Chapter 12
Native and Cultivated Truffles of North America

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12.1 Introduction

Of the many truffles indigenous to North America, seven species are noted for their culinary value. Four species known collectively as the Oregon truffles are found on the west coast, while three others are found in the southern and eastern portions of the continent. North America also has European truffle species planted in orchards of inoculated trees established across much of the continent. Both the harvest of indigenous truffles and cultivation of European species are largely undeveloped industries with great cultural and commercial potential, although both face significant challenges (Pilz et al. 2009).

12.2 Oregon Truffles

At a conference entitled *Mushrooms and Man*, held in Corvallis, Oregon, on November 6–8, 1977 (Walters 1977), the recently named Oregon white truffle (James Trappe, personal communication) was proclaimed by Chef James Beard to be as good as the Italian white truffle. As one of the most influential chefs in US history, Chef Beard's statement contributed to the development of a commercial market for Oregon truffles over the ensuing decades. His praise is echoed by other prominent chefs, some of whom have expressed a preference for Oregon truffles over the celebrated European species (e.g., Czarnecki 1995). Oregon truffles have also received higher scores than their more famous counterparts in taste and aroma tests where panelists were asked to state which truffle they preferred without knowing in advance what species were presented, their relative prices, or where

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they originated (Charles Lefevre, unpublished data). These results (and accolades by renowned chefs) do not establish that Oregon truffles are "better" than the more expensive European truffles, but they do suggest that Oregon truffles merit serious attention and further study. Whether Oregon truffles are capable of favorable comparison with the European species is often irrelevant, however, given current harvest methods and their negative impact on overall quality of truffles available on the market.

12.2.1 Harvest Methods

The harvest of truffles employs flies, pigs, and trained dogs, but before a truffle industry existed in North America, there was no need for these animals. Study and surveys of the many indigenous hypogeous fungi were conducted with rakes, which was appropriate for research purposes, and had little impact considering the relatively small areas searched. Raking continued to be employed during the early development of the commercial industry in Oregon, but the habitat impact of raking quickly became extensive, and the sale of immature and unripe truffles adversely impacted their culinary reputation (Trappe 1989, 1990).

Evidence for growing disappointment with Oregon truffles was reflected in their market value, which declined precipitously in the 1980s (Stan Patterson, personal communication; Dennis Morgan, personal communication) and continued to decline between 1992 and 1998 (Lefevre et al. 2001; Schlosser and Blatner 1995). By 1998 prices had become unresponsive to supply, even in low-productivity years (Lefevre et al. 2001). Trappe (1989, 1990) called for a transition from raking to the exclusive use of truffle dogs both as a way to prevent widespread disruption of the forest floor and to selectively and reliably harvest ripe truffles. Others have reiterated the problem and repeated the call for a transition to truffle dogs (e.g., Bunyard 2008; NATS 2010; Renowden 2005; Trappe et al. 2007; Work 2008), but raking continues to be the predominant harvest method for Oregon truffles (Bauer 2012; Lefevre et al. 2001; Lefevre 2010; Pilz et al. 2009; Terry 2010).

As a natural consequence of raking, truffles are collected at all stages of maturity. Because truffles only ripen at the end of their development and tend to be consumed quickly by mycophagous animals, the proportion of truffles ripe at any given time tends to be low. Many unripe truffles are too immature to develop aroma, and the remainder must be ripened artificially to produce their aroma. The process of identifying and discarding those with no potential to ripen and ripening those that are sufficiently mature requires some education and experience (Czarnecki 1995; NATS 2010; Pilz et al. 2009) and largely explains the potential for disappointment among chefs who lack this understanding. One advantage of ripening truffles artificially is the ability to serve them 2 or 3 weeks earlier than they would ripen naturally, effectively extending the season. However, as Marin (1985) demonstrates, the intensity and complexity of artificially ripened truffles' aroma diminish as a function of the proportion of spores that have reached maturity, suggesting that truffles harvested early and ripened artificially will, on the whole, fail to reach their culinary potential. Nevertheless, that period of time early in each season when few truffles ripen naturally often coincides with the late fall and early winter holiday season when demand for truffles is high, and raking may often be the only way to satisfy this seasonal demand. High demand early in the season and the fact that some harvesters are resistant to arguments in favor of dogs (e.g., Bauer 2012) represent a form of inertia that may hinder a transition in harvest methods from rakes to trained truffle dogs.

Growing disparagement of Oregon truffles and prices effectively "hitting bottom" by 1998 created a bleak outlook for the Oregon truffle industry. More recently, however, three separate efforts appear to have contributed to signs of recovery. The first was a conscientious effort by one company to avoid purchase of immature truffles and to ripen the truffles they purchase prior to sale. This company charges prices approximately twice those of established purveyors (Bryan McCormick, personal communication). The second effort, started in 2005, was a concerted drive to recruit dog trainers to specialize in training truffle dogs for demonstrations and seminars held at the Oregon Truffle Festival and to promote the use of truffle dogs through the festival. After several years, a limited supply of truffles harvested exclusively with the assistance of trained dogs became available locally at prices somewhat higher than those ripened prior to sale (Toby Esthay, personal communication; Eric Lyon, personal communication). The third was the Oregon Truffle Festival itself, founded in 2006, with its visible effort to promote Oregon truffles and the extensive media coverage produced by that promotion. The combined effect of these efforts is reflected in prices for both white and black truffles that have either been on an upward trend [compare Lefevre et al. (2001) and Schlosser and Blatner (1995) with Terry (2010) and Czap (2012)] or may be bifurcating, with prices for raked truffles without prior ripening increasing at a slower pace, while truffles either ripened prior to sale or harvested by dogs command substantially higher prices. At the very least, prices for all Oregon truffles, including those harvested with rakes, have once again become responsive to changes in supply (Scott Cossairt, personal communication; Owen Rice, personal communication). In some cases, prices for Oregon truffles have reached $1,100.00/kg, substantially exceeding those of the summer and autumn variants of *Tuber aestivum* Vittad. within the same markets (Ian Purkayastha, personal communication; Toby Esthay, personal communication). Improvement in the reputation of Oregon truffles and maintenance of the upward trend in prices may continue with increased truffle dog use and with proposed certification standards to ensure that truffles are harvested by dogs (Pilz et al. 2009).

