

The ecology of the Rutaceae in the Sydney region of south-eastern Australia: Poorly known ecology of a neglected family

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The Rutaceae is an important worldwide family. In Australia, members of the family have radiated across the landscape from rainforests, moist and dry eucalypt forests, heaths, alpine areas and deserts.

Some 71 native taxa (in 14 genera) of Rutaceae occur in the Sydney Region, representing some 3% of the native vascular plant flora of the region. Species richness is greatest in heaths, woodlands and dry forests on sandstone derived soils. A number of species occur in moist forest, while a few species occur in riparian forests, rainforests or forests on clay soils or soils derived from granite. The most species rich genera are *Boronia* and *Zieria* (both 18 species). Fifteen species in the region are rare or threatened at the state or national level, with a further 2 species poorly known and likely candidates as threatened species. There are 17 species endemic to the Sydney region, 11 of which are rare or threatened.

Most species flower in winter to spring with seeds released in October to December. There are two basic modes of dispersal in the family in the Sydney Region. Firstly, a few species, generally associated with rainforests, disperse seeds widely via fleshy fruits that are taken by birds and probably mammals. Secondly, most Rutaceae species have limited dispersal ability and have short range initial ballistic dispersal of seeds from fruits at maturity followed by secondary seed dispersal primarily by ants. In this latter group, seeds are generally dispersed less than a few metres. There is a high level of seed dormancy at seed release. Members of the Rutaceae are likely to have persistent soil seedbanks with germination linked to fire, except perhaps for species in rainforest or rainforest margins (where the nature of possible seedbanks is unknown). Heating of the soil during fire is one mechanism for breaking seed dormancy and allowing germination. Other mechanisms, i.e. smoke and the interaction of fire related germination cues may also be important. Fire is a widespread disturbance affecting vegetation in the Sydney Region. Within the Rutaceae in the Sydney region, a mixture of fire-sensitive and resprouting species occur, although details for many species are lacking. To maintain the floristic diversity in the family, effective management of such plant communities requires sufficient times between fires for seedlings to flower and replenish the soil seedbanks, as well as for juveniles of resprouting species to become fire-resistant.

The ecology of Rutaceae species remains poorly understood, a pattern typical across Australia, with a few notable exceptions. There have been no comprehensive demographic studies of members of the family in Sydney, and only limited attempts to examine aspects of the biology of the species in the family. In particular, the seed biology and ecology of the family and the impact of fire on species are poorly understood. This review poses a number of questions for research on members of the Rutaceae.

Introduction

In this paper I define the Sydney Region as the Central Coast and Central Tableland botanical divisions (cf. Benson & McDougall 2001). Members of the Rutaceae are an important element of the flora of the Sydney Region. There are some 71 currently recognised native taxa (in 14 genera) in the Rutaceae in the Sydney Region, representing around 3% of the vascular plant flora in the area. The most diverse and widespread genera are *Boronia* (18 species), *Zieria* (18 species), *Philotheca* (7 taxa) and *Leionema* (6 species).

I will attempt to address what we currently know or can infer about the behaviour of rutaceous species in the Sydney Region, including an understanding of the dynamic processes within the life cycle of species from flowering and seed production through seed dispersal, the seedbank, germination and establishment. I will ask if we have enough information to begin to assist the management of these species and the communities in which they occur, whilst at the same time, stressing what further work is needed so that management does effectively promote the conservation of all members of the Rutaceae. In particular, I consider species which are of conservation significance, whether locally or nationally (e.g. rare or threatened, protected plants) and how we may begin to guide management of these important species.

In trying to assess the ecology of a diverse array of species such as that occurs within the Rutaceae, it is important to understand the dynamics of the species involved in relation to any major disturbance regimes that may operate in the region. In this paper, I look at what is known of how members of the Rutaceae are able to persist within plant communities in the Sydney Region under a regime of repeated fires, as fire is the major disturbance influencing these communities. While other disturbances may play a role in certain vegetation communities (e.g. flooding in riparian communities or swamps, the formation of canopy gaps in rainforests), the impact of fire occurs in all plant communities, including rainforests, and is a key determinant in the maintenance of populations of Rutaceae species in the Sydney region.

Nomenclature follows Harden (1991) and subsequent revisions that have been included in Plantnet (plantnet.rbgsyd.nsw.gov.au), e.g. for *Eriostemon*, *Leionema*, *Philotheca* and *Nematolepis*, the recent revisions by Wilson (1998a, 1998b).

Distribution patterns

Members of the Rutaceae in the Sydney region are most diverse in the floristically rich heaths, woodlands and forests on nutrient poor soils derived from sandstone. This floristic diversity is largely confined to the tribe Boronieae. It appears that there has been some speciation of shrubby species of the Boronieae in these communities in the Sydney region. These communities are particularly floristically diverse (Rice &

Westoby 1983, Adam et al. 1989, Keith & Myerscough 1993). Such a pattern of high diversity in nutrient-poor soils is comparable to the situation in heaths and woodlands of south-western Western Australia, South African fynbos and the matorral of South America (Rice & Westoby 1983, Adam et al. 1989, Keith & Myerscough 1993).

Table 1. Rutaceae of conservation significance in Sydney region. Local endemic species are marked with a hash.

State or nationally threatened (TSC Act¹)

Endangered: *Asterolasia elegans*[#], *Leionema lachnaeoides*[#], *Zieria bauerlenii*[#], *Zieria covenyi*[#], *Zieria granulata*[#], *Zieria obcordata*

Vulnerable: *Boronia deanei*, *Leionema sympetalum*[#], *Zieria involucreta*^{*}, *Zieria murphyi*[#], *Zieria tuberculata*

Nationally Rare (ROTAP²)

Boronia fraseri[#], *Boronia rubiginosa*, *Boronia serrulata*[#], *Philothea obovalis*[#]

Poorly known

Asterolasia buxifolia[#] (newly rediscovered, likely to be endangered), *Leionema* sp. Hungryway Creek[#]

Rare or declining in Sydney region³

Phebalium squamulosum subsp. *argenteum*

Local endemics

Asterolasia buxifolia[#], *Asterolasia elegans*[#], *Asterolasia rivularis*[#], *Boronia floribunda*[#], *Boronia fraseri*[#], *Boronia serrulata*[#], *Crowea saligna*[#], *Leionema lachnaeoides*[#], *Leionema* sp. Hungryway Creek[#], *Leionema sympetalum*[#], *Philothea hispidula*[#], *Philothea obovalis*[#], *Zieria bauerlenii*[#], *Zieria covenyi*[#], *Zieria granulata*[#], *Zieria involucreta*[#], *Zieria murphyi*[#]

Disjunct distributions

Zieria caducibracteata

Southern limit in Sydney region

Acronychia wilcoxiana, *Boronia mollis*, *Boronia rubiginosa*, *Correa lawrenciana* var. *macrocalyx*, *Geijera salicifolia* var. *latifolia*, *Zieria furfuracea*, *Zieria laxiflora*

Northern limit in Sydney region

Boronia deanei, *Boronia nana* var. *hyssopifolia*, *Boronia thujona*, *Leionema diosmeum*, *Leionema lamprophyllum* subsp. *orbiculare*, *Philothea buxifolia* subsp. *buxifolia*, *Philothea buxifolia* subsp. *obovata*, *Philothea scabra* subsp. *latifolia*, *Philothea scabra* subsp. *scabra*, *Philothea trachyphylla*, *Zieria caducibracteata*, *Zieria tuberculata*

NPWS Act Schedule 13 protected plants

Boronia (all species, except threatened species)

Correa alba

Crowea (all native species)

Phebalium squamulosum

Philothea (all species previously recognised as *Eriostemon* except threatened species)

¹NSW *Threatened Species Conservation Act* 1995; ²Briggs & Leigh (1996); ³Benson & McDougall (2001), excludes species considered to be state or nationally rare or threatened.

