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A COMPARISON OF TAXONOMIC KEYS TO SPECIES WITHIN THE GENUS *RUSSULA*

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Abstract

More than 700 dried collections of *Russula* from a large scale four-year study conducted in the western Cascade Range of Oregon were examined and identified with the aid of several recently published species descriptions and keys to species within the genus *Russula*. Few regional taxonomic references to this genus were available at the time of the study. The strengths and limitations of the keys to this and other situations are described. A comparison of each key's species or species groupings for the species we encountered is provided. Suggestions for identifying *Russula* species in large scale ecological studies are discussed.

Introduction

The recent advent of large scale ecological studies designed to provide knowledge about fungal communities and species diversity has created a dilemma for mycologists with respect to accurately and efficiently processing large numbers of collections. In ideal situations, mycologists limit collections of fungi in a day to numbers that allow meticulous examination and recording of detailed fresh notes. Specimens are then dried and later positively identified to species using both macro- and microscopic characters.

Ecological studies typically require sampling from randomly selected areas large enough in size to ensure adequate sporocarp production for statistical comparisons. Collecting sporocarps to satisfy this requirement can be problematic in seasons with above average fruiting, especially if 1) the season with increased sporocarp productivity occurs early in the study when protocols are new to field assistants, 2) regional taxonomic materials do not exist for the dominant genera, or 3) sufficient numbers of trained mycologists are unavailable. This combination of circumstances occurred in our recent 4-year study (Smith *et al.* submitted) designed to compare differences in fungal species diversity among successional age classes of Douglas-fir (*Pseudotsuga menziesii* Mirb. [Franco]). First year preliminary results of our study are summarized by O'Dell *et al.* (1992).

Several genera, including *Russula,* were particularly problematic. *Russula* is a large genus with about one hundred species in the Pacific Northwestern region of the United States (Woo 1993, Thiers 1997a). Species determination typically is difficult and requires extensive notes from fresh material. At the time of the field study, regional taxonomic materials for the Pacific Northwest for the identification of *Russula* species were either in progress or did not

exist. By completion of the study, several references were available, begging the reexamination of our *Russula* collections.

Our purpose in this paper is to 1) present the strengths and limitations of recently published and existing keys to species and species groups within the genus *Russula* by Arora (1986), Woo (1993), and Thiers (1994, 1997a), and 2) provide comparison charts for rapid placement of *Russula* collections within species groups to more efficiently process *Russula* collections in large scale ecological studies.

Materials and Methods

The field study site was located in and near the H. J. Andrews Experimental Forest on the Willamette National Forest (Lane and Linn Counties) in the western Cascade Range of Oregon. The study area lies within the Western Hemlock Zone (300-1,550 m) and is dominated by Douglas-fir (Franklin and Dyrness 1984). Sporocarp sampling occurred in Spring and Fall, 1991-1994, beginning in Fall 1991. Ectomycorrhizal mushroom sporocarps were collected within a 3-week period from a total area of 6,300 m^2 each collecting season.

Fresh notes critical to species identification were recorded for the nineteen *Russula* collections in Fall 1991. The available field crew was unprepared to record fresh notes adequate for species identification for each *Russula* collection in Fall 1992, when over 300 collections of *Russula* made up only fifteen percent of the total collections for that season. Fresh collections of *Russula* species were separated, however, into broad species groups outlined by Arora (1986), on the basis of gill, spore, stipe, and cap colors, bruising reactions, taste, and odor. We created a chart for easy comparison of these characters prior to the Fall 1993 field season **(Table 1).** Use of this chart and more familiarity with the genus resulted in the recording of more complete fresh notes in Fall 1993 and 1994, than in 1992. No chemical tests were performed on fresh material. Collections were dried in portable or on-site dehydrators for twelve to twenty-four hours.