In Oregon, using truffle dogs rather than rakes is likely to generate additional benefits to the industry beyond their contribution to higher quality, improved reputation, and higher prices. These include more efficient harvest of truffles that are widely dispersed and prevention of damage to subsequent crops, thereby increasing harvester yields. For example, dogs may lead to increased yields from a particular site by preventing the premature harvest of later-maturing species during the harvests earlier in the season (see *Tuber oregonense* Trappe, Bonito & Rawlinson and *T. gibbosum*

Harkn. below). Similarly, dogs permit harvest of multiple flushes, where raking brings about a premature end to production on a particular site for the remainder of the season (see *Leucangium carthusianum* (Tul. & C. Tul.) Paol. and *Kalapuya brunnea* Trappe, Trappe & Bonito below). Dogs also reduce the time and effort required to locate widely dispersed truffles (e.g., Smith et al. 2012 found harvest rates for *T. lyonii* Butters increased by approximately a factor of five using a trained dog over harvesters using rakes) and may increase the rate at which truffles are harvested on marginally productive sites. Use of dogs may thereby allow productive harvest over greatly expanded areas of forestland in western Oregon and Washington. Similarly, dogs are more efficient during low-productivity years when truffles tend to be widely dispersed in otherwise productive patches. Harvesters using dogs will thus achieve higher yields when prices are higher. The greater efficiency of dogs during periods of low productivity also effectively extends the harvest season past the point when it would ordinarily end for all Oregon truffle species. Dogs may even allow productive harvests of two species year-round (see *L. carthusianum* and *K. brunnea* below). Other benefits associated with the use of dogs include reduced ecological and aesthetic disruption of the forest litter layer and upper soil horizons and the negative public reaction that raking for truffles generates. Finally, the use of dogs to locate truffles is uniquely appealing to food, travel, and news media, attracting positive attention to the truffle industry and to the region.

12.2.2 Tuber oregonense, *Oregon Winter White Truffle*

The common name "Oregon white truffle" was originally associated with the Latin binomial *Tuber gibbosum* that was later found to be a species complex and was split into four species (Bonito et al. 2010): *T. oregonense* (Fig. 12.2e), *T. gibbosum* (Fig. 12.2d), *T. bellisporum* Bonito & Trappe, and *T. castellanoi* Bonito & Trappe. Although their geographic ranges largely overlap, the latter two are rare, and little is known of their habitat or seasonality. *Tuber gibbosum* and *T. oregonense* are both common and abundant in western Oregon and Washington. The commercial harvest of Oregon white truffles is concentrated during late fall and winter when *T. oregonense* tends to reach maturity while *T. gibbosum* is typically only beginning to develop. Thus, in early November, it was more likely to have been *T. oregonense* rather than *T. gibbosum* that James Beard actually praised.

Like other *Tuber* species, *T. oregonense* appears to produce a single annual crop of sporocarps that require several months to reach maturity and to produce the aroma that is the source of their culinary value. The first immature sporocarps are often observed September through early October and reach full size between mid-October and early November. Undisturbed sporocarps in the soil do not produce noticeable aroma until sometime after they mature, indicated by darkening of the gleba from white to brown or dark brown. The aroma production lasts for a period of days prior to spoiling. The onset of natural ripening varies annually, from late November to late January. The conclusion of the season beyond which few

T. oregonense sporocarps are found varies from mid-February to mid-March. The seasonality of *T. oregonense* ripening also varies geographically, with its onset and conclusion varying by as much as a month from one locality to the next within a season.

As with other truffles, production varies annually with weather conditions affecting both number and size of sporocarps. Conditions within the geographic range of all Oregon truffles are consistently dry during midsummer. Precipitation and temperatures become more variable from late summer to early autumn, which appears to be the critical period when weather conditions affect truffle yields in western Oregon (Luoma 1991). Although no formal study of the relationship between weather conditions and production of any Oregon truffle species has been conducted, it is understood among harvesters that late summer rains and cool conditions tend to produce higher yields, while dry weather and unusually high temperatures extending into autumn tend to produce lower yields.

Tuber oregonense is found under a wide range of conditions in natural *Pseudotsuga menziesii* var. *menziesii* (Mirb.) Franco (Douglas fir) forests throughout its range in western Oregon and southwest Washington (Fig. 12.1c), but it appears to reach its greatest abundance under a relatively narrow range of conditions that are often easily and accurately recognized from great distances, including from aircraft and satellite imagery. Like many European truffle species that thrive on fallow agricultural land that has become overgrown with suitable host trees (Hall et al. 2007), Oregon truffles thrive in similarly anthropogenic habitats with a history of use as farm or pastureland that have been planted with Douglas fir. The most productive habitats tend to be created when Douglas fir is either planted with the intention of producing Christmas trees that are subsequently neglected or to convert abandoned farm or pasture into timberland. Less frequently, Oregon truffle habitat is created when Douglas fir is planted as an ornamental in residential or semirural settings or during restoration of riparian vegetation to enhance spawning habitat for anadromous fish. These afforested stands of Douglas fir develop a distinctive appearance and are frequently adjacent to open farmland making them conspicuous.

Because truffle spores are naturally transported by animals, dispersal in the short term is limited to the territorial reach of the various mycophagous animals that eat them (Jacobs and Luoma 2008). Perhaps as a result, Oregon truffles do not tend to be found in isolated stands of Douglas fir surrounded for some distance by open farmland or pasture and are more likely to be found in stands established near older existing Douglas fir that can provide a source for spore inoculum and small mammal vectors.

