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Confirming the presence of some introduced Russulaceae species in Australia and New Zealand

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Abstract: To aid the identification of Russulaceae associated with non-native introduced trees in urban areas, botanical gardens, and plantation forestry we sequenced selected material in the fungaria of AD & MEL (Australia) and PDD (New Zealand). Phylogenetic analysis and morphology support the presence of 13 species: *Lactarius deliciosus* (L.) Gray, *L. glyciosmus* (Fr.) Fr., *L. pubescens* Fr., *L. pyrogalus* (Bull.) Fr., *L. quietus* (Fr.) Fr., *L. rufus* (Scop.) Fr., *L. turpis* (Weinm.) Fr., *Russula amoenolens* Romagn., *R. cessans* A.Pearson, *R. ionochlora* Romagn., *R. laccata* Huijsman, *R. nitida* (Pers.) Fr., and *R. praetervisa* Sarnari. The species are found in association with various introduced gymnosperm and angiosperm ectomycorrhizal trees, and the fungi all appear to be of European origin. We provide brief descriptions, images and briefly discuss their origins and ecology.

Keywords: Russulaceae, introductions, naturalised, New Zealand, Australia

Introduction

The family Russulaceae is one of the larger groups of ectomycorrhizal fungi. Species in the Russulaceae are often large, colourful and noticeable, but they are not always easy to identify.

New Zealand and Australia have many indigenous species in the family, with only a small proportion formally described. These species are frequent in natural habitats and in association with native trees and shrubs in several indigenous plant families, primarily Myrtaceae, Nothofagaceae and Fabaceae (Field *et al.* 2015; Tedersoo & Brundrett 2017; Brundrett & Tedersoo 2018). There has been a historical trend of adopting the names of similar-looking taxa from the northern hemisphere. However, characterisation using modern sequence-based methods always demonstrates these species are different from those found in the northern hemisphere. For example, the native species *Lactifluus austropiperatus* T.Lebel & L.Tegart and *Lf. albopicrus* T.Lebel & L.Tegart, growing in association with eucalypts, were shown to be distinct from the similar northern hemisphere species *Lf. piperatus* (L.) O.Kuntze or *Lactarius pubescens* Fr. (Crous *et al.* 2020).

In addition to dealing with these incorrectly named records, there are several introduced species of Russulaceae that are commonly reported from urban areas, plantation forestry and other modified habitats dominated by introduced plants.

From the beginning of European colonisation of Australasia in the 18th century, many exotic tree species from the northern hemisphere have been introduced for commercial forestry, flood erosion control, amenity value as street trees and in parks and gardens. Some of these trees support ectomycorrhizal associations, e.g., Betulaceae, Fagaceae, Salicaceae & Pinaceae. However, the early host introductions were not always simultaneously accompanied by ectomycorrhizal fungi. In commercial conifer forestry the initial widespread absence of associated ectomycorrhizal species hindered growth in conifer plantations (Marx 1991). In both Australia and New Zealand, subsequent accidental and deliberate introductions have led to the presence of exotic representatives from most ectomycorrhizal fungal groups in association with exotic trees. Some incidental introductions include prized edible species, such as *Boletus edulis* Bull. (Wang *et al.* 1995; Catcheside & Catcheside 2012) and *Lactarius deliciosus* (L.) Gray, whilst others are toxic and responsible for fatalities, such as *Amanita phalloides* Secr. (Rees *et al.* 2009; Roberts *et al.* 2013). Species in the Russulaceae often have a disagreeable hot or peppery taste, some are known to contain gastric irritants, for example *Russula emetica* (Schaeff.) Pers. (Lincoff & Mitchel 1977), whilst others, for example the introduced *Lactarius turpis* (Weinm.) Fr., are known to contain carcinogenic compounds

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(Sterner *et al.* 1982). In addition, several edible mycorrhizal species have been deliberately introduced into cultivation (Hall & Wang 2002; Guerin-Laguette *et al.* 2014). The introduced European trees commonly associated with ectomycorrhizal fungi are dominated by species of oak, birch, willow and pine. The typical forms of these trees are shown in Figs 1 and 2.

Here we assess the reports of some of the species commonly encountered by the public and mushroom enthusiasts and to which northern hemisphere names have been applied. This preliminary assessment is based on a selected subset of the collections available in the Fungaria of Australia and New Zealand.

Methods

We surveyed the Russulaceae collections in selected fungaria: MEL (Royal Botanic Gardens Victoria, Melbourne, Australia), AD (State Herbarium of South Australia) and PDD (National Fungarium, Landcare Research - Manaaki Whenua, Auckland, New Zealand). While not exhaustive, these collections are representative of the range of introduced Russulaceae to be found in

Fig. 1. Common introduced ectomycorrhizal host trees: **A, B** Pedunculate oak (*Quercus robur*); **C, D** birch (*Betula pendula*). — A Gertrud K (flickr 37352016150), CC BY-NC-SA; A inset Degtyarev Nikolai Ivanovich (iNaturalist 62096254), CC BY-NC; B Chris (iNaturalist 108752769), CC BY-NC; C Сергей (iNaturalist 106302050), CC BY-NC; C inset Sergey Mayorov (iNaturalist 53131580), CC BY-NC; D Evgeny Boginsky (iNaturalist 73092373), CC BY-NC.

Australia and New Zealand. Representative collections identified as species originally described from the northern hemisphere were examined further. Priority examination was given to collections accompanied by photographs and descriptions of fresh material. Some older herbarium material is in poor condition, making it difficult to obtain sequence data, and even some morphological characters (pellis structure and spores) have deteriorated to the point that species determination/confirmation was not necessarily possible.

Here we provide brief descriptions for the taxa confirmed as present in Australia and New Zealand. Macromorphological details were derived from the photographs and notes associated with the collections and supplemented by information from northern hemisphere popular guides (Breitenbach & Kränzlin 2005; Kibby 2016, 2017; Laessoe & Petersen 2019) together with regional revisions (Sarnari 1998; Verbeken *et al.* 2018; Heilmann-Clausen *et al.* 1998). Microscopy was carried out on critical collections and presented where relevant.

Georeferenced collection and observation data for taxa in the Russulaceae from Australia and New Zealand were downloaded from the Global Biodiversity Information

Fig. 2. Common introduced ectomycorrhizal host trees: **A, B** Willow (*Salix* spp.); **C, D** Monterrey pine (*Pinus radiata*). — A Yukki Qiu (iNaturalist.org 32556414), CC BY-NC; B Rod (iNaturalist 43194202); C Paula Greer (iNaturalist 36524985); D Radinis (iNaturalist.org 32132415), CC BY-NC.

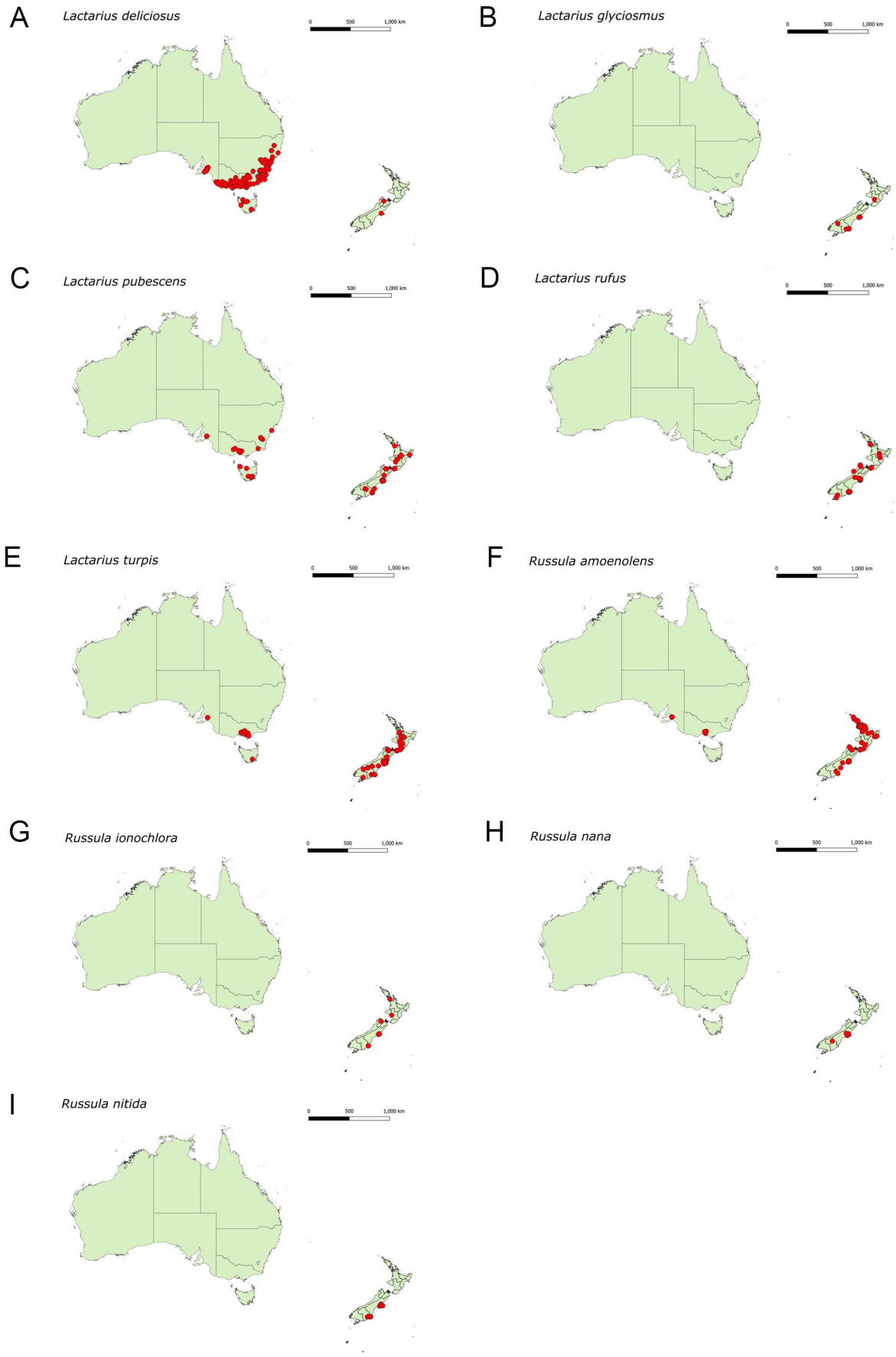

Fig. 3. Occurrence records for introduced Russulaceae in Australia and New Zealand.