In 1997, we examined the dried collections and similarly categorized the species groups among all years. Small portions of dried basidiocarps squash-mounted in 5 percent KOH, and stained with 1 percent cotton blue (Johansen 1940) or with Melzer's reagent (Melzer 1924) were examined microscopically for spore size, shape and ornamentation, pileocystidia presence and abundance, and pileus structure. Iron sulfate ($FeSO_4$), 4-dimethylaminobenzaldehyde (PDAB), and sulfovanillin were tested on small portions of the dried stipe, cap and gills of some species groups (Buyck 1989, Fatto 1995).

Specimens were keyed with Arora (1986), Woo (1993), and Thiers (1994, 1997a). Taxa also were compared to descriptions of recently described *Russula* species by Thiers (1997b). All possible identities were listed and fresh notes were consulted for species determination. When no fresh notes were available, specimens were keyed through probable sections of the keys and unlikely determinations eliminated. Differences among the various keys in identification of species or species groupings were noted with the voucher specimen. Representative voucher collections of identified species were accessioned into the Oregon State University Herbarium (OSC).

Results

Twenty-five species or species groups of *Russula* within 2 subgenera, *Russula* and *Compacta,* were identified from 739 collections **(Table 2).** With the exception of one collection in Spring 1992, all were collected in Fall. Extreme variation in *Russula* sporocarp production occurred among Fall seasons, resulting in more or less detailed fresh notes for species identification. *Russula* collections accounted for between 9% and 31% of the fungi collections each Fall season, and 16% of the nearly 4,600 total collections of fungi in our study. The number of *Russula* species or species groups varied between 3 and 23 per Fall season and 44% of the species appeared in only one of the four Fall seasons **(Table 2).** Only *R. albonigra* was found in all Fall seasons **(Table 2).**

Russula collections, identified in the field with Arora (1986), from 1991, 1993, and 1994 keyed either to the same species or to a closely related species in both Woo (1993) and Thiers (1997a). Species or species groups identified in our study are compared with species concepts in Thiers (1997a) and Woo (1993) in **Table 3.** Some infrequently collected species, *R. amoenolens* Romagn., *R. decolorans* Fr., *R. pectinatoides* Peck do not appear in **Table 3.**

The paucity of notes on fresh material in 1992 made identification of collections difficult, although certain species groups were easier to identify from dried specimens than others. Species within the subgenus *Compacta* were relatively easy to confirm because of their distinctive bruising reactions and typically larger, more robust basidiomata. Determinations of species within the subgenus Russula were more problematic. Fifty-four percent of *Russula* collections from Fall 1992 fit into either the *R. integra* Fr. or the *R. alutacea* (Pers.) Fr. species complex (Smith *et al.* submitted).

Discussion and Conclusions

The genus *Russula* is divided into two subgenera, *Compacta* and *Russula*. Characters of fresh material such as cap color(s), spore print color, and taste are essential for determining this first level of grouping in all current keys to the genus. Other distinguishing characters of sections and subsections within these subgenera are not consistent among the keys tested. Size, shape, texture and bruising reaction of the basidiomata distinguish some sections or species groups, although variation occurs with age and maturity. Members of the subgenus *Compacta,* for example, are generally large and robust, short stemmed, and often bruise gray, red or black. Cap color is often variable within species of both subgenera and many pigments are affected by water or sunlight (Arora 1986, Largent 1986, Singer 1986). Cap and stipe color, however, often are useful characters for identifying dried specimens because pigmentation, including bruising reactions, typically is retained. Spore print color ranges from white to deep yellow-ochre and is a more reliable key character than gill color. Gill color may differ from spore color and assuming the two to be the same is a mistake easily avoided by making a spore print.

