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High-elevation gray morels and other *Morchella* species harvested as non-timber forest products in Idaho and Montana

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We investigated post-fire morels (*Morchella* species), especially the "gray" morels of Idaho and Montana, by collecting ecological and genetic data and by interviewing commercial mushroom harvesters and buyers. Gray morels fruited exclusively in high-elevation *Picea/Abies* forests that had burned the preceding summer, predominantly in zones of moderate fire intensity as indicated by a layer of dead conifer needles on top of the fire ash. Genetic analysis revealed five varieties of morels among our specimens. Mushroom harvesters confirmed that gray morels are economically crucial to their business because they are typically large, heavy, and durable. Harvesters and buyers described the varieties of morels they encountered differently than mycologists did, but cooperative research could facilitate mutual understanding of morel diversity and benefit everyone involved.

Keywords: Morels, non-timber forest products, wildfire, forest ecology, taxonomy, commercial harvesters, mushroom buyers

Introduction

The business of harvesting and marketing wild edible forest fungi in northwestern North America has grown dramatically over the last two decades. Mushroom harvest now provides a supplementary, if not primary, source of income for many people (McLain & Jones, 1997, McLain, 2000). In 1992, 65% of mushroom harvesters surveyed collected mushrooms for supplemental income, and the remaining 35% collected mushrooms as their primary source of income (Schlosser & Blatner, 1995). The same study showed that more pounds of morels (1.3 million) were harvested and sold in the Pacific Northwest than any other type of mushroom. With increasing demand for such delicacies, and the corresponding decrease in timber harvest, mushrooms are recognized as a valuable forest resource.

Several species of morels occur in western North America; however, most do not have valid scientific names (Weber *et al.*, 1996). Morels have complex reproductive strategies, their ecology is poorly known, and they fruit under a variety of environmental conditions. True morels (the genus *Morchella*) are easily distinguished from other mushrooms, but identifying and naming species can be difficult (Weber 1995). Although evidence suggests that some species of morels might be ectomycorrhizal (Buscot & Kottke, 1990; Buscot, 1992; 1993; Dahlstrom *et al.*, 2000; Harbin & Volk, 1999), other species are thought to be saprobes, decomposing organic matter (Ower, 1982).

Wildfires frequently stimulate flushes of some morel species during the following spring or summer, particularly in cold-temperate, boreal, or high-elevation conifer forests of western North America. Conversations with harvesters and forthcoming data (Pilz *et al.*, 2004) suggest that the productivity of burn morels then declines rapidly in subsequent years. When large crops of morels occur in well-defined areas that are relatively easy to traverse, ideal conditions exist for commercial harvesting.

Morels known as 'gray morels,' or simply 'grays' by commercial and recreational harvesters might include several distinct species that fruit following fires. The taxonomy of these morels has received little attention from scientists in North America. We are unaware of any validly published scientific names that can be applied with confidence to members of this group. The name "*Morchella atrotomentosa*" has been used in some publications (McKnight, 1987; Obst & Brown, 2000), but that name has not been validly published in accordance with the *International Code of Botanical*

Nomenclature (Greuter *et al.*, 2000). This taxonomic uncertainty hinders research into the ecology, productivity, and management of burn morels.

The purpose of this study was to document the habitat conditions and fruiting substrates of post-fire morels of the intermountain West and to determine species diversity among morels collected in these habitats. Because mushroom harvesters and buyers have extensive experience with observing field conditions that are favorable for morel fruiting (McLain, 2000), we also wished to evaluate the degree of correspondence between their knowledge and our results.

Habitats and fruiting substrates were described with site visits, species diversity among collected specimens was determined with molecular methods of genetic analysis, and harvester and buyer knowledge was documented through interviews and participation in their activities.

