A Preliminary Review and Multiple-entry Key to the Rust Fungi on Cyperaceae and Juncaceae in Indiana

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The *Manual of the Rusts in United States and Canada* (1), the crucial reference for identification of this highly important group of plant parasitic fungi in North America, was published in 1934, the 50th year of the Indiana Academy of Science. As a pilot project to develop techniques for revising the manual, including computer-aided compilations of distributions and generation of new keys, a subset of the North American rust fungi, the Indiana species, was chosen for review in 1984, the 100th year of this academy. The most recent compilation of the Indiana rust fungi was in 1916-1921 (3).

Because the 165 species listed by Jackson (3) still make a large group, the focus of this paper was further narrowed. Rust fungi attack hosts in many families of flowering plants (about 100 in North America—1), but certain families are especially burdened with these pathogens. The rust fungi on nearly all of these major host groups (Gramineae, Leguminosae, etc.) have been re-studied since 1934, except for those of Cyperaceae. In fact, Savile (10) called for a "moratorium" on the publication of records on *Carex* rusts until a thorough study could be done. This paper is a first step in such a study. The rushes (Juncaceae) often occur together with the Cyperaceae in nature. Their rust pathogens should be studied along with those on the sedges, for they may be related as their hosts are (9). Aecia of the Indiana sedge/rush pathogens are on hosts representing nine other families of flowering plants.

Specimen label information and annotation notes, especially including camera lucida drawings and spore measurements, were collated for the 650 specimens of Indiana rust fungi on sedges and rushes in the Arthur Herbarium (PUR), Purdue University, West Lafayette, IN. In addition, forty previously overlooked collections were found on phanaerogamic specimens in the Kriebel Herbarium of Purdue University and twenty new collections were made in the field.

Of the Arthur Herbarium specimens, 90% are at least 60 years old. Knowledge of the hosts and rusts has increased over the last six decades, the distribution of these taxa has probably changed, and the dried specimens no longer contain viable spores for re-verification of the life cycle studies performed by Arthur (1). In addition, the distribution data are skewed towards Tippecanoe County (57% of the PUR specimens) and away from eastern and southern Indiana: no specimens are available for any species from 44 of the 92 Indiana counties, including Allen, Delaware, Floyd, Vanderburgh, and Wayne. This is an example of the distribution of collectors, not of the taxa collected (5). Clearly, systematic state-wide collecting of fresh specimens is necessary for valid biogeographical or phenological hypotheses. A series of such trips is being planned for 1985.

Fifteen species of rust fungi are known on Cyperaceae in Indiana, but only three on Juncaceae. Only two of the more than 100 genera of rust fungi are represented here: *Puccinia* and *Uromyces*. A taxonomic "splitter" might add at least six other sedge rust species for the state, and five more occur nearby in Wisconsin or Michigan. Although one would expect Indiana to have been well-surveyed, the complete life cycles of four (*U. junci-effusi* Syd., *U. minutus* Diet., *U. rhynchosporae* Ell., and *U. valens* Kern) of these 18 rust species are still unknown. The other species are heteroecious and macrocylic (1). Fifty-six of the 217 species of Cyperaceae in Indiana (2) have been collected with rust on them (26%), but only four of the 26 species of Juncaceae in this state (15%) are known hosts.

Four of the Indiana rust species are known from only one county (*P. obscura* Schroet. ex Pass., *U. americanus* Speg., *U. junci-effusi,* and *U. valens*); three from two counties (*P. minutissima* Arth., *U. minutus*, and *U. rhynchosporae*), and five others from three to six counties (*P. cyperi* Arth., *P. eleocharidis* Arth., *P. obtecta* Peck, *U. lineolatus* (Desm.) Schroet. in Rabh., and *U. perigynius* Halst.). *Puccinia canaliculata* (Schw.) Lagh. has been found in nine counties, P. *angustata* Peck in 10, *U. silphii* Arth. in 19, *P. bolleyana* Sacc. in 22, *P. caricina* in 23 (including *P. caricina* var. *limosae* (P. Magn.) Jörst. from one county), and *P. dioicae* P. Magn. in 31 counties. None of these are as widespread as their hosts. For example, *Scirpus cyperinus* (L.) Kunth. is known from at least 50 counties (2), or five times as many counties as its rust pathogen, *P. angustata*. Maps of all rust species collections were prepared, but none showed any coherent geographic trends.

