be recognized; Spjut proposes to recognize many more new species.

Because *Taxus* has been notoriously taxonomically difficult, it is felt that molecular data will be needed to evaluate systematic relationships and to guide selection of reliable morphological characters for generating a taxonomic key. In one unpublished study comparing DNA (using 4 restriction enzymes and PCR generating 1,350 different observations) among a limited sampling (~40 specimens) of *Taxus* from North America, Europe, China, Philippines, and Taiwan, nine different DNA "groups" of *Taxus* were reportedly recognized; however, two groups (*T. wallichiana*, *T. contorta*) of eight morphological groups or subgroups recognized by Spjut (*T. baccata*, *T. canadensis*, *T. contorta*, *cuspidata*, *T. globosa*, *T. sumatrana*, *T. wallichiana*, *Taxus* sp.) may not have been included in the DNA analysis.

Resources Needed. Travel and salary funds for field work and study of herbarium specimens will be needed. Field work is proposed to obtain fresh and dried specimens of all currently recognized and theoretical species for molecular (isozymes, DNA) and morphological (anatomical) studies. Emphasis would be on wild species in European countries, Nepal, China if feasible, Taiwan, Philippines, Celebes, Sumatra, and possibly others. During this travel Kew might be visited to study the Linnaean type for *T. baccata*, and this and other herbaria might also be visited to select specimens for loans, to look for possible types that might not be easily recognized by curators, and to consult rare-book literature not available at NAL.

Technical assistance will be required for obtaining SEM of various leaf epidermal features, PCR data, isozyme data, illustrations of key characteristics, and computer hardware and software may be required to perform the cladistic and phenetic analyses.

Attachment: References

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KEY TO THE SPECIES OF TAXUS

R. W. Spjut

April 24, 1995

1. Leaves appearing two-ranked, not overlapping to slightly overlapping; mostly subtropical Asia & N. America..... 2
1. Leaves appearing in several series of two-ranks, or appearing in more or less equidistant spirals around the stem, often crowded and overlapping; temperate Eurasia & N. America..... 22
2. Lower leaf midrib distinctly differentiated from the stomatal bands, often more discolored reddish-brown in the herbarium (as also the marginal areas of leaf) than stomatal bands, the epidermal cells glossy and often inflated (60x), usually without papillae, especially on the lower half of the leaf; papillae when present often erect on the cell surface rather than projecting sideways over the cell walls (400x); leaves relatively thin, less than 350 μm thick, often flat and abruptly recurved near the margin, except in *T. kingstonii* (x section, 10x)..... 3
2. Lower leaf midrib similar to stomata bands, not distinctly differentiated, sometimes with scattered stomata, appearing dark green to yellowish-green or reddish-brown upon drying, always papillose; papillae projecting sideways over the cell walls, and often erect from the surface of the cell; leaves relatively thick, 350-500 μm thick, often gradually recurved from the mid region, broad linear to broadly elliptical, obtuse, acute, or acuminate..... 11
3. Ventral surface of leaf with a narrow region of glossy inflated nonpapillose cells near the margin, generally of 2-8 rows of nonpapillose cells followed by 5-8 papillose cells; leaf midrib usually rounded on ventral surface, or not elevated; leaves relatively narrow, often crowded and overlapping, acuminate..... 4
3. Ventral surface of leaf with a broad region of glossy inflated nonpapillose cells between the margin and stomata band, usually with 10-36 rows of cells bordering the stomata bands; leaf midrib on ventral surface usually elevated and flattened; leaves usually distant, or margins of adjacent leaves nearly touching and closely parallel..... 7
4. Leaves uniformly distributed, not overlapping, concolorous on both surfaces, flat, lanceolate; midrib and marginal cells on ventral surface of leaf uniformly rectangular; Taiwan, Philippines, Sumatra..... *Taxus sumatrana*
4. Leaves crowded, overlapping, generally darker green above than below, convex to concave, linear; midrib and marginal cells on ventral surface of leaf irregularly angular and inflated in part..... 5
5. Leaves rigid, slightly curved as in the English yew (*T. baccata*), acute, often more than 300 μm thick with liplike margins, plane to convex in x section; branchlets relatively short,