Most of the Rutaceae species in such habitats are shrubs that form part of heaths or the dense and diverse understorey of woodlands. They are generally not dominant members of the shrub layer, but may be locally abundant. Some species, in particular a number of *Zieria* species and *Asterolasia* species, and a few *Boronia* species, occur in moist eucalypt forests, generally over sandstone but sometimes on clay. A few species are confined to riparian zones (*Leionema* species) or to rainforests or the margins of rainforests (*Acronychia* species, *Geijera salicifolia*, *Melicope micrococca*, *Sarcomelicope simplicifolia* and *Zieria tuberculata*).

A high proportion of the members of the Rutaceae in the Sydney region are endemics (24%) (Table 1). Endemic species predominantly occur in the heaths and dry forest communities and within them predominantly on sandstone derived soils. Species from the moister forest habitats, including rainforests, are generally more widespread, although they may reach their limit of distribution in the Sydney Region (Table 1). There is also a high level of endemism in Rutaceae in some other regional floras (45% in limestone flora of South African lowland fynbos, Willis et al. 1996; 47% in Hamanstop and 64% in Agulhas Plain of Southern Africa, Cowling et al. 1992).

Ecological patterns

The patterns of distribution and endemism in Rutaceae from the Sydney Region will be influenced by a range of factors (edaphic, climatic, biotic, ecological disturbance regimes, historical evolutionary patterns etc.). Here I examine what is known about the present day ecological patterns in the Rutaceae and where we need more research to understand what the patterns may be and what process drive these patterns.

Plant–animal interactions

Flowering and seed production

Patterns of flowering in Rutaceae in the Sydney Region have been well documented. Most species flower in winter to spring or early summer (Price 1963, Benson & McDougall 2001), with the timing of flowering varying slightly from year to year depending on environmental conditions and location within the Sydney Region. Flowering coincides with a number of other non-rutaceous species. A number of species, particularly *Boronia* species, *Phebalium* species and *Philotheca* species are particularly showy and add to the colour of spring flowering in Sydney sandstone vegetation. Fruiting usually follows flowering by several months with many species maturing fruits in October to December. There is a trend for flowering and fruiting to be earlier in the north of the region and later in the far south and west of the region. Most seed release occurs in October to December.

A few species flower outside the general winter/spring pattern. These include the local rainforest species, e.g. *Acronychia* species, *Geijera salicifolia* var. *latifolia*, *Melicope micrococca* (flowering in late summer to autumn), and a few other taxa, e.g. *Boronia nana* var. *hyssopifolia* and *Crowea saligna* (summer), *Correa alba* var. *alba* and *Sarcomelicope simplicifolia* subsp. *simplicifolia* (autumn) (Price 1963, Benson & McDougall 2001).

However, whilst the timing of flowering and fruiting is reasonably well known, there has been no quantification of the magnitude of flowering or fruiting in Rutaceae species in relation to the ecology of the species and the disturbance regimes they are exposed to (e.g. fire, flood, light gaps). Nor is there an understanding of the interaction of species of Rutaceae with other taxa (both plant and animal) that may influence flowering and fruiting levels.

Future research questions:

1. What is the magnitude of fruiting in relation to times since fire, plant age and plant size for a range of species of Rutaceae?
2. What factors influence flowering and fruiting in species of Rutaceae?

Pollination and breeding systems

Armstrong (1979) summarises the observed pollinators and likely breeding system in the Tribe Boronieae. Self compatibility appears to be confined to some species of *Boronia* and *Zieria*. Weston et al. (1984) list a number of *Boronia* species as either self compatible (*B. anethifolia*, *B. nana*, *B. parviflora*, *B. polygalifolia*) or self incompatible (*B. anemonifolia*, *B. bakeriana*, *B. mollis*, *B. ledifolia*, *B. pinnata*, *B. rigens*, *B. serrulata*, *B. thujona*). Armstrong (2002) found 64% of *Zieria* species he tested were self compatible and this characteristic has also been observed in *Zieria prostrata* (Hogbin unpubl.). *Zieria baeuerlenii* and *Z. covenyi* are known to be pollen sterile (Armstrong 2002) and only appear to reproduce vegetatively (Armstrong 2002, Barratt 1997). A number of *Zieria* species may have low pollen viability in some individuals, but not all (e.g. *Z. aspalathoides*, *Z. furfuracea*, *Z. laxiflora*, *Z. robusta* — Armstrong 2002). For the non-Boronieae species, Adams and Williams (2001) found *Geijera salicifolia* to be outcrossing on the north coast of NSW, while an *Acronychia* sp. (*A. imperforata*) failed to develop fruits under either bagged or open pollination treatments, implying that there may be yearly variation in fruiting success in this genus.

A range of insect pollination vectors has been observed on the sclerophyllous members of the Rutaceae and most genera have a range of insect pollination vectors with a preference for a particular group of insects (Armstrong 1979), e.g. *Boronia* (mostly bees, occasionally beetles, flies, moths or butterflies), *Crowea* (butterflies), *Philotheca* (mostly butterflies, occasionally beetles, flies, bees or moths), *Asterolasia* and *Phebalium* (mostly beetles, occasionally flies and bees), *Eriostemon* (mostly beetles, occasionally bees and butterflies), *Zieria* (mostly flies, occasionally beetles, bees and butterflies, see Armstrong 2002). Clifford and Drake (1981) report several bee genera as pollinators for *Boronia* (i.e. *Exoneura*, *Homalictus*, *Lasioglossum*). Birds are thought to be the major pollinators for a few species, including *Correa* species, (Clifford & Drake 1981, Paton 1986), except *C. alba*, and some *Leionema* species, including *L. sympetalum*. For *Correa*, both honeyeaters and parrots have been seen feeding on flowers (Paton & Ford 1977, Clifford & Drake 1981) and pollen has been found on honeyeaters (Paton & Ford 1977) suggesting they are likely pollinators. The impact of the introduced honey bee, *Apis mellifera*, on pollination and subsequent seed production in Rutaceae is unknown. While native bees are known to pollinate a range of genera in the Rutaceae (Armstrong 1979, Clifford & Drake 1981), whether honey bees have an impact on their biology is unclear (cf. Sugden & Pyke 1991). Huryn (1997) found honeybees were important pollinators of the bird-pollinated *Correa reflexa*.

Future research questions:

1. What are the breeding systems of Rutaceae in the Sydney Region?
2. Are there any host-specific or genera-specific plant-pollinator relationships in species of Rutaceae?
3. What is the impact of feral bees on seed set and seed fitness in Rutaceae species?

Seed predation

The nature and impact of seed losses from predispersal seed predators in Rutaceae is unknown, although seed predators are known from the family elsewhere (NPWS 1998, Hogbin unpubl. for *Zieria prostrata*). Wasps may be key seed predators in this family (Armstrong 2002, Auld unpubl.) and they are known to be important seed feeders in other families, e.g. Fabaceae (Auld 1991). Seed predation levels of 50% have been observed in the field in *Zieria laevigata* (Armstrong 2002). Armstrong (2002) found *Eurytoma* (Hymenoptera: Eurytomidae) wasps from stem galls in *Zieria laevigata* and *Z. laxiflora*. These wasps are known to be seed feeders in a wide range of local plant taxa (Auld 1991) and this may include Rutaceae species. The impact of any seed predator is unknown but may explain the low levels of seed viability observed in seed collections from some taxa, e.g. *Boronia*. In some rainforest taxa, parrots (including crimson rosellas and king parrots) have been observed to take fruits of *Geijera salicifolia* var. *latifolia* and *Melicope micrococca* (Floyd 1989). These birds most likely consume seeds and act as seed predators (cf. French 1992).