One-third of the Indiana sedge or rush collections bearing rust fungi could be assigned to *P. caricina*, one-third to *P. dioicae*, and the remaining third to all the other 16 species combined. *Puccinia caricina* is now known on 17 species of *Carex* in Indiana and on 110 species when all U.S. and Canadian records are counted. *Puccinia dioicae* has 26 Indiana *Carex* hosts and 137 total north of Mexico. Verifying the identity of the host fragments in many of the old PUR collections is probably impossible, but a large number of the hosts were originally named by Dr. K.K. Mackenzie of the New York Botanical Garden, one of the foremost *Carex* scholars ever, so they probably can be accepted as correct. When all the North American collections are tabulated, a tendency appears for these two rust species to favor certain of the sections of the genus *Carex* (7). For example, 36 species of the section Ovales harbor infections of *P. dioicae*, but *P. caricina* is found in the PUR collections on only one species of Ovales, *Carex multicostata* Mkze. from California. Section Acutae (especially *C. aquatilis* Wahl. and *C. stricta* Lam.) consistently includes hosts for *P. caricina* (16 to 2 for *P. dioicae*). Some other sections for which the rust species show preferences (based on PUR records) include Bracteosae (3 species are hosts for *P. caricina*, 11 for *P. dioicae*), Atratae (6, 1), Cryptocarpae (4, 0), Laxiflorae (6, 1), Limosae (5, 0), Montanae (1, 9), Multiflorae (0, 6), Pseudocypereae (4, 1), Stellulatai (0, 9), Sylvaticae (= Debiles, 5, 2), and Triquetrae (3, 1). *Puccinia dioicae* hosts are more common in *Carex* subgenus *Vignea, P. caricina* hosts in subgenus *Eucarex.* A few sections include species susceptible to both rust species: Divisae (3, 3), Heleonastes (= Canescentes, 5, 3), Hirtae (2, 4), Lupulinae (2, 3), Paludosae (3, 4), Phyllostachyeae (2, 2), Virescentes (4, 2), and Vesicariae (= Physocarpae, 3, 3). Nevertheless, these trends may be useful as predictors. The first rust collection on *Carex davisii* Schw. & Torr. was predicted to be *P. caricina* because section Gracillimae included three sedge species attacked by *P. caricina* but only one by *P. dioicae* and, in fact, the collection did key to *P. caricina* (5). In the Gramineae, such fidelity of rust fungi to certain host tribes has been used to show that a grass genus with the "wrong" rust pathogen should be reassigned to a different tribe (4). The section preferences of the rust fungi should now be reported to *Carex* specialists who might use them to spot similar host taxonomy corrections.

These two common rust species, *P. caricina* and *P. dioicae*, may actually be species complexes, with arrays of aecial hosts in different families. Therefore, each may be groups of sibling species or races isolated reproductively by their different aecial hosts, yet scarcely or not at all separable by fungal morphology. In Europe, inoculation studies have shown consistent separation of populations, which are recognized as distinct species (1), and Savile has used those segregate names for his North American sedge rust collections (10). The detailed life cycle studies on North American collections reported by Arthur (1) suggested a trend to host specialization, but not strong enough to support delimitation of species at this time. Varieties or formae speciales (f. sp.) may be justifiable. The populations of spores collected from the various aecial hosts as yet show no readily identifiable patterns of favoring certain species or sections of the telial host genus *Carex* and no immediately obvious geographic trends on the broad scale. Perhaps fine-grained ecological data, such as whether the *Ribes*-infecting isolates of *P. caricina* come from drier or higher ground than the aecial collections from *Urtica* hosts, may yield some guidance (8). No experiments ever have tested whether these rust fungi are merely opportunistic, producing pathotypes that may utilize either aecial host species if it is present and environmental conditions are right.