Facility (GBIF 2021). Many northern hemisphere species recorded in these datasets most probably refer to different indigenous taxa in natural habitats and we have excluded them from our analysis (Appendix 1). Only those species supported by sequenced collections have been considered further. Occurrence maps (Fig. 3) were generated for the included species using the GBIF data download (GBIF 2021). We excluded species known from a single locality or those with no georeferenced locality data. It is important to note these maps do not represent species distributions, for which much more extensive systematic survey data would be necessary, including environmental DNA-based sampling.

Representative recent collections were selected for sequence barcoding. DNA extractions were carried out on fungarium samples using the EZNA forensic DNA kit (Omega Bio-tek, USA) or the REDExtract-N-Amp Plant PCR Kits (Sigma Aldrich, USA). The Internal Transcribed Spacer barcode region (ITS) was amplified using the standard primer pairs ITS1f/ITS4 (White *et al.* 1990; Gardes & Bruns 1993).

Twenty-six new *Lactarius* and 22 new *Russula* ITS sequences were generated for this study. Together with some data from introduced species already available in GenBank, 29 *Lactarius* and 23 *Russula* ITS sequences from Australia or New Zealand were available for analysis. Datasets for phylogenetic analyses were assembled in two steps for each genus separately. A preliminary Maximum Likelihood analysis was performed with the Australasian sequences and unpublished ITS datasets from validated European collections, including as many type specimens and as many described species as available. Identifications of Australasian specimens were then confirmed or updated and based on these results smaller subsets of publicly available ITS sequences were composed, also including non-European species where appropriate. All specimens and sequences utilised are listed in Appendix 2. The final datasets comprise 82 sequences for *Lactarius* and 101 sequences for *Russula*.

Alignments were made with the on-line version of MAFFT v. 7 (Katoh *et al.* 2019) using the iterative refinement method E-INS-I. Three *Lactarius* subgenus *Plinthogalus* and two *Lactifluus* species were utilised as outgroup for the *Lactarius* and *Russula* analysis respectively. Phylogenetic analyses were performed with Maximum Likelihood in RAxML v. 8.2.12 (Stamatakis 2014) using the CIPRES Science Gateway v. 3.3 (Miller *et al.* 2010). Trees were visualized in FigTree v. 1.4.2.

Results

Sequence data of Australia/New Zealand collections together with comparative authoritative data are presented in Fig. 4 (*Lactarius*) and Fig. 5 (*Russula*).

We confirm the presence of 13 introduced species that are mycorrhizal with introduced angiosperm and gymnosperm hosts from a variety of modified habitats. Some species are members of groups where the taxonomy is complex or requires clarification, for example *Russula amoenolens*, *Russula nana*/*R. laccata* and *Russula ionochlora*. Issues associated with correct identification are discussed under the species entries. We have not assessed the status of all the northern hemisphere names used in Australia and New Zealand and it is probable that examination of material from a wider range of fungaria, in combination with increased collecting effort, will uncover more species.

Species descriptions

Lactarius deliciosus (L.) Gray

Nat. Arr. Brit. Pl. 1: 624 (1821). **IF224737.**

Pileus 40–120 mm diam., convex becoming centrally depressed, with an incurved margin, later becoming infundibuliform, surface viscid becoming dry, pale orange to salmon coloured, often with scrobicules, indistinctly zonate, bruising orange-red and then green. *Lamellae* subdecurrent, crowded, orange discolouring orange-red then green where bruised. *Stipe* 20–50 × 10–15 mm pale orange, surface with a whitish bloom and brighter orange scrobicules. *Latex* bright orange but slowly turns red (30 mins+). *Smell* fruity. *Taste* mild. *Spores* 7–11 × 5–8 µm ornamented with ridges forming a reticulum. **Figs 3A, 6A & B.**

English common name. Saffron milkcap.

Notes. *Lactarius deliciosus* is a widely consumed popular edible mushroom and was deliberately introduced into New Zealand (Guerin-Laguette *et al.* 2014). It is strictly associated with *Pinus* species. In Europe, *Lactarius quieticolor* Romagn. and *L. deliciosus* are sometimes confused in the field. *Lactarius quieticolor* differs microscopically in possessing spore ornamentation of thicker ridges. Macroscopically *L. quieticolor* shows variability in pileus and stipe colours, presence of scrobicules on the stipe and latex colour. *Lactarius deliciosus* prefers calcareous sandy soils, whereas *L. quieticolor* is often found on acidic sandy soils. *Lactarius deliciosus sensu stricto* is confirmed as the species introduced in both Australia and New Zealand. This contrasts with South America and South Africa where sequenced samples from pine plantations are closer to *L. quieticolor* (Chavez *et al.* 2015; Silva-Filho *et al.* 2020). As with many edible or common taxa there are relatively few fungarium collections, with currently no collections from Western Australia, Northern Territories or Queensland, and fewer than five from New South Wales and the Australian Capital Territory (AVH 2021). In New Zealand the species is restricted to a relatively few plantations where it has been cultivated.

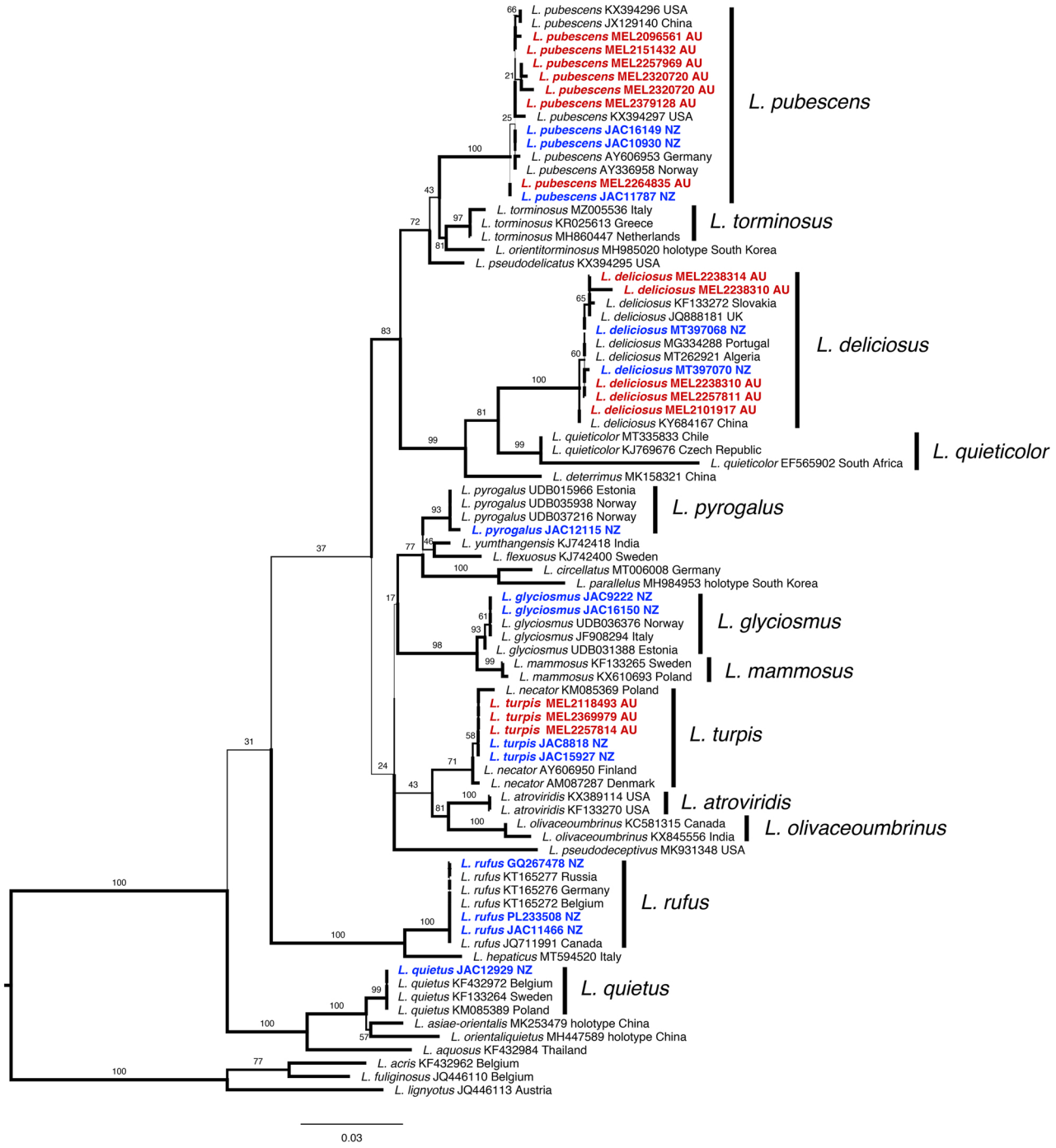

Fig. 4. Phylogeny showing *Lactarius*/*Lactifluus* species introduced in New Zealand (blue) and Australia (red).

Material examined

NEW ZEALAND. SOUTH ISLAND. Canterbury, Lincoln [with *Pinus radiata* D. Don], May 2014, *A. Guerin-Laguette s.n.* (PDD105248); Tasman, Neudorf Road, Neudorf Mushrooms [with *P. radiata*], 15 May 2015, *P. Leonard s.n.* (PDD107611).

AUSTRALIA. SOUTH AUSTRALIA. Fleurieu Peninsula, Kuitpo State Forest, Heysen Trail, old forestry trials [with *P. radiata* and *P. canariensis* C. Sm.], 21 June 2002, *J.E. Tonkin 1021* (MEL2238314).

VICTORIA. Ballan-Daylesford road, 1.5 km from Melbourne-Ballarat Freeway, roadside verge [with *P. radiata*], 15 May 2001, *J.E. Tonkin 814* (MEL2101917); Princes Hwy, roadside verge c. 10 km north of Sale [with *P. radiata*], 27 May 2002, *J.E. Tonkin 1017* (MEL2238310).

TASMANIA. Waterworks Reservoir Reserve, Hobart, 20 Apr. 1996, *A.V. Ratkowsky 123* (MEL2257811).

Lactarius glyciosmus (Fr.) Fr.