Although tastes and odors are useful to identification, few are applied to a taxonomic level higher than species. Taste of the cap (acrid, bitter, fungal, peppery), in conjunction with other characters, distinguishes some sections or species of *Russula*. Evaluation of taste and odor depends on both experience

and ability of the researcher to detect often subtle differences. Some people fail to detect the extreme peppery taste of *R. emetica* (Schaeffer: Fries) S.F. Gray and *R. silvicola* Shaffer, whereas others describe even mild Russula species as acrid or bitter (personal observation). Odor, when distinguishing a *Russula* species, is typically distinctive and easily detected. In our study, odors were not well retained in dried specimens, except in the *R. fragrantissima* group, where the maraschino cherry odor is retained to varying degrees. Odors, therefore, must be recorded in the fresh notes.

Chemical tests on fresh material are helpful for the identification of some species or groups. Chemical tests on dried material generally are not reliable (Buyck 1989, 1995, Thiers 1997a). Buyck (1989) distinguished the subsection *Viridantinae* (*Russula xerampelina* group) from the rest of the subgenus *Russula* by a greenish-gray compared to a pink-orange reaction to $FeSO_4$ on the stipe. Woo (1993) recognizes five varieties of *R. xerampelina,* united by a browning reaction to handling, odor of crab or fish, and flesh turning greenish-gray on contact with iron salts. Three of these varieties, *R. xerampelina, R. elaeodes* (Bres.: Romagn.) Bon, and *R. semirubra* Singer are given species status in Thiers (1997a).

A complete description for a *Russula* collection requires about 20 min for fresh and 15 min for microscopic characters. Although fresh character notes are essential to reduce the taxonomic possibilities, we found microscopic characters more helpful than macroscopic for distinguishing among many *Russula* species, especially when notes for fresh characters were scant. The structure of the pileus and hymenium, and spore shape and ornamentation were particularly important to identification. Additional characters used in the identification of the genus *Russula* are described in Largent *et al.* (1987), Buyck (1991a,b), and Fatto (1995).

Woo's (1993) field key encompasses species reported from Oregon, Washington and Idaho. While it relies primarily on fresh macroscopic characters, it provides information on spore size and ornamentation. Thiers' (1997a) key, written for California species, may not include some Oregon taxa, yet distinguishes more species than either Woo (1993) or Arora (1986). It proved most useful in determining species from dried collections because it relies less on characters of fresh material than either Woo (1993) or Arora (1986). Arora's (1986) key is an easy to use and comprehensive guide for *Russula* species in the Pacific Northwest. Most species, however, are listed under a few large species assemblages and identifications must be compared with more detailed or up-to-date references. Errors from other taxonomic works have been included in Arora (1986). *Russula placita* Burl., for example, was erroneously described by McKenny and Stuntz (1971) as mild tasting, but is in fact described as acrid in the type description (Burlingham 1915), as well as in Woo (1993) and Thiers (1997a).

Some difficult to distinguish species in Arora (1986) are based on European names, out-of-date taxonomy, or expanded species concepts. For example, the European species *Russula sororia* (Fr.) Romell, represents a species group in Arora (1986) that includes associates of pine *(Pinus spp.)* and Douglas-fir as well as oak *(Quercus spp.). R. sororia,* strictly an oak associate (Fries 1821), is easily confused with several peppery tasting, brown to grayish-brown capped

pine-associated *Russulas* including the European *R. pectinata* (Bull.) Fr. (with a more yellow cap), and two North American species, *R. pectinatoides* (also with a more yellow cap and with darker spores) and *R. amoenolens* (Thiers 1997a). Romagnesi (1967) considered *R. sororia* and *R. amoenolens* synonymous, although other authors have maintained them as distinct (Schaeffer 1952, Singer 1986).

Arora (1986) applies the name *Russula subnigricans* Hongo, described from Japan, for a similar Pacific Northwest species. Although others have reported *R. subnigricans* in the eastern United States (Shaffer 1962, Weber and Smith 1985), Bills (1985) determined these collections to be *R. eccentrica* Peck, based on an eccentric stipe, pink to red or vinaceous lamellae and reddish wounding with no gray or black. Our collections, identified in the field as *R. subnigricans sensu* Arora (1986), key to *R. nigricans* (Bull.) Fr. in Woo (1993) and *R. dissimulans* Shaffer in Thiers (1997a). The range in spore size best fits the description of *R. dissimulans.* Singer (1986) suggested that *R. dissimulans* be considered a subspecies of *R. nigricans* because of considerable integration of characters between the two.