There is a slight morphological trend in the urediniospores of *P. caricina* collections. If the ranges of urediniospore length and width are plotted on a graph (Figure 1), the collections associated with aecia on *Urtica* spp. have the largest urediniospores (data from 1), and those from sedge infections following aecia on *Ribes* spp. are smaller, with a narrower length range. Most *P. caricina* urediniospores have 3 (or 4) equatorial germination pores. A variant form with one pore near the hilum of the spore occurs on *Ribes* and is intermediate in size between the two former groups. No patterns of urediniospore morphology, host supraspecific taxa fidelity, or geography are evident at this time to sort out aecial populations of *P. dioicae* on Onagraceae, Phrymaceae, Valerianaceae, Thymeleaceae (these collections have been challenged as actually belonging to a grass rust—10), or several tribes of the Compositae. The reported variations in aeciospores (10) have not yet been reviewed in this study.

Finally, a preliminary multiple-entry key was developed as a working tool, based on published descriptions of these taxa (1). Because this type of key requires that all potentially useful character states be scored for all taxa, it is useful for finding gaps or inconsistencies in the data and, thus, show which taxa need further review. For example, in its current form, some leads show that the published literature contains synonymous or inconsistently applied terminology. Others, such as color characters, are probably too subjective to prove useful. Instructions for the use of this type of key are given by Pitt (6). Subsequently, the characters for each taxon can be listed as formulae (part IV of the key) and be readily translatable to a computerized key. Comparisons of the formulae reveal that some taxa are not clearly separable by the key, unless the host has been identified first. Measurements of a sample of spore lengths and widths are also necessary for identification of uredinial states of five of the rust taxa on *Carex*, for telial specimens of three of these, and for uredinial material of the two *Puccinia* rusts on *Scirpus*. Given an allowance for variation in some characters, such as spore shape, the other taxa can be keyed out by qualitative features once the host is known.

In summary, as a sample subset and first step towards a revision of the present manual of North American rust fungi (1), the species were reviewed that infect members of the Cyperaceae and Juncaceae in Indiana. The incomplete distribution records and the need for further life cycle studies indicate that only collecting and testing of new specimens, supported by computerized data management, will provide complete, correct information from which to produce an up-to-date manual.

J.F. Hennen offered critical advice on the ms.

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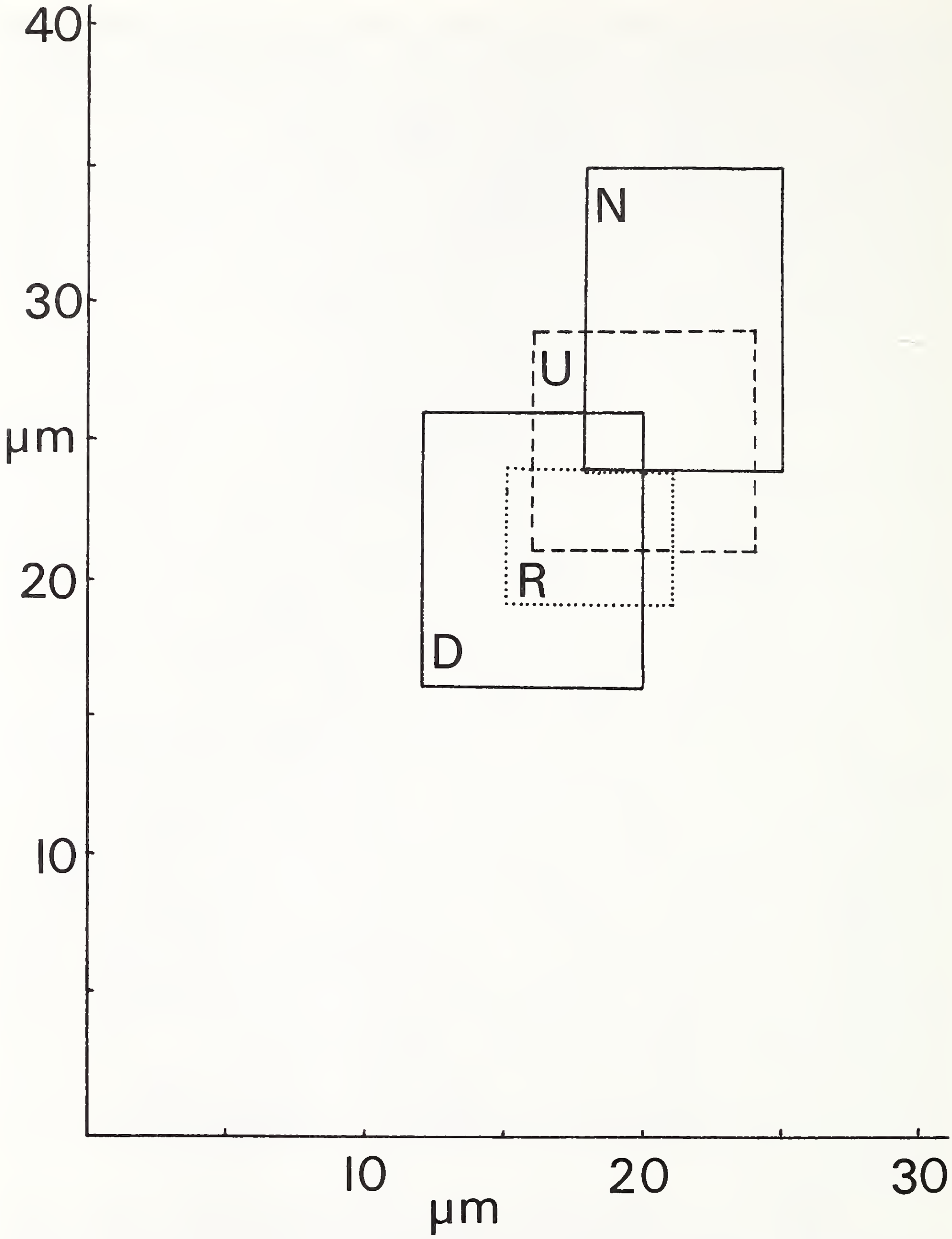