Future research questions:

1. What are the seed predators of sclerophyllous Rutaceae and what is the magnitude of seed losses and impacts?
2. What role do predispersal seed predators play in limiting the replenishment of soil seedbanks after fire and hence, in influencing the minimum fire free intervals between fires recommended for management of natural communities?
3. How do the effects of predation vary spatially and temporally and in relation to fire regimes?
4. Are there host-specific, or genera-specific, insect predispersal seed predators in sclerophyllous species of Rutaceae, as occur in the Fabaceae and Proteaceae?

Seed dispersal

Two contrasting modes of dispersal are apparent in the Rutaceae in the Sydney Region (Table 2). The genera largely confined to rainforests or the margins of rainforests (*Acronychia*, *Geijera* and *Sarcomelicope*) all have fleshy fruits and are likely to have both local and more distant seed dispersal by birds and possibly mammals such as possums (Table 2, Floyd 1989). The dormancy characteristics of their seeds and factors controlling seed germination and successful establishment are unknown.

There may be additional ant dispersal of some of these species, e.g. *Acronychia oblongifolia* (Westoby et al. 1990).

Table 2. Dispersal syndromes in Rutaceae of the Sydney region

Tribe/genus/species	Evidence in Sydney region (or elsewhere)
Wide dispersal	
Toddalieceae	
<i>Acronychia</i>	fleshy-fruited, dispersed by birds ^{4,5,7} and probably mammals and possibly ants ¹⁰
Zanthoxyleae	
<i>Geijera</i>	fleshy-fruited, dispersed by birds ^{4,6} and probably mammals
<i>Sarcomelicope</i>	fleshy-fruited, dispersed by birds ⁴ and probably mammals
Local dispersal — all with initial ballistic dispersal	
Boronieae	
<i>Asterolasia</i>	myrmecochochory
<i>Boronia</i>	myrmecochochory — all species ³ , <i>Boronia fraseri</i> ⁹ , <i>B. ledifolia</i> ⁹ , <i>B. parviflora</i> ⁹ , <i>B. pinnata</i> ⁹ , <i>B. serrulata</i> ⁹
<i>Correa</i>	probably myrmecochochory ¹⁰
<i>Crowea</i>	myrmecochochory – all species ³ , <i>C. saligna</i> ⁹
<i>Eriostemon</i>	myrmecochochory (<i>E. australasicus</i> ⁹)
<i>Leonema</i>	myrmecochochory – a few species ³
<i>Nematolepis</i>	probably myrmecochochory
<i>Phebalium</i>	myrmecochochory – many species ³ , <i>P. squamulosum</i> ⁹
<i>Philotheca</i>	myrmecochochory – <i>P. salsifolia</i> ⁹
<i>Zieria</i>	myrmecochochory – many species with elaiosome structure ^{1,8} , <i>Z. laevigata</i> ^{1,2} , possibly a myrmecochochore ⁹
Zanthoxyleae	
<i>Melicope</i>	probably myrmecochochory ¹⁰

Note references in bold are from work based, or largely based, in Sydney Region:

¹ **Armstrong 2002**; ² **Auld unpubl**; ³ **Berg 1975**; ⁴ Floyd 1989; ⁵ Ford 1986; ⁶ Forde 1986; ⁷ **Kenny unpubl**; ⁸ **Powell & Armstrong 1980**; ⁹ **Rice & Westoby 1981**; ¹⁰ **Westoby et al. 1990**.

Sclerophyllous species of the Rutaceae, generally from the heaths and dry forests, have an initial ballistic release of seeds when fruits mature (the fruit is a schizocarp capsule) (Table 2, Westoby et al. 1990). This ballistic dehiscence moves seeds up to a few metres from the parent (cf. Berg 1975). These species are then likely to be myrmecochochorous, with ants acting as the main secondary dispersal agent (Table 2). This is a comparable situation to South African Fynbos Rutaceae species (Le Maitre & Midgley 1992) but such a combination of ballistic and ant dispersal is uncommon in world floras (Willson et al. 1990).

There is evidence for ant movement of seeds in a number of Rutaceae taxa in the Sydney Region (Table 2). Myrmecochorous taxa have seeds with attachments that are attractive to ants (Armstrong 2002, Westoby et al. 1990). These likely serve as both a handle for ants to move seeds and as a food reward for the ants. The presence of such bodies is well illustrated for *Zieria* species in Powell and Armstrong's (1980) examination of seeds testas. Westoby et al. (1990) have examined the seed structure associated with attracting ants and quantified the relative weight of the seed and the dispersal structure. They found a range of structures on seeds of *Boronia*, *Correa*, *Crowea*, *Eriostemon*, *Melicope*, *Phebalium*, *Philotheca* and *Zieria* and such structures represented a range of percent total diaspore weights. In *Boronia*, *Eriostemon* and *Melicope*, there was a flap covering the opening in the outer seed coat and soft white material between the testa and a thin brittle dark brown outer coat that was attractive to ants. In *Correa*, there was an elaiosome on most seeds, while for *Crowea* the ant attractant was a soft brown coating over the entire seed and a flap of white tissue over this. In *Philotheca*, the ant attractant included soft material in a pocket in the seed coat and a flap over that.

Berg (1975) and Rice and Westoby (1981) have shown that myrmecochory is widespread in the flora of southeastern Australia particularly in heathlands and related shrub dominated vegetation communities. Whilst seed movement by ants in Rutaceae species is likely to be common in the Sydney region, the fate of such seeds is essentially unknown. Berg (1975) found three seeds of *Boronia ledifolia* deposited near the nest of *Aphaenogaster longiceps*, a known seed dispersing ant (Hughes & Westoby 1992). A number of roles for ant dispersal of seeds have been postulated (see Auld 1996). Dispersal distance and burial in safe sites (Hughes & Westoby 1992) may be key issues for Sydney Rutaceae species. Westoby and Rice (1981) suggest that ballistic dispersal and ant dispersal move seeds similar distances and that ant dispersal may be important to added distance movement. Gomez and Espadaler (1998a) estimated that there is a mean dispersal distance of 0.96 m (range 0.01–77 m) for worldwide published studies of ant dispersal of seed. However, not all movements of seeds by ants are beneficial to plants. Some ant species consume much of the seed they move (Hughes & Westoby 1992) while others seeds may be buried in 'unsafe' sites (Auld 1986a) and such seeds are effectively lost from the soil seed-bank. Generally two types of seed movement by ants are recognised in the Sydney Region (cf. Auld & Denham 1999), viz. movement of whole seeds versus movement of the elaiosome with little seed movement. These different outcomes are the result of a range of different seed sizes and sizes of myrmecochorous ant species. Small ant species (e.g. *Crematogaster*, small *Iridomyrmex*, *Pheidole*) generally remove the elaiosome in pieces *in situ*, as the seed is too heavy for individuals to move very far. This generally results in small (generally less than 20 cm) seed movements. Large, often solitary foraging ants (e.g. *Rhytidoponera*, large *Iridomyrmex*, *Dolichoderus*) remove the seed using the elaiosome as a handle to the nest, where the seeds may be ejected (Fig. 1) or be stored in caches (Auld 1986a, Hughes & Westoby 1992). These movements by large ants may involve moving the seed greater distances than movements by small ants. Gomez and Espadaler (1998b) found that both ant size and the distance to the nest entrance influenced dispersal distance in the Mediterranean spurge, *Euphorbia characias*.