Notably absent from our collections was *Russula xerampelina,* a commonly encountered species that has been reported from the study area (Rhoades 1973). It is possible that climatic conditions during the time of our study were not conducive to the fruiting of this species because nearly half of the *Russula* species appeared in only one of the four Fall seasons. Although it is unlikely that the pungent and diagnostic odor would have gone unnoticed, a slight possibility exists that it was not recorded in the fresh character notes for collections identified only to genus. The odor is typically not retained in dried collections, and morphologically this species cluster may be confused with several *Russula* taxa including *R. alutacea, R. cessans* Pearson, and *R. integra.*

In studies where large numbers of sporocarps likely will be collected, we suggest limiting the study to certain genera or deciding prior to collecting the level of identification for taxa for which regional taxonomic materials are unavailable. Because some fresh character notes are essential, field assistants must be familiar with these for species identification. We recommend preparing character description sheets outlining fresh characters critical to the species identification of specific genera. We hope our comparison of the available keys to species within the genus *Russula* and discussion of fresh notes necessary for organizing collections will assist others with efficiently determining *Russula* species in challenging situations.

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Table 1.
Field characters for identifying *Russula* taxa, based on species and species group descriptions in Arora (1986).

Species group	Cap diam. (cm)	Cap color	Spore print color	Gill color	Gill arrangement	Bruising reaction	Taste	Odor	Distinguishing characters
R. aeruginea	3-9	dull to dark green, with brown, gray or yellowish tints	creamy to pale yellow or pale orange-yellow	white to pale yellow, often with brownish stains	close	none	mild		smooth green cap with no red or purple, mild taste, pale yellow spore print
R. albidula gp.	3-8	white, often light tan at center	white or creamy-white	white or creamy-white	close	none	acrid		white cap, modest size, acrid taste, smaller and more fragile than *R. brevipes*
R. albonigra	7-20	white, bruising gray then black	white	creamy-white, staining gray or black	alternating long and short	cap, gills, stipe bruise gray or black	mild or slightly acrid		all parts blackening in age or when handled
R. alutacea gp.	5-20	dark red to purple-brown, tan to straw at center or throughout, or with olive shades or a mixture	ochre-yellow	pale to dull ochre	close	none, stipe sometimes pinkish	mild	mild	medium to large, cap mixture of purple, red-rose with green to olive patches, mild tasting, yellow to dark yellow-spored
R. brevipes	7-30	whitish, often discolored	whitish	white or creamy-white	alternating long and short	none	acrid		large size, dull white, centrally depressed cap, inrolled margin when young, not blackening or reddening when bruised, acrid taste
R. cremoricolor	3-10	white to pale yellow-white center often darker	white	white	fairly close	none	acrid	mild or slightly fragrant	small, white to pale yellow cap, white spores, acrid taste
R. cyanoxantha	5-18	mixture of dull purple, green, olive, yellow blue-green white, brown	white	white or with a few brownish stains	many forked at least once	none, flesh in base of stalk sometimes grayish	mild	mild, pleasant	fairly large size, variegated cap, white gills and spores, firm white stalk, mild taste
R. decolorans gp.	5-15	dull red to orange, with yellow or coppery-brown, margin striate in old age	pale yellow to pale ochre	creamy to pale ochre, sometimes staining gray in age	fairly close	all parts turning gray or black when bruised or exposed	mild	mild	graying flesh, reddish to orange cap, mild taste, robust
R. densifola	5-15	white, bruising reddish to gray-brown to black	white	whitish, developing sordid red to gray stains in age	alternating long and short	cap, gills, stipe bruise reddish then gray-brown to black	usually acrid		slow staining of wounded tissue to reddish then grayish-brown or black, crowded gills, thick cap

Table 1. *(Continued)*
Field characters for identifying *Russula* taxa, based on species and species group descriptions in Arora (1986).