FIGURE 1. Urediniospore size ranges in *Puccinia caricina* and *P. dioicae* on *Carex* spp. N—from uredinal infections of *P. caricina* following aecia on *Urtica* spp.; R—from *P. caricina* uredinia following aecia on *Ribes* spp.; U—one-pored urediniospore variants of *P. caricina* following aecia on *Ribes* spp.; D—urediniospores of *P. dioicae*. Based on data from Arthur (1).

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Multiple-Entry Key to Species of Puccinia and Uromyces on Indiana Cyperaceae and Juncaceae

I. A. Fungus Taxa.

1. *P. angustata* s. 1.
2. *P. bolleyana*
3. *P. canaliculata*
4. *P. caricina* s. 1.
4a. *P. caricina* var. *limosae*
5. *P. cyperi*
6. *P. dioicae* s. 1.
7. *P. eleocharidis*
8. *P. minutissima*
9. *P. obscura*
10. *P. obtecta*
11. *U. americanus*
12. *U. junci-effusi*
13. *U. lineolatus*
14. *U. minutus*
15. *U. perigynius*
16. *U. rhychosporae*
17. *U. silphii*
18. *U. valens*

I. B. Key to Host Taxa. (Bold face type indicates rust taxa appearing under more than one lead).

1. *Carex*—2, 4, 4a, **6**, 8, 14, 15, 18
2. *Cyperus*—3, 5
3. *Dulichium*—**6**
4. *Eleocharis*—7
5. *Eriophorum*—**1**
6. *Juncus*—12, 17
7. *Luzula*—9
8. *Rhynchospora*—16
9. *Scirpus*—**1**, 10, 11, 13

II. Key to Uredinial Material.

A. Number of Germination Pores per Spore.

1. One—**4**
2. Two—1, 2, 3, **4**, **5**, 6, 8, 9, 10, **14**, 15, 16, 17
3. Three—**4**, **4a**, **5**, **7**, **12**, 13, **14**
4. Four—**4**, **4a**, **5**, **7**, **11**, **12**, 13, 18
5. Five—**7**, **11**
6. Six—**11**

B. Spore Germination Pore Position.

1. Superequatorial to Apical—**1**, 2, 6, 8, 9, 15, 17
2. Equatorial—**1**, 3, **4**, 4a, 5, 7, 10, 11, 12, 13, 14, 16, 18
3. Near Hilum—**4**