- straight and rigidly spreading; male bud cones 1.5-2 mm wide; mid region of leaf on ventral midrib without papillae, or with papillae positioned more on the upper surface of the cell than along the cell walls; China (Yunnan), Taiwan (Tongshi); Philippines; stomata usually in regular rows, often aligned longitudinally and transversely; a variable species possibly divisible into several varieties or species..... **Taxus kingstonii**
5. Leaves flaccid, straight, acuminate, usually less than 300 μ m thick; concave, or recurved near margins, not particularly liplike along margins; branchlets relatively long and flexuous; male bud cones ca. 1 mm wide; midrib on ventral surface of leaf with papillae positioned marginally or centrally, or papillae absent; stomata with incomplete rows developing between the regular rows..... 6
 6. Papillae on ventral surface of leaf positioned marginally; China (Yunnan), Philippines, Taiwan (Hualien), Celebes....
..... **T. phytonii var. phytonii**
 6. Papillae on ventral surface of leaf positioned centrally, or absent; Taiwan (Tongshi), Philippines..... **T. phytonii var. obscura**
 7. Leaves lanceolate to narrowly elliptic, acuminate, mostly plane or flat, not channeled to slightly channeled along dorsal midrib, 2.0-4 cm long and 2.0-4 mm wide; most epidermal cells on ventral midrib and margin of leaf narrowly rectangular, rarely inflated, usually more than 5 times longer than wide..... 8
 7. Leaves usually broad linear for most of the length, acute, not flat, puckered along upper midrib, often gradually recurved from midrib to margin with an elevated midrib on both surfaces that is rounded above and truncate (flat) below, 2.5-3 cm long and 2.0-3.0 mm wide; most epidermal cells on ventral midrib and marginal areas irregularly rectangular, or broadly rectangular and inflated, rarely more than 3 times longer than wide (60x)..... 9
 8. Branching mostly isodichotomous; leaves becoming discolored on drying; ventral surface of leaf with about 13-15 nonpapillose cells near the margin; India (Khasi Hills), China (Yunnan)..... **Taxus acuminata**
 8. Branching mostly anisodichotomous; leaves remaining green when dried; ventral surface of leaf with 27-36 nonpapillose cells near the margin, usually wider than the adjacent stomata band; China (Yunnan, Guangzhou, Sikong, Kwangsi, Sichuan), Taiwan (Hualine), Celebes..... **Taxus celebica**
 9. Midrib on ventral surface of leaf with uniformly rectangular cells; Sumatra, Philippines, Taiwan..... **Taxus sumatrana**
 9. Midrib on ventral surface of leaf with irregularly widened or inflated cells..... 10
 10. Branchlets mostly isodichotomous (dividing into branches of equal length) at 45° from the main axis which zigzags; leaf margins of adjacent leaves closely parallel and almost touching, usually becoming discolored reddish-brown on drying; China (Shikiong, Yunnan, Szechuan, Kwiangsi, Chekiang, Kweichow, Anwhei, Guizhou, Hupeh, Hunan); Taiwan

