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## FUNGAL INVADERS

*Peter Johnston and Peter Buchanan, Landcare Research, Private Bag 92170, Auckland, John Leathwick, Landcare Research, Private Bag 3127, Hamilton, and Shannan Mortimer, Auckland University, Private Bag 92109, Auckland.*

The Landcare Research 'Invasive fungi in native ecosystems' programme (Johnston & Buchanan 1997) is a first attempt to measure the impact of introduced non-pathogenic fungi on New Zealand's indigenous communities. Although the consequences of such fungi invading indigenous ecosystems have not been considered in the past, they may be far-reaching, especially for a long-isolated island biota such as New Zealand's. Invading fungi could displace native fungi from the communities in which they occur, and disrupt natural fungal successions in these communities. Fungi are basic to many biological processes within forests. Flow-on effects from the displacement of native fungal species could include the disruption of food chains of indigenous insects and birds, and, for mycorrhizal fungi, changes to the vigour of host trees.

The fungal invaders programme aims to address the following questions:

- What is the extent of the invasion of native ecosystems by exotic fungi?
- What characteristics allow some exotic fungal species to invade indigenous ecosystems?
- What are the biological consequences of these invasions?

The programme has focussed initially on two invasive macrofungi, each with conspicuous sporocarps. The large ectomycorrhizal mushroom, the 'fly agaric' (*Amanita muscaria*), and the small wood-rotting 'orange pore fungus' (*Favolaschia calocera*), both introduced to New Zealand in historically recent times, are known to be invading indigenous forests at some sites.

### Extent of invasion

A public survey was initiated to gather information on the distribution of *Amanita muscaria* and *Favolaschia calocera* in indigenous forests in New Zealand. Over the first six months of 1997 posters and leaflets publicising the programme, and requesting records of sightings of the two fungi, were distributed. This was achieved primarily with the assistance of the Department of Conservation (DOC), with many DOC visitor centres and field centres setting up displays on the programme. In addition, the Auckland Regional Authority visitor centres at Hunua and Arataki, and the Auckland Museum helped publicise the programme in the Auckland area.

Responses were received from over 200 people nation-wide, many reporting several records of one or both of the fungi. The first positive result from this programme is to show that public surveys by 'parataxonomists' provide a potentially useful way to gather information on the distribution of fungi. The ephemeral nature of fungal fruiting bodies means that without input from a large number of people over an extended period, even this most basic of information is often very difficult to gather (May 1997).

### *Amanita muscaria*

*Amanita muscaria*, first reported from New Zealand in the late 1880s (Armstrong 1880), is now common throughout the country in human-modified habitats. As an ectomycorrhizal mushroom growing only in association with the roots of suitable trees, it is found under a wide range of introduced broad-leaved trees and conifers including oak, radiata pine, macrocarpa, and eucalypts. It has long been known to have the ability to form mycorrhizae with *Nothofagus* trees established in nurseries and subsequently planted into gardens or parks. Stevenson (1958, 1962) first reported it from natural stands of *Nothofagus* from the Nelson Lakes National Park. Since then it had been found at other sites in the Nelson Lakes area (Johnston & Buchanan 1997), but prior to the Fungal Invaders survey had not been reported from *Nothofagus* forest in other areas. The survey revealed *A. muscaria* to be widespread in *Nothofagus* forests in the northern half of the South Island, and also that it occurs in a few sites in the central North Island (Figure 1). In contrast to the numerous records from *Nothofagus*, there is only a single, unconfirmed record from *Leptospermum scoparium* and *Kunzea ericoides*, the other native ectomycorrhizal trees in New Zealand, this from the Bay of Islands area in the northern North Island.

To date, all information on the distribution of *A. muscaria* is based on observations of the sporocarps. We plan to investigate how the presence of individual sporocarps relates to the frequency of *A. muscaria* mycorrhizae on *Nothofagus* roots at a micro-site scale. This will provide some of the basic data needed to understand the biological consequences of such invasions. This study will involve both morphological and molecular characterisation of *A. muscaria* mycorrhizae on *Nothofagus* roots. This base-line information will be useful to estimate whether the presence of *A. muscaria* affects the diversity of indigenous ectomycorrhizal species at the invaded sites.

In most localities where it occurs, *Amanita muscaria* is present at numerous separate sites within a few kilometres of each other. The inset maps in Figure 1 show examples of local distributions at a larger scale for the Wangapeka Track area in Nelson and the Bealey River area in Canterbury. The same kind of distribution was evident in Abel Tasman National Park and the Pelorus Bridge area. Such a distribution pattern might be explained by some local feature of the environment, or the fungus, or the host in these localities. Alternatively, it may represent local spread subsequent to a single invasion. If we can determine which of these possible explanations is valid, then it should be possible to predict which kinds of sites are likely to be invaded by this mushroom in the future. At several of the invaded sites a second introduced mycorrhizal associate of Pinaceae, *Suillus piperatus*, was also found. This might suggest that, in some cases at least, features of the site at which invasion is occurring may be more important than features of the host or fungus population at that site.