Species group	Cap diam. (cm)	Cap color	Spore print color	Gill color	Gill arrangement	Bruising reaction	Taste	Odor	Distinguishing characters
R. emetica gp.	3-10	red, center often darker, fading in age or rain to pink, orange, or blotched with white	white	white or creamy-white	close	none	acrid	mild	small red cap, white stem and gills, very peppery taste
R. fragilis	2-5	purple to pinkish olive-brown, greenish, yellow, or a mixture, often blackish at the center and pinkish-yellow at the margin	whitish	white or creamy-white	fairly close	none	acrid	variable	small cap, variegated, center dark, pink toward margin and gray-olive between, fragile texture, peppery taste, white gills, white spores, similar to *R. gracilis* but with a white stalk
R. fragrantissima gp.	5-15(20)	yellowish to brown, ochre, orange-brown	pale orange-yellow	creamy-white, becoming pale ochre, brownish spotted in age	fairly close	none	gills acrid	sweet	cap yellow brown with striate margin, penetrating odor reminiscent of maraschino cherries
R. gracilis gp.	2-8	pinkish with dull green or olive to brown-black center and pale pinkish margin	creamy to pale	whitish to creamy-white or tinged yellowish	close	stipe white to variegated or with pinkish flush	acrid		fragile pinkish stalk, yellowish spores, peppery taste, variegated pinkish or pink and greenish cap
R. integra gp.	3-12	gray-vinaceous to gray-brown to bright or rusty-red, paler toward margin	yellow-ochre	white becoming yellowish or pale ochre	close	none, stipe sometimes with brown or yellow-brown spots and stains	mild	mild	cap gray-vinaceous to gray-brown, mild odor and taste, yellow spores, stem long long and white or brown-stained
R. maculata gp.	4-10(12)	red to pink, reddish-orange, yellowish-tan whitish, or a mixture	yellow-ochre	creamy to white becoming pale ochre	close	none, white stalk sometimes brownish-stained	mild or slightly peppery		cap color variable, variable, oak associate, yellow spores, fragile texture in age
R. mariae	2-7	purple to reddish purple to dark crimson	creamy-yellow	white becoming creamy or pale yellow	close	none	mild or slightly acrid		dry, velvety or finely powdered reddish to purple cap, creamy-white spore print, mild taste
R. placita gp.	2-7(10)	vinaceous to brownish purple, sometimes darker or brownish-yellow at center	yellow-ochre	white or creamy becoming yellowish or dull ochre	close	none	mild*	mild	small, fragile, yellow-spored, cap cap color variable with some purple or red-purple

Table 1. *(Continued)*
Field characters for identifying *Russula* taxa, based on species and species group discriptions in Arora (1986).

Species group	Cap diam. (cm)	Cap color	Spore print color	Gill color	Gill arrangement	Bruising reaction	Taste	Odor	Distinguishing characters
R. rosacea (=R. sanguinea)	3-12	red, fading in age to pink or pink blotched with white	pale yellow	creamy-white to pale yellowish	close	none	acrid	mild	red cap, red to rosy stem, creamy gills and peppery taste
R. sororia gp. *(=R. amoenolens)*	4-12	grayish- to hazel-brown when young, paler towards margin	creamy to pale yellow	white or creamy, often brownish or rusty-stained in age	close	none	mild or slightly acrid, gills slowly acrid	rancid	moderate size, brown to gray-brown to straw-colored cap, striate margin in age, peppery-tasting gills, unpleasant odor
R. subnigricans gp.	(5)9-20(30)	whitish turning grayish or reddish brown	white	staining dark or sordid red	alternating long and short	cap, gills, stipe slowly bruise reddish then more brown-gray	mild to slightly bitter	rank	hard stem, brittle texture, large size, gills reddening in age or where wounded
R. xerampelina	5-30	red to dark red to purple, or brownish-olive often with green, brown, yellow-brown, or purple-brown	yellowish	creamy-white becoming yellowish or staining brown	close	flesh and gills bruising brown, stalk staining yellowish when scratched	mild	mild, fish-like odor in age	cap viscid or with adhering debris, stem pinkish, staining yellow and brown, yellow spore print, mild taste, fishy odor at maturity, gills darkening in age

