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Managing *Persoonia* (Proteaceae) species in the landscape through a better understanding of their seed biology and ecology

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Abstract: *Persoonia* (family Proteaceae) is a diverse genus of 99 species, mainly of woody shrubs and small trees, that are endemic to Australia. The fleshy fruits that characterise these plants are an important resource in otherwise resource-depauperate ecological communities. However, this genus is highly under-represented in restoration and conservation programs, as its species are notoriously difficult to propagate and transplant in the wild. Understanding the mechanisms that control seed production, viability, dormancy and germination will hasten progress on *Persoonia* propagation. Here we review *Persoonia* studies to reveal the nature of, and variability within, the genus. We identify key factors that need to be addressed; specifically, those affecting fruit set, endocarp degradation and subsequent propagation of *Persoonia*. This synthesis of current knowledge provides important material to inform management of this taxon in the landscape, and outlines several important priorities for future seed biology research on the genus. We outline several important priorities for future seed biology research on the genus.

Keywords: Endocarp, germination, plant ecology, propagation, restoration, seed production

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Introduction

Success in many natural revegetation and restoration projects depends on the establishment of a wide range of species, but is often limited to those that are easy to collect, propagate and establish. Proteaceae are important keystone species in many restoration projects (Roche et al., 1997; Koch, 2007b; Stingemore & Krauss, 2013), be it at the landscape scale, with species of *Banksia*, *Grevillea* and *Hakea* being commonly used, or the translocation of a single threatened species (e.g. *Persoonia pauciflora*). Seed production in woody-fruited Proteaceae can vary significantly, from zero to tens of thousands of seeds on a single plant in any given season (Groom & Lamont, 1998). Seeds of some Proteaceae species are relatively easy to germinate but because many species occur in fire-prone habitats, germination may be cued to fire, and can be difficult to germinate due to specific conditions being required to break the complex dormancy mechanisms (Van Staden & Brown, 1977; Morris, 2000; Morris et al., 2000; Arnolds et al., 2015; Chia et al., 2016).

Persoonia is one genus within the Proteaceae that has very complex dormancy mechanisms. This genus includes many species that are the subject of restoration or conservation projects and include *Persoonia longifolia* (southern Western Australia), *Persoonia pauciflora* (Hunter Valley, NSW), *Persoonia hindii* (Newnes Plateau, NSW) and *Persoonia hirsuta* (Sydney Basin, NSW). However, their inclusion is hampered by consistently poor propagation success (Cambededes & Balmer, 1995; Ketelhohn et al., 1996; Bauer & Johnston, 1999). For example, *Persoonia longifolia* plants were present in areas of Western Australian jarrah woodland prior to bauxite mining in the 1960s (Koch 2007a; 2007b). The mine site restoration plan for these areas included a target of restoring the ecosystem to a state comparable with pre-mining, but although *Persoonia longifolia* had viable seeds, they could not be germinated and were absent from rehabilitation projects (Koch, 2007b). Recent research on the seed ecology of this species (Chia et al., 2015), including how seasonality and fire affect *in situ* fruit set, dormancy release and germination, identified the seasonal conditions and length of time required for dormancy to break and germination to occur in the soil (Chia et al., 2016).

We see a focus on plant ecology to be of great value for progress in conservation and restoration. It is evident that re-establishing new populations, or augmenting extant populations through translocation, requires a detailed understanding of how the plants interact in the natural environment, if they are to have long-term success. We argue that progress on *Persoonia* seed production and propagation will be facilitated by understanding the mechanisms in nature that control seed production, viability, dormancy and germination. This review aims to identify major research priorities and develop a logical framework to guide future investigations towards a more systematic approach to resolve species persistence in the landscape. Such an approach could also have benefits for other Proteaceae with a similar seed

biology to *Persoonia*, and may be relevant to other families with similarly deep, intractably dormant seeds.

The genus *Persoonia*

Species of *Persoonia* (family Proteaceae) range from low prostrate or spreading shrubs to small trees (Appendix 1); they are characterised by light green foliage with high morphological variability across species, and yellow hermaphroditic flowers (Weston 2003; Fig. 1). A maturing ovule forms a fleshy drupaceous fruit comprising a single hard woody stone containing either one or two seeds (Fig. 2), and an embryo can have up to nine cotyledons (Weston, 2003). All 99 species are endemic to Australia, and together the genus occupies 64 of the 87 national bioregions (IBRA7; Appendix 1), but is largely absent from central arid regions. Including subspecies there are 115 taxa, 72 endemic to eastern Australia, 42 to Western Australia, and one across northern Australia. Nine species are listed as threatened, endangered or critically endangered under the Australian *Environment Protection and Biodiversity Conservation Act, 1999* (eight species occur in NSW; Appendix 1), being impacted by several anthropogenic factors, including land clearing, mining, habitat fragmentation, grazing, slashing and predation. There is a distinct lack of ecological and seed biology data on *Persoonia*; much of this research has been conducted on eastern Australian *Persoonia* species (Table 1).



