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On the cover is the Australian tachinid fly (***Trigonospila brevifacies***), a parasitoid of other insects, specifically larvae of a number of Lepidoptera. It was introduced into New Zealand as a biological control agent for pest leaf roller moths, is also known to affect non-target and non-pest species, and to compete with native parasitoids.

**Contact:**
epress@unitec.ac.nz
www.unitec.ac.nz/epress/
Unitec Institute of Technology
Private Bag 92025,
Victoria Street West
Auckland 1142
New Zealand

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# The *Nephrolepis* Boston fern complex (including *Nephrolepis exaltata* [L.] Schott), Nephrolepidaceae, naturalised in New Zealand.

**Mark Large**
Associate Professor,
Environmental and Animal Sciences Network,
Unitec Institute of Technology

**Lizzy Farrington**
Student BAppSci,
Environmental and Animal Sciences Network,
Unitec Institute of Technology

## Abstract

*Nephrolepis cordifolia* (ladder fern) is widely recorded as an invasive weed, and is naturalised in New Zealand. The first records of this plant being wild date from the 1970s. The presence of other native species of *Nephrolepis* (in particular *N. flexuosa* Colenso) potentially complicates the recognition of the naturalised species. However, *N. cordifolia* has been easily distinguished by the presence of 'bulbils' or 'tubers' that appear along wire-like runners. In this paper we report the presence of the Boston fern complex (including *N. exaltata*) now apparently wild in the Auckland region. This aggregate is without bulbils and may superficially be confused with the other native and non-native species.

## Introduction

The genus *Nephrolepis* Schott consists of around thirty species (Hovenkamp & Miyamoto, 2005). Brownsey and Smith-Dodsworth (1989) identified three species as being present in New Zealand: *N. cordifolia* (L.) C. Presl; *N. hirsutula* (Forst. F.) C. Presl; and *Nephrolepis* sp. (*N. cordifolia sensu* Allan 1961). Unfortunately, the nomenclatural history of the New Zealand taxa is confusing and still not completely clear.

*Nephrolepis flexuosa* Colenso was reinstated as a valid name by de Lange et al. (2005) and equates to *Nephrolepis* sp. of Brownsey and Smith-Dodsworth (1989). However, to complicate matters, Hovenkamp & Miyamoto (2005) referred the type and name *N. flexuosa* incorrectly to *N. cordifolia*. (Their *N. cordifolia* var. *pseudolauterbachii* Hovenkamp et Miyam. appears to be a new name for *N. flexuosa* as it occurs in wider Polynesia. See de Lange 2016a).

The taxon treated by Brownsey & Smith-Dodsworth (1989) (and Sykes, 1977) as *Nephrolepis hirsutula* is now regarded as *N. brownii* (Desv.) Hovenkamp et Miyam. (de Lange et al., 2006; de Lange, 2015; 2016b). Although Hovenkamp and Miyamoto (2005) regard *N. brownii* as indigenous only to the Malesia and possibly the western edge of Polynesia, they suggest with some uncertainty that this taxon was introduced to the rest of the Pacific. Indeed, *N. brownii* and *N. flexuosa* are considered indigenous to the New Zealand region albeit with a wider Austro-Indo-Pacific range (see de Lange, 2016a & b). Unfortunately, issues associated with application of the nomenclature make an exact assessment of the true range difficult. Within New Zealand *N. brownii* is found in the Kermadec Islands (Dayrell, Raoul, Macauley and Curtis Islands) whereas *N. flexuosa* is known from Raoul Island, and the North Island, where it is primarily associated with the geothermal fields from Rotorua to Taupo (see Sykes, 1977; Brownsey & Smith-Dodsworth, 1989; de Lange, 2016a & b).

The non-native *Nephrolepis cordifolia* (L.) Presl (ladder fern or tuber ladder fern) is widely present, at least in northern regions, as an invasive weed, and is regarded as being fully naturalised in New

Zealand (Heath & Chinnock, 1974; Brownsey et al., 1985; Brownsey & Smith-Dodsworth, 1989; 2000; Froude, 2002; Howell & Sawyer, 2006). The first records of this plant in the wild date from the 1970s (Webb, Sykes & Garnock-Jones, 1988). However, herbarium material collected by Bell (AK289696) records its presence in Auckland gardens from the late nineteenth century (1889). This species is registered on the Global Invasive Species Database (GISD, 2016) and is included within many local authority pest management plans. The presence of the indigenous *N. flexuosa* on the mainland (both in the wild and occasionally in cultivation) potentially complicates the identification of this naturalised species. *N. cordifolia* is usually distinguished from it by the presence of 'bulbils' or 'tubers' that appear along wire-like runners (tubers are completely lacking in the native species). Although Lamoureux (1982) cautions that these tubers are not always present, particularly in climbing material, they can usually be found within the larger colony. (*N. brownii* is relatively distinct from both by being tuber-less and in having fronds with long, sickle-shaped pinnae and fringed scales).