### *Favolaschia calocera*

*Favolaschia calocera*, a saprobic wood-decayer, has been known in New Zealand for about 30 years. The first herbarium specimen is dated 1969, suggesting that it was first introduced during the 1960s. Although the individual fruiting bodies of this fungus are small, it fruits in large swarms and this, together with its bright orange colour, means it is unlikely to have been missed by the several field mycologists active in the 1940s and 1950s, if it had been present. Hood (1992) considered *F. calocera* may have been present in New Zealand as early as 1906, based on a report by Masee (1906, as *F. thwaitesii*). However, Masee's description does not match *Favolaschia* in several respects. Unfortunately Masee's collection can not be found in the herbarium at Kew. *Favolaschia calocera* is thought to be native to Madagascar, the type locality, and has otherwise been recorded only from New Zealand and Norfolk Island. The report from Norfolk Island is recent (Heinno Lepp, pers. comm.), and probably represents a range extension from New Zealand.

First recorded from both Auckland City and Mt Pirongia in 1969, *F. calocera* was reported as far south as Nelson, Punakaiki (Paparoa National Park), and the Chatham Islands in 1986, 1992, and 1993, respectively, and we expected the survey to reveal a continued southward spread. However, although the survey greatly increased the number of sites from which this fungus was known, its southern limit was extended by only a few kilometres. The southern-most record in last year's survey was from near Hokitika, only about 60 km further south than Punakaiki.

Several fungal species of tropical origin show a similar geographic range in New Zealand. We tested whether further spread of *F. calocera* is being limited by climate, using a climate-matching programme.

*Favolaschia calocera* was reported from over 200 sites (black dots on Figure 2) throughout most of the North Island, and the northern part of the South Island. GIS databases were used to estimate values for a range of environmental variables for each of these sites. These included: mean annual temperature; average minimum temperature of the coolest month; mean annual solar radiation; minimum humidity (lowest mean monthly humidity); and, minimum rainfall/PET ratio (lowest mean monthly ratio of rainfall to potential evaporative transpiration). Across the complete set of distribution records the extreme values for each of the environmental variables were noted, and these were mapped across New Zealand as a whole. The separate layers were combined to generate a map which acts as a predictive model of the environmental conditions in which *F. calocera* is able to grow, and hence the limits of its geographic range (Figure 2). These results suggest that the distribution of *F. calocera* is close to its climatic limit in New Zealand, probably reflecting its putative tropical origin.

However, when we compared the growth rate on agar plates of *F. calocera* with that of several indigenous saprobic wood-rotting basidiomycetes, the results were unexpected. Compared with most of the indigenous species tested (*Bjerkandera adusta*, *Gloeoporus dichrous*, *Pycnoporus coccineus*, *Schizopora* sp., and *Trametes versicolor*), *F. calocera* had a lower optimum growth temperature for growth, and a lower tolerance to temperature extremes. This appears to be inconsistent with the hypothesis that it is a tropical species at the limits of its climatic tolerance in New Zealand. Future observations on its distribution both in New Zealand and

Madagascar will test the validity of our climate-matching model. The environmental variables selected were those found to be most useful in similar studies on plant distributions in New Zealand. Whether or not a different set of variables may be more appropriate for New Zealand fungi has yet to be investigated.

### Characteristics allowing some exotic fungal species to invade indigenous ecosystems

As noted above, an understanding of the features which allow some fungi to become invasive will allow us to predict the likely sites of future invasion by these fungi. Some of these features are likely to reflect the rate of production and viability of propagules, degree of substratum specificity, rate of hyphal growth, and competitive interactions in confrontations between hyphal fronts.

The abundance of *Favolaschia calocera* fruiting bodies at some sites suggests that it may be displacing the native wood-rotting species normally expected at these sites. The sporocarps of *F. calocera* in New Zealand are known to contain strobilurans (Gillian Nicholas, Canterbury University, pers. comm.), compounds with anti-fungal properties. The production of these compounds may be one mechanism giving it a competitive advantage over native fungi; possibly excluding them from, or displacing them from wood in which they are normally found.

We tested the competitive ability of *F. calocera* against a range of native wood-rotting basidiomycetes on both agar plates and a sawdust medium at 20°C, the optimum growth temperature for *F. calocera* on agar. In most cases, when the colonies of the two competing species met deadlock ensued, with each fungus maintaining exclusive colonisation of its part of the medium. In almost all cases the amount of substratum colonised by *F. calocera* was less than that of the native species, reflecting its generally slower rate of growth. This *in vitro* experiment found no evidence that *F. calocera* has a particular competitive advantage over native wood-rotting fungi in terms of capture of substratum resource.