Fig. 1. Morphological variation within the *Persoonia* genus. **A-** *Persoonia myrtilloides* plant; **B-** *Persoonia levis* plant; **C-** *Persoonia hirsuta* plant, and; **D-** *Persoonia pauciflora* plant (Photos by N. Emery).

Table 1. *Persoonia* species that have been studied for breeding system, fruit set and/or seed germination. Several species have had multiple independent studies that measured one or more component of the reproductive niche (see Appendix 2 for References)

Species	Distribution (state)	Habitat ¹	Rarity ²	Fire response ³	Breeding System ⁴	Fruit set ⁵	Germination ⁶
<i>Persoonia bargoensis</i>	NSW	DSF, DW	En*, Vu†	1	SC		
<i>Persoonia elliptica</i>	WA	DSF, DW	NL	3		39%	
<i>Persoonia glaucescens</i>	NSW	DSF	En*, Vu†	1	NC	18%; 86%	
<i>Persoonia juniperina</i>	NSW, SA, TAS, VIC	DSF, H	NL	2	SC	40%; 30—41.4%	
<i>Persoonia lanceolata</i>	NSW	DSF	NL	1	NC	41%; 88%; 97%	~10.0%
<i>Persoonia levis</i>	NSW, VIC	DSF, DW	NL	3	NC	5—55%; 52%	50.0%
<i>Persoonia longifolia</i>	WA	DSF, DW	NL	3		10%; 98.3%	31.8—94.7%
<i>Persoonia mollis</i> subsp. <i>maxima</i>	NSW	DSF	En*†	1	NC	18%; 89%	
<i>Persoonia mollis</i> subsp. <i>nectens</i>	NSW	DSF	NL	1	NC	35%; 91%	~40.0%
<i>Persoonia myrtilloides</i>	NSW	DSF, DW	NL	1	NC	10—70%	
<i>Persoonia rigida</i>	NSW, VIC	DSF	NL	1	SC	67%	
<i>Persoonia sericea</i>	QLD, NSW	DSF, WSF	NL	2			87.5%
<i>Persoonia virgata</i>	QLD, NSW	DSF	NL	1	NC	36.1—41.6%; 48.9%	50%; 58.8— 87.5%; 100%

¹ DSF = dry sclerophyll forest, DW = dry woodland, H = heath, WSF = wet sclerophyll forest

² En = endangered, NL = not listed under state or national legislation, Vu = vulnerable; * threatened status listed under state/territory legislation; † threatened status listed under the national EPBC Act

³ Ability to resprout following fire: 1 = cannot resprout and reliant on seeds, 2 = can resprout from base only. 3 = can resprout from base and stems; Rymer (2006)

⁴ NC = non-compatible breeding system, SC = self-compatible breeding system; reference list available in Appendix 2

⁵ Fruit set from outcrossed pollination reported in the literature as of 23/04/2018; reference list available in Appendix 2

⁶ Germination results reported in the literature as of 23/04/2018; reference list available in Appendix 2

Field ecology behaviour

Some *Persoonia* species occur across multiple climatic zones, but others are more localised including several of the rarer obligate-seeding species in the Sydney region, and these species often establish alongside roads and tracks. For example, *Persoonia hirsuta* plants occur in drainage lines along track edges with the largest populations along disturbed road easements (N. Emery, pers. obs. 2017). Myerscough et al. (2000) postulated that soil disturbance events might substitute for the effects of fire, particularly in environments with long inter-fire intervals.

Persoonia species lack the proteoid roots (characteristic of most Proteaceae species) that aid inorganic nutrient absorption, yet plants often occur in well-drained, nutrient-poor acidic soils such as the sandstone and shale soils of the Sydney region (Myerscough et al. 2000; Weston 2003). As individual plants can thrive in their environments it is possible that unknown mycorrhizal associations might occur in the roots. *Persoonia pauciflora* plants often occur at the base of Broad-leaved Ironbark (*Eucalyptus fibrosa*) or Spotted Gum (*Corymbia maculata*) trees (N. Emery, pers. obs. 2017), which might indicate a possible relationship between these species.

Flowering times

Peak flowering in most Western Australian *Persoonia* species occurs over winter and spring, and eastern Australian species

predominantly flower during summer and autumn (Bernhardt & Weston 1996; Table 2). Some species such as *Persoonia pinifolia* can produce flowers for most of the year. Eastern Australian *Persoonia* species experience a high frequency of hybridisation (Myerscough et al. 2000) that could be explained by a combination of coinciding distributions, flowering times and/or pollinators, as well as a lack of pre-zygotic barriers for interspecific pollen (Bernhardt & Weston 1996).