*Nephrolepis exaltata* is widely available as a house plant, generally known as 'Boston Lace' or 'Boston Fern'. Until recently (see Large, 2016a & b) this taxon has not been regarded as naturalised in New Zealand. However, the risk of it becoming established was indicated as early as 1998 by Sandra Van der Mast (Van der Mast & Hobbs, 1998) who suggested that it could "grow aggressively if planted outside in a suitable sheltered location". This is particularly true in northern regions of New Zealand. Between 2014 and 2016 several naturalised populations of crested and semi-crested forms were discovered in the Auckland region in the Waitakere Ranges (Waiatarua and Oratia) and from northern Auckland (Whangaparoa/Orewa). There colonies were from roadside bank sites, with one at Oratia from a stream bank location. There is also a possible presence in Hawkes Bay (P.J. de Lange pers. comm.). These populations are free from any rhizome tubers and superficially resemble forms of the commercially available 'Boston fern'. Unfortunately, 'Boston fern' is best regarded as a complex of varieties from various sources, consequently recognition and assessment of the taxon in the wild is difficult. Plants are sold internationally under many named varietal forms including 'Boston Lace', 'Teddy Junior', 'Blue Bells', 'Whitmanii', 'Aurea', 'Chidsii', 'Elegantissima', 'Hillii', 'Mini Ruffle', 'Florida Ruffle', 'Fluffy Duffy', 'Massii', 'Silver Balls', 'Green Fantasy', 'Montana', 'Todeoides', 'Rooseveltii', 'Compacta', 'Dallas', or as *Nephrolepis exaltata* cv Bostoniensis (Hovenkamp & Miyamoto, 2005). The varieties are known for the many forms of cresting giving the fronds a delicate, curled, or lace-like appearance and are often assumed to be sterile/non-viable. Various forms have been (and still are), sold in New Zealand (including 'Teddy Junior', 'Blue Bells' and 'Massii'), however, the exact determination to named taxa may be confusing. The aim of this study is to highlight the presence of this plant now in the wild and begin work needed to understand its genetic variability.

## Materials & Methods

In this preliminary study, material was collected from three of the populations in the Waitakere Ranges (two Waiatarua and one Oratia) and from a northern Auckland (Whangaparoa/Orewa) population. Herbarium vouchers were made for all material collected and are held at the Unitec herbarium. A full list of herbarium voucher specimens for this material is available from the authors.

Where present, mature fertile fronds were also gently dried in spore packets and the spores extracted. As spore size may vary depending on pretreatment (Large & Braggins, 1991) measurements were made under the same conditions with spores mounted in 10% glycerine and stained with cotton blue. Spores and scales were examined under a compound microscope (Olympus BH2) at 400x magnification.

By way of comparison, representative herbarium material held in the collection of the Auckland Museum (AK) (details are available from the authors) was also studied of *Nephrolepis*

**Figure 1**. Nephrolepis. 1a 1b 1c 1d

1a. *N. cordifolia* growing on bank, Mt Albert, Auckland.

1b. *Nephrolepis* sp. Showing a mature frond with crests. Plant growing on road bank at Waiatarua.

1c. Frond without cresting from same population as image

1d. *Nephrolepis* sp. Mature frond showing slightly upturned pinnae. Plant growing on road/streamside bank Oratia.

*brownii, N. flexuosa, N. exaltata* and *N. cordifolia*, as well as fresh material of this latter species sampled from Mt Albert, Auckland. The aim was to compare general form including frond, scales, rhizome and spore morphology.

## Results

### Frond morphology

Assessment of the populations from northern Auckland (Orewa) and the Waitakere Ranges (Waiatarua and Oratia) showed considerable variation (see Figure 1). Mature fronds from two populations at Waiatarua (and from Orewa) were drooping c. 100-800mm long, c.80-140mm wide (Figure 1b). Pinnae at the mid-point of these fronds were 30(47)70mm, n=50 long, sub alternate to almost opposite and heavily crested (to bi-pinnate) with numerous fringed pinnules. Fronds from the Oratia population (Figure 1d) were semi-erect to drooping, 100-700mm long and c.60-150mm at the widest point (mid frond). Pinnae were sub-alternate, crinkled (rather than crested) and 40(50)80mm, n=50 long.