- (Mt. Ammashan)..... **Taxus mairei var. mairei**
10. Branchlets mostly anisodichotomous (dividing into branches of unequal length) at 45-90°; leaves not spreading uniformly, usually alternately close and distant, often remaining green when dried; India, Nepal, China (Shikiong, Yunnan, Sichuan, Kwiangsi, Chekiang, Kweichow, Anwhei, Guizhou, Hupeh, Hunan)...
..... **Taxus mairei var. speciosa**
11. Bud scales soon deciduous, or occasional scales present..... 11
11. Bud scales mostly persistent in several or more series..... 14
12. Leaves long acuminate, usually 8-12 times longer than wide, 2.5-4.0 cm long; seeds maturing on 2nd-yr or older twigs, obtuse at apex; Viet Nam, China (Yunnan)..... **Taxus wallichiana**
12. Leaves abruptly acute, 2-8(-10) times longer than wide, 1.5-2.5 cm long; seeds usually maturing on the current season growth, occasionally found on both the first and second year twigs, acute or obtuse at apex..... 13
13. Leaves concave, at least when dry; lower epidermal cells in longitudinal section appearing regularly rectangular in shape; common, China (Sichuan, Yunnan, Hubei, W Hupeh, Guizhou)..... **Taxus chinensis var. chinensis**
13. Leaves mostly flat; lower epidermal cells irregularly rectangular; China (Sichuan: Mt. Omei)..... **Taxus chinensis var. complanata**
14. Second or third year twigs dark reddish to purplish-brown, abruptly changing color from the younger growth of yellowish-green, smooth; stomata often in more than 10 rows/band; NE India, Bhutan, Sinkiang, China (Sichuan, Yunnan); a variable species possibly divisible into 3 or more varieties..... **Taxus wallichiana**
14. Older twigs gradually becoming yellowish-green, or yellowish-brown, or yellowish-gray, or yellowish-orange, or reddish-orange; stomata often more than 10 rows/band..... 15
15. Upper epidermal cells angular in x sect., isodiametric or taller than wide (except in *T. chinensis* & *T. ocreata*); papillae always present on ventral leaf midrib, usually developing along cell walls..... 16
15. Upper epidermal cells elliptical in x sect., 1.5-2x wider than tall; papillae variable on ventral leaf midrib, absent, indistinct, or distinct and positioned marginally to centrally on the cells..... 21
16. Stomata 10 or more rows/band; Asia..... 17
16. Stomata 4-9 rows/band; N. America..... 20
17. Epidermal cells 50 µm tall and wide; leaves slightly overlapping as in *T. brevifolia*, 1.5-2 cm long, 3.0-3.5 mm wide; bud scales large, ovate-deltoid; 3 mm long, 2 mm wide; older twigs appearing scaly due to remnants of raised petioles; rare, Burma..... **Taxus suffnessii**
17. Epidermal cells 12-25 µm tall; leaves mostly appearing two-ranked; bud scales less than 2 mm long and wide; older twigs appearing striate or smooth..... 18

18. Leaves generally distant, distinctly two-ranked; upper epidermal cells resinous (appearing dark reddish in old herbarium specimens); NE India, Bhutan, Sinkiang, China (Sichuan, Yunnan)..... 19
18. Leaves crowded, overlapping; upper epidermal cells mostly inflated and hyaline..... 4
19. Leaves 3.0-3.5 mm broad, recurved more near margins; China (Yunnan)..... **Taxus ocreata**
19. Leaves 1.5-2.0 mm broad, recurved from near the mid region.... rare, China (Yunnan)..... **Taxus chinensis var. scutata**
20. Lower epidermal cells irregularly widened and strongly inflated; stomata 4-7 rows/band; NW N. America (Alaska to California, Idaho and Montana); variable in habit..... **Taxus brevifolia**
20. Lower epidermal cells mostly rectangular, of uniform width, slightly inflated; stomata 6-9 rows band..... 21
21. Lower midrib papillae small, inconspicuous; stomata 6-8 rows/band; NW Florida..... **Taxus floridana**
21. Lower midrib papillae large, prominent; stomata 8-9 rows/band; southern Mexico to British Honduras and El Salvador. **Taxus globosa**
22. Lower surface of leaves mostly without papillae except near corners of scattered accessory cells and subsidiary cells; low shrubs under 2.5 m high, branches layering under or over soil and rocks; eastern North America, Manitoba to Newfoundland to North Carolina..... **Taxus canadensis**
22. Leaves with papillae throughout the stomatal bands..... 23
23. Leaf mesophyll with sclerified resin cells, appearing as reddish beads in dried herbarium specimens (easily seen under low magnification, 10x); ventral leaf midrib always papillose..... 24
23. Leaf mesophyll lacking sclerified cells, in dried specimens parenchyma cells often collapsed or not evident; ventral leaf midrib papillose or not papillose.....25
24. Leaves relatively long and narrow, usually 8-10 times longer than broad, mostly erect to spreading, abruptly recurved near margins Himalaya; bud scales deciduous; Afghanistan, Nepal, India..... **Taxus contorta**
24. Leaves 3-5 times longer than wide, divaricate, slightly recurved near margins; bud scales persistent; Bhutan, China (Yunnan)..... **Taxus mucronata**
25. Leaves narrowly to broadly elliptical, oblong or obovate, short, less than 15 mm long, not more than 3 times longer than wide... 26
25. Leaves linear, long, usually more than 15 mm long, or more than 5 times longer than wide..... 27
26. Ventral epidermal leaf cells highly irregular in shape; papillae absent on ventral midrib; origin unknown, possibly a hybrid between *T. baccata* and *T. umbraculifera*, cultivar..... **Taxus tardiva**
26. Ventral epidermal cells more or less uniformly rectangular;