Interviews

The study was conducted from late June to early August 1999. USDA Forest Service personnel and researchers at Oregon State University provided the original leads for how and where to contact individual harvesters and buyers. The senior author and her assistant visited two mushroom-buying stations on several occasions, the first in La Grande, OR, and the second in Darby, MT. Harvesters and buyers who heard about our interest in classification schemes usually became interested in our research and allowed us to conduct informal interviews with them. In total, we interviewed one full-time and two part-time buyers, as well as one full-time and two part-time harvesters. Two of the buyers were also harvesters, and the third had previously been a harvester.

Following protocol of Alexiades (1996), we conducted semi-structured interviews with the harvesters and buyers. We took photographs of fresh mushrooms that had been brought in for sale (Fig 1) as well as dried ones that were ready to be shipped to various consumers. On several occasions, we were participant observers, accompanying harvesters in the field.

Site selection

Based on discussions with researchers, USDA Forest Service personnel, harvesters, and buyers, we sought areas that had been burned within the last year, were above 2000 m in elevation and the snow had recently melted, and where harvesters were collecting at the time of the study.

We sampled three sites where morels were fruiting following forest fires during summer 1998 (Fig 2). The first site, the 'Hamilton/Bend Fire,' was in the Bitterroot National Forest, along the border between Idaho and Montana. The second, the 'Challenge Fire,' was in northern Montana, outside of Glacier National Park, in the Hungry Horse Ranger District of the Flathead National Forest. The third, the 'Rye Creek Fire,' was south of Darby, MT, also in the Bitterroot National Forest.

All three sites burned heterogeneously; burn intensity ranged from low-intensity under-burns to high-intensity crown fires. Underlying soils were heated to varying degrees. Each site exhibited rolling terrain. Standing dead snags and prostrate boles were scattered throughout each site, especially on the inclines (Fig 3). The volcanic ash soils at each site were topped with a thick layer of wood ash from the fire, and singed reddish conifer needles covered the ground in moderately burned areas. Flowing creeks existed on all the sites.

Hamilton/Bend Fire

The original forest consisted of Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), and lodgepole pine (*Pinus contorta* subsp. *murrayana* (Grev. & Balf.) Critchf.). Heavy snowpacks prevented access to this remote site until less than a week before we visited the area. We collected samples from elevations ranging from 2100 to 2300 m.

There was very little growth of new vegetation aside from the scattered tufts of grasses and sedges, where the ash layer was thinner and the fire had burned less

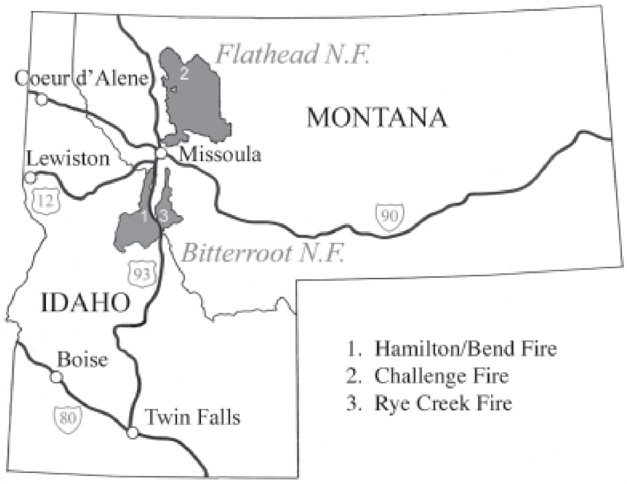

Fig 2 Bitterroot and Flathead National Forests and the wildfire study sites.

Fig 1 Processing morels at a buying station.

Fig 3 Wildfire-burned forest habitat of gray morels.

Fig 4 Freshly harvested gray morels with thick flesh.

Fig 5 Gray morel growing in the "red needle zone."

Fig 6 Gray morels growing in the shade of a log.

intensely. Annual precipitation in the area is from 63 to 76 cm with up to 3 m of snow in winter (Ray Rodriguez, Pers. Comm., Fire Specialist, USDA Forest Service, Darby Ranger District and Historical Visitor Center, Bitterroot National Forest, Darby, MT).