C. Spore Length.

1. ≥ 36 μm—**7**,**11**
2. 25-35 μm—**1**, **2**, **3**, **4**, **5**, **6**, **7**, **9**, 10, **11**, **12**, **13**, **15**, **16**, **18**
3. < 25 μm—**1**, **2**, **3**, **4**, 4a, **5**, **6**, 8, **9**, **12**, **13**, 14, **15**, **16**, 17, **18**

D. Spore Shape.

1. Ellipsoid—**1, 2, 3, 4, 4a, 5, 6, 7, 8, 9,** 10, **11, 12, 13, 14, 15, 16 17,** 18
2. Obovoid—**1, 2, 3, 4, 4a, 5, 6, 7, 9, 13, 14, 15, 16, 17**
3. Globoid—**6, 8, 9, 15**
4. Oblong—**11**

E. Spore Wall Color.

1. Cinnamon-brown—1, **3, 4,** 4a, 5, 6, 7, 10, 11, 12, 13, 14, 15, **17, 18**
2. Chestnut-brown—2, **4,** 14, **18**
3. Golden- or yellowish-brown—**3,** 8, 9, 16
4. Golden-yellow—**17**

F. Sorus Color.

1. Cinnamon-brown—1, 3, 4, 4a, 5, 6, 7, **9,** 10, 11, 12, 13, 14, 15, 17, 18
2. Chestnut-brown—2, 8, 16
3. Golden-brown—**9**

G. Sorus Emergence.

1. Sorus Erumpent, Pulverulent—1, 2, 4, 4a, 6, 8, 9, 10, 12, 13, 14, 15, 18
2. Sorus Tardily Naked or Opening Only by Slits—3, 5, 7, 11, 16, 17

H. Sorus Position.

1. Hypophyllous—1, 2, 3, 4, 4a, 5, 6, 8, **9, 10, 12, 13,** 14, 15, 16, **17,** 18
2. Epiphyllous—**9, 10, 12, 13, 17**
3. Culmicolous—7, **9,** 11, **17**

III. Key to Telial Material.

A. Number of Cells per Teliospore.

1. Two—1, 2, 3, 4, 4a, 5, 6, 7, 8, 9, 10
2. One—11, 12, 13, 14, 15, 16, 17, 18

B. Pedicel Color.

1. Colored—1, 3, 5, 7, 8, 9, 10, **11,** 12, 13, 17
2. Colorless—2, 4, 4a, 6, **11,** 14, 15, 16, 18

C. Pedicel Length.

1. Less than length of spore—3, 4, 4a, 5, **6,** 7, 8, **9,** 10, 11, 13, 14, **15**
2. About length of Spore—1, 2, **6, 9,** 12, **15,** 16, **17**
3. Longer than Spore—**17,** 18

D. Sorus with Paraphyses.

1. No—1, 2, 4, 4a, 5, **6,** 7, 8, 9, 12, 13, 14, 15, 16, 17, 18
2. Yes—3, **6,** 10, 11

E. Sorus Emergence.

1. Erumpent Early, Pulverulent—1, 2, 4, 4a, **6,** 7, 8, 9, 12, 13, 14, 15, 16, 18
2. Remaining Covered or Loculate—3, 5, **6,** 10, 11, 17

F. Spore Wall Thickness at Apex.

1. $>$ 10 μm—**1, 2, 4, 5, 6, 8, 9, 10, 13, 15**
2. 5-10 μm—**1, 2, 3, 4, 4a, 5, 6, 7, 8, 9, 10, 11,** 12, **13,** 14, **15, 16,** 17, 18
3. $<$ 5 μm—**1, 3, 4, 7, 11, 16**

G. Spore Length.

1. $>$ 50 μm—**1, 2, 3, 4, 5, 6, 7, 8,** 10, **11, 13**
2. $>$ 25-20 μm—**1, 2, 3, 4,** 4a, **5, 6, 7, 8,** 9, **11, 12, 13, 15, 16,** 17, 18
3. $\leq$ 25 μm—**12,** 14, **15, 16**