Epicr. Syst. Mycol. 348 (1838). **IF120552.**

Pileus 20–55 mm diam., a small central depression developing with age, greyish lilac, sometimes varying to a pale buff, thin fleshed. *Lamellae* decurrent,

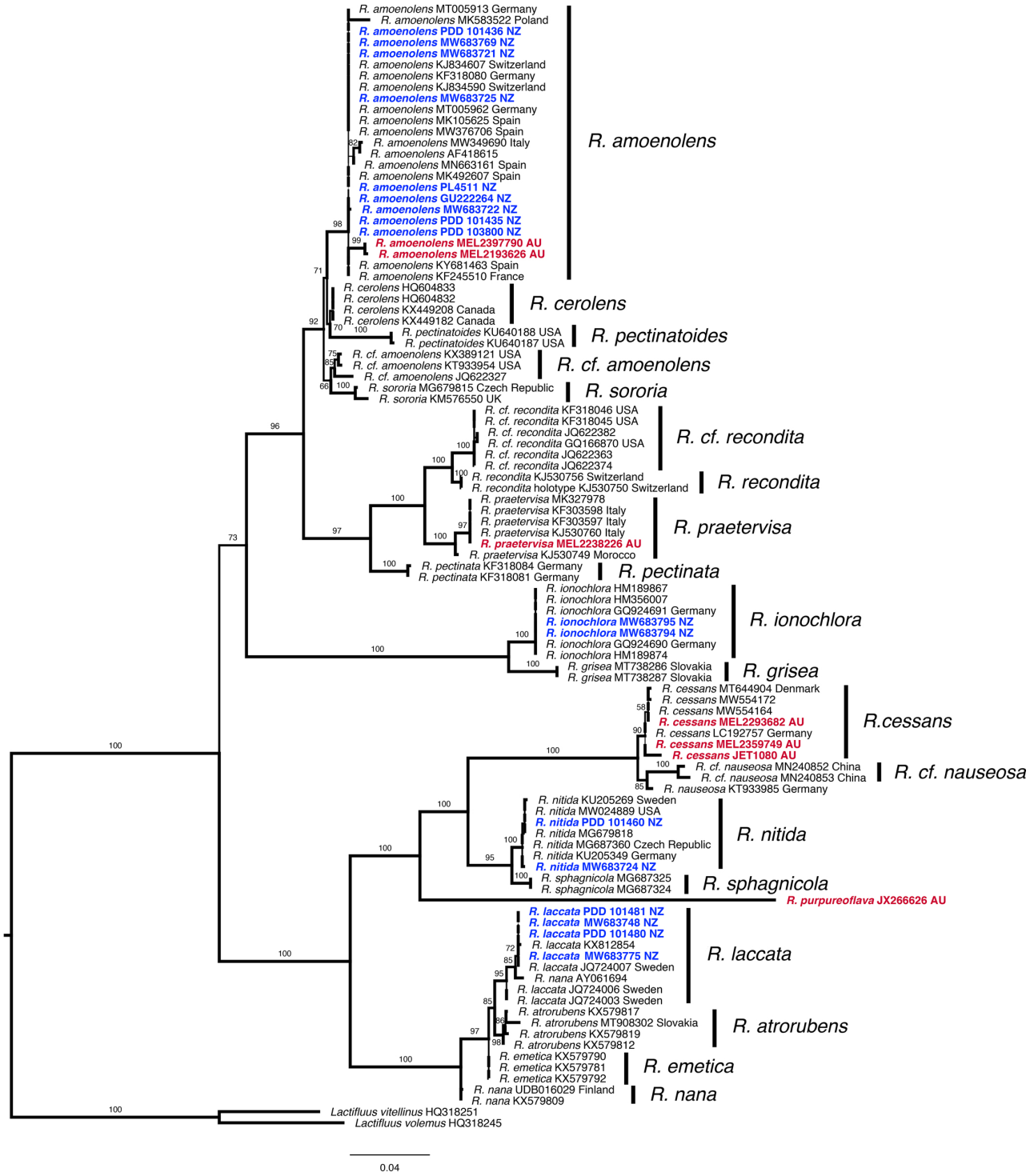

Fig. 5. Phylogeny showing *Russula* species introduced in New Zealand (blue) and Australia (red).

crowded, vary in colour from a pale yellowish to pale flesh, turning to a greyish lilac with age. *Stipe* 25–65 × 4–12 mm, same colour as cap, but sometimes is a little paler or with a yellowish hue. *Latex* white with an initially mild, later with a slightly acrid taste. *Smell* of coconut. *Taste* mealy to slightly bitter. *Spores* 8–9 × 5–6 µm, broadly elliptic, ornamentation verrucose, connected by thin ridges in an incomplete network. **Figs 3B & 6C.**

English common name. Coconut-scented milkcap.

Notes. *Lactarius glyciosmus* is reported as edible. It is one of several introduced species associated with birch (*Betula* spp.). *Lactarius mammosus* Fr. differs macroscopically from *L. glyciosmus* by the darker colours and the mostly firmer basidiocarps, and the association primarily with pines (note has also been found occasionally with birch). Microscopically, the spores are longer and more distinctly reticulate in *L. mammosus*.

Known from the South and North Islands of New Zealand but not currently known from Australia.

Material examined

NEW ZEALAND. SOUTH ISLAND. Canterbury, Christchurch, Opawa [with *Betula pendula* Roth], 22 May 2005, *H. Greenep* (PDD80929); Canterbury, Lincoln, Lincoln University [with *B. pendula*], 12 Jan. 2005, *J.A. Cooper* (PDD80997); Canterbury, Lincoln, opposite University [with *B. pendula*], 22 Apr. 2011, *J.A. Cooper* (PDD96188).

Lactarius turpis (Weinm.) Fr.

Epicr. Syst. Mycol. 335 (1838). **IF201186**

Pileus 80–200 mm diam., when young with a somewhat depressed centre, with velvety zones, sometimes a shaggy rim, olive brown or yellow-green, often sticky or slimy in the middle, becoming funnel-shaped and the colour darkens to blackish in age. *Lamellae* somewhat decurrent, dirty white, stained olive-brown by old milk. *Stipe* up to 70 × 30 mm, similar colour to cap, but much lighter, sometimes with scrobiculae. *Latex* white turning brown. *Smell* indistinct. *Taste* (especially the milk) acrid. *Spores* 7 × 6 µm, ornamented with ridges. The application of alkali to the pileus produces a strong purple reaction. **Figs 3E & 6D.**

English common name. Ugly milkcap.

Notes. There are reports (Laessoe & Petersen 2019; Sterner *et al.* 1982) that the species contains carcinogenic compounds and should not be consumed. The species appears to be strictly associated with birch (*Betula* spp.) in Australasia, but in the northern hemisphere, while it is common under birch, it is also more broadly associated with spruce, pine and other trees in mixed woodland. It is characterised by an untidy appearance, yellow/green tinges, latex turning brown, and the purple reaction of the pileus to alkali. Recent molecular research shows that there are two similar species in Europe. One of them is conspecific with the North American species *Lactarius sordidus* Peck. Morphological and ecological characters to distinguish the two species are currently being studied (Nuytinck *et al.*, in prep.) but it seems, *L. sordidus* is more commonly associated with coniferous hosts.

Currently known from south-eastern Australia and widely distributed in New Zealand.

Ongoing debate surrounds the correct name for this taxon which has been variously referred to as *Lactarius plumbeus* (Bull.) Gray, *L. necator* (Bull.) Pers. and *L. turpis*. All three names have been used in Australasia for the single species we refer to as *L. turpis*. Noordeloos & Kuyper (1999) established that the original descriptions of *L. necator* and *L. plumbeus* are inconsistent with the modern interpretation of the taxon. They rejected *L. plumbeus* and sought to stabilise the use of *L. necator* as the preferred name by the designation of a neotype consistent with modern interpretation. However, that neotype is inadmissible (Art. 3.9; Turland *et al.* 2018) because a lectotype should be selected from the available illustrations associated with the protologue or the sanctioning treatment (Art. F.3.9; May *et al.* 2019). Currently no lectotypes for these names have been designated. *Lactarius turpis* remains the earliest unambiguous name for the taxon under consideration.

Material examined

NEW ZEALAND. NORTH ISLAND. Rangitikei, Raethi, 20 Jan. 2014 [with *Betula pendula*], *A & R Freeston* (PDD98854).

SOUTH ISLAND. Nelson, Isel Park [with *Betula* sp.], 12 Apr. 2003, *P. Leonard* (PDD77751); Canterbury, Hanmer [with *B. pendula*], 21 Feb. 2004, *J.A. Cooper* (PDD79875); Canterbury, Diamond Harbour [with *B. pendula*], 10 Apr. 2006, *J.A. Cooper* (PDD87001); Nelson, Stephens Island, 5 Mar. 2004 [with *Betula* sp.], *P. Leonard* (PDD104401).

AUSTRALIA. SOUTH AUSTRALIA. Mt Lofty Botanic Gardens [with *B. pendula*], 31 May 2003, *P. Catcheside 1453* (AD-C58553); Mt Lofty Botanic Gardens [with *B. pendula*], 26 Apr. 2008, *P. Catcheside 2828* (AD-C58084, AD-C59947).

VICTORIA. Rawson [with *Betula* sp.], 28 May 2013, *N.G. Karunajeewa 617* (MEL2369979).

TASMANIA. Pipeline Track [with *B. pendula*], 18 May 1996, *A.V. Ratkowsky 130* (MEL2257814).

Lactarius pubescens Fr.

Epicr. Syst. Mycol. 335 (1838). **IF157260.**

Pileus 25–100 mm wide, pileus margin rolled inward and bearded with coarse white hairs when young, becoming broadly convex with a depressed centre, fibrillose except for the centre, which is sticky and smooth when fresh, white to cream, becoming reddish-orange to vinaceous on the disc with age. *Lamellae* attached to slightly decurrent, crowded, seldom forked, whitish to pale yellow with pinkish tinges, slowly staining brownish ochraceous when bruised. *Stipe* 20–65 × 6–13 mm, silky, whitish when young, becoming ochraceous from the base up when older, apex usually tinged pinkish, often with a white basal mycelium. *Latex* white, unchanging, not staining tissues, taste acrid. *Smell* faintly like geraniums or sometimes pungent. *Taste* acrid. *Spores* 6–8.5 × 5–6.5 µm, elliptic, ornamented with amyloid warts and ridges that sometimes form a partial reticulum, prominences up to 1.5 µm high. **Figs 3C, 6E & F.**

English common name. Downy milkcap.