Tuber oregonense is found beneath trees of various ages, from 6 years or possibly younger in some managed Christmas tree orchards (Charles Lefevre, unpublished observation) to as old as 60 years (Chris Melotti, personal communication). They often fruit most prolifically in stands between the ages of 15 and 30 years, although there are notable exceptions. In one former Christmas tree plantation visited annually by the North American Truffling Society, production was first observed when the trees were 6 years old and reached significant yields

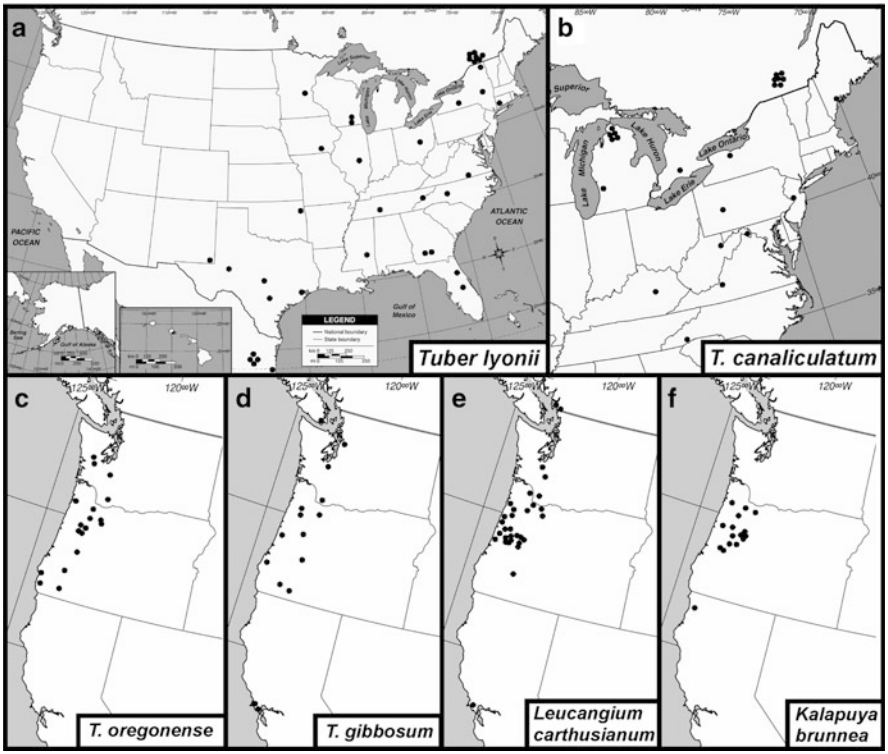

Fig. 12.1 Collection locations for (**a**) *Tuber lyonii* (modified from Trappe et al. 1996), (**b**) *T. canaliculatum*, (**c**) *T. oregonense*, and (**d**) *T. gibbosum* specimens examined in Bonito et al. (2010) and collection locations for (**e**) *Leucangium carthusianum* and (**f**) *Kalapuya brunnea* specimens held in the OSC herbarium

when the stand reached 8 years old (Paul Bishop, personal communication). The trees had been planted approximately 1.5-m apart and quickly become overcrowded. Truffle production also declined precipitously within 10 years of its onset in this closely planted stand, where stands planted at approximately 3-m spacing tend to both begin production later after the canopy closes and to produce truffles significantly longer (Charles Lefevre, unpublished observation). Examples like this suggest that stand densities may influence both the onset and duration of fruiting.

Oregon white truffles were long thought to associate exclusively with the coastal variety of Douglas fir, *P. menziesii* var. *menziesii*. However, *T. oregonense* has been observed fruiting beneath pure stands of both *Abies procera* Rehder (Margie Millard, personal communication) and *A. grandis* Lindl. (Ken Austin, personal communication) in overgrown Christmas tree plantations containing no *P. menziesii* within 100 m or more.

12.2.3 Tuber gibbosum, *Oregon Spring White Truffle*

The first immature *T. gibbosum* typically reach a size sufficient to easily locate them during the month of January, although some may be observed as early as October. They typically complete their growth within a month of becoming visible and ripen naturally over an extended period between January and mid-July with the majority ripening during the months of June and July.

Despite their development several months later than *T. oregonense*, their productivity follows a pattern similar to that of *T. oregonense* with highly productive years for one likely to also be highly productive for the other. This suggests that the productivity of both species is influenced by similar seasonal factors.

Tuber gibbosum reaches its greatest production in habitats similar to that of *T. oregonense*, and they are often found intermixed within the same stands of trees. As a result, immature *T. gibbosum* is often harvested with *T. oregonense*, which both contaminates the *T. oregonense* crop with immature *T. gibbosum* that have no capacity to ripen while simultaneously destroying the *T. gibbosum* truffle crop on that site. Use of trained dogs obviates this problem.

The principal host tree of *T. gibbosum* is *P. menziesii* var. *menziesii*, but they are known to occur in at least one pure stand of approximately 20-year-old *A. procera* planted as a Christmas tree orchard. The geographic range of *T. gibbosum* (Fig. 12.1d) differs from that of *T. oregonense* with collections from further north in NW Washington and British Columbia and further south in Northern California than any known collections of *T. oregonense* (Bonito et al. 2010).

Despite the fact that *T. gibbosum* is the name that has long been associated with Oregon white truffles, its harvest volumes is significantly lower than the more recently described *Tuber oregonense*. The relative disregard of *T. gibbosum* by harvesters may be explained by the fact that its harvest season coincides with the much larger morel and spring *Boletus* harvest in the Pacific Northwest. Some chefs who use *T. gibbosum* feel that it has the same appeal as *T. oregonense* (Jack Czarnecki, personal communication), although their aromas are not identical (Trappe et al. 2007).