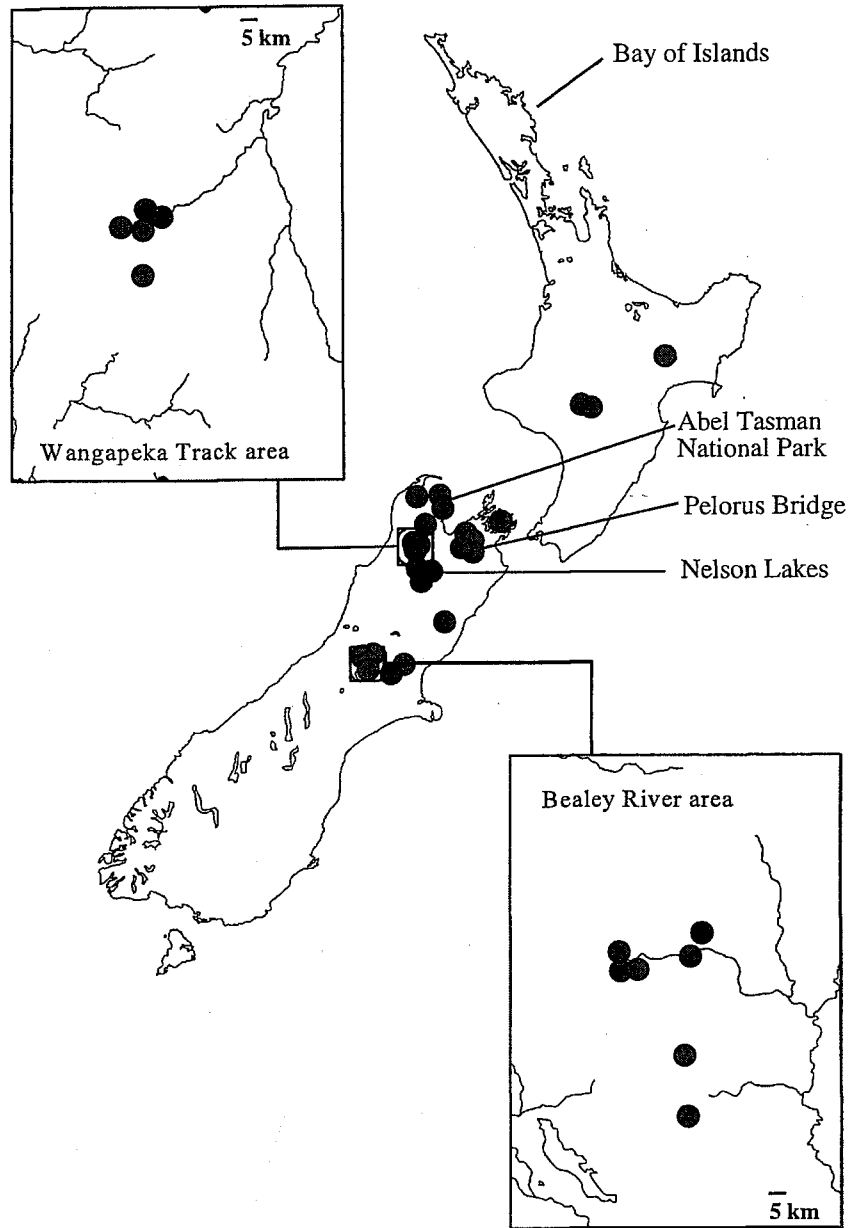
Possible explanations for this unexpected result are that the experimental conditions we used do not adequately reflect the situation in nature; that *F. calocera* produces strobilurans in sporocarps but not in vegetative mycelium; that the fungi against which we tested *F. calocera* are not those with which it is competing in nature; or that the presence of large numbers of fruiting bodies of this fungus on hosts does not reflect the colonisation of large volumes of wood. Another possibility is that *F. calocera* is not out-competing other fungi, but that it is filling an empty niche. *F. calocera* appears to be particularly common in highly modified bush remnants. It may be that native fungi have difficulty in adapting to such human-modified habitats. In this case, the presence of *F. calocera* in a given habitat may be an indicator of a depauperate microbial biota. It is also possible that *F. calocera* has a competitive advantage in its ability to fruit and disperse spores more quickly than native species, and that it thus has a greater chance of occupying substratum as it becomes available.

### Biological consequences of invasions by non-pathogenic fungi

We will further investigate whether these fungi are having any effect either on biologically similar native fungi occurring at invaded sites, or on the trees, shrubs and other organisms found at these sites. We plan to determine the impact of *Amanita muscaria* on the diversity of native ectomycorrhizal species using PCR-based molecular techniques. Mycorrhizal species diversity will be compared genetically using mycorrhizal root samples taken from *Nothofagus* trees at both invaded and non-invaded sites.

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**Figure 1.** Distribution of *Amanita muscaria* in native forest, based on results of the Fungal Invaders public survey.



**Figure 2.** Map predicting the maximum geographic range of *Favolaschia calocera* in New Zealand. The map is based on a set of environmental variables being estimated for each of the distribution records from the Fungal Invaders public survey, with the extreme range for all of the variables being mapped across the country as a whole (see text).