Notes. Always associated with birch (*Betula* spp.). *Lactarius pubescens* is considered toxic by some authors (Hall *et al.* 2003), although the acrid taste reduces the likelihood of consumption. It can be confused with

L. torminosus (Schaeff.) Pers., which is also a tomentose and acrid species growing with birch. The colours in *L. pubescens* are much paler, almost whitish, while *L. torminosus* always has the dominant pinkish brick tone. The spores of *L. torminosus* are distinctly larger than those of *L. pubescens*. *Lactarius torminosus* is not currently confirmed to be present in Australia or New Zealand and records under this name are likely misidentifications.

Currently known from southern Australia and widely distributed in New Zealand.

Lactarius pubescens is part of a species complex consisting of several closely related species, some of which are hard to delimit based on ITS sequences alone (Nuytinck *et al.* 2014). More study is needed to disentangle this complex. In our phylogenetic analyses three species that are well separated are included: *L. pubescens*, *L. orientitorminosus* H. Lee, Wisitr. & Y.W. Lim and *L. torminosus*. Other species like *L. scoticus* Berk. & Broome and *L. tesquorum* Malençon are excluded from the analysis, because their species delimitation is unclear.

Material examined

NEW ZEALAND. NORTH ISLAND. Gisborne, Eastwoodhill Arboretum [with *Betula pendula*], 16 May 2013, *J.A. Cooper* (PDD97028)

SOUTH ISLAND. Canterbury, Christchurch Riverview Terrace [with *B. pendula*], 1 Jan. 2005, *H. Greenep* (PDD86879); Canterbury, Christchurch, Little Hagley Park [with *B. pendula*], 26 Mar. 2009, *J.A. Cooper* (PDD95387); Canterbury, Lincoln, opposite University [with *Betula* sp.], 22 Apr. 2012, *J.A. Cooper* (PDD96184); Nelson, Rabbit Island [with *B. pendula*], 28 Apr. 2012, *P. Leonard* (PDD102724).

AUSTRALIA. SOUTH AUSTRALIA. Adelaide, St Peters [with *B. pendula*, 20 May 1980, *I. McDonald I-25* (AD-C31546); Mt Lofty Botanic Gardens [with *B. pendula*], 7 June 2000, *P. Catcheside 449* (AD-C58319); South Australia, Mt Lofty Botanic Gardens upper carpark [with *B. pendula*], 13 May 2001, *P. Catcheside 769* (AD-C58547).

AUSTRALIAN CAPITAL TERRITORY. Canberra, Macquarie, 8 km NW of Capital Hill [with *Betula* sp.], 28 Mar. 1995, *H. Lepp 1155* (MEL2096561).

VICTORIA. Eastern Highlands, Malinns', 53 km N of Orbost on the Bonang Road [with *B. pendula*], 26 May 2002, *K.R. Thiele 2778* (MEL2151432).

TASMANIA. Richmond [with *B. pendula*], 24 Apr. 2003, *J. Piscioneri 388* (MEL2257969).

Lactarius pyrogalus (Bull.) Fr.

Epicr. Syst. Mycol. 339 (1838). **IF157078.**

Pileus 50–100 mm diam., convex to flat, later becoming funnel shaped, sometimes faintly concentrically banded, thin fleshed, becoming sticky when moist, grey fawn, sometimes with a yellowish tinge, and pink and purple tinges not unknown. *Lamellae* slightly decurrent, yellow to flesh coloured, though later become a cinnamon-ochre colour, well-spaced. *Stipe* 40–60 × 7–15 mm, cylindrical but sometimes slightly swollen at the base, whitish or concolorous with the cap; flesh whitish. *Latex* abundant white, drying grey with greenish tinge. *Smell* slightly fruity. *Taste* very hot, acrid. *Spore print* light ochre. *Spores* 7–8 × 5.5–7 µm, broadly elliptic, ornamentation of warts joined by moderately thick ridges in a well-developed network, 1 µm high. **Fig. 6G.**

English common name. Fire-milk lactarius.

Notes. *Lactarius pyrogalus* is not considered edible due to the intensely hot and unpleasant taste. In Australasia it is currently only found in association with hazel (*Corylus avellana* L.). In Europe, *Lactarius circellatus* Fr. has similar colours and microscopical features to *L. pyrogalus*, however *L. circellatus* is strictly associated with hornbeam (*Carpinus* L.). Furthermore, *L. pyrogalus* differs by the more distant lamellae, which are often darker and more yellowish.

Lactarius pyrogalus is currently known only from a single site in New Zealand.

Material examined

NEW ZEALAND. NORTH ISLAND. Wairarapa, Masterton, Upper Manaia Road [with *Corylus avellana*], 5 June 2011, *D. Batchelor* (PDD96354); Wairarapa, Masterton, Upper Manaia Road [with *C. avellana*], 1 May 2012, *D. Batchelor* (PDD102506).

Lactarius quietus (Fr.) Fr.

Epicr. Syst. Mycol. 343 (1838). **IF157234.**

Pileus 50–80 mm diam., convex becoming flattened with small depression in the centre, dull matt reddish brown with a tint of cinnamon, sometimes with darker concentric bands or spots, dry, not sticky when moist. *Lamellae* slightly decurrent, brownish-white becoming pale reddish brown with mauve hints in age. *Stipe* 40–90 × 10–15 mm, same colour as cap, or a little darker. *Latex* white or cream in colour, initially thick becoming whey-like in age. *Smell* strong oily, likened to 'bedbugs' or 'wet laundry'. *Taste* mild at first, becoming acrid. *Spores* 7.5–9 × 6.5–7.5 µm, oval with plentiful warts joined by numerous ridges, forming a well-developed network. **Fig. 6H.**

English common name. Oak milkcap, oakbug milkcap.

Notes. *Lactarius quietus* is recognised from the characteristic association with oaks (*Quercus* spp.), the reddish brown colours, the often somewhat zonate aspect and the distinct smell of Pentatomidae bugs, the so-called stink bugs or bedbugs. This smell is described by some people as rancid oil or wet laundry. The species can be confused with two rare European species: *Lactarius zugazae* G. Moreno, Montoya, Bandala & Heykoop (only known from a few records in Southern Europe), which has a more greasy and reddish-vinaceous

Fig. 6. **A** *Lactarius deliciosus*; **B** scrobiculae of *L. deliciosus*; **C** *L. glyciosmus* (PDD113295); **D** *L. turpis* (PDD113074); **E** *L. pubescens* (PDD113294); **F** bearded margin of *L. pubescens*; **G** *L. pyrogalus*; **H** *L. quietus* (PDD 97029). — G epopov (iNaturalist 25893615), CC BY.

Fig. 7. A *Lactarius rufus* (PDD105425); **B** *Russula amoenolens*; **C** *R. amoenolens*, white form (PDD106199); **D** *R. cessans* (MEL2238226); **E** *R. ionochlora* (PDD80994); **F** *R. laccata*; **G** *R. nitida* (PDD 86996); **H** *R. praetervisa* (MEL 2359749). — B davidwhyte (iNaturalist 36154374), CC BY-SA; F alice_shanks (iNaturalist 9635839), CC BY-NC.

pileus and a taste of raw cauliflower. Another similar and related species is *L. fraxineus* Romagn., which is smaller, with a more sticky pileus and stem, and without the characteristic smell. Neither of these rare species is reported from Australasia. *Lactarius quietus* var. *incanus* Hesler & A.H.Sm., described from North America with oaks, has a fragrant smell like burnt sugar and is phylogenetically distinct. Early reports of *L. quietus* from Australia compiled by May & Wood (1997) can be discounted as misidentifications, as no evidence of association with exotic trees was provided in the original reports.

Lactarius quietus is currently known only from a single site in New Zealand.

Material examined

NEW ZEALAND. NORTH ISLAND. Gisborne, Eastwoodhill Arboretum [with *Quercus* sp.], 16 May 2013, *P. Leonard* (PDD97029).

Lactarius rufus (Scop.) Fr.

Epicr. Syst. Mycol. 347 (1838). **IF229473.**

Pileus up to 80 mm diam., initially convex, often with a small central umbo, becoming flat, eventually acquiring a shallow central depression, dark brick, bay, or red-brown, dry and matt. *Lamellae* slightly decurrent, cream, becoming coloured as the pileus in age, only paler. *Stipe* 30–50 × 5–15 mm, cylindrical, the same colour or paler than cap. *Latex* watery white, initially mild, gradually becoming very hot, and acrid after a minute or so. *Smell* none. *Taste* the same as the latex. *Spores* broadly ellipsoidal, 6.5–9 × 5.5–6.5 µm, ornamented with a well-developed and almost complete network of ridges. **Figs 3D & 7A.**

English common name. Rufous milkcap.

Notes. *Lactarius rufus* is widely reported across the northern hemisphere in association with birch, spruce, firs and pines. In New Zealand *Lactarius rufus* is reported only with pines, and especially with *Pinus radiata* in plantations (Walbert *et al.* 2010). Though variable in colour, the species is recognized by the red/brown pileus surface (especially when young) and the burning acrid taste. It can be confused with the European *Lactarius hepaticus* Plowr., which is currently not confirmed from Australasia. *Lactarius hepaticus* has a smoother and usually duller brown pileus, and a mild to bitter taste. The literature reports of *L. rufus* from Australia by Eygelsheim (1981) can be discounted as there is no evidence of association with exotic trees.

Currently known only from New Zealand.

Material examined

NEW ZEALAND. SOUTH ISLAND. Canterbury, Christchurch, Bottle Lake [with *Pinus radiata*], 26 Dec. 2009, *J.A. Cooper* (PDD95619); Christchurch, Bottle Lake [with *P. radiata*], 31 May 2010, *J.A. Cooper* (PDD95865); Christchurch, Bottle Lake [with *P. radiata*], 26 Mar. 2011, *J.A. Cooper* (PDD96173); Christchurch, Spencer Park [with *P. radiata*], 2 Jan. 2014, *J.A. Cooper* (PDD105425).

Russula amoenolens Romagn.