H. Spore Wall Color.
1. Cinnamon-brown—**1, 3,**
2. Chestnut-brown—**1,** 2, 4, 4a, **5,** 6, **7,** 8, **9,** 10, 12, 13, 14, 15, **16,** 17, 18
3. Yellow or Golden—**9, 11**
4. Colorless—**11**
5. Paler in Lower Part of Spore—**3, 5, 7, 16**

I. Teliospore Shape.
1. Clavate—**1, 2, 3,** 4, **5, 6, 7, 9, 10, 16**
2. Oblong—**2, 3,** 4a, **5, 6,** 7, 8, **11**
3. Obovoid—**12,** 14, **15,** 17, 18
4. Ellipsoid—**9, 12,** 13, **15, 16**
5. Cylindric—**1, 10, 11**
6. Cuneiform—**16**

J. Teliospore Apex.
1. Rounded or Obtuse—**1,** 2, **3, 4, 4a, 5, 6, 7,** 8, **9, 10,** 13, **14, 15, 16, 17, 18**
2. Truncate—**4a, 5, 6, 7, 9,** 11, *12, 14, 15, 16, 17*
3. Acute, Acuminate, or Pointed—**1, 3, 4, 10, 12, 15, 16, 17, 18**

IV. Species Formulas (compiled by listing each lead in the key under which the species occurs). Uredinial states are listed first.

1. 2, 12, 23, 12, 1, 1, 1, 1; 1, 1, 2, 1, 1, 123, 12, 12, 15, 13.
2. 2, 1, 23, 12, 2, 2, 1, 1; 1, 2, 2, 1, 1, 12, 12, 2, 12, 1.
3. 2, 2, 23, 12, 13, 1, 2, 1; 1, 1, 1, 2, 2, 23, 12, 15, 12, 13.
4. 1234, 23, 23, 12, 12, 1, 1, 1; 1, 2, 1, 1, 1, 123, 12, 1, 1, 14.

4a. 34, 2, 3, 1, 1, 1, 1, 1; 1, 2, 1, 1, 1, 1, 2, 2, 2, 12.

5. 234, 2, 23, 12, 1, 1, 2, 1; 1, 1, 1, 1, 2, 12, 12, 25, 12, 12.
6. 2, 1, 23, 12, 2, 2, 1, 1; 1, 2, 12, 12, 12, 12, 12, 2, 12, 12.
7. 345, 2, 12, 12, 1, 1, 2, 3; 1, 1, 1, 1, 1, 23, 12, 25, 12, 12.
8. 2, 1, 3, 13, 3, 2, 1, 1; 1, 1, 1, 1, 1, 12, 12, 2, 2, 1.
9. 2, 1, 23, 123, 3, 13, 1, 123; 1, 1, 12, 1, 1, 12, 2, 23, 14, 12.
10. 2, 1, 2, 1, 1, 1, 1, 12; 1, 1, 1, 2, 2, 12, 1, 2, 15, 13.
11. 456, 2, 12, 14, 1, 1, 2, 3; 2, 12, 1, 2, 2, 23, 12, 34, 25, 2.
12. 34, 2, 23, 1, 1, 1, 1, 12; 2, 1, 2, 1, 1, 2, 23, 2, 34, 23.
13. 34, 2, 23, 12, 1, 1, 1, 12; 2, 1, 1, 1, 1, 12, 12, 2, 4, 1.
14. 23, 2, 3, 12, 12, 1, 1, 1; 2, 2, 1, 1, 1, 2, 3, 2, 3, 12.
15. 2, 1, 23, 123, 1, 1, 1, 1; 2, 2, 12, 1, 1, 12, 12, 2, 34, 123.
16. 2, 2, 23, 12, 3, 2, 2, 1; 2, 2, 2, 1, 1, 23, 23, 25, 146, 23.
17. 2, 1, 3, 12, 14, 1, 2, 123; 2, 1, 23, 1, 2, 2, 2, 2, 3, 123.
18. 4, 2, 23, 1, 12, 1, 1, 1; 2, 2, 3, 1, 1, 2, 2, 2, 3, 13.