- papillae present on ventral midrib..... 19
27. Upper leaves with free portion of petiole twisted counterclockwise and upwards away from the branch so that the basal part of the leaf blade overlaps on the upper surface of stem, the leaves generally ascending towards the stem apex, and in the same plane (upper surface of leaf with upper surface of stem); ventral surface of leaf with 4-6 rows of irregular short rectangular nonpapillose cells near the margin followed by 4 or more rows of wider or longer, often wavy or papillose cells that extend to the stomata region; stomata 8-11 (-12) rows/band..... 28
27. Upper leaves with free portion of petiole bent at the junction of the blade and petiole so that the leaves spread nearly at right angles from the stem and slightly twisted so that the upper surface of the leaf is perpendicular to the stem axis, or petioles of upper leaves not twisted or bent; ventral surface of leaf with 8-20 rows of regular to irregular rectangular nonpapillose cells near the margin followed by 1 or more rows of longer papillose cells that extend to the stomata band; stomata 8-16 rows/band..... 30
- 28 Leaves mostly straight except near base; epidermal cells on ventral surface of leaf with papillae mostly along the cell walls; leaf parenchyma usually with 1 long row of palisade cells; SW Asia, cultivated (typical European yew)....
..... **Taxus baccata**
28. Leaves falcate (sickled-shaped), often broadly curved dorsally and downward in the mid region; epidermal cells on ventral surface of leaf with papillae slightly away from the margin, or crowded towards the center of the cell; leaf parenchyma with 2 short rows of palisade cells..... 29
29. Leaves spreading uniformly around the branches near apex, often 2.5-3 mm wide; ventral leaf surface with 9 or more rows of smooth cells near the margins; cultivated (Irish yew)..
..... **Taxus fastigiata variants**
29. Leaves in several series of two ranks, 2.0-2.5 mm wide; ventral leaf surface with 4(-6) rows of smooth cells near the margin; Europe? cultivated ("Cheshuntensis" and other cultivars)..... **Taxus baccata variants**
30. Leaf blades relatively thick (more than 300 μ m thick), straight, plane to concave, gradually recurved from midrib to margins; ventral surface of leaf with mostly short irregularly angular cells between margin and midrib..... 31
30. Leaves relatively thin, less than 300 μ m thick, slightly falcate, slightly concave but more abruptly recurved near margins; ventral surface of leaf with mostly long rectangular cells..... 36
31. Leaves not in equidistant whorls, except near apex, lateral leaves often spreading in one plane and upper and lower leaves occasionally erect..... 32
31. Leaves radially disposed around the stem, often crowded and overlapping..... 33