12.2.4 Leucangium carthusianum, *the Oregon Black Truffle*

The Oregon black truffle, *Leucangium carthusianum* (Fig. 12.2a), received its culinary debut in the 1980s early in the development of the Oregon truffle industry (Lefevre et al. 2001). *L. carthusianum* was included in the study of hedonic response to Oregon truffles by Marin (1985) as a species with culinary appeal that was not harvested for culinary use at the time. In that study, panelists were significantly more likely to prefer the aroma of *L. carthusianum* over that of *T. gibbosum*, which may have contributed to its subsequent commercial exploitation. Despite their later introduction to culinary use, prices and harvest volumes of

Fig. 12.2 Truffle species with recognized culinary and commercial value indigenous to North America: (**a**) *Leucangium carthusianum*, (**b**) *Imaia gigantea* (photo courtesy of Todd Elliott), (**c**) *Kalapuya brunnea*, (**d**) *Tuber gibbosum*, (**e**) *T. oregonense*, (**f**) *T. canaliculatum* (photo courtesy of Gregory Bonito), and (**g**) *T. lyonii*

Oregon black truffles quickly surpassed those of Oregon white truffles (Lefevre et al. 2001; Schlosser and Blatner 1995).

The commercial raking of *L. carthusianum* takes place over a long season typically starting in October and concluding in May. In contrast to the commercial-raking season, collections from the Oregon State University herbarium (OSC) indicate that *L. carthusianum* fruits year round, and when dogs are used as the harvest method, ripe sporocarps are observed year round. Despite ripening throughout the year, the culinary quality of *L. carthusianum* appears to vary seasonally. Some harvesters, buyers, and chefs indicate that truffles producing the most appealing aromas tend to be more abundant during the spring.

Annual variation in *L. carthusianum* productivity follows patterns similar to white truffles, with cool and moist conditions in late summer and early autumn producing the highest yields and dry and/or hot conditions in late summer or early autumn producing poor yields. Black and white truffles do not respond identically to weather conditions, however, and there are occasional seasons when white truffles are plentiful while black truffles are scarce. Oregon black truffle yields generally appear to be more variable, from a near absence of sporocarps in some seasons to abundance in others. Oregon white truffle yields, in contrast, appear to be somewhat less variable and more reliable from the harvester's perspective.

Unlike *Tuber* species, *L. carthusianum* production appears to take place in a succession of flushes several weeks apart over the course of the season. The different flushes might represent wholly separate crops, but that seems unlikely given that yield trends established early in the season appear to characterize the entire season. Wholly separate crops, in contrast, might produce greater variation in yields from one crop to the next. This pattern of multiple flushes suggests that, like many other mushrooms, the crop develops in a series of cohorts arising from a single population of primordia (Stamets 2000). A transition from raking to using dogs will thus permit harvest of multiple flushes from the same site where raking early in the season tends to cause production to cease in that location for the remainder of the season presumably by disrupting resting primordia.

L. carthusianum was originally described from collections located beneath *Pinus sp*. in Chartreuse, France, but in North America, it appears to be exclusively associated with *P. menziesii* var. *menziesii* and is found west of the Cascade Mountains from northern California to southern British Columbia (Fig. 12.1e). Like *T. oregonense* and *T. gibbosum*, *L. carthusianum* thrives in anthropogenic habitats, particularly Douglas fir forests planted on former pasture or farmland. The most productive stands tend to be older than those producing the largest crops of white truffle species, and harvesters frequently observe that stands producing white truffles can undergo a transition with black truffles displacing white truffles over a period of years. Some harvesters speculate that black truffle inoculum may be introduced inadvertently or, in some cases, intentionally by the harvesters. Whether or not that is the case, *L. carthusianum* does appear to occupy a later successional niche in these afforested plantations and can occasionally be found in abundance within stands substantially older than 30 years (Dennis Morgan, personal communication).

L. carthusianum can also become highly productive in other habitat types, including areas that have never undergone a conversion to pasture or farmland (Dennis Morgan, personal communication; Stan Patterson, personal communication). Due to the secretive nature of truffle harvesting, the characteristics of other productive stand types are not well known. However, with the introduction of truffle dogs to forests of western Oregon and Washington, it is now apparent that *L. carthusianum* is more widespread than those areas where commercial harvests have taken place historically. Dogs are easily able to locate truffles too widely dispersed to be worth the indiscriminate effort of raking for them and may effectively enable profitable harvest over very large areas of forest that are not currently considered productive.

12.2.5 Kalapuya brunnea*, the Oregon Brown Truffle*

The Oregon brown truffle, *K. brunnea* (Fig. 12.2c), is the most recent addition to Oregon's truffle harvest industry. Like *T. oregonense*, it was harvested and sold for culinary use for a number of years prior to publication of its description and Latin binomial (Trappe et al. 2007, 2010). *K. brunnea* is less common and abundant than the other commercially important Oregon truffles, and its harvest is almost entirely a desirable form of "bycatch" by harvesters seeking *L. carthusianum* under young Douglas fir in western Oregon (Fig. 12.1f). Like all Oregon truffles, its habitat is not limited to the afforested plantations where most commercial harvesting tends to take place. Unlike the other Oregon truffle species, it is not known to associate with hosts other than *P. menziesii*. While relatively uncommon, it is highly regarded and receives prices comparable to, or slightly higher than, Oregon black truffles (Bryan McCormick, personal communication; Toby Esthay, personal communication).

The seasonality of *K. brunnea* follows a pattern similar to that of *L. carthusianum* with a long harvest season during which truffles ripen naturally in flushes from early autumn to late spring and possibly year round. Annual productivity also appears to be correlated with that of *L. carthusianum*, with relatively high production of both species some years contrasting with near absence in others. *K. brunnea* however is less abundant than *L. carthusianum* under all circumstances. Because *K. brunnea* tends to fruit in lower densities, the use of dogs greatly facilitates its harvest, and like *L. carthusianum*, the use of dogs will enable harvest of subsequent flushes from a particular site, where raking does not. The increased use of trained truffle dogs in Oregon may lead both to greater volumes of *K. brunnea* becoming available on the market and to a better understanding of its distribution and habitat.