Challenge Fire

The Challenge Fire burned more hectares than were burned at the Hamilton/Bend site. The tree species composition of the original forest was similar to that of the Hamilton/Bend area. The site was easy to access, and we inferred from severed morel stalks that morels had been harvested in this area before our visit. Samples taken from this site were collected on two occasions, all from an elevation of about 2000 m.

The Challenge Fire also exhibited regeneration of grasses, distributed widely along the streambanks. Post-fire salvage logging impacted the site in some areas (Betty Kuropat, Pers. Comm., Forest Products specialist, USDA Forest Service, Hungry Horse Ranger District, Flathead National Forest, Hungry Horse, MT). Twelve to 18 cm of volcanic ash, from several major eruptions of Mount St. Helens and Crater Lake, lie above deeper soils derived from aged Cambrian/Mesozoic sandstone and shale parent material (Dean Sirucek, Pers. Comm., Hydrologist, USDA Forest Service, Hungry Horse Ranger Station, Hungry Horse, MT).

Rye Creek Fire

Ponderosa pine (*Pinus ponderosa* Dougl. ex Loud.) and Douglas-fir (*Pseudotsuga menziesii* v. *glauca* (Beissn.) Franco) originally dominated the northern slopes of this site. Like the Challenge Fire area, it was easily accessible by vehicle and, as a result, extremely well picked-over.

As recently as the 1960s, this site was extensively disturbed by salvage logging that resulted in high road densities and numerous stream crossings; as a result, 50% of the soil surface area was compacted to some degree. Most of the area was lightly or moderately burned. Salvage logging followed this fire as well, although Forest Service personnel took precautions to minimize further soil disturbance. Three watersheds drain the area: Rye Creek, Spring Gulch, and Fox Creek. Coarse sandy-loams make the Rye Creek soils very erodible, and streambeds contained a large proportion of sand (Mike Jakober, Pers. Comm., Fish Biologist, USDA Forest Service, Sula District, Bitterroot National Forest, Sula, MT). Some grasses had regenerated.

Field Collection

Within the sites where morels were found, we began our search along creeks (running or dry) and visually scanned 1.5 m to each side of the creek bed. We specifically looked in sheltered microsites, such as under fallen boles, among tree roots, and in clusters of conifer needles. We then moved up surrounding slopes in a switchback pattern. A ‘sample’ was defined as one to several morels (either solitary or clumped) in close proximity to one another and with similar fruiting body morphology. Individual specimens representing different degrees of maturity (using size as an indicator of age) were included when possible.

To facilitate subsequent recognition of fresh characters, we used color slide film to photograph the mushrooms in their natural habitat before picking them. For spore prints, we then selected one specimen per sample (usually the largest and most mature) and laid the morel on a clean glass slide. We wrapped the morel and slide loosely in a piece of wax paper, twisting the ends closed before placing the specimen in a wax bag and leaving it undisturbed for at least 8 hours or until a spore print was visible. Spore prints were labeled and wrapped in aluminum foil. Location of the site, features of the microsite, and morphology of the specimens were recorded for each sample immediately upon collection. Specimens used for spore prints were sliced lengthways one or more times to fit into a forced-air electric food-dehydrator. We then cut a small piece of tissue (approximately 5 mm^3) from the inside of the stem or cap of these morels with a clean knife blade and placed the excised tissue into a container with 5 ml of saline buffer solution for subsequent genetic analysis. When all the genetic samples and slides were labeled, we sliced the remaining morels for drying.

Morphological and genetic analysis

DNA was extracted from tissue preserved in saline solution and analyzed by using standard molecular methods of genetic analysis, namely polymerase chain reaction (PCR) and restriction fragment length polymorphism (RFLP) techniques. Methods of DNA extraction, PCR amplification and RFLP followed laboratory protocols set by Gardes & Bruns (1993). We used fungal specific primers *ITS1f* and *ITS4* for dilution (Gardes *et al*., 1991), and restriction enzymes *Hinf*I, *Dpn*II, and *Hae*III to produce RFLP patterns.