32. Leaves mostly spreading in two-ranks; Russia, Manchuria, NE China, Korea, Japan..... **Taxus umbraculifera var. latifolia**
32. Leaves spreading irregularly, or mostly pointing upwards, cultivars (apparent hybrids between *T. umbraculifera* var. *nana* and *T. cuspidata* var. *hicksii*)..... **Taxus x hunnewelliana**
33. Leaves spirally arranged around the branches, erect to spreading, or the blades sharply curved downwards..... 34
33. Leaves spreading more at right angles from each other and from branches..... 35
34. Leaf blades strongly curved downwards..... **Taxus fastigiata**
34. Leaf blades straight to slightly curved or twisted..... 35
35. Leaves mostly erect, especially on erect branches; petioles not twisted, or occasionally twisted; Japan, Korea, cultivated...
..... **Taxus umbraculifera var. nana**
35. Leaves often abruptly divaricate or sharply bent downwards at the junction between the blade and petiole; petioles of upper leaves twisted; E Russia, Japan, cultivated.....
..... **Taxus umbraculifera var. umbraculifera**
36. All leaves spreading mostly in one plane of two ranks, or all erect on horizontal branches..... 37
36. Lateral leaves spreading in one plane, upper and lower leaves either more erect, or sharply bent downwards..... 38
37. Leaves obtuse at apex; Caucasus Mountains near the Black Sea in Russia, NE Turkey, NE China, E Russia, Manchuria, Korea, Japan, cultivated..... **Taxus microcarpa**
37. Leaves acuminate; cultivar..... **Taxus cuspidata var. thayeri**
38. Upper and lower leaves more erect than lateral leaves, 2.0-2.5 cm long in wild plants..... 39
38. Upper and lower leaves sharply bent between blade and petiole, divaricate, or reflexed, mostly under 2.0 cm long..... 40
39. Upper surface of leaves glossy and smooth; cultivars (apparent hybrids between *T. umbraculifera* var. *nana* and *T. cuspidata* var. *cuspidata*; the name *T. caespitosa* may also apply here; it has been described as a low shrub with branches that layer, reportedly occurring in North Korea and Japan; its type has not been studied)..... **Taxus x hunnewelliana**
39. Upper surface of leaves dull, wrinkled; Japan, Russia (Ukraine, Caucasus Mountains near Black Sea), Sweden, Romania, and probably elsewhere in Europe, cultivated.....
..... **Taxus cuspidata var. cuspidata**
40. Decurrent petioles flaring from stem; leaves densely crowded, not appearing at definite right angles from each other, remaining green when dried; branches of current season green to yellowish-green; Japan, cultivated.....
..... **Taxus cuspidata var. hicksii**
40. Decurrent petioles closely adhering to stem; leaves lax, appearing regularly at right angles from each other, turning reddish upon drying; branches of current season reddish-orange or

greenish-orange; Japan, cultivated (type is possibly a
hybrid between the wild form and *T. umbraculifera* var.
umbraculifera)..... *Taxus cuspidata* var. *hatfieldii*

*SHOW: Taxus species - character list.

*CHARACTER LIST

- #1. <nomenclature>/
- #2. <habit, stem dominance>/
 1. shrub with multiple basal stems but none dominant/
 2. shrub without a central dominant stem/
 3. tree with a distinct trunk, adventitious shoots or other secondary stems sometimes present/
- #3. stems <habit, erect?>/
 1. erect/
 2. ascending/
 3. decumbent/
- #4. <habit, height>/
 - m high/
- #5. <habit, across>/
 - m broad/
- #6. <habit, vegetative reproduction>/
 1. lower branches layering/
 2. reproducing by adventitious shoots/
 3. reproducing evidently by only seed/
- #7. ultimate branches <monopodial or dichotomous types>/
 1. monopodial/
 2. anisodichotomous/
 3. isodichotomous/
- #8. second or third year twigs <color change>/
 1. abruptly changing color, usually from yellowish-green to dark reddish-purple/
 2. gradually changing from yellowish-green to yellowish-red, or yellowish-orange, or yellowish-brown/
- #9. bud scales <presence>/
 1. mostly persistent/
 2. occasional ones persistent from a bud/
 3. completely deciduous except on current season growth/
- #10. bud scales on <persistence, age of growth>/
 - year twigs/
- #11. bud scales <texture>/
 1. thick/
 2. chartaceous/
- #12. bud scales <color>/
 1. yellowish/
 2. greenish/
- #13. bud scales <change in color with age>/
 1. turning grayish/