12.3 Prospects for Cultivation of Native Oregon Truffles

As successful cultivation of European truffles has spread across the globe, interest in cultivation of native Oregon truffles has grown as well. Farmers are already establishing productive "orchards" without intending to do so suggesting that a crude form of cultivation is already possible simply by planting Douglas fir in the vicinity of existing stands and in the same widespread soil types (Pilz et al. 2009) where Oregon truffles already occur. Considering the predictability with which harvesters recognize and locate stands producing Oregon truffles, this simple emulation of the habitat may be a reliable way to achieve truffle production. However, the experience of harvesters also suggests that yields may remain highly variable both among stands and spatially within productive stands.

Several Oregon farmers have attempted to either introduce or enhance truffle production beneath established stands of young Douglas fir by broadcasting spores in a water suspension. Several widely publicized claims of success have gained attention (e.g., Dubarry and Bucquet-Grenet 2001). Unfortunately, there are no reported attempts to conduct this sort of field inoculation using the controls necessary to measure a treatment effect.

Inoculation of Douglas fir roots with *T. oregonense*, *T. gibbosum*, and *L. carthusianum* has been conducted in the laboratory producing seedlings well colonized by ectomycorrhizae of the various truffle species (Charles Lefevre, unpublished data). Because the methods are not yet cost effective, no significant attempts have been made to establish orchards using seedlings inoculated under controlled conditions. Numerous growers have attempted a crude form of inoculation by dipping the roots of commercially available Douglas fir seedlings into truffle spore slurries, but no verifiable claims of success either in producing truffle ectomycorrhizae or in producing truffles within orchards established using this inoculation method currently exist.

The principal impediment to progress with cultivating Oregon truffles is their current relatively low commercial value and the relatively small economic impact of truffle production in the Pacific Northwest (Pilz et al. 2009). Cultivation of Oregon truffles may nevertheless be worth further investigation. Given low historic prices paid to harvesters on the order of USD $220/kg (Lefevre et al. 2001; Schlosser and Blatner 1995) and yields in naturally producing stands reaching 5–30 kg/ha (Lefevre et al. 2001), gross returns from naturally occurring, unmanaged *L. carthusianum* patches exceed those of many agricultural crops.

The natural production of Oregon truffles beneath Douglas fir trees also appears to be compatible with other simultaneous land uses with little or no additional establishment or management costs. Most sites where truffles are currently harvested are principally used for timber production, but there is also an example of commercial truffle harvests beneath Douglas fir planted in a riparian zone that serves to enhance salmon spawning habitat (Maxwell 2005a). Establishment of the afforested plantations where Oregon truffle production is greatest is precisely the kind of project that the Oregon Department of Forestry supports through the Forest Resource Trust as a way to offset CO_2 emissions (Cathcart 2000). In addition, restoration plantings designed to enhance salmon spawning habitat are currently funded by the Conservation Reserve Enhancement Program administered by the U.S. Department of Agriculture (USDA 2011).

The economics of farming Oregon truffles will naturally improve if the current trend toward higher prices paid to harvesters using trained dogs and employing more stringent grading standards continues. The transition to exclusive use of dogs may also increase efficiency of harvest and increase yields of black and brown truffles by protecting the primordia that comprise subsequent flushes. Similarly, the outlook for cultivation of Oregon truffles will improve if methods can be developed to consistently produce the 20–50 kg/ha yields observed in European truffle orchards (Bonet and Colinas 2001).

Management methods with potential to influence production of Oregon truffles include irrigation to emulate beneficial weather conditions in late summer, soil amendments to optimize nutrients and pH for truffle production, and stand density management. Planting density and thinning treatments both affect the speed of canopy closure, the rate of litter layer buildup, and the crown ratio of the trees, among other factors that may influence the timing, abundance, and yield of truffle harvests. Apart from anecdotal reports of truffles reaching exceptional sizes on sites subjected to fertilization, lime application, and chemical weed control (Trappe 1990; Bonito et al. 2010), no other published reports discuss effects of forest management interventions on production of Oregon truffles.

12.4 Other North American Truffle Species with Culinary and Commercial Potential

At least three indigenous truffle species with notable culinary value are found in southern and eastern North America. These include *Tuber lyonii*, *Tuber canaliculatum* Gilkey, and *Imaia gigantea* (Imai) Trappe & Kovács. Though relatively unknown, their occurrence near many of North America's largest population centers and in the southern states has potential to generate significant culinary and cultural interest among local chefs and media. These species are harvested and sold for culinary use, although their annual harvest is currently insignificant.

Of these species, the best known is *Tuber lyonii*, the pecan or Texas truffle (Fig. 12.2g), which is found from central Mexico to southeastern Canada, roughly throughout the eastern third of the continent (Fig. 12.1a).

Tuber lyonii is associated with several host tree genera, including members of *Quercus*, *Crataegus*, *Tilia* (Trappe et al. 1996), *Corylus* (Bruhn 2007), and the pecan tree, *Carya illinoinensis* (Hanlin et al. 1989). Its fruiting season extends from March to February throughout its geographic range (Trappe et al. 1996), but it appears to vary in different regions. For example, the season for *T. lyonii* in south Georgia where it is currently collected for culinary and commercial purposes is limited to August through October (Smith et al. 2012). Like Oregon truffles, *T. lyonii* is frequently collected in natural forests but is also observed fruiting abundantly in anthropogenic habitats, most notably managed pecan orchards (Bonito et al. 2011; Hanlin et al. 1989), as well as ornamental plantings (Taber 1990), and as a contaminant in orchards of *Corylus avellana* L. inoculated with European truffle species (Bruhn 2007; Tom Michaels, personal communication). Many of these settings are routinely subjected to irrigation, fertilization, and chemical weed control. In orchards established for cultivation of the European truffles, *T. lyonii* is found in spite of heavy applications of calcium carbonate lime used to effect radical increases in soil pH. Its natural affinity for environments characterized by various horticultural interventions and broad climatic and edaphic latitude suggests that *T. lyonii* may be an excellent candidate for cultivation and potentially co-cropping with pecans, which has been discussed by Bonito et al. (2012) at greater length.

Like *T. lyonii*, the culinary value of *T. canaliculatum* (Fig. 12.2f) has been recognized for decades (e.g., Trappe 1990), although there are few reports of its harvest by amateur mycologists or commercial harvesters. The geographic range of *T. canaliculatum* extends over most of the eastern United States (Fig. 12.1b), where it is associated with a broad range of host species (Trappe 1990), particularly members of the *Pinaceae* and *Fagaceae*. It is likely, given the scant records of its occurrence, that it is seldom prolific. However, as at least one harvester in Maryland has found, the use of trained truffle dogs may enable productive harvest of *T. canaliculatum* sporocarps otherwise too widely dispersed to be effectively located by other means (Jeffrey Long, personal communication). Seedlings of *Pinus taeda* have been successfully inoculated with *T. canaliculatum* under laboratory conditions (Gregory Bonito, personal communication), and similar to other commercially important truffle species, *T. canaliculatum* sporocarps have been found in the anthropogenic environment of a backyard garden (Donna Mitchell, personal communication).

The truffle species most recently introduced to culinary use in North America is *Imaia gigantea* (=*Terfezia gigantea* Imai) (Fig. 12.2b), a close relative of *L. carthusianum* (Kovacs et al. 2008). Its distribution is limited to disjunct populations in Japan and in the eastern United States (Kovacs et al. 2008; Trappe and Sundberg 1977). The principal habitat in the United States is an uncommon and ecologically sensitive environment in which commercial harvest, particularly using rakes, may be undesirable (Alan Muskat, personal communication). It is harvested for culinary use on a small scale in western North Carolina. Efforts to inoculate *Pinus* spp. seedlings L. with *I. gigantea* under laboratory conditions are underway (Alan Muskat, person communication), although experimental orchards remain to be established.

12.4.1 Cultivation of European Truffles in North America

As the Oregon truffle industry began to develop, farmers around the country began to plant orchards of *Corylus* and *Quercus* inoculated with *Tuber melanosporum* Vittad. The first fruiting of *T. melanosporum* outside of its natural habitat in southern Europe took place in 1987 (Bruce Hatch, personal communication) beneath 5-year-old inoculated hazelnut trees planted in Mendocino County, California (Bland 2010; Bruce Hatch, personal communication; Olivier et al. 1996; Don Reading, personal communication; Rigdon 1994). The production of truffles from the orchard was significant given its size (Rigdon 1994), and the orchard continued to produce truffles through 2007 (Bland 2010). Since that initial success, several other orchards in the United States have produced *T. melanosporum* sporocarps (e.g., O'Neill 2007), and as of March 2012, one orchard in central Idaho had produced the first *T. borchii* Vittad. sporocarps (Paul Beckman, personal communication). Orchards of trees inoculated with *T. aestivum* (both summer and autumn variants) and *T. magnatum* Pico are also established in the United States and Canada, but have not yet born fruit. The inoculated seedlings used in these orchards are produced by a growing number of nurseries in the United States and Canada, and new orchards are established at a rate of several hundred per year. Most North American truffle orchards established to date are small with few exceeding 5 ha.

North American regions with winter and summer temperatures potentially suitable for cultivation of *T. melanosporum* occupy two large areas of the continent based loosely on AHS (1997) and climate maps included in Stamper and Koral (1979). One lies in a strip of relatively mild climate along the west coast extending from southernmost Canada to northernmost Mexico encompassing most of the area west of the Cascade mountain range and most of northern California but narrowing to the coast in central and southern California. This region also includes an extension inland to central Idaho along the Snake River Valley and a strip in California along the foothills of the Sierra Nevada range. The other major region forms a wedge with its point in New Mexico and extends to the east through the panhandle of Texas to encompass most of Oklahoma, Tennessee, and North Carolina. The northern boundary of this region includes southern Missouri, southernmost Illinois, much of Kentucky, southern West Virginia, and the non-mountainous areas of Virginia. The southern boundary of this region includes northern Arkansas, northern Mississippi, northern Alabama, north Georgia, and much of South Carolina. These boundaries are tenuous considering the imprecise knowledge of the truffles' climatic tolerances, as well as variation in meso- and microclimatic influences that may permit or prevent successful production of *T. melanosporum*. The northern boundary is also determined to some extent by the grower's tolerance for risk of frost damage to the truffle crop, which, for example, might extend the region into warmer sites in southern Indiana and southern Ohio for those growers who either take measures to mitigate winter temperature extremes or are comfortable with routine partial crop losses, and occasional total losses due to freezing conditions during the winter harvest season. Precipitation during the summer is insufficient to support reliable production of *T. melanosporum* throughout much of both major regions, and irrigation is generally advised by nurseries producing inoculated trees.

It is worth noting that climatic conditions in summer throughout much of both regions are significantly warmer than the climates in the natural habitat of *T. melanosporum* in southern Europe. Inclusion of these regions is based on successful production of truffles in several orchards in North Carolina where mean daily temperatures in summer exceed those in the producing regions of France, Italy, and Spain by 3 °C or more (Hall et al. 2007). The tolerance of *T. melanosporum* to summer heat is of less practical concern in Europe where the Mediterranean Sea interrupts the climate transect than it is in North America where large areas of the continent fall at latitudes lower than the southern limits of European *T. melanosporum* production. There is, for example, one report of modest *T. melanosporum* production at approximately 30° latitude in Dripping Springs, Texas (Price 2005), which, if borne out in additional orchards in similar summer climates, would greatly expand the area of potentially suitable climates into regions not only with warmer mean daily temperatures, but also warmer extremes and hot weather (daily high temperatures above 30 °C) exceeding 120 days over the course of the year (AHS 1997).

The regions of North America with climates potentially suitable for cultivation of *T. aestivum* and *T. borchii* cover a substantial portion of the continent, as both *T. aestivum* (Chevalier et al. 1978) and *T. borchii* (Hall et al. 2007) do in Europe. Based loosely on USDA (2012), AHS (1997), site-specific weather data available online (e.g., http://www.wunderground.com), and climate data compiled in Hall et al. (2007), the regions of North America where both species might be cultivated successfully largely encompass the climates suitable for *T. melanosporum* and extend into parts of the continent with somewhat colder winters, including parts of the Great Lakes region in the Midwest and Northeast, the southern Plains states, mountainous areas of the southwest and northern Mexico, and those regions of southern Canada with relatively mild winters on both coasts and in the Great Lakes region.

The calcareous soils required by *T. melanosporum* and *T. aestivum* are uncommon in those parts of North America with climates suitable for their cultivation, and most growers must apply lime at a rate of 60–90 tons/ha to their soils to raise the pH. While it is well documented that *T. melanosporum* and *T. aestivum* can be produced successfully in soils that have been subjected to major modification of pH (Hall et al. 2007), effects on soil biota, nutrient cycling, and truffle production resulting from lime applications on this scale are not well understood.

Other challenges facing growers of European truffles in North America include endemic fungal diseases of the principal host trees and mycophagous animals. The eastern filbert blight, *Anisogramma anomala* (Peck) E. Müll., has caused severe mortality of *Corylus avellana* inoculated with *Tuber melanosporum* in Mid-Atlantic region orchards, and it is likely to be problematic for truffle growers throughout the East Coast and Midwest regions where the disease is endemic, as well as the Pacific Northwest where it has naturalized within commercial hazelnut orchards. Sudden oak death disease, *Phytophthora ramorum* Werres & de Cock, has similarly caused severe mortality among *Q. ilex* Lour. trees that are naturalized in coastal California where truffle cultivation provides a natural complement to the wine industry. Throughout most of the Western United States, various rodent species commonly referred to as pocket gophers (family *Geomyidae*) may be uniquely problematic in truffle orchards where they not only browse the cambium layer of lateral roots and belowground portions of the stem, causing mortality among the host trees, but also consume truffles, which they are likely to encounter among the roots during the months of development and maturation prior to ripening. These as well as those challenges and uncertainties associated with truffle cultivation generally require research and subsequent modification of methods to adapt to local conditions.

12.5 Conclusion

The market potential for truffles in North America remains encouraging given growing culinary sophistication among American consumers as well as the "local" movement for sourcing food ingredients (Pilz et al. 2009). The United

States in particular has a unique opportunity to not only cultivate European truffles like other regions around the world but also to develop industries around the harvest and potential cultivation of indigenous truffles.

In Oregon and the Pacific Northwest, development of an industry based on the harvest of indigenous truffles is well underway, and with the introduction of truffle dogs, it is beginning to overcome negative perceptions resulting from sales of immature and unripe truffles. In spite of a difficult early history, the Oregon truffle industry has become a celebrated part of the larger wild mushroom industry in the Pacific Northwest and is promoted in conjunction with the wine and tourism industries to position the region as a culinary destination.

Wild production of Oregon truffles is currently abundant, due in large part to an abundance of suitable habitat. Sustaining a truffle harvest industry in the Pacific Northwest may eventually require cultivation of Oregon truffles. The habitats where Oregon truffles tend to be most productive are ephemeral and result from conversion of agricultural land to timber production; thus, trends in agricultural economics, rural land use taxation, and population demographics, among other human factors, become major influences on the long-term supply of Oregon truffles. If at some point these factors lead to a decline in the rate Douglas fir is planted on farmland, then production of Oregon truffles will also decline unless efforts are made to advance agricultural production of these species.

Culinary use of other indigenous truffle species has only just begun elsewhere on the continent. The increased availability of truffle dogs may both facilitate the development of these industries and help to prevent the kind of setback to their reputations suffered by the Oregon truffles.

Despite early success with cultivation of *T. melanosporum* in North America and promising market conditions (Pilz et al. 2009), cultivation of European truffles in orchards of inoculated trees has progressed slowly. The challenges faced by growers in North America include those of seedling quality assurance (e.g., Maxwell 2005b) and a general lack of agronomic expertise specific to truffles. The nascence of the industry is also reflected in the demographics of growers, relatively few of whom have agricultural backgrounds. This inexperience is often evident in a failure to effectively manage both competing vegetation and animal pests. Efforts to address these challenges are underway, and if the trajectory of increased professionalism in the North American wine industry can serve as a model, development of industry infrastructure, research funding, and technical expertise are likely to increase in parallel with increasing numbers of successful truffle growers.

References

American Horticultural Society (1997) Plant heat zone map. American Horticultural Society (AHS), Alexandria, VA

Bauer K (2012) Foraging Oregon truffles is dirty work, but the payoff is delicious. Oregonian 13 Mar 2012

Bland A (2010) Black diamonds. North Bay Bohemian 23 June 2010 http://www.bohemian.com/northbay/black-diamonds/Content?oid=2174821
Bonet JA, Colinas C (2001) Cultivo de *Tuber melanosporum* Vitt. Condiciones y rentabilidad Forestalia 5:38–45
Bonito G, Trappe J, Rawlinson P, Vilgalys R (2010) Improved resolution of major clades within Tuber and taxonomy of species within the *Tuber gibbosum* complex. Mycologia 102(5):1042–1057. doi:10.3852/09-213
Bonito G, Brenneman T, Vilgalys R (2011) Ectomycorrhizal fungal diversity in orchards of cultivated pecan (*Carya illinoinensis*; Juglandaceae). Mycorrhiza 21:601–612
Bonito G, Smith M, Brenneman T, Vilgalys R (2012) Assessing ectomycorrhizal fungal spore banks of truffle producing soils with pecan seedling trap-plants. Plant Soil. doi:10.1007/s11104-012-1127-5
Bruhn JN (2007) How widespread is the pecan truffle (Texas truffle)? Pecan Grower 18:50–51
Bunyard B (2008) Truffles and false truffles: a primer. Fungi 1(3):13–15
Cathcart JF (2000) Carbon sequestration: a working example in Oregon. J For 98:9
Chevalier G, Desmas C, Frochot H, Riousset L (1978) L'espèce *Tuber aestivum* Vitt. I. Définition. Mushroom Sci 10:957–975
Czap N (2012) In oregon, truffles are no match for wet noses. New York Times Published 7 August 2012. http://www.nytimes.com/2012/08/08/dining/training-dogs-to-find-truffles-in-oregon.html?pagewanted=all
Czarnecki J (1995) A cook's book of mushrooms. Artisan, New York
Dubarry F, Bucquet-Grenet S (2001) The little book of truffles (translated by Bacon J). Flammarion, France
Hall I, Brown G, Zambonelli A (2007) Taming the truffle. Timber Press, Portland, OR
Hanlin RT, Wu M, Brenneman TB (1989) The occurrence of *Tuber texense* in Georgia. Mycotaxon 34:387–394
Jacobs K, Luoma D (2008) Small mammal mycophagy response to variations in green-tree retention. J Wildl Manag 72(8):1747–1755
Kovacs G, Trappe J, Alsheikh A, Boka K, Elliott T (2008) *Imaia*, a new truffle genus to accommodate *Terfezia gigantea*. Mycologia 100:930–939. doi:10.3852/08-023
Lefevre C (2010) Truffles and truffle cultivation in North America. In: Proceedings of the 3° Congresso Internazionale di Spoleto Sul Tartufo. Spoleto, Italy, 25–28 Nov 2008
Lefevre CK, Pilz D, Trappe JM, Molina R (2001) Tuber gibbosum and Leucangium carthusianum: ecology, harvesting and marketing. In: Proceedings of the 5th international congress on the science and cultivation of truffles and other edible hypogeous mushrooms. Federation Française des Trufficulteurs, Paris, pp 214–217
Luoma DL (1991) Annual changes in seasonal production of hypogeous sporocarps in Oregon Douglas–fir forests. In: Ruggiero LF, Aubry KB, Carey KB, Huff MH (Tech Coord) Wildlife and vegetation of unmanaged Douglas-fir forests. USDA Forest Service General Technical Report PNW–GTR–285. Pacific Northwest Research Station, Portland, OR
Marin A (1985) An analytical and sensory evaluation of the aroma volatiles of *Tuber gibbosum*. MS Dissertation, Oregon State University, Corvallis, OR
Maxwell J (2005a) The fungus among us. Audubon Magazine January 2005. http://archive.audubonmagazine.org/features0501/fungus.html
Maxwell J (2005b) You: Truffle Baron. Forbes January 2005
North American Truffling Society (NATS) (2010) Ethical, sustainable and common sense guide to harvesting truffles. http://www.natruffling.org/guide.htm
O'Neill M (2007) Coveted, French, and now in Tennessee. New York Times, 28 Feb 2007
Olivier JM, Savignac JC, Sourzat P (1996) Truffe et trufficulture. Fanlac. Périgueux, France
Pilz D, Lefevre C, Scott L, Julian J (2009) Oregon culinary truffles: an emergent industry for forestry and agriculture. http://www.Oregontruffles.org
Price A (2005) Truffles in Texas? Austin American Statesman 11 July 2005
Renowden G (2005) The truffle book. Limestone Hills, Amberley

Rigdon JE (1994) Californians claim to unearth secret of raising truffles. Wall Street Journal 25 March 1994. http://www.joanrigdon.com/clips/truffle.html

Schlosser WE, Blatner KA (1995) The wild edible mushroom industry of Washington, Oregon and Idaho: a 1992 survey. J For 93(3):31–36

Smith M, Bonito G, Sharma J, Long J, Davis-Long B, Brenneman T (2012) Pecan truffles (Tuber lyonii) what we know and what we need to know. Georgia Pecan Mag Spring:52–59

Stamets P (2000) Growing gourmet and medicinal mushrooms, 3rd edn. Ten Speed, Toronto

Stamper E, Koral RL (1979) Handbook of air conditioning, heating and ventilation, 2nd edn. Industrial, New York

Taber RA (1990) Observations on the ecology of the Texas truffle, *Tuber texense*. In: Proceedings of the second international congress on the truffle. Spoleto, Italy, 1988, p 331

Terry L (2010) How long can they go? Oregon truffle thieves stoop to steal valuable delicacy. The Oregonian 12 Mar 2010

Trappe J (1989) Are commercial rakers killing our truffles? Mushroom J 7:23

Trappe J (1990) Use of truffles and false truffles around the word. In: Proceedings of the second international congress on the truffle. Spoleto, Italy, 1988, p 19

Trappe JM, Sundberg WJ (1977) *Terfezia gigantea* (Tuberales) in North America. Mycologia 69:433–437

Trappe JM, Jumpponen AM, Cázares E (1996) NATS truffle and truffle-like fungi. 5. *Tuber lyonii* (= *T. texense*), with a key to the spiny-spored *Tuber* species groups. Mycotaxon 60:365–372

Trappe MJ, Evans F, Trappe JM (2007) Field guide to North American truffles. Ten Speed, Berkeley, CA

Trappe MJ, Trappe JM, Bonito G (2010) *Kalapuya brunnea* gen. & sp. nov. and its relationship to the other sequestrate genera in *Morchellaceae*. Mycologia 102:1058–1065. doi:10.3852/09-232

USDA (2011) Fact sheet: conservation reserve enhancement program. http://www.fsa.usda.gov/Internet/FSA_File/crep_oregon_st.pdf

USDA (2012) Plant Hardiness Zone Map. Agricultural Research Service, U.S. Department of Agriculture. http://planthardiness.ars.usda.gov

Walters T (1977) Mushrooms and man. Linn-Benton Community College, Albany, OR

Work DC (2008) (Re)discovering the Oregon truffle. Fungi 1:4–12