Results

Morel classification schemes differed in many ways between the individuals we interviewed, although common threads existed. One buyer believed gray morels to be fire adapted, and considered them 'mutations' of another commercially important variety, the burn morels. Another buyer agreed that gray morels were especially well adapted to harsh environments that had been greatly altered by intense fires, and that gray morels had only been discovered as a recreational or commercial resource within the past decade. All harvesters and buyers agreed that only the gray morel had a 'double wall,' a feature that refers to alternating darker and lighter layers of flesh seen when the stem is cut in cross section during harvesting. Grays were therefore heavier, more durable, and worth more money per specimen than other morel varieties, because morels are sold by weight (Fig 4). Harvesters mentioned that triple-walled morels, even larger and more dense than grays, are harvested, although not in large quantities.

Harvesters directed us to the exact sites and microsites where morels fruited, specifying true fir stands that had been burned within the past year. They recommended open areas where reddish conifer needles littered the forest floor (Fig 5). Harvesters explained that 'red' needles indicated a burn of the desirable intensity. Our observations concurred with those of harvesters that gray morels fruited predominantly in areas littered with dead conifer needles, and they were the only morel we encountered in such areas. We found them only in high-elevation conifer forests, in stands dominated by Engelmann spruce and subalpine fir that had burned the preceding summer. The other kinds of morels we found fruited only in the ponderosa pine and Douglas-fir stands of the Rye Creek wildfire.

Of the 44 samples gathered in the field, all were collected from northeast-facing slopes. Thirty-eight samples were single specimens, and the remaining six were found in a single cluster. We found morels predominantly in the shade of fallen boles, along the path of roots, in protected areas at the base of standing trees, and in other sheltered microsites (Fig. 6). Morels followed the contours of the landscape, often fruiting within 3 m, although not closer than 0.3 m to streambeds (whether water was still running or not). On two occasions, we found morels growing out of decayed wood. In all other cases, morels fruited among clumps of burned conifer needles and grew out of the ash.

Although we collected and identified several potential species, gray morels fruited in greatest abundance, and continued fruiting later into the season than other commercially harvested varieties. Fresh morels brought to buying stations were almost exclusively gray morels.

Of the 44 morels, only 31 yielded useful PCR products and thus were included in Table 1. Genetic analyses showed five varieties of morels. Of the 44 original samples, 22 could be confidently grouped as gray morels using morphological characters. 20 of these grays amplified and yielded uniform genetic results that differed from the other morels. The 11 other specimens that amplified fell into one of four different genetic groupings (Table 1), but no consistent morphological differences were apparent among them.

The gray morels from this study matched those described by Obst & Brown (2000). Morel heads were gray to brownish-gray, becoming lighter with increasing size. Stems varied from dark gray to whitish, becoming lighter with increasing size. Heads had irregularly patterned pits. Pits were smaller and more firmly compressed in small specimens than in large ones. A coating of small hairs covered the surface of small heads, becoming less noticeable, on larger specimens. Gray morels were particularly thick, hefty, and sturdy, and exhibited the feature harvesters described as double walls.

In addition to gray morels, we collected what many harvesters call 'natural black morels' (*M. elata sensu lato* (Smith *et al*., 1981; Weber, 1995)), although the

Table 1. Restriction fragment band sizes (in base pairs) of putative morel taxa analyzed in this study.