- 2. turning brownish/
- #14. bud scales <series>/
series/
- #15. lower bud scales <size>/
mm long/
- #16. leaves <deciduous>/
 - 1. persistent on older twigs/
 - 2. soon deciduous/
- #17. leaves <color>/
 - 1. dark green/
 - 2. light green/
 - 3. reddish-green/
 - 4. yellowish-green/
- #18. leaves <arrangement on twigs>/
 - 1. in one series of two-ranks/
 - 2. in equidistant spirals/
 - 3. in several series of ranks, but not in equidistantly spiraled/
- #19. leaves <uniformity in distribution>/
 - 1. clustered more on some parts of the twigs/
 - 2. uniformly distributed/
- #20. leaves <shape>/
 - 1. linear/
 - 2. oblong/
 - 3. lanceolate/
 - 4. elliptic/
- #21. leaf blades <straight or curved>/
 - 1. straight/
 - 2. curved downwards/
 - 3. curved upwards/
 - 4. bent/
- #22. leaves <twisted or bent at petiole>/
 - 1. on the upper side of branches with twisted petiole/
 - 2. on the upper side of branches with petioles sharply bent more than twisted/
 - 3. all erect or ascending, not twisted or bent at petiole/
- #23. leaves <length>/
cm long/
- #24. leaves <width>/
mm wide/
- #25. leaves <thickness>/
mm thick/
- #26. leaves <margin>/
 - 1. plane/
 - 2. gradually recurved/

3. abruptly recurved near the margin/
 4. revolute near the margin/
 5. *convex*
- #27. leaves <degree of angle recurved at the margin>/
degrees recurved near the margin/
- #28. leaves with decurrent petiole <length>/
mm long/
- #29. upper midrib of leaves <elevation>/
1. flattened, not elevated/
 2. elevated but flattened/
 3. rounded/
 4. acute/
- #30. lower midrib of leaves <elevation>/
1. not elevated/
 2. recessed/
 3. elevated but flattened/
 4. rounded/
 5. acute/
- #31. lower midrib of leaves <color>/
1. reddish/
 2. orange/
 3. yellowish/
 4. green/
- #32. upper epidermal cells in cross section <relative width>/
1. wider than tall/
 2. mostly isodiametric/
 3. taller than wide/
- #33. upper epidermal cells in cross section <average height in microns>/
microns tall/
- #34. upper epidermal cells in cross section <average width in microns>/
microns wide/
- #35. upper epidermal cells in cross section <shape>/
1. ellipitic/
 2. globose/
 3. rectangular/
 4. squarrose/
 5. parabolic/
- #36. upper epidermal cells in cross section <firmness>/
1. thin-walled/
 2. thick-walled/
- #37. upper epidermal cells in cross section <inflated>/
1. inflated/
 2. not inflated/
- #38. upper epidermal cells in cross section <sclerified>/
1. sclerified, appearing reddish in color/
 2. not sclerified, appearing hyaline/