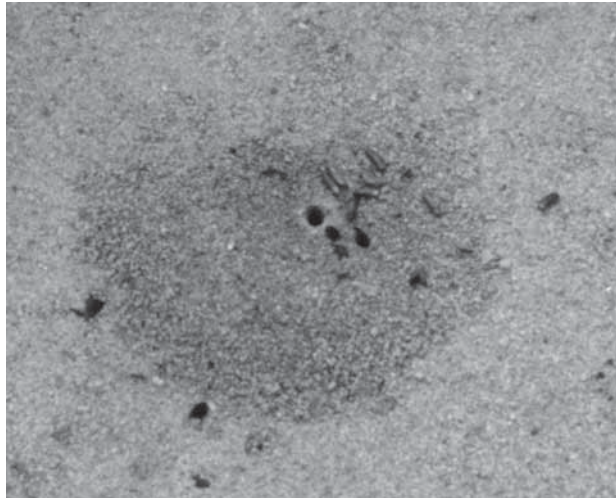


Fig. 1. Seeds of *Zieria laevigata* (black) and *Hibbertia* sp. around ant nest.

It is likely in species of Rutaceae, that dispersal distances attributable to ants are small (1–few metres) as occurs in other local myrmecochorous species (Westoby & Rice 1981, Auld 1986a, Hughes & Westoby 1992) and comparable heathy species in South African Fynbos (Willis et al. 1996). At present we have virtually no detailed knowledge of the nature of interactions between a range of ant species and the range of myrmecochorous Rutaceae species.

There has also been a record for possible bird dispersal of a myrmecochorous Rutaceae species. Rose (1973) found a few seeds of *Eriostemon australasius* and other seeds in the gut of a lyrebird at Bobbin Head. If these seeds pass through the gut intact, the lyrebird may act as an occasional dispersal agent. This may be significant for chance, albeit very rare, increased distance dispersal of seeds.

Given that the dispersal modes of Rutaceae species vary in relation to habitat distribution, what are the consequences for fragmentation of the landscape in the Sydney Region? For those taxa with wide dispersal by birds, movement of seeds into or out of current habitats is dependant upon providing or maintaining corridors for bird movements. In most Rutaceae, however, dispersal distances will be very limited. This means that such species will now be isolated by fragmentation and unlikely to be able to move their seeds across unsuitable habitat (in particular habitat unsuitable for the ants that act as seed dispersers). Consequently, local extinctions of Rutaceae species in fragmented habitats are not likely to be reversible without human intervention. This has particular consequences for how we manage species of conservation significance.

Future research questions:

1. Are all Rutaceae species in dry heath, woodland and forest habitats myrmecochorous?
2. What are the fates of seeds moved by ants? Is there a relationship between distances seeds are moved and the size of the ant species moving seeds?
3. Does myrmecochory add to ballistic dispersal distance?
4. What are the key advantages and disadvantages for ant dispersal in Rutaceae seeds?
5. What is the fate of seeds/fruits moved by vertebrate dispersers in fleshy-fruited species?
6. Can corridors be designed to allow movement of avian seed dispersers for rainforest species?
7. Do chance seed movements by birds occur for myrmecochorous species in moist eucalypt forest habitats? If so, do they play an important, if infrequent, dispersal role?

Other interactions

A few mycorrhizal associations have been found with Rutaceae species. Vesicular-arbuscular mycorrhizae have been reported in *Boronia thujona* and *Eriostemon australasius* (Bellgard 1991), including both pre- and post-fire in *E. australasius* (Bellgard et al. 1994). The importance of mycorrhizae to plant growth in Rutaceae species remains to be investigated.

Finally, the impact of the pathogen *Phytophthora cinnamoni* on Rutaceae in the Sydney region is unknown. The pathogen is present in a wide range of locations in the region (Mc Dougall unpubl.) and members of the Rutaceae in other parts of their range are known to be susceptible (e.g. *Correa reflexa*, Weste & Kennedy 1997).

Future research questions:

1. What is the role of the relationship between Rutaceae species and mycorrhizae?
2. What is the impact of *Phytophthora cinnamoni* on Rutaceae species and habitats in the Sydney region?

Seed ecology

Seed dormancy, viability, germination and establishment

Remarkably little is known about the seed biology of Rutaceae in the Sydney Region.

There have been attempts to understand germination as a means of propagating plants, either for forestry (Floyd 1989) or the nursery trade (Wrigley & Fagg 1979, Elliot & Jones 1982, 1984, 1986, Lamont 1985b), but little attempt to relate this to stimuli for germination in the wild.

Table 3. Seed dormancy, viability and germination cues in Rutaceae of the Sydney region.

Tribe/genus Species examples	Dormancy (%)	Viability (%)	Post-fire seedlings	Germination cue
Boroniaceae				
<i>Asterolasia</i>				
<i>A. elegans</i>	49–100 ^{3,16}	88–98 ^{3,16}	yes ¹⁶	fire, heat ^{2,16}
<i>Boronia</i>			yes ^{2,4,12}	
<i>B. ledifolia</i>	100 ^{2,10}	10–97 ^{2,10}	yes ²	fire, heat ^{2,10}
<i>B. serrulata</i>	yes	40 ¹¹	yes ²	fire ²
<i>Correa</i>	?	?	yes	fire?
<i>Crowea</i>	yes ¹²	?	yes	fire?
<i>Eriostemon</i>				
<i>E. australasius</i>	25–100 ^{10,13,15}	90 ¹⁰	yes ^{4,11}	fire, heat + smoke combined ¹⁰
<i>Leionema</i>	?	?	yes	fire, smoke in WA species ⁵
<i>Nematolepis</i>	?	?	?	easily raised from seed ⁷
<i>Phebalium</i>				fire, no smoke in WA species ⁵
<i>P. squamulosum</i>	94–99 ¹⁰	93 ¹⁰	yes	fire, no heat or smoke known ¹⁰
<i>Philotheca</i>	<94 ⁸	?	yes ⁵	fire
<i>Zieria</i>			yes	
<i>Z. arborescens</i>	?	?	yes ⁶	fire, heat ⁶
<i>Z. involucrata</i>	40–100 ^{2,3}	69–96 ^{2,3}	yes ²	fire, heat ²
<i>Z. laevigata</i>	98–100 ¹⁰	79 ¹⁰	yes ²	fire, heat ¹⁰
Zanthoxyleae				
<i>Geijera</i>	?	?	?	germination unpredictable ⁷
<i>Melicope</i>	?	?	?	17% germination of fresh seed ⁷
<i>Sarcomelicope</i>	?	?	?	erratic seed germination ⁷
Toddalieceae				
<i>Acronychia</i>	yes ⁹	?	No	difficult to germinate; 5% germination of fresh seed ⁷

Note References in bold are from work based or largely based in Sydney Region:

¹ **Armstrong 2002**; ² **Auld unpubl. & pers. observations**; ³ **Auld et al. 2000**; ⁴ **Benson 1985**; ⁵ Dixon et al. 1995; ⁶ Floyd 1976; ⁷ Floyd 1989; ⁸ Gillespie et al. 1996; ⁹ Hopkins & Graham 1987; ¹⁰ **Kenny unpubl.**; ¹¹ **Lamont 1985b**; ¹² **Leishman & Westoby 1998**; ¹³ McIntyre & Veitch 1972; ¹⁴ Melick & Ashton 1991; ¹⁵ Nixon 1980; ¹⁶ **Scott 1994**.

Virtually nothing is known concerning dormancy and germination in the non-sclerophyllous Rutaceae of the Sydney Region. Germination is often reported as difficult (Elliot & Jones 1982), and Melick and Ashton (1991) could find no evidence of seed germinating from a soil seedbank in rainforests habitats which included *Acronychia oblongifolia*. This may reflect low seed viability, little or no seed in the seedbank or mostly dormant seed. The latter scenario appears most likely, as in north Queensland, *Acronychia vestita* and two *Euodia* species form persistent soil seedbanks (Hopkins & Graham 1987). Seed of these species are hard and impermeable to water (Hopkins & Graham 1987).

The sclerophyllous species have high levels of seed dormancy allowing persistent soil seedbanks (Table 3). Generally, it is recognised that germination is difficult, but rarely have a range of dormancy breaking cues, ones that mimic cues that occur in the field, been applied to a viable seed sample. Until this is achieved across a range of taxa, conclusions will be limited.

Nonetheless, there has been some work which has begun to unravel the patterns of dormancy in the Rutaceae of the Sydney Region though this has been confined to a few sclerophyllous shrubby taxa. From this work, two patterns emerge. Firstly, viability of seed lots is extremely variable, with examples of very low seed viability recorded in collections of seed from the field (Table 3). These seeds appear externally to be intact, but are often lacking the endosperm and embryo. This pattern of low seed viability has been found in some *Boronia* species from southwestern Western Australia (Bell et al. 1993). In contrast, Roche et al. (1997) found high levels of seed viability in four out of five *Boronia* species, a *Correa* sp., a *Diploaena* sp. and *Geleznowia verrucosa* from southwestern Western Australia.

Secondly, the seed coat may act as a physical barrier to imbibition. Scarification has been successful in breaking seed dormancy in *Eriostemon australasius* (Nixon 1980) and there is evidence that heat is involved in the breaking of seed dormancy in a range of genera from fire-prone habitats (Table 3). The observed patterns are similar to those in native legumes in the same habitats (Auld & O'Connell 1991) and other taxa elsewhere in fire-prone habitats in the world (Martin et al. 1975, Floyd 1976, Jeffery et al. 1988, Keeley 1991), including some species of Rutaceae in South Africa (e.g. *Agathosma* species, Bell et al. 1993). The initial patterns found seem to be similar to that of legumes with temperatures of 80–100°C being most favourable for breaking seed dormancy. Generally, temperatures of 120°C are lethal to seeds. Soil temperatures under fires in the Hawkesbury Sandstone soils around Sydney have been examined by Auld (1986b) and Bradstock and Auld (1995). They found that lethal soil temperatures for seeds are likely to be confined to near the surface (0–1 cm or 0–2 cm). Below this zone there is a zone of soil heating that should break seed dormancy and below this, soil heating should be insufficient to break seed dormancy. The actual amount of soil heating in the soil is controlled by the amount of fine fuel consumed by the fire (Bradstock & Auld 1995).

There is also some emerging evidence that heat and smoke may interact in breaking seed dormancy in some taxa (Kenny unpubl., Table 3). Smoke has been shown to break seed dormancy for some species of Rutaceae from southwestern Western Australia, including some *Boronia* species (but not others), *Diploaena* sp., *Geleznowia verrucosa* and *Philotheca spicata* (Dixon et al. 1995, Roche et al. 1997). In fire-prone habitats of the Sydney Region, fire is the major stimulus to breaking seed dormancy and allowing subsequent seed germination in plants from many families. In these habitats, recruitment is generally limited to the immediate post-fire period (Auld 1986b, Auld & Tozer 1995) as occurs elsewhere (Weiss 1984, Tyler 1995). Given that pulses of seed germination have frequently been observed after fires (Table 3), it is likely that there are fire-related germination cues in species of Rutaceae in the Sydney Region and similar sclerophyllous species elsewhere.

Whilst the pattern of germination post-fire in relation to soil heating has been examined in the legume *Acacia suaveolens* (Auld 1986b, Bradstock & Auld 1995), given the potential interaction of heat and smoke cues, the comparable pattern in Rutaceae species is unknown. Consequently we have no understanding of the pattern and magnitude of residual seeds in the soil after a fire and the implications for fire management.

Future research questions:

1. Are there interactive effects of heat and smoke on breaking seed dormancy in sclerophyllous Rutaceae?
2. What is the role of hardseededness and heat shock in controlling germination in Rutaceae?
3. Does seasonality and embryo morphology influence dormancy and the release from dormancy in seeds of Rutaceae?
4. What is the interaction between fire, breaking of seed dormancy and the distribution and magnitude of residual post-fire soil seedbanks?

Seedbank dynamics

There is virtually no information on the longevity of seed or the nature of soil seedbanks in the Rutaceae. For those species with bird dispersal of seeds, it appears from work outside the Sydney Region, that some of these taxa have long-lived soil seedbanks (e.g. *Acronychia* sp., Hopkins & Graham 1987) and this may be a typical pattern in other bird dispersed Rutaceae taxa, rather than the alternative of having short-lived seeds and only a transient soil seedbank (sensu Parker & Kelly 1989). For those many shrubby species with limited dispersal in fire-prone habitats, it would be expected that seed would persist in the soil between fire events. The nature of this persistence (seed longevity, variation between and within species) is again largely unexplored. Auld et al. (2000) found that there was considerable variation in the degree and pattern of seed longevity in 12 shrub and 2 graminoid species in the Sydney Region. Their study considered two threatened Rutaceae species (*Asterolasia elegans* and *Zieria involucrata*). In both these species, there were moderate levels of seed dormancy at seed release and the non dormant seed fraction decayed away over time. Dormant seeds showed no evidence of decay over a two year period, implying the establishment of relatively long-lived persistent soil seedbanks in these species. This clearly may be a common pattern in species in fire-prone habitats in Sydney and throughout the world (Parker & Kelly 1989, Pierce & Cowling 1991, Tyler 1996). In moist forest habitats, *Zieria arborescens* also forms a persistent soil seedbank (Floyd 1976, Wang 1997). Where a seedbank is lost (removed in clearing), this can affect the ability of species to recolonise the cleared habitat. Morrison et al. (1995) found the abundance of *Boronia ledifolia* and *Eriostemon australasius* were reduced in an area where the topsoil was removed 71 years previously, compared to an adjacent area where the topsoil was left intact.

Future research questions:

1. What are the seed viability, dormancy and longevity patterns in the field in a range of both myrmecochorous shrubby and bird dispersed species of Rutaceae?
2. Do all Rutaceae species have persistent soil seedbanks?

Survivorship and growth

Beyond noticing a post-fire flush of seedlings, there has been an absence of demographic work on growth and survival in the Rutaceae in the Sydney region.

There are a few studies that give some guide to initial survival of seedlings. On the north coast of NSW, Benwell (1998) found seedling survival rates one year post-fire of 69–74% (*Boronia falcifolia*, a resprouting plant not found in Sydney region), 29–77% (*B. saffrolifera*, a resprouting plant not found in the Sydney Region), 73–100% (*Eriostemon australasius*) and 20–62% (*Zieria laevigata*). A number of sclerophyllous species appear to be quick growing after fire. Lamont (1985a) found that for the fire-sensitive *Boronia serrulata*, 20% of seedlings flowered some 20 months after a wildfire, while for *Eriostemon australasius* (also fire sensitive at the study site) 100% of seedlings flowered. Benson (1985) found longer maturation times after fire for several fire-sensitive species, viz. 4 years for *E. australasius*; 4–5 years for *Boronia ledifolia* and *Philotheca buxifolia*; 5 years for *B. serrulata* and *P. salsolifolia*. Maryott-Brown and Wilks (1993) suggest *Zieria involucrata* takes 2–4 years to produce seeds. Data for *Boronia serrulata* from 4.5 years after the January 1994 fires (Auld & Ooi, unpubl.) found that while a number of seedlings from the fire had matured and were flowering (65%, 32%, 91% across three sites in Royal NP), many were still immature and most plants were still small (<60cm high) even seven years post-fire (Fig. 2). Consequently, the magnitude of individual flowering would not be as great per plant as in longer unburnt sites (although total flowering in a population may be greater if there is significant plant mortality over time). Longevity of shrubby Rutaceae is largely unknown. In Rutaceae in South African Fynbos longevity is suggested to be 10+ years (Le Maitre & Midgely 1992). In the Sydney region, Maryott-Brown and Wilks (1993) suggest *Zieria involucrata* may live for 10–20 years, but quantitative data are lacking for all Rutaceae in the Sydney region. Most species in heaths and woodlands may not be long-lived once the dominant structural components over top them. Clemens and Franklin (1980) note that *Zieria laevigata* was rarely found in heathland greater than 10 years post-fire at North Head. *Boronia serrulata* is often associated with sandstone rock outcrops in heaths and in areas long unburnt may be restricted to more open patches associated with these sandstone outcrops, as occurs with some other fast-growing fire-sensitive species such as *Acacia suaveolens* (Auld pers observ.).

For moist forest species, Floyd (1976) notes that *Zieria arborescens* can colonise burnt sites rapidly and that it matures quickly. Such species may be more shade tolerant, as Floyd (1976) suggests for *Z. arborescens*, than sclerophyllous heath/woodland species.



Fig. 2. Seven year old *Boronia serrulata* plants, mostly under 60 cm in height.

Future research questions:

1. What are the growth and survivorship patterns of post-fire seedlings in sclerophyllous species?
2. How does seed production vary in relation to plant growth and time since fire? How does this influence how quickly species replenish their soil seedbanks after fire?
3. What are the patterns in juvenile and adult survival?
4. Are there competitive interactions between shrubby Rutaceae species and community dominants in both dry forest/woodland/heath and moist forest habitats?
5. What are the factors influencing recruitment and growth in species associated with rainforests or riparian vegetation?

Fire response

Using the system of Gill (1981) members of the Rutaceae can be divided into different functional groups in terms of how they cope with fire. There have been several reports of the fire response of species of Rutaceae in the Sydney Region and others from outside the region that include species whose distribution extends into the region. The former provides a record of local fire response while the latter may give some indication of the likely fire response within the region. In the simplest terms, the fire response of species of Rutaceae covers both fire sensitive species with a soil-stored seedbank and species resprouting via root suckers or basal sprouts that also possess a soil-stored seedbank (Table 4). Both strategies exist side by side in a range of species within the one plant community.

Table 4. Simplified fire response of Rutaceae genera in the Sydney region, with known examples

Fire response: FS fire sensitive with a soil seedbank; R resprouting via root suckers or basal sprouts and with a soil seedbank.

Tribe/genus	Fire response	Known examples
Boroniaceae		
<i>Asterolasia</i>	FS	<i>Asterolasia elegans</i> ^{3,18}
<i>Boronia</i>	a mixture of FS and R	FS: <i>B. algida</i> ¹² , <i>B. anethifolia</i> (probably ⁷), <i>B. fraseri</i> (probably ⁷), <i>B. ledifolia</i> ^{3,6,7,12} (note basal resprouting has been observed in this species), <i>B. mollis</i> ¹² , <i>B. nana</i> var. <i>hyssopifolia</i> ¹² , <i>B. polygalifolia</i> ¹² (may also resprout ⁷), <i>B. serrulata</i> ^{3,6,7,12,14} , <i>B. thujona</i> ⁷ . R: <i>B. bakeriana</i> ¹² , <i>B. deanei</i> ⁷ , <i>B. floribunda</i> ^{7,12} , <i>B. microphylla</i> ^{7,12} , <i>B. parviflora</i> ^{12,13,17} , <i>B. rubiginosa</i> (possibly ⁷). Some species may be both R or FS e.g. <i>B. anemonifolia</i> ^{7,12} , <i>B. pinnata</i> ^{7,10,11,12,17}
<i>Correa</i>	variable R/FS	<i>Correa reflexa</i> var. <i>reflexa</i> recorded as both R and FS ^{10,12}
<i>Crowea</i>	FS	<i>Crowea saligna</i> ^{7,12}
<i>Eriostemon</i>	FS ^{3,6,10,11,12,14,17}	Occasional populations may have some resprouting ^{5,7} and it may resprout outside the Sydney region ⁸
<i>Leionema</i>	FS?	<i>Leionema diosmeum</i> ^{12,13}
<i>Nematolepis</i>	R ?	
<i>Phebalium</i>	FS/R?	<i>Phebalium squamulosum</i> subsp. <i>squamulosum</i> is FS ^{9,13}
<i>Philotheca</i>	Variable FS/R	FS: <i>P. buxifolia</i> subsp. <i>buxifolia</i> ^{7,12} with occasional resprouting ¹² , FS/R: <i>P. buxifolia</i> subsp. <i>obovata</i> ^{7,9} , <i>P. hispidula</i> ^{7,12} , <i>P. obovalis</i> ^{7,12} , <i>P. salsolifolia</i> subsp. <i>salsolifolia</i> ^{6,7,9,11,17} , R: <i>P. myoporoides</i> subsp. <i>myoporoides</i> but may be FS in high intensity fire ¹² , <i>P. scabra</i> subsp. <i>scabra</i> ¹²
<i>Zieria</i>	a mixture of FS and R	FS: <i>Z. involuocrata</i> mostly FS but some limited resprouting ^{3,15} , <i>Z. laevigata</i> ^{3,7,9,17} but may resprout elsewhere ⁸ or may possess a lignotuber ² , <i>Z. murphyi</i> ¹² , <i>Z. smithii</i> ¹¹ but may occasionally resprout ^{2,12} . R: <i>Z. aspalathoides</i> ^{2,12} , <i>Z. bauerlenii</i> ⁴ , <i>Z. covenyi</i> – likely root suckers ² , <i>Z. cytisoides</i> ¹² , <i>Z. laxiflora</i> ^{2,12} , <i>Z. robusta</i> ¹² Variable FS/R: <i>Z. fraseri</i> subsp. <i>compacta</i> ^{2,12} , <i>Z. pilosa</i> ¹²
Zanthoxyleae		
<i>Geijera</i>	?R ¹²	
<i>Melicope</i>	R	<i>Melicope micrococca</i> ¹
<i>Sarcomelicope</i>	FS/R	Can resprout after low intensity fire but not after high intensity ¹²
Toddalieae		
<i>Acronychia</i>	R to occasionally FS	<i>A. oblongifolia</i> ¹⁶ , on north coast can resprout after low intensity fire but not after high intensity ⁹

Note References in bold are from work based, or largely based, in Sydney Region:

¹ Adam & Williams 2001; ² Armstrong 2002; ³ Auld unpubl.; ⁴ Barratt 1997; ⁵ Bellgard et al. 1994; ⁶ Benson 1985; ⁷ Benson & Mc Dougall 2001; ⁸ Benwell 1998; ⁹ Bradstock et al. 1997; ¹⁰ Fox 1988; ¹¹ Fox & Fox 1986; ¹² Kenny & Bradstock, NPWS fire register; ¹³ Keith 1991; ¹⁴ Lamont 1985a; ¹⁵ Maryott-Brown 1994; ¹⁶ Melick & Ashton 1991; ¹⁷ Myerscough et al. 1995; ¹⁸ Scott 1994.

Kenny (unpubl.) estimates that there are approximately 1.9:1 obligate seeders compared to resprouters in the Rutaceae in the Sydney region. In the Sydney Region, the species associated with rainforests have some ability to resprout, frequently dependent upon fire intensity (Table 4). In the sclerophyllous shrubs, most genera contain a mixture of species that are killed by fire and those that can resprout after fire (Table 4). A few taxa may be variable in that some populations may have the ability to partially resprout, whereas other populations are predominately obligate seeders (e.g. *Eriostemon australasius*). Essentially, some species may be killed by fires in some situations and not others. The reasons behind such variability in fire response largely remain to be examined in fire-prone communities. The response of any one species may be variable across its distribution (Auld 1996) in response to: a) variation in the amount of heating that the resprouting organ or its dormant buds receives during a fire (Gill 1981); b) the interaction between plant size (or at least the size of the potential resprouting organ), depth of burial of the resprouting organ and the heat output of the particular fire; c) the genetic variation within a species (some forms of a species may have evolved different responses to others); and d) variation in particular site characteristics. Consequently, the interpretation of reported variation in fire response in any species must be made in the light of the above four factors.

Future research questions:

1. What is the fire response of all species of Rutaceae?
2. For resprouters, what proportion of individuals can resprout in response to fires of varying fire intensity and season? How is this influenced by the size structure of the populations and depth of burial of resprouting organ?
3. How does the fire response of species vary across different sites and spatial scales?

Conservation status

The Sydney Region contains a number of local endemic Rutaceae (17 species). A high proportion of these (76 %) are nationally threatened or rare, or poorly known and likely to be rare or threatened (Table 1). Within *Zieria*, with 18 species in the Sydney Region, there are 5 endemics and all are threatened species (Table 1). A number of endemic species frequently have restricted distributions (e.g. *Asterolasia buxifolia* with currently one known location; *A. elegans* with less than 10 known locations in a restricted area (Scott 1994 and pers comm.); *Leionema lachnaeoides* with less than 10 locations in a restricted area (NPWS 2000); *Zieria bauerlenii* which is known from only small area near Nowra (Barratt 1997); *Z. covenyi* which is only known from one location in the upper Blue mountains). For these highly restricted species stochastic processes may be a threat to the survival of local populations.

As with other rare plant species in the Sydney Region, habitat loss as a result of urban and rural development has been, and continues to be, a threat. Where bushland habitat remains there are a number of threats to the survival of Rutaceae plants and the communities they inhabit. These threats include weed invasion,

nutrient enrichment, disturbance via rubbish dumping, vehicle use, and a failure to implement the appropriate fire regime required by species, in particular the impact of a regime of high fire frequency (see below). This has the consequence of affecting the local survival of a number of populations, which may be of conservation significance. For example a number of species are of conservation significance as they are at the limit of their geographical range or they represent disjunct populations of a wider distribution (Table 1).

Some key examples of threats operating on Rutaceae species in the Sydney Region are:

Asterolasia elegans an endangered species

This Sydney endemic is restricted to the Maroota area of north-west Sydney in open forests of *Eucalyptus piperita*, *Allocasuarina torulosa*, *Ceratopetalum gummiferum* and *Syncarpia glomulifera* (Scott 1994). Only a few locations were known in 1994 (Scott 1994), although several more have been found since (Scott unpubl.). Known population sizes vary from 800 to over 12,000 (Scott 1994, unpubl.). Adult plant survival is high over a 2 year period and populations appear to be structured based on a single post-fire recruitment event (Scott 1994). The species is killed by fire and relies on seed germination after fire to maintain populations. Seeds dormancy is broken by soil heating (Scott 1994). Consequently, populations require a sufficiently long fire-free interval for the species to mature and replenish its soil seedbank and too frequent fire is considered to be a threat to the species. Other threats are currently minor and only affect a part of known populations. These threats include weeds, road maintenance, dumping of rubbish and vehicles (Scott 1994). As all sites are not currently reserved, there is also the threat of loss of habitat in the future.

Zieria bauerlenii an endangered species.

Barratt (1997) has carried out survey and ecological studies on this species that is restricted to a single creekline near Nowra. His work indicates that the species may have no successful sexual reproduction as there is no evidence of fruiting and the species is likely to be pollen sterile (Barratt 1997, Armstrong 2002). Richardson (1994) found that pollen collected from flowers was 95% sterile. Known patches of plants are likely to be clonal and hence it is important to protect all remaining patches as the species will lack the ability to recolonise sites. The species can resprout after fire (Barratt 1997), although the impact of varying fire regimes on the species is unknown. Threats to the species include localised habitat disturbance (e.g. trail, pipeline, powerline maintenance and use), weed encroachment, trampling, inappropriate fire regimes and possibly rabbit browsing (Barratt 1997). As the one catchment where the species is known remains outside a designated conservation reserve, the species is potentially subject to further habitat loss from any future urban developments.

Leionema lachnaeoides an endangered species

This Sydney endemic is restricted to a few locations in the Blue Mountains (Cohn 1993, NPWS 2000). Less than 300 adult plants are known in the wild, with population size estimates varying from 4–108 individuals across sites (Cohn 1993, NPWS 2000). Little is known of the biology of the species or how it is impacted on by fire. The species is currently threatened by upslope impacts that may lead to site disturbance and the increased risk of weed encroachment (Cohn 1993, NPWS 2000) and at least at one site is currently affected by the impacts of human visitors.

While most of the sclerophyllous species are associated with sandstone, and such areas are the best conserved in conservation reserves around Sydney, there are still sandstone areas outside conservation reserves that are being lost. For some species the management of the extensive reserve system around Sydney is the key to the long-term survival of the species, along with protection of remnant habitat outside the reserve system. A key example is:

Boronia serrulata (Native Rose)

This Sydney endemic is famous for its attractive floral displays in heaths and woodlands in spring. It is confined to sandstone vegetation on ridges and plateaus, often associated with sandstone outcrops (Lamont 1985a) around Sydney and was previously harvested for cut flowers from the wild. Currently, its distribution extends from Dharawal State Recreation Area in the southwest of Sydney through to Brisbane Waters and Marramarra NP in the north. Across this distribution it is known from a number of conservation reserves (Dharawal SRA, Royal NP, Heathcote NP, Garigal NP, Ku-ring-gai Chase NP, Brisbane Water NP, Marramarra NP, Mougamarra Nature Reserve). In other areas, outside these reserves, there has been extensive clearance of its habitat and this continues in the north-west of Sydney (ESP 1998). Within the reserve system, the only currently known potential significant threat at present is high fire frequency (NSW Scientific Committee 2000). However, the impact of *Phytophthora cinnamoni* on *B. serrulata* is unknown and this pathogen is widespread in parts of the conservation estate (e.g. Royal NP) (Keith pers comm.) and may prove to be a threat to the species in the future. The species is fire-sensitive and must rely on seed germination after a fire to maintain populations, although in heaths where *B. serrulata* occurs on rock shelves/outcrops, fire may be patchy and some individuals may survive a fire on isolated rock shelves or outcrops (Benson 1985, pers observ.). At present, data from at least a significant part of the reserves where *B. serrulata* occurs indicates that the habitat of the species is not being subject to a regime of too frequent fire. This situation may be changing in Royal NP where there have now been three major fires in twelve years (1988, 1994, 2001–02). Active management of these reserves is needed to ensure that this potential threat does not occur for *B. serrulata*. Limited sampling within Dharawal SRA, Royal NP and Ku-ring-gai Chase NP in 1998 indicated that there were a number of large populations following the 1994 fires (estimates of 133; 500; 506; 5 250; 141 600 plants, with densities ranging from 0.04–5.9 m⁻²). Estimates of population size will vary markedly depending on time since the last fire at the site, as the species declines above ground in long unburnt habitats, but may have a large persistent soil seed-bank. Re-sampling after the 2001–02 fires is needed to determine if fire frequency is beginning to impact on the species in Royal NP and Dharawal SRA.

Outside these conservation reserves, in order to conserve *Boronia serrulata* across its range, and hence conserve the genetic diversity within the species, it is important to conserve a range of populations of the species. Overall the species is best considered as near threatened (sensu IUCN 1994) and thus is dependent upon managing the conservation reserves to avoid the impacts of frequent fire. The former threat of wildflower picking does not appear to be an issue for the species at present.

Future research questions:

1. What are the management requirements for the long-term conservation of rare and threatened species of Rutaceae?
2. What is the conservation status of the poorly known species such as *Asterolasia buxifolia* and *Leionema* sp. Hungryway Creek?
3. Is continued loss of habitat in the Sydney Region likely to result in other species of Rutaceae becoming threatened?
4. Is the frequency of fire in Royal NP now beginning to impact on Rutaceae species such as *Boronia serrulata*?

Commercial utilisation

A number of non threatened Rutaceae species are currently listed as Protected plants on Schedule 13 of the National Parks and Wildlife Act 1967 (Table 1). These listings were initiated as a consequence of harvesting of flowers, foliage or seed of the species. However, there is no effective monitoring system to assess the magnitude or impact of any current harvesting of Rutaceae (or other plant taxa) in the wild. There are suggestions that *Boronia serrulata* was heavily utilised in harvests from the wild for cut flowers in the first half of the 20th century. This may possibly have severely depleted populations of the species in the Darkes Forest area (Keith pers comm.). Given that *B. serrulata* has a soil seedbank, harvesting would have to have been extensive over many years to have any chance of eliminating populations, although population declines would readily have occurred. Harvesting of inflorescences has been suggested as a factor that could be detrimental to *Boronia megastigma* in Western Australia as it is associated with a significant increase in plant mortality (Christensen & Skinner 1978). Wild harvesting of plant taxa including Rutaceae should be avoided, unless there is documented evidence that such harvesting is sustainable.

Future research questions:

1. Do the details of previous harvesting areas/amounts for *Boronia serrulata* when compared with current distributions and estimates of abundance indicate past declines or long term impacts?
2. What is the current, and future projected, nature of any harvesting from the wild of Rutaceae material? What is the minimum dataset required to begin to assess any sustainable harvesting levels?

Management of species in fire-prone habitats

A key issue for the long-term survival of most Rutaceae species in the Sydney Region is fire management and the management of fire regimes (fire frequency; fire intensity; fire season; and fire spatial extent). More work is needed to unravel how fire and germination in Rutaceae are linked. Auld (1996) detailed the nature of how different components of the fire regime may impact on plants in the Sydney region. Likely key issues for the shrubby Rutaceae are:

1. Avoidance of high frequency fires (listed as a Key Threatening Process under the NSW *Threatened Species Conservation Act 1995*, NSW Scientific Committee 2000) that could cause population declines or local extinction, particularly in fire-sensitive species. It is likely that maturation times for seedlings of fire sensitive shrubs will be variable (see above), but may be slow compared to some fast growing species such as *Acacia suaveolens* or *Actinotus helianthi*. In addition, plants may be small when first mature (e.g. *Boronia serrulata*) and seed output may be low until plants grow.

Rutaceae shrubs are likely to have some resilience to frequent fire as they have soil seedbanks. Where heat is a major cue to breaking seed dormancy (as occurs in some Rutaceae, Table 3) not all seeds are likely to germinate after a single fire. However, any residual may not be available to germinate in the next fire (e.g. it may be buried too deeply to be heated sufficiently to break seed dormancy). As well there may be an interaction between heat and smoke in breaking seed dormancy in shrubby Rutaceae (Table 3) and this may lead to a relatively smaller residual of seeds in the soil after a fire. It may be that certain species may be quick enough to flower and fruit after fire so that high fire frequency is not likely to be a threat. Some species may be more favoured by short-fire intervals compared to co-habiting species (e.g. *Zieria laevigata*, Morrison et al. 1996). Clearly more work in this area is needed and high frequency fire should be avoided until this occurs.

2. There must also be sufficient time between some fires for resprouting species in order for seedlings to grow big enough to become fire-resistant. This is currently unquantified for Rutaceae species.

3. The more heat a fire produces (a component of intensity) the more plant death that will occur (e.g. in resprouting species), and the longer that will be needed before the next fire for recovery. As well, the amount of soil heating in a fire is likely to influence post-fire germination in shrubby Rutaceae species. In general, the more fine ground fuel that is consumed in a fire the more soil heating that occurs (Bradstock & Auld 1995). This can lead to seeds being killed if they lie near the soil surface (0–2 cm deep) but prolific germination from seeds buried deeper in the soil.

4. The impact of season of burning on survival of sclerophyllous Rutaceae species is unknown, although McLaughlin (1998) has noted that the historical season of burn in the Sydney region has changed since European settlement.

5. The impact of patchiness and spatial extent of fires on Rutaceae is also largely unknown. The localised habitat of some species may promote variation in fire behaviour and lead to patchiness of burnt and unburnt areas, e.g. *Boronia serrulata* may survive some fires on, or in association with sandstone rock shelves/outcrops. This ability will increase the probability of a species persisting at a site even under high fire frequency (although clearly abundances may be severely reduced).

Future research questions:

1. What are the primary and secondary juvenile periods, and the time to fire resistance across a range of species, sites and seasons? Such data will allow an assessment of the resilience of species to frequent fire, and comparisons of Rutaceae species with other co-habiting taxa.
2. What is the level of residual seedbank in soil for Rutaceae after fire and its distribution in the soil profile? How is this influenced by the fire-related dormancy breaking cues, fire intensity and fire seasonality?
3. How does season of burn affect germination and seedling survival after fire?
4. What is the interaction between season of burn and any fire-related germination cues?

Table 5. Summary of major ecological attributes involved in Rutaceae ecology in Sydney region compared with other families (Fabaceae, Myrtaceae, Proteaceae) and compared with South African Fynbos vegetation.

Fire response: FS fire sensitive; R resprouting.

Major ecological attributes								
Region/ taxonomic group	Fire res- ponse	Primary juvenile period	Life span (years)	Pollin- ators	Seed pre- dators	Dispersal	Seed- banks	Germination cues
Sydney region								
Fabaceae ^{1,2} (230 species)	FS/R	1+	5+	insects	weevils wasps	ants ballistic birds	soil, persistent	fire, heat
Myrtaceae ^{3,6} (225species)	FS/R	2->20+	20->200	insects mammals	ants ??	ants wind birds mammals	soil, persistent canopy	fire, heat, smoke?
Proteaceae ^{4,7} (134species)	FS/R	5-8+	15-100?	insects birds mammals	weevils parrots mammals	ants wind birds mammals	soil, persistent canopy	fire, heat and smoke season
Rutaceae (71 species)	FS/R	2-5+	??	insects/ occas. birds	wasps?	ballistic ants birds	soil, persistent	fire, heat and smoke
South African Fynbos⁵								
Fabaceae (640 species)	FS/R	1+	5+	insects	??	ants	soil	fire, heat scarification
Proteaceae (320 species)	FS/R	4+	6+	insects birds rodents	??	ants wind	soil, canopy	fire, cold, fluctuating temperatures
Rutaceae (260 species)	FS/R	2+	10+	insects	??	ants	soil	fire, heat, fluctuating temperatures

¹ Auld 1996; ² Benson & McDougall 1996; ³ Benson & McDougall 1998; ⁴ Benson & McDougall 2000; ⁵ Le Maitre & Midgley 1992; ⁶ Myerscough 1998; ⁷ Myerscough et al. 2000.

Conclusions

Members of the Rutaceae are a significant component of particularly the heaths, woodlands and dry forests in association with sandstone soils in the Sydney region. At the same time, currently the study of the ecology of species within the family remains largely rudimentary. Given that members of the family are significant components of the stunning floral displays around Sydney in spring, this is somewhat surprising. There is some understanding of the biology of Rutaceae species from limited specific work and from work on plant communities around Sydney. In broad terms what patterns we see in the sclerophyllous Rutaceae in the Sydney region are comparable to patterns in Rutaceae in the South African fynbos vegetation (cf. Le Maitre & Midgley 1992) and other major plant families in the Sydney Region, particularly the Fabaceae (see Table 5). There is less diversity in some ecological attributes (pollinators, dispersal agents, seed storage mechanisms) than in diverse families such as the Myrtaceae and Proteaceae. However, some attributes are relatively unique (ballistic and ant dispersal combination, which is only shared with some Fabaceae species). For other attributes we simply do not have sufficient knowledge about members of the Rutaceae to make valid cross family or region comparisons (e.g. seed predators, plant longevity). Management of Rutaceae species, and in particular the high proportion of threatened or rare species in the family in Sydney, is limited by our lack of understanding of the ecology of species in this family.

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