		RESTRICTION ENZYME		
PUTATIVE TAXA (Pt)	Number of specimens analyzed[a]	DpnII	HaeIII	HinfI
Gray morels	20	402	372/175/132	442/316/222/(184)[b]
Pt 2	2	428/264	407/107/87	283/122/(109)
Pt 3	2	447/258	364/128/112/87	380/299/106
Pt 4	5	442/258	361/126/94/84	373/295/105
Pt 5	2[c]	442/255	(564)/404/128/106/85	389/247/121

[a] Not all specimens yielded useful PCR products, only clear results are listed
[b] Molecular bands shown in parentheses only occurred in one specimen
[c] One of these specimens was a vouchered reference, NSW # 7749, identified as *Morchella elata sensu lato* (Smith *et al*., 1981; Weber, 1997) and collected May 29, 1996, in a nonburned area along US Forest Service Road 21 in the Wallowa-Whitman National Forest of Union County in northeastern Oregon.

term 'naturals' is applied by some harvesters to any non-burn morel. *M. elata* specimens appeared single-walled, weighed less than grays, displayed a relatively uniform ladder-like arrangement of head pits, and had long and whitish stalks. Specimens were found late in the fruiting season at the same time, and in the same areas that grays fruited. The other putative morel taxa we identified with genetic analysis were insufficiently sampled to describe morphologically.

Discussion

The concurrence between harvesters and Obst & Brown (2000) regarding the reddish needles suggests that gray morels grow better in areas of moderate burn severity than in areas of greater or lesser severity. In these areas, the fire did not immediately torch the crowns of dominant conifers but was sufficiently hot and long-lasting to kill the trees so that their singed or dried needles dropped after the fire.

Fire volatizes different nutrients at different temperatures. Even large fires are not often above 750 degrees C, and calcium, magnesium, and sodium often stay *in situ* as large components of ash. The ash layer that is retained in high-elevation sites such as those in this study might be desirable for morel fruiting because it raises soil pH, increases carbonate concentrations, and increases the water-holding capacity of the underlying soils (Dean Sirucek, Pers. Comm., Hungry Horse Ranger Station, Hungry Horse, MT).

Fire neutralizes organic acids, might reduce the concentrations of substances that inhibit the growth of fungi that typically fruit after soils have been heated (Duchesne & Weber, 1993), and removes litter that could inhibit ascocarp formation (Apfelbaum *et al.*, 1984). Combustion releases mineral nutrients otherwise tightly bound in organic matter (Agee, 1993), and morels (or other fungi that fruit shortly after a fire) might be taking advantage of the surge of mineral nutrients that leach through the soil profile from wood ash.

Harvesters told us that patterns of morel fruiting follow shifting moisture and temperature gradients, beginning on warm south-facing slopes or exposed areas and ending on relatively cool, moist sites such as northern exposures at high elevations. Precipitation has a strong influence on morel crops, and in dry years morels are more likely to appear in damp areas than in exposed, dry habitats (Weber, 1995). This might explain why gray morels were found along streambeds in sheltered microsites rather than in more exposed areas. During a moist season, gray morels might fruit in widespread spatial patterns. Obst & Brown (2000) also found gray and natural morels fruiting concurrently, but at their sub-arctic boreal forest sites, they noted gray morels growing on exposed, drier, higher ground, whereas natural (black) morels grew in sheltered, moist, low-lying areas.

Harvesters and buyers used different vocabulary and classification schemes for describing these morels than scientists did. Harvesters used the terms 'hybrids'and 'mutations' to describe morel variation rather than scientific terms such as 'species,' 'varieties,' or 'forms.' Perhaps, in part, this discrepancy reflects current lack of agreement among mycologists about species distinctions and proper scientific names for western North American morels.

Involving harvesters in future research projects to clarify morel taxonomy and ecology would have several benefits. Harvesters could provide specimens from the groups of morels they recognize by using morphological features, habitat, time of fruiting, or other factors. Such spatially-extensive and observation-based sampling could provide a much broader and more complete representation of potential morel diversity than a few researchers or paid crews could accomplish. Harvester involvement also could help to clarify differences in the appearance of morels that are correlated with environmental factors, fruit-body age, or local strains, even if the morels are not determined to be separate species based on genetic analysis. Interviews, such as those we conducted, are an important first step in developing harvester interest in such participatory research but offer little tangible benefit to the harvester. Financial compensation, public acknowledgement of their expertise, co-authorship of publications, and improved communication with managers and scientists are all possible incentives for harvesters to lend their talents to collaborative research.

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