- #39. lower epidermal midrib and marginal cells in cross section <relative size to upper>/
1. smaller than those on the upper surface/
2. similar to those on the upper surface/
3. larger than those on the upper surface/
- #40. lower epidermal midrib and marginal cells in cross section <color>/
1. reddish/
2. orange/
3. yellowish/
4. green/
- #41. lower epidermal cells in cross section <average height in microns>/
microns tall/
- #42. lower epidermal cells in cross section <average width in microns>/
microns wide/
- #43. stomata bands <color>/
1. reddish/
2. orange/
3. yellowish/
4. green/
- #44. stomata bands <color>/
1. broader than the marginal region/
2. equal to the marginal region/
3. less than the marginal region/
- #45. stomata <number of rows>/
rows/
- #46. stomata <distinctness of rows>/
1. in distinct rows, separated by 1-2 rows of accessory cells/
2. not in distinct rows, stomata often appearing crowded/
- #47. stomata <continuous>/
1. interrupted/
2. continuous/
- #48. stomata <color>/
1. greenish/
2. yellowish-green/
3. yellowish-orange/
4. blackish/
- #49. stomata <immersed>/
1. immersed/
2. flush/
3. exserted/
- #50. subsidiary cells with <position of papillae>/
1. central papillae/
2. submarginal papillae/
3. marginal papillae/
- #51. accessory cells <proximity to subsidiary cells>/

1. inflated/
 2. thin-walled but not inflated/
 3. thick-walled/
- #52. accessory cells <position of papillae>/
1. with marginal papillae/
 2. with submarginal papillae/
 3. with central papillae/
- #53. marginal area of leaf adjacent to stomata <number of cells>/
cells wide/
- #54. marginal area of leaf with cells <differentiation>/
1. similar to accessory cells in stomata band/
 2. abruptly differentiated, or appearing distinctly different than those in stomata band/
- #55. differentiated marginal cells <discoloration in dried specimens>/
1. discolored in dried specimens, usually reddish-brown/
 2. not markedly discolored upon drying, usually similar in color to stomata bands/
- #56. marginal cells adjacent to stomata <relative shape>/
1. of uniform width/
 2. of irregular width/
- #57. marginal cells adjacent to stomata <relative length>/
times longer than wide/
- #58. marginal cells adjacent to stomata <relative shape>/
1. angular at the corners/
 2. rounded at the corners/
- #59. marginal cells adjacent to stomata <inflated>/
1. inflated/
 2. thin-walled but not inflated/
 3. thick-walled/
- #60. marginal cells adjacent to stomata <development of papillae>/
1. with equally developed papillae on all cells/
 2. with papillae developed more on some cells than others/
 3. without papillae/
- #61. papillae on marginal cells <development of papillae>/
1. present on most rows of cells except the outer 4/
 2. present on two-thirds or more of the cell rows/
 3. present on half to two-thirds of the cell rows/
 4. present on one third to nearly half cell rows/
 5. present on only 1-3 rows of cells, or less than one-third/
- #62. papillae on marginal cells <position of papillae>/
1. marginal/
 2. submarginal/
 3. central/
- #63. papillae on marginal cells <general shape>/
1. globose/

2. egg-shaped/
 3. sausage-shaped/
- #64. papillae on marginal cells <prominence>/
1. low and distinctly separated/
 2. low and indistinct, usually anastomosed/
 3. prominent and distinctly separated/
 4. prominent but anastomosed/
- #65. papillae on lower midrib <present or absent>/
1. absent/
 2. present/
- #66. papillae on lower midrib <position, center or margin of cell?>/
1. marginally positioned/
 2. submarginally positioned/
 3. centrally positioned/
- #67. lower midrib cells <color as seen on the surface>/
1. yellowish/
 2. reddish/
 3. greenish/
- #68. lower midrib cells <regular or irregular in shape>/
1. regularly rectangular/
 2. irregularly rectangular/
- #69. lower midrib cells <relative length to width>/
times longer than wide/
- #70. papillae on lower midrib <no. rows per cell>/
rows across cell/
- #71. palisade parenchyma <number of rows>/
1. 1 row/
 2. 2 rows/
 3. 3 or more rows/
- #72. palisade <length in microns>/
microns long/
- #73. spongy parenchyma cells<shape>/
1. globose/
 2. elliptical/
- #74. spongy parenchyma cells<sclerified>/
1. sclerified and resinous/
 2. not sclerified, sometimes appearing resinous/
- #75. vascular strand <color>/
1. greenish/
 2. reddish-orange/
 3. yellowish/
 4. white/
- #76. vascular strand <shape>/
1. round/