*acrid according to the type collection, Thiers (1997a), and Woo (1993).

Table 2.
List of *Russula* species or species groups found in four Fall seasons at the H. J. Andrews Experimental Forest.

Russula species or group	Fall 1991	Fall 1992	Fall 1993	Fall 1994
R. aeruginea		X	X	X
R. albidula		X	X	
R. albonigra	X	X	X	X
R. alutacea gp.		X	X	X
R. amoenolens				X
R. brevipes	X	X		X
R. cascadensis		X		X
R. cerolens gp.		X		X
R. cessans gp.		X	X	X
R. cf. cyanoxantha			X	X
R. cremoricolor				X
R. crenulata				X
R. decolorans			X	X
R. densifolia				X
R. dissimulans				X
R. ellenae				X
R. fragilis		X	X	X
R. fragrantissima	X			X
R. gracilis				X
R. integra gp.		X	X	X
R. laurocerai				X
R. pectinatoides				X
R. placita			X	
R. sanguinea		X		X
R. sp. nov. "B"				X

Table 3.
***Russula* collections from the H. J. Andrews Experimental Forest. Collections were identified fresh with Arora (1986), dried, and then identified with Thiers (1997a) and Woo (1993).**

Arora 1986	Thiers 1997a	Woo 1993
R. aeruginea	*R. aeruginea*	*R. aeruginea*
R. albidula gp.	*R. albidula*	*R. albidula* or *R. cremoricolor*
R. albonigra	*R. albonigra*	*R. albonigra*
R. alutacea gp.	*R. alutacea* or *R. cessans* based on ±pileocystidia, spore size and ornamentation	*R. cessans*
R. brevipes	*R. brevipes* var. *brevipes* or *R. cascadensis* based on spore size and ornamentation	*R. brevipes* or *R. cascadensis*
R. cremoricolor	*R. cremoricolor* or *R. crenulata* based on ±pileocystidia and spore ornamentation	*R. cremoricolor* or *R. consobrina* based on color changes
R. cyanoxantha	*R. cyanoxantha* but spore shape and ornamentation differs from our specimens	*R. cyanoxantha* best fit
R. densifolia	*R. densifolia*	*R. densifolia*
R. fragilis	*R. fragilis*	*R. fragilis*
R. fragrantissima gp.	*R. fragrantissima* or *R. laurocerai* based on +reaction of pileocystidia to sulfovanillin, and spore size and ornamentation	*R. fragrantissima*
R. gracilis gp.	*R. gracilis*	*R. gracilis*
R. integra gp.	*R. integra*	*R. integra;* not easily keyed
R. placita gp.	*R. alutacea, R. cessans,* or *R. placita* based on taste, staining of stipe, ±pileocystidia, spore size and ornamentation	*R. cessans* or *R. placita* based on taste and staining of stipe
R. rosacea	*R. sanguinea* (=R. rosacea) or *R. ellenae* based on spore size and ornamentation	*R. rosacea*
R. sororia gp.	*R. cerolens* or *R. amoenolens* based on tree associate and spore ornamentation	*R. pectinata* or *R. consobrina*
R. subnigricans gp.	*R. dissimulans*	keys to *R. nigricans* but our specimens with spores larger and more like those of *R. dissimulans*