Bull. Mens. Soc. Linn. Lyon 21: 111 (1952). **IF305349.**

Pileus 20–70 mm, hemispherical and deeply inrolled when young, later plane to infundibuliform, strongly grooved, moist, pale tan to dark brown, and with a pure white version also known. *Lamellae* white, often forked. *Stipe* 25–55 × 10–20 mm, cylindrical to ventricose. *Smell* sour or rancid and often described as like ripe camembert cheese, although different people interpret the smell variably. *Taste* extremely acrid. *Spores* 6.5–8 × 4.5–6 µm ornamented with isolated conical warts. **Figs 3F, 7B & C.**

English common name. Camembert brittlegill.

Notes. *Russula amoenolens* is a very common introduced species to which various names have been applied in Australia and New Zealand, including *R. amoenolens*, *R. sororia* (Fr.) Romell, *R. pectinata* Fr. and *R. pectinatoides* Peck. Sequence data suggest all Australasian collections under these names refer to a single species we are calling *R. amoenolens* and it is identical to collections from various parts of Europe.

The species has a broad ectomycorrhizal host affiliation that in New Zealand includes pines (*Pinus* spp.), cedar (*Cedrus deodara* (Roxb.) G.Don), lime (*Tilia cordata* Mill.), oak (*Quercus robur* L.), and beech (*Fagus sylvatica* L.). While in Australia, this species has currently only been found affiliated with oak species. In Spain, Santolamazza-Carbone *et al.* (2019) found *R. amoenolens* on ECM root tips of *Eucalyptus nitens* (H.Deane & Maiden) Maiden and *E. globulus* Labill. suggesting the potential for the species to associate with native *Eucalyptus* in Australia. The spread of introduced ectomycorrhizal species within native ecosystems is documented in the case of *Amanita muscaria* and *Nothofagus* Blume, and *R. amoenolens* may, in future, show a similar pattern.

Stevenson (1981) referred to collections of a species with limes in a New Zealand park as *R. pectinata*/*pectinatoides*. Recent re-collections from under the same trees in Wellington confirm *R. amoenolens* and not *R. pectinata* or *R. pectinatoides*. Current phylogenetic data indicate there are other distinct taxa in the group identified as *R. amoenolens*. Further work is necessary to establish the correct application of names in this species complex. The similar but phylogenetically distinct *Russula praetervisa*, recorded from Australia, typically has red staining at the stem base and a less fetid odour. Records of *R. pectinata* and *R. pectinatoides* from Australia compiled by May & Wood (1997) are generally of a fungus growing in native forests and are likely to be misidentifications for a native species, such as *Russula neerimea* Grgur.

Material examined

NEW ZEALAND. NORTH ISLAND. Auckland, Sandringham, Potter's Park [with *Pinus radiata*], 16 July 1967, *R.F.F.R. McNabb* (PDD26579); Auckland, Sandringham, Potter's Park [with *P. radiata*], 18 June 1967, *R.F.F.R. McNabb* (PDD26580); Auckland, Auckland Domain [with *Quercus* sp.], 16 Apr. 1972, *G.M. Taylor* (PDD84320); Auckland, Old Govt. House, 22 Apr. 1982, *G.M. Taylor* (PDD85681); Wellington, Botanic Gardens, 25 July 1960, *G. Kelly & J. Mason* (PDD86112); Auckland, Western Park [with *Quercus* sp.], 30 Apr. 2006, *P.R. Johnston* (PDD88354); Wellington, Central Park [with *Tilia* sp.], *G. Stevenson* (PDD90385); Wellington, Central Park [with *Pinus* sp.], 30 Apr. 1978, *G. Stevenson* (PDD90386); Wellington, Central Park [with *T. cordata*], 25 Feb. 2012, *J.A. Cooper* (PDD96535); Wairarapa, Greytown, Kuratawhiti Street [with *T. cordata*], 10 May 2007, *S. Cook* (PDD104432).

SOUTH ISLAND. Canterbury, Christchurch, Hagley Park, 24 Mar. 1968, *R.F.F.R. McNabb* (PDD31687); Canterbury, Christchurch, Little Hagley Park [with *Pinus maritima*], 29 May 2004, *J.A. Cooper* (PDD80615); Canterbury, Christchurch, Little Hagley Park [with *Quercus robur*], 25 Mar. 2005, *J.A. Cooper* (PDD80693); Canterbury, Christchurch, Cholmondley Park [with *Tilia cordata*], 12 Mar. 2005, *J.A. Cooper* (PDD80743); Canterbury, Lincoln, CASC [with *Q. robur*], 5 Jan. 2005, *J.A. Cooper* (PDD80990); Canterbury, Christchurch, South Hagley Park [with *P. radiata*], 9 Jan. 2005, *J.A. Cooper* (PDD80993); Otago, Kuriheka [with *Quercus* sp.], 10 Jan. 1970, *L.R. Taylor* (PDD84226); Canterbury, Christchurch, Hagley Park [with *Pinus* sp.], 13 Apr. 2009, *J.A. Cooper* (PDD95417); Canterbury, Lincoln, CASC grounds [with *Leptospermum scoparium* J.R.Forst. & G.Forst.], 22 Apr. 2013, *J.A. Cooper* (PDD96849); Nelson, Golden Downs [with *Populus* sp.], 21 Mar. 2004, *P. Leonard* (PDD101436); Canterbury, Christchurch, Little Hagley Park [with *Q. robur*], 21 Mar. 2014, *J.A. Cooper* (PDD105522); Canterbury, Christchurch, Ernle Clark Reserve [with *Q. robur*], 30 Jan. 2016, *J.A. Cooper* (PDD106199).

AUSTRALIA. VICTORIA. Melbourne, Camberwell, Range St [with *Quercus palustris* Munchh.], 19 May 2003, *J.H. Ross 4130* (MEL2193626); Victoria, Melbourne, South Yarra, the Domain [with *Quercus* sp.], 11 May 2016, *T. Lebel 2745* (MEL2397790).

Russula cessans A.Pearson

Naturalist 101 (1950). **IF305359.**

Pileus 30–100 mm diam., convex becoming broadly convex to flat, viscid when wet, blood red to purplish red to brownish purple, often with a darker centre; on drying out pink/red around the margin. *Lamellae* adnexed, close, pale yellow maturing to a deep orange-ochre. *Stipe* 25–50 × 8–20 mm, typically slightly swollen towards base, white, not bruising. *Smell* not distinct. *Taste* mild. *Spore print* yellow. *Spores* 8–9 × 7–8 µm, subglobose to broadly ellipsoid; ornamented with warts to 1 µm connected with short lines in a partial net. **Fig. 7D.**

English common name. Tardy brittlegill.

Notes. *Russula cessans* is known from only a few collections in Australia. The reddish to purple cap, yellowish-orange lamellae and white stipe with mild taste and odour, and association with pines is distinctive. It resembles a native Australian species, *Russula purpureoflava* Cleland, that is associated with *Eucalyptus*. However, our molecular analyses place that species quite distant from *R. cessans*. Some collections originally identified as *Russula integra* (L.) Fr. were found to be *R. cessans*. The name *R. integra* has been applied broadly to any purplish toned *Russula* found with exotic trees. More collections identified as *R. integra* require examination to exclude its presence. The species is typically brown tinged with violet, purple, yellow or green, and the spore print is bright yellow.

Material examined

AUSTRALIA. VICTORIA. Melbourne, Banyule, Yallambie Park [with firs], 15 May 2012, *P.M. Grey 2012/1* (MEL2359749); Victoria, Balnarring, Buckley Nature Reserve, Myers Road boundary [with *Pinus radiata*], 12 June 2004, *J.E. Tonkin 1139* (MEL2293682); Victoria, Daylesford-Ballan Road, c. 1 km north of Ballarat Fwy turnoff, on eastern verge [with *Pinus radiata*], 20 Apr. 2003, *J.E. Tonkin 1080* (MEL2238372).

Russula ionochlora Romagn.

Bull. Mens. Soc. Linn. Lyon 21: 110. **IF305380.**

Pileus 50–100 mm, hemispherical becoming centrally depressed to slightly infundibuliform, dry, margin ± grooved, colour very variable, but always with yellowish-green or magenta pastel shades accompanied by grey, pink or light brown. *Lamellae* white becoming cream coloured, with lamellulae, sometimes rust-spotted. *Stipe* 40–80 × 10–20 mm, cylindrical. *Smell* none to faintly fruity. *Taste* mild to slightly acidulous. *Spores* 6.5–8.5 × 5–6.5 µm with a low ornamentation of partially connected warts. **Figs 3G & 7E.**

English common name. Oil-slick brittlegill.

Notes. This species has a rather broad host affiliation in New Zealand that includes oaks, limes and cedar. The colour variation has led to the interchangeable use of the names *Russula grisea* Fr. and *R. ionochlora*. The two species are documented to be closely related and morphologically separated by rather subtle differences in the pileus cuticle structure. However, different concepts of *R. grisea* are found in the literature and current phylogenetic data indicates some complexity. In this instance our sequences fall in a clade that probably corresponds to *R. ionochlora*. It is the sister clade of *R. grisea*. A type study is needed to settle this question.

Only known from New Zealand.

Material examined

NEW ZEALAND. SOUTH ISLAND. Canterbury, Lincoln, CASC grounds on roadside [with *Cedrus libani* A.Rich.], 27

Apr. 2011, *J.A. Cooper* (PDD96205); Canterbury, Lincoln, Liffey [with *Quercus robur*], 5 May 2011, *J.A. Cooper* (PDD96220); Canterbury, Christchurch, Thorrington St [with *Tilia cordata*], 30 Jan. 2016, *J.A. Cooper* (PDD106200).

Russula laccata Huisman

Fungus (Wageningen) 25: 40 (1955). **IF305382.**

Pileus 15–50 mm, hemispherical becoming flat, with slightly depressed centre, always sticky, at first dark purple/olive brown later becoming paler to olive brown with purple, magenta and sometimes with blue/greens particularly at edge, edge often lightly grooved. *Lamellae* white, without lamellulae. *Stipe* to 50 × 10 mm, white, sometimes bruising pink at the extreme base. *Smell* fruity. *Taste* very hot. *Spores* 7.5–8.5 × 5.5–7.5 µm with prominent warts forming an almost complete reticulum. **Figs 3H & 7F.**

Notes. *Russula laccata* and *R. nana* Killerm. are small red species that are closely related (Noffsinger & Cripps 2021). In Europe, *R. laccata* is described as laccate-capped species, often with purple-red to carmine colours and associated with willows in swampy areas. *Russula nana* is reported as having scarlet-red to pink-red caps and being non-laccate, associated with dwarf willows and *Dryas* L., but also reported with *Helianthemum* Mill. in the UK (Kibby 2012). However, the circumscription and distribution of these two similar species requires further investigation. New Zealand collections are usually laccate, with red/purple/blue colours and found along riverbanks and swampy areas where willow (e.g. *Salix fragilis* L., *S. caprea* L., *S. cinerea* L., *S. matsudana* L., *S. babylonica* L.) have invaded or been established for flood control.