- 2. short elliptic/
- 3. long elliptic/

- #77. <monoecious?>/
 - 1. dioecious/
 - 2. monoecious/

- #78. male cone scales <number>/
 - in series/

- #79. pollen sacks <number>/
 - /

- #80. female cone scales <number>/
 - /

- #81. seed <angularity>/
 - 1. angular/
 - 2. rounded/

- #82. seed <shape>/
 - 1. globose/
 - 2. conical/
 - 3. obconical/

- #83. seed <length>/
 - mm long/

- #84. seed <diam.>/
 - mm diam./

- #85. seed <rim>/
 - 1. thickened at the base/
 - 2. not thickened/

- #86. seed <scar>/
 - 1. recessed at attachment point/
 - 2. flat with the attachment point/
 - 3. convex at the attachment point/

- #87. seed <apex>/
 - 1. tapering to the apex from the middle/
 - 2. abruptly tapering near apex/

- #88. habitat/
 - 1. forest/
 - 2. forest margins/
 - 3. open scrub/

- #89. elevation/
 - m/

- #90. geography <continental>/
 - 1. Central America/
 - 2. North America/
 - 3. Africa/
 - 4. Europe/

5. Asia/
6. cultivated/

#91. geography <North American types>/

1. Pacific Northwest/
2. Chihuahuan and Great Basin Desert/
3. Sonoran Desert/
4. Southeastern US/
5. Eastern/
6. California/
7. Mexico/

#92. geography <Eurasian>/

1. Southwest Asia/
2. Central Asia/
3. Sino-Japanese/
4. China/
5. Himalayan/
6. IndoChina/
7. *Malaysia*

#93. geography <African countries>/

1. Algeria/
2. Morocco/
3. Tunisia/

#94. geography <European countries>/

1. England/
2. France/
3. Germany/
4. Italy/
5. Austria/
6. Switzerland/
7. Poland/
8. Czechoslovakia/
9. Belgium/
10. Russia/
11. Scandanavia/

#95. geography <southwest Asia, countries>/

1. Turkey/
2. Iran/

#96. geography <Asia-major>/

1. Afghanistan/
2. Pakistan/
3. India/
4. Nepal/
5. Bangladesh (and Khasi Hills)/
6. Bhutan/
7. Burma/
8. China/
9. Russia/
10. Mongolia/
11. North Korea/
12. South Korea/
13. Japan/
14. Taiwan/

15. Philippines/
16. Celebes/
17. Sumatra/
18. North Viet Nam

#97. geography <Russian regions>/

1. W of Black Sea/
2. Black Sea (Caucasus)/
3. Turkeman/
4. Kazakh/
5. Siberia/
6. Sakhalin/

#98. geography <China regions>/

1. ~~Tien Shan~~ / Sinkiang
2. Szechuan/
3. Yunnan/
4. Kweichow/
5. Kwangsi/
6. Kwangtung/
7. Fukien/
8. Kiang/
9. Hunnan/
10. Hupei/
11. Chekiang/
12. Shantung/
13. Shansi/
14. Hopei/
15. Liaoning/
16. Manchuria/
17. Tibet

#99. geography <Japan regions>/

1. Hokkaido (Yezo, includes Sapporo)/
2. Honshu (Yokohama)/

#100. <References>/

#101. <Comments>/

#102. <Specimens studied>/

#103. geography <Japan subdivision of Honshu>/

1. Northern <Ou or Tohoku Dist, Mt. Hayachine, Mt. Zao (Zaosan)/
2. Central <Kanto, Chubu, Mt. Yatsu, Fuji, Hakuba, Shirouma, Haku (Hakusan), Ibuki, Kinki; Tokai-do Tosan-do>/
3. Western <Shikoku, Kyushu, Mt. Kuju, Kirishima, Takokuma, Kurokami; San'yo-do, Nankai-do, Saikai-do>/