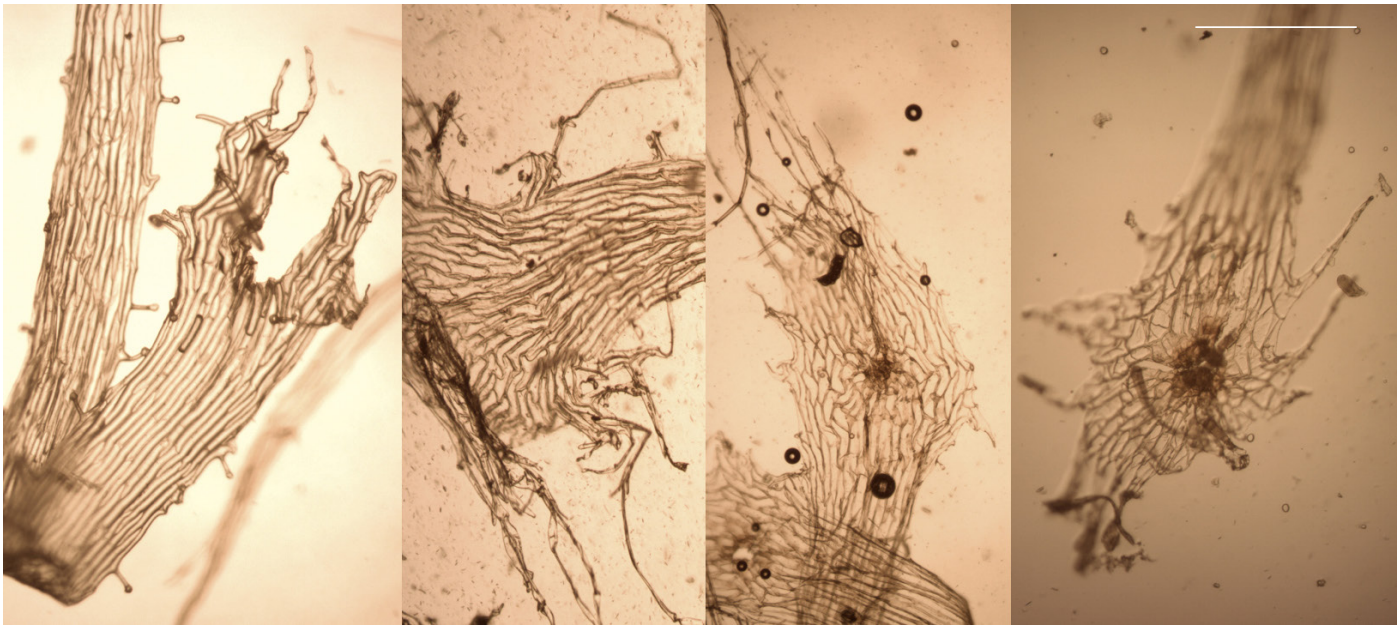
Fronds from material of *Nephrolepis exaltata* examined from herbarium material (AK) and living plants were 300-700mm long and 60-90mm wide, with alternate to sub-alternate pinnae, that are deltoid in shape, glabrous and 23(41)70mm, n=40 long. Fronds of *N. cordifolia* tended to be rigid, c.100-600mm long and c.40-60mm wide (Figure 1a) with pinnae measured at mid length of the frond 20(23)45mm, n=60 long.

### Scale morphology

Material from two of the Waitakere Ranges populations (both from Waiatarua), and that from Orewa, showed linear-lanceolate, long-attenuate scales with glandular-like protrusions from the edges (Figure 2a). Scales from material of *Nephrolepis cordifolia* are similar, but differ by having long hair-like spiky projections and spiky edges with no sign of any glandular-like protrusions (Figure 2b). Material from the Oratia population had scales that were more elongate, linear, long-attenuate, often with a dark basal spot (Figure 2c) similar to those observed from herbarium material of *N. exaltata* (Figure 2d).

### Spore morphology

All of the crested material from the Waitakere



2a 2b 2c 2d

**Figure 2.** *Nephrolepis* scale morphology.

2a. Scale from *Nephrolepis* sp. Waiatarua. Frond stipe material showing glandular-like marginal projections. Same plant as 1b. Image taken at 100x magnification.

2b. Scale from the frond stipe of *N. cordifolia* showing the longer tapering hair-like projections. 100x magnification.

2c. Scale from *Nephrolepis* sp. frond stipe material Oratia (same plant as 1d) showing basal 'spot'.

2d. Scale from frond stipe material of *N. exaltata* (AK112286) showing similar basal 'spot'. Scale bar upper right = c.100 µm

3a 3b

**Figure 3.** Spore morphology.

3a. *Nephrolepis cordifolia* (same plant from Mt Albert as in Figure 1a).