Pollination

Many Proteaceous species produce large inflorescences with copious amounts of nectar, making them well-suited for vertebrate pollination (Carolin, 1961; Collins & Rebelo, 1987). *Persoonia* species, in contrast, have small yellow flowers that are most notably pollinated by bees and wasps (Carolin, 1961; Collins & Rebelo, 1987; Bernhardt & Weston, 1996). It was originally postulated that a mutualistic relationship exists between *Persoonia* and small native, hairy *Leioproctus* bees (Hymenoptera: Colletidae) (Bernhardt and Weston 1996). *Leioproctus* have since been observed to pollinate numerous *Persoonia* species including *Persoonia glaucescens*, *Persoonia lanceolata*, *Persoonia mollis* subsp. *maxima*, *Persoonia mollis* subsp. *nectens* and *Persoonia virgata* (Wallace et al., 2002; Rymer et al., 2005). Other bee pollinators known to visit *Persoonia* include *Exoneura* spp. (Bernhardt & Weston, 1996), *Tetragonula carbonaria* (formerly *Trigona*) (Wallace et al., 2002), and the European honeybee *Apis mellifera* (Bernhardt & Weston, 1996; Wallace et al., 2002; Rymer et al., 2005; Chia et al., 2015).

Species	Distribution (state)	Peak flowering time (month)											
		winter			spring			summer			autumn		
		J	J	A	S	O	N	D	J	F	M	A	M
<i>Persoonia subtilis</i>	NSW												
<i>Persoonia subvelutina</i>	ACT, NSW, VIC												
<i>Persoonia juniperina</i>	NSW, SA, TAS, VIC												
<i>Persoonia asperula</i>	NSW, VIC												
<i>Persoonia brevifolia</i>	NSW, VIC												
<i>Persoonia chamaepeuce</i>	NSW, VIC												
<i>Persoonia confertiflora</i>	NSW, VIC												
<i>Persoonia levis</i>	NSW, VIC												
<i>Persoonia linearis</i>	NSW, VIC												
<i>Persoonia rigida</i>	NSW, VIC												
<i>Persoonia silvatica</i>	NSW, VIC												
<i>Persoonia arborea</i>	VIC												
<i>Persoonia gunnii</i>	TAS												
<i>Persoonia moscalii</i>	TAS												
<i>Persoonia muelleri</i> subsp. <i>angustifolia</i>	TAS												
<i>Persoonia muelleri</i> subsp. <i>densifolia</i>	TAS												
<i>Persoonia muelleri</i> subsp. <i>muelleri</i>	TAS												

Manipulative pollination experiments suggest that *Persoonia* species have a breeding system that favours out-crossing (Krauss, 1994; Cadzow & Carthew, 2000; Wallace et al., 2002; Table 1). In *Persoonia mollis*, for example, 20% of out-crossed flowers set fruit compared to just 1% of selfed flowers (Krauss, 1994). Furthermore, pollen tubes were not present in the ovaries of self-pollinated flowers. The experimentally-manipulated result for out-crossed flowers also reflected the natural pollination level, with 17% of unmanipulated flowers setting fruit (Krauss 1994). Similarly, *Persoonia virgata* pollination experiments showed weak self-compatibility, as fruit set was significantly lower in self-pollinated flowers (6.6%) than cross-pollinated flowers (48.9%) (Wallace et al., 2002). Krauss (1994) first noted the possibility of a post-zygotic mechanism within *Persoonia* seeds that caused the majority of selfed fruits to be prematurely terminated between 4 and 30 weeks following pollination. In *Persoonia juniperina* it was reported that 76% of selfed fruits terminated during the maturation period compared to 33% for open-pollinated fruits (Cadzow & Carthew 2000). Alternatively, self-compatibility has been reported in *Persoonia*, as pollen tubes were frequently observed in self-pollinated flowers of *Persoonia rigida*, and final differences in the number of matured fruit from self- and cross-pollinated flowers were not statistically significant (Trueman & Wallace, 1999). Self-compatibility has also been documented for *Persoonia juniperina* and *Persoonia bargoensis* (Cadzow and Carthew 2000; Field et al. 2005).

Fruit set success

Flowers of Australian Proteaceae are hermaphroditic and typically produce a very low rate of fruit set – around 5% (Ayre & Whelan, 1989). Fruit set success varies considerably among *Persoonia* species, and has been documented in

re-sprouting and obligate seeding species (Table 1). Fruit set in *Persoonia longifolia* was reported to be more variable among plants within a population than between populations, and to be positively correlated with plant height and time since last fire (Chia et al., 2015). The availability of carbohydrates that could be transferred from branches to the fruits was reported to be positively correlated with fruit size in *Persoonia rigida*, and fruit set on leaf-bearing branches being 4-6 times higher than defoliated branches (Trueman & Wallace 1999). Minimal vegetative growth during fruit maturation was observed on *Persoonia virgata* plants (Bauer et al. 2001). The slow development of *Persoonia* embryos coupled with the requirement of nutrient uptake for embryo growth, suggests that most of the plant resources are allocated to fruit development during the fruiting season (Strohschen, 1986).

Fruit maturation

Persoonia peak flowering and fruit set precedes a long and highly variable period of fruit maturation reported to require at least 2 months. In some species it can take up to a year for fruits to fully mature and drop