Only known from New Zealand.

Material examined

NEW ZEALAND. SOUTH ISLAND. Canterbury, Christchurch, Travis Wetland Park [with *Salix caprea*], 8 Feb. 2009, *J.A. Cooper* (PDD95269; Canterbury, Christchurch, Travis Wetland Park [with *Salix* sp.], 29 Dec. 2009, *J.A. Cooper* (PDD95623); Canterbury, Ohoka [with *S. fragilis*], 4 Jan. 2009, *J.A. Cooper* (PDD 95647); Canterbury, Lindis Pass Road, Lindis River [with *S. fragilis*], 12 May 2010, *J.A. Cooper* (PDD96519); Canterbury, Oxford [with *Salix* sp.], 7 May 2010, *P. Leonard* (PDD101480).

Russula nitida (Pers.) Fr.

Epicr. Syst. Mycol. 361 (1838). **IF211457.**

Pileus 20–60 mm diam., convex becoming flat or depressed, margin strongly furrowed, purple to pink, thin-fleshed. *Lamellae* adnexed, widely spaced and shallowly intervenose, cream. *Stipe* 20–90 × 5–20 mm white or pinkish. *Smell* not distinct. *Taste* mild to slightly acidic. *Spores* 8–11 × 6–9 µm, hyaline; ornamented with spines and without connectives. **Figs 3I & 7G.**

English common name. Purple swamp brittlegill.

Notes. A relatively easy species to identify, fruiting consistently with birch, especially where they occur along riverbanks. The phylogeny presented does not include a sequence of the type and is based on the morphological and ecological concept of this species in Europe.

Currently known only from South Island, New Zealand.

Material examined

NEW ZEALAND. SOUTH ISLAND. Otago, Dunedin, Waiora Scout Camp, Whare Flat [with *Betula* sp.], 11 May 2008, *P. White* (PDD101460); Canterbury, Christchurch, Opawa [with *B. pendula*], 22 May 2005, *H. Greenep* (PDD80930); Canterbury, Lincoln, Lincoln University [with *B. pendula*], 12 Jan. 2005, *J.A. Cooper* (PDD80998); Canterbury, Christchurch, Fifield Terrace [with *B. pendula*], 5 Apr. 2006, *J.A. Cooper* (PDD86996); Canterbury, Christchurch, Riverlaw Terrace [with *B. pendula*], 13 Mar. 2008, *J.A. Cooper* (PDD95369).

Russula praetervisa Sarnari

Monogr. Ill. Gen. Russula Europa 1: 463 (1998). **IF446396.**

Pileus 25–80 mm diam., convex becoming broadly convex to flat with slightly depressed centre, with bumpy striate margin, viscid when wet, various shades of dull yellowish brown, sometimes with an olive tinge, often with a darker centre. *Lamellae* adnexed, close, pale cream or yellowish, becoming light ochre in age, some forking. *Stipe* 28–50 × 5–15 mm, white, often with reddish-brown or purplish rusty spots near base. *Smell* old or burnt rubber, oily, sometimes fishy. *Taste* oily, mild or only very slightly bitter. *Spore print* dark cream. *Spores* 7–8.5 × 5.5–7 µm, ellipsoidal; ornamented with warts to 0.7 µm connected by ridges in partial mesh. **Fig. 7H.**

Notes. *Russula praetervisa* is part of a group of similar species including *R. amoenolens*, *R. sororia*, *R. pectinata* and *R. pectinatoides*. It is mostly found under evergreen oaks (*Quercus ilex* L. & *Q. suber* L.), but has been recorded under pines (*Pinus pinaster* Aiton, *P. pinea* L. and *P. halepensis* Mill.; Melera *et al.* 2017). Careful microscopic observation and chemical testing is necessary to separate this species (slightly bitter tasting, spores with warts connected in a partial mesh) from several other similar species. *Russula recondita* Melera & Ostellari, not yet recorded from New Zealand or Australia, has a paler cap, mild taste and fruitier smell, and spores with isolated warts barely connected by short lines, and very broad host association. The common *R. amoenolens* does not have red staining at the stipe base and has a stronger fetid odour. The species has not yet been found in New Zealand.

Material examined

AUSTRALIA. VICTORIA. Melbourne, Royal Botanic Gardens Victoria, garden bed at entrance to Gardens

House [with *Quercus* sp.], 16 Apr. 2002, *J.E. Tonkin 927* (MEL2238226).

Discussion

This survey includes verified records of fungal species in the Russulaceae family that have been introduced into Australia and New Zealand. These species are usually associated with introduced plants in modified habitats. Documenting the occurrence and distribution of these introduced fungal species is important for several reasons: (1) the majority of introduced fungi are concentrated in urban areas where they are more likely to be gathered for consumption; (2) the general ability of the public to correctly identify fungal species is low, due to lack of accessible information allowing unambiguous identification, and the inherent difficulty in identifying fungi; (3) a greater understanding of the occurrence and distribution of verified records provides useful insights into the ecology of these fungi.

Species occurrence data available for Australia and New Zealand and made available through aggregation portals, such as the Atlas of Living Australia (ALA) and the Global Biodiversity Information Facility (GBIF), contain records of taxa we have not included in this report (Appendix 1). Reports of these taxa require confirmation as present in Australia or New Zealand through the deposit of verified and sequenced collections in recognised fungaria. There are several sources of potential error in these data. *Russula* and *Lactarius* contain many species that are difficult to identify from macromorphology, and in some groups species concepts and correct names remain uncertain. Also, historically the names of similar northern hemisphere species have been applied to several indigenous taxa in Australia and New Zealand. There are no verified reports of ectomycorrhizal species with a natural north/south hemisphere distribution. Modern phylogenetic data confirm that different biogeographic regions usually support indigenous macro-fungal species, often with restricted distributions and sometimes with very similar morphology (cryptic species) (Li *et al.* 2010; Bazzicalupo *et al.* 2018). The indigenous species in natural habitats are often undescribed or difficult to identify and so it is unsurprising to find many misidentifications in the available records. There remains the possibility of the unrecognised spread of introduced exotic species and there are some reports of novel associations of introduced fungi with native trees and subsequent spread into native habitats (e.g. Dunk *et al.* 2012).

Another source of potential systematic misidentification results from eDNA data from the Biome of Australia Soil Environments (BASE) (Bissett *et al.* 2016). The data are associated with two issues: (1) the relatively short ITS1 sequence region used for the survey does not adequately resolve many species; (2) accurate matching is dependent on representative species barcodes being present in the dataset used for matching, and the coverage of southern hemisphere fungal taxa in these databases remains relatively poor. This dataset reported species that, as currently identified, are unlikely to be present in Australia and it was excluded from our analysis.

Records of introduced host-fungal associations provide useful insights into the ecology of these systems. Species of introduced ectomycorrhizal fungi have been implicated in the spread of wilding pines in New Zealand, and as food for introduced pest animal species as part of that process (Wood *et al.* 2015). Many ectomycorrhizal species are host-restricted, at least at family level. However, in their introduced range, changes in the patterns of host associations relative to their native range have been detected, and this has implications for understanding the invasive spread of both the fungi and their host plants (Dickie *et al.* 2017). Some studies have shown that the formation of new associations between introduced fungi and native host species is low (Dickie *et al.* 2010), whilst there are well documented exceptions, for example *Amanita muscaria* has spread into *Nothofagus* forests in both Australia and New Zealand (Dunk *et al.* 2012; Orlovich & Cairney 2004). In New Zealand, the species has currently spread throughout most native southern beech forests. The impact of invasive *Amanita muscaria* on native mycorrhizal fungi is unknown. Observation and collection data indicate other introduced ectomycorrhizal species have the potential to become similarly invasive, such as species of *Paxillus* (Batsch) Fr., *Hebeloma* (Fr.) P.Kumm., *Laccaria* Ber. & Broome and boletes. For example, in New Zealand's South Island, the braided river systems are often flanked by willows, originally planted for river management purposes, but now spreading inland into native forests providing a potential pathway for spread of associated mycorrhizal fungi. In urban areas, there are verified records of introduced species associated with planted native species, for example PDD95499 (SCD 2021) is a record of the introduced *Hebeloma mesophaeum* (Pers.) Quél. and PDD106951 is a record of the introduced *Xerocomellus cisalpinus* (Simonini, H.Ladurner & Peintner) Klofac, both in mycorrhizal association with planted native *Fuscospora solandri* (Hook.f.) Oerst. Conversely, indigenous ectomycorrhizal fungal species, which normally associate with indigenous hosts, have the potential to associate with introduced trees, which may then provide pathways for range expansion. For example, in New Zealand, there are recent records of *Amanita marmorata* (Cleland & E.-J.Gilbert) E.-J. Gilbert, in the death-cap group, forming associations with *Pinus radiata* in plantation forests (PDD99082). The species is naturally associated with myrtaceous hosts in Australia and New Zealand. Tracing the historical pathways by which exotic ECM fungi have been introduced can provide important insights into how ectomycorrhizal fungal species are initially translocated, and subsequently become established and spread.

All the currently known introduced species of *Russula* and *Lactarius* appear to be European in origin and are associated with introduced European and North American trees in several families (Pinaceae, Fagaceae, Malvaceae, Betulaceae, Salicaceae). Historical records indicate that "larch, spruce and scotch firs" were first introduced into Australia prior to 1840, presumably from England (Kloot 1985). It is interesting to note the absence of North American ectomycorrhizal *Russula* and *Lactarius* species in *Pinus radiata* plantations. The North American *P. radiata* (Monterey pine) was first introduced into Australia and New Zealand in the 1850s (Fielding 1957; Berg 2008). The plants were shipped in wardian cases and said to originate in Exeter, England (Wilson 1983). The plants were the progeny of material sent to England from the USA in 1833 by David Douglas. These original plants from England were probably carrying ectomycorrhizal fungi on their roots, but not of North American origin. There have been subsequent introductions of a relatively smaller number of ectomycorrhizal fungi from North America, for example, *Suillus pungens* Thiers & A.H. Sm., *S. quiescens* T.D. Bruns & Vellinga and *S. salmonicolor* (Frost) Halling, which are associated with *Pinus radiata* in New Zealand (SCD 2021).

The diversity of introduced ectomycorrhizal species discussed in this paper is incomplete for Australia. The limited current knowledge of introduced species will change as more collections are made in broader geographic regions of Australia. There is an important role for citizen science platforms like *iNaturalist* in documenting the indigenous and introduced fungi and highlighting the potential occurrence of newly introduced species for subsequent confirmation through the deposit and analysis of vouchers in recognised fungaria. While quarantine regulations are now in place to prevent the introductions of potentially new problematic species; many of the taxa discussed here are historical legacies predating current regulations.

In New Zealand, the *Hazardous Substances and New Organism (HSNO) Act 1996*, section 44 (General Duty to Inform), states that "Every person is under a duty to inform the Ministry, as soon as practicable in the circumstances, of the presence of what appears to be an organism not normally seen or otherwise detected in New Zealand." The act is intended to facilitate the detection of organisms that are "capable, or potentially capable, of causing unwanted harm to any natural and physical resources or human health". The *HSNO Act* supports the protection of New Zealand's economy and natural environment. The implementation of the act implies the existence of a complete and maintained inventory of all organisms present in New Zealand. The New Zealand Organisms Register (NZOR) is an information infrastructure intended to deliver the inventory of recorded organisms. However, this inventory of recorded organisms will be a fraction of the total, which will include undescribed species and undetected introduced species. Increasingly, the detection and validation of species present in an area is being facilitated by the collection and interpretation of eDNA data. The accuracy of these surveys depends critically on the existence of verified sequence barcodes. In New Zealand there is an ongoing effort to generate sequence barcodes for the described fungal species to support the implementation of the *HSNO Act* and also the interpretation of eDNA data. The work necessarily includes all fungal species, and not just those that are potentially pathogenic or invasive. For the agaricoid fungi an additional focus has been the verification of the presence of introduced species. That program of work has provided a substantial baseline of data. For these reasons, New Zealand is relatively well-documented for the species included in this report.

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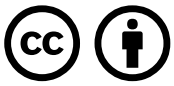

Appendix 1. Species with New Zealand/Australia observation/collection records available through GBIF but without sequence verified collections.

Taxon	Data Source	Comment
Lactarius ruginosus	BRI, loc. Fraser Island	Likely misidentification of an indigenous species in natural habitats
Lactarius subdulcis	Fungimap, MEL2118486A, MEL2069101A, MEL2336349A, HO513643, BRI-AQ0811039, and literature reports	Likely misidentifications of indigenous species in the *L. eucalypti* group in natural habitats
Lactifluus corrugis	Duke University, loc. Northern Territories	Likely misidentification of an indigenous species in natural habitats
Lactifluus luteolus	BRI-AQ0798418, Queensland	Likely misidentification of an indigenous species in natural habitats
Lactifluus piperatus	Numerous records from widespread locations	Likely misidentification of an indigenous species in natural habitats
Lactifluus volemus	NYBG, Queensland	Likely misidentification of an indigenous species in natural habitats
Multifurca furcata	BRI-AQ0796297, Queensland	Misidentification of *M. stenophylla* indigenous species in natural habitats
Russula adusta	Numerous records from widespread locations and literature reports	Likely misidentifications of indigenous species (in the Compacta group) in natural habitats
Russula alutacea	MEL2367990A, Victoria	Likely misidentification of an indigenous species in natural habitats
Russula cerolens	Duke University, NZ Northland, Waikato & Bay of Plenty, with *Pinus*	Likely misidentifications of *Russula amoenolens*
Russula cinereovinosa (as *R. cinereopurpurea*)	NYBG, unlocalised	Likely misidentification of an indigenous species in natural habitats
Russula compacta	Numerous records from widespread locations and literature reports	Likely misidentifications of indigenous species (in the compacta group) in natural habitats
Russula cyanoxantha	Numerous records from widespread locations and literature reports	A widely misapplied name. Likely misidentifications of indigenous species in natural habitats
Russula delica	Several records from widespread locations and literature reports	Likely misidentifications of indigenous species (in the compacta group) in natural habitats
Russula emetica	Numerous records from widespread locations	A widely misapplied name. Likely misidentifications of indigenous species in natural habitats
Russula foetens	Numerous records from widespread locations and literature reports	A widely misapplied name. Likely misidentifications of indigenous species in natural habitats, such as *R. neerimea*, and/or species in the introduced Ingratula group
Russula foetida	Several records	Probable recording errors for *Russula foetens*, which see
Russula fragrantissima	NYBG, Western Australia	Likely misidentification of an indigenous species in natural habitats
Russula grata	Numerous records from widespread locations	Misapplication in eDNA data
Russula integra	Several records	Likely misidentifications of indigenous species in natural habitats and/or species in the introduced Ingratula group

Taxon	Data Source	Comment
Russula mariae	Several records from widespread locations and literature reports	Likely misidentification of an indigenous species in natural habitats
Russula nigrescentipes	BRI-AQ0795169, Queensland	Likely misidentification of an indigenous species in natural habitats
Russula nigricans	Several records	See the correct name *Russula adusta*
Russula rosacea	Several records, including iNaturalist Australia	The name has been generally used as a misapplication of *Russula sanguinaria*, but Australian records are likely misidentifications
Russula rosea	iNaturalist Australia	A misidentification
Russula rubra	BRI-AQ0812680, BRI-AQ0645914, Queensland, and literature reports	Likely misidentifications of an indigenous species in natural habitats
Russula sanguinea	iNaturalist Australia and literature reports	Likely misidentifications of an indigenous species in natural habitats
Russula schaefferi (as *Gymnomyces brunnescens*)	Harvard University, Tasmania	A misidentification of an indigenous species
Russula violeipes	Numerous records from widespread locations	Misidentifications in eDNA data
Russula virescens	iNaturalist Australia	Likely misidentifications of an indigenous species in natural habitats
Russula xerampelina	Several records, including iNaturalist Australia and literature reports	Likely misidentifications of an indigenous species in natural habitats

Appendix 2. Sequence data used in the analysis. Newly generated sequences are highlighted in bold.

Species	Collection/Fungarium number	Country of origin	ECM Host	GenBank/UNITE ITS accession number
Lactarius acris	GENT:BG2011-31	Belgium		KF432962
Lactarius aquosus	GENT:KW 231	Thailand		KF432984
Lactarius asiae-orientalis	KUN-HKAS 61370 Holotype	China		MK253479
Lactarius atroviridis	GENT:AV05-306	USA		KF133270
Lactarius atroviridis		USA		KX389114
Lactarius circellatus	KR-M-0044647	Germany		MT006008
Lactarius deliciosus		Algeria		MT262921
Lactarius deliciosus	MEL2101917	Australia	*Pinus radiata*	**MZ519802**
Lactarius deliciosus	MEL2238310	Australia	*Pinus radiata*	**MZ519800**
Lactarius deliciosus	MEL2257811	Australia	*Ulmus*	**MZ519801**
Lactarius deliciosus	JET1021: MEL2238314	Australia	*Pinus radiata*	**MZ519804**
Lactarius deliciosus	JET1017: MEL2238310	Australia	*Pinus radiata*	**MZ519803**
Lactarius deliciosus	HKAS 94736	China	*Pinus*	KY684167
Lactarius deliciosus		New Zealand	*Pinus pinea*	MT397068
Lactarius deliciosus		New Zealand	*Pinus radiata*	MT397070
Lactarius deliciosus		Portugal		MG334288
Lactarius deliciosus	GENT: JN 2001-046	Slovakia		KF133272
Lactarius deliciosus	2006 09 12 2	UK		JQ888181
Lactarius deterrimus	KUN-HKAS 61943	China	*Pinus armandii*	MK158321
Lactarius flexuosus	GENT:RW2136	Sweden		KJ742400
Lactarius fuliginosus	GENT:DS 06-310	Belgium		JQ446110
Lactarius glyciosmus	TUF117427	Estonia		UDB031388
Lactarius glyciosmus	E.Cautero 1315	Italy		JF908294
Lactarius glyciosmus	JAC9222: PDD80997	New Zealand	*Betula pendula*	**MW683723**
Lactarius glyciosmus	JAC16150: PDD113295	New Zealand	*Betula* sp.	**MW683881**
Lactarius glyciosmus	O-F-260397	Norway		UDB036376
Lactarius hepaticus	Hal-BP-102	Italy	*Halimium halimifolium*	MT594520
Lactarius lignyotus	GENT:KVP 08-083	Austria		JQ446113
Lactarius mammosus	IK-00156	Poland		KX610693
Lactarius mammosus	UPS: UE09.09.2004-5	Sweden		KF133265
Lactarius turpis	MEL2257814	Australia	*Betula pendula*	**MZ519806**
Lactarius turpis	JET1125: MEL2118493	Australia	Nothofagaceae & *Eucalyptus regnans*	**MZ519805**
Lactarius turpis	MEL2369979	Australia	*Betula*	**MZ519807**
Lactarius necator		Denmark	*Fagus sylvatica*	AM087287
Lactarius necator	TUB:hue203	Finland		AY606950
Lactarius necator	ID PAN 744	Poland		KM085369
Lactarius olivaceoumbrinus	UBCF23766	Canada		KC581315
Lactarius olivaceoumbrinus	PU_1008	India	*Abies*	KX845556
Lactarius orientaliquietus	KUN-HKAS 61966 Holotype	China		MH447589
Lactarius orientitorminosus	TPML110928-063 Holotype	South Korea	*Quercus*	MH985020
Lactarius parallelus	HCCN12093 Holotype	South Korea		MH984953
Lactarius pseudodeceptivus	Smith 71932	USA		MK931348
Lactarius pseudodelicatus	MONT:CLC512	USA	*Populus tremuloides*	KX394295
Lactarius pubescens	MEL2151432	Australia	*Betula pendula*	**MZ519810**

Species	Collection/Fungarium number	Country of origin	ECM Host	GenBank/UNITE ITS accession number
Lactarius pubescens	MEL2257969	Australia	*Betula pendula*	**MZ519811**
Lactarius pubescens	JEich15: MEL2320720	Australia	*Betula pendula*	**MZ519808**
Lactarius pubescens	MEL2096561	Australia	*Betula pendula*	**MZ519809**
Lactarius pubescens	MEL2264835	Australia	*Betula pendula*	**MZ519812**
Lactarius pubescens	MEL2379128	Australia	*Betula pendula*	**MZ519814**
Lactarius pubescens	JEich15: MEL2320720	Australia	*Betula pendula*	**MZ519813**
Lactarius pubescens		China	*Ostryopsis davidiana*	JX129140
Lactarius pubescens	TUB:hue135	Germany		AY606953
Lactarius pubescens	JAC10930: PDD95387	New Zealand	*Betula pendula*	**MW683764**
Lactarius pubescens	JAC16149: PDD113294	New Zealand	*Betula* sp.	**MW683880**
Lactarius pubescens	JAC11787: PDD96184	New Zealand	*Betula* sp.	**MW683793**
Lactarius pubescens	GENT:AV 96-931	Norway		AY336958
Lactarius pubescens	MONT:EB300-15	USA		KX394296
Lactarius pubescens	MONT:CLC539	USA	*Populus tremuloides*	KX394297
Lactarius pyrogalus	TAAM204056	Estonia		UDB015966
Lactarius pyrogalus	JAC12115: PDD96354	New Zealand	*Corylus avellana*	**MW683797**
Lactarius pyrogalus	O-F-260512	Norway		UDB037216
Lactarius pyrogalus	O-F-22147	Norway		UDB035938
Lactarius quieticolor	CONC-F 0810	Chile	*Pinus radiata*	MT335833
Lactarius quieticolor	GENT:RW&AV 3193	Czech Republic		KJ769676
Lactarius quieticolor		South Africa		EF565902
Lactarius quietus	GENT:KW131	Belgium		KF432972
Lactarius quietus	JAC12929: PDD97029	New Zealand	*Quercus* sp.	**MW683811**
Lactarius quietus	ID PAN 600	Poland		KM085389
Lactarius quietus	UPS:UE16.09.2004	Sweden		KF133264
Lactarius rufus	GENT:KW500	Belgium		KT165272
Lactarius rufus		Canada		JQ711991
Lactarius rufus	GENT:JN 2012-022	Germany		KT165276
Lactarius rufus	JAC11466: PDD95865	New Zealand		**MW683782**
Lactarius rufus	PL233508	New Zealand		**MZ619132**
Lactarius rufus	K80S07	New Zealand	*Pinus radiata*	GQ267478
Lactarius rufus	GENT:KVP10-030	Russia		KT165277
Lactarius torminosus	GENT:JN 2011-086	Greece		KR025613
Lactarius torminosus	IZS81737/10-138	Italy		MZ005536
Lactarius torminosus	CBS197.72	Netherlands		MH860447
Lactarius turpis	JAC8818: PDD 79875	New Zealand	*Betula pendula*	**MW683715**
Lactarius turpis	JAC15927: PDD 113074	New Zealand	*Betula* sp.	**MW683866**
Lactifluus vitellinus	GENT:HTL 348	Thailand		HQ318251
Lactifluus volemus	GENT:KVP 08-039	Thailand		HQ318245
Russula amoenolens	MEL2193626	Australia	*Quercus canariensis*	MZ519815
Russula amoenolens	MEL2397790	Australia	*Quercus*	MZ519816
Russula amoenolens	MICH12838	France		KF245510
Russula amoenolens	2010BT118	Germany		KF318080
Russula amoenolens	KR-M-0044645	Germany		MT005913
Russula amoenolens	KR-M-0044213	Germany		MT005962
Russula amoenolens	ET15M	Italy	*Quercus ilex*, *Pinus halepensis*	MW349690

Species	Collection/Fungarium number	Country of origin	ECM Host	GenBank/UNITE ITS accession number
Russula amoenolens	JAC9208: PDD80990	New Zealand	*Quercus robur*	**MW683721**
Russula amoenolens	JAC10961: PDD95417	New Zealand	*Pinus*	**MW683769**
Russula amoenolens	PL 9111: PDD101435	New Zealand	*Quercus*	**MZ619133**
Russula amoenolens	PDD103800	New Zealand	*Pinus nigra* subsp. *laricio*	**MZ619135**
Russula amoenolens	JAC9273: PDD80743	New Zealand	*Tilia* × *europaea*	**MW683725**
Russula amoenolens	CS R04: PDD77763	New Zealand		GU222264
Russula amoenolens	JAC9217: PDD 80993	New Zealand	*Pinus radiata*	**MW683722**
Russula amoenolens	PL4511	New Zealand		**MZ619136**
Russula amoenolens	PL121304: PDD 101436	New Zealand	*Populus*	**MZ619134**
Russula amoenolens		Poland		MK583522
Russula amoenolens	AH:46371	Spain	*Quercus* sp.	MK105625
Russula amoenolens	LUGO:ECC18051601	Spain	*Quercus pyrenaica*	MW376706
Russula amoenolens	16N	Spain	*Eucalyptus nitens*	MK492607
Russula amoenolens	280	Spain	*Eucalyptus globulus*	KY681463
Russula amoenolens	146	Spain	*Castanea sativa*	MN663161
Russula amoenolens	Lug14488	Switzerland		KJ834607
Russula amoenolens	115	Switzerland		KJ834590
Russula amoenolens	TUB:nl27.9.95.6		*Quercus*	AF418615
Russula atrorubens		Slovakia		MT908302
Russula atrorubens	TU101718			KX579812
Russula atrorubens	TU106570			KX579819
Russula atrorubens	TU106421			KX579817
Russula cerolens		Canada	*Quercus garryana*	KX449208
Russula cerolens		Canada	*Quercus garryana*	KX449182
Russula cerolens	UBC:F18895			HQ604833
Russula cerolens				HQ604832
Russula cessans	MEL2359749	Australia	*Pinus*	**MZ519819**
Russula cessans	MEL2293682	Australia	*Pinus radiata*	**MZ519818**
Russula cessans	JET1080: MEL2238372	Australia	*Pinus radiata*	**MZ519817**
Russula cessans	DMS-9333482	Denmark		MT644904
Russula cessans	OSA:MY-7811	Germany		LC192757
Russula cessans	130732MFBPC626			MW554164
Russula cessans	130732MFBPC599			MW554172
Russula cf. amoenolens	TENN:067119	USA	*Tsuga*	KT933954
Russula cf. amoenolens		USA		KX389121
Russula cf. amoenolens				JQ622327
Russula cf. nauseosa	LT06	China		MN240852
Russula cf. nauseosa	XYY02	China		MN240853
Russula cf. recondita	F:PRL7415	USA	*Quercus*	GQ166870
Russula cf. recondita	NYBG:672053	USA		KF318046
Russula cf. recondita	MI:6271	USA		KF318045
Russula cf. recondita				JQ622374
Russula cf. recondita				JQ622363
Russula cf. recondita				JQ622382
Russula emetica	UBC F30056			KX579781
Russula emetica	UBC F30121			KX579790

Species	Collection/Fungarium number	Country of origin	ECM Host	GenBank/UNITE ITS accession number
Russula emetica	UBC F30123			KX579792
Russula grisea	SAV F-1395	Slovakia		MT738286
Russula grisea	SAV F-1436	Slovakia		MT738287
Russula ionochlora	982_ITS1F_TUBE300908_ed	Germany	*Alnus* & *Quercus*	GQ924691
Russula ionochlora	978_ITS1F_ITS4_TUBE220708_ed	Germany		GQ924690
Russula ionochlora	JAC11808: PDD96205	New Zealand	*Cedrus libani*	**MW683794**
Russula ionochlora	JAC11831: PDD96220	New Zealand	*Quercus robur*	**MW683795**
Russula ionochlora	BB72_404_Ah_210507		*Fagus sylvatica*	HM189867
Russula ionochlora	BB72_408_Bv_210507_R67		*Fagus sylvatica*	HM356007
Russula ionochlora	BB72_403_Bv_210507_R15		*Fagus sylvatica*	HM189874
Russula laccata	PDD101480	New Zealand	*Salix*	**MZ619137**
Russula laccata	PDD101481	New Zealand	*Salix*	**MZ619138**
Russula laccata		Sweden	*Salix*	JQ724007
Russula laccata		Sweden	*Salix*	JQ724003
Russula laccata		Sweden	*Salix*	JQ724006
Russula laccata	TU<EST>:101871			KX812854
Russula nana	TU101701	Estonia	*Picea*, *Betula* & *Pinus sylvestris*	KX579809
Russula nana	TUF101878	Finland	*Betula*	UDB016029
Russula nana	JAC10821: PDD95269	New Zealand	*Salix caprea*	**MW683748**
Russula nana	JAC11191: PDD95650	New Zealand	*Salix fragilis*	**MW683775**
Russula nana				AY061694
Russula nauseosa	GENT:FH-12-173	Germany		KT933985
Russula nitida	PRM922555	Czech Republic		MG687360
Russula nitida	KR:0004221	Germany		KU205349
Russula nitida	PL232508: PDD101460	New Zealand	*Betula*	**MZ619139**
Russula nitida	JAC9223: PDD80998	New Zealand	*Betula pendula*	**MW683724**
Russula nitida	UPS:UE08.07.2004-2	Sweden		KU205269
Russula nitida	WTU-F-073255	USA	*Betula*	MW024889
Russula nitida	PRM922543			MG679818
Russula pectinata	2012BT30	Germany		KF318084
Russula pectinata	2010BT02	Germany		KF318081
Russula pectinatoides	F1116010	USA		KU640187
Russula pectinatoides	F1115989	USA		KU640188
Russula praetervisa	MEL2238226	Australia	*Quercus canariensis*	**MZ519820**
Russula praetervisa	17220	Italy		KF303597
Russula praetervisa		Italy		KF303598
Russula praetervisa	142	Italy		KJ530760
Russula praetervisa	12.065	Morocco		KJ530749
Russula praetervisa				MK327978
Russula recondita	4141	Switzerland		KJ530756
Russula recondita	LUG:19058 Holotype	Switzerland	*Corylus maxima* 'Purpurea'	KJ530750
Russula sororia	PRM 935984	Czech Republic		MG679815
Russula sororia	LM1532	UK	*Quercus robur*	KM576550
Russula sphagnicola	PRM922122			MG687324
Russula sphagnicola	PRM922121			MG687325