3b. Two spores from *Nephrolepis* sp. Waiatarua material, upper showing signs of collapse (same scale as 3a. Image taken at 400x magnification. Scale bar lower left = 20µm.

Ranges and Orewa populations showed 40-50% abnormal spores which were highly irregular in shape and apparently empty of living material (Figure 3b). Those spores that appeared normal were monolete, linear and irregularly tuberculate. Exospore was present and was slightly undulate. Of those that could be measured, dimensions were polar P10(17)23µm, equatorial (E) 20(25)29µm (n=50).

## Discussion

This study represents the first formal survey indicating that the 'Boston fern' complex is becoming naturalised in northern New Zealand (see Large, 2016a & b for a first notification). However, the exact genetic nature of the wild populations within that complex is not clear. On examining the crested material from various localities it is apparent that there are several entities present, all of which confirm a *sens. lat.* definition of the commonly named 'Boston fern'. Material collected from localities around

Waiatarua in the Waitakere Ranges and Orewa in northern Auckland (Figures 1b & 1c) does not appear to be equivalent to that seen at Oratia (also Waitakere Ranges) (Figure 1d). In these former plants, fronds are frilled, crested almost bipinnate and elongated, whereas those from the latter plants are wider, shorter, and much less frilled, almost 'crinkled'. It is worth emphasising that neither form has tubers, given that the presence of this character has been used to distinguish the invasive *Nephrolepis cordifolia.*

The frilled nature of the fronds also appears to be variable, with some material within the same population without cresting (Figures 1b & 1c). Preliminary observation suggests stress-environmental factors may induce at least some of the cresting. Similar variation has been induced experimentally by manipulating temperature and light (Hvoslef-Eide, 1991).

Spore form shows a high degree of irregularity and abortion (Figures 3a & 3b). Dimensions are not strictly comparable to those given by Large and Braggins (1991) for *Nephrolepis cordifolia* P17(19)22, E27(31)33 (see Figure 3a for an image taken in this study) or *N. flexuosa* P18(23)25, E26(35)42; nor are they similar to that reported for *N. exaltata* E25(30)34. (See Nauman, 1981 and Tryon & Lugardon, 1991, for a general discussion on spore size and morphology). Although the high degree of abortion recorded here may be in part due to unsuitable climatic conditions during spore formation, it is also often indicative of hybrid origin/genetic irregularity (Nauman, 1981).

*Nephrolepis exaltata*, originally from Southern USA, Central and South America, has long been associated with many of the selected varieties of 'Boston fern'. The original Boston form ('Bostoniensis') being reported from a shipment of *N. exaltata* sent to Boston from Philadelphia in 1894 (Kessler, 2004). Hovenkamp and Miyamoto (2005) suggest that this form is also a hybrid due to its genetic instability. Material from Oratia (Figure 1c) is suggestive of *N. exaltata* parentage (in both frond and scale form). However, not all forms known under the 'Boston fern' umbrella are necessarily associated with *N. exaltata*. Yahaya et al. (2016) using molecular markers, indicate that *N. brownii, N. biserrata* (Sw.) Schott and *N. cordifolia* may be central species in the formation of some of 'Boston fern' hybrids. The crested material from two of the Waitakere Ranges (Waiatarua) populations certainly shows some similarity with the latter species (especially in non-crested frond and scale morphology), albeit lacking the tubers.

Given that the species *Nephrolepis exaltata* is now reported naturalised as far afield as the Canary Islands, Africa, Asia, India and Polynesia, with populations in Africa considered fertile and gametophytes produced in India (Javalgekar & Mahabale, 1959; Muthukumar & Prabha, 2012), there is a need to understand this complex in more detail and to assess the varieties for potential risk of naturalisation.

Unfortunately, we do not have an accurate assessment of parentage or a full genetic analysis of the material we have observed wild in New Zealand, other than it conforms to the wider 'Boston fern' complex. Plants in the Waitakere Ranges are forming large dense clumps very similar to those produced by *Nephrolepis cordifolia*. Although these wild populations are likely to be garden escapees and of clonal origin, all plants seen to date are periodically producing some spore material. Consequently, studies are underway to assess genetic variability along with long-term spore and possible gametophyte viability.

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## Author's bios

**Mark Large** is an Associate Professor of Botany within Unitec's Environmental and Animal Sciences Pathway.

Contact: **mlarge@unitec.ac.nz**

**Lizzy Farrington** studies biodiversity at Unitec. She has a particular interest in environmental management and invasive species. She is involved with Iwi in the Coromandel region, helping to maintain a large area of native bush. Lizzy is also currently engaged in work on Kauri die back in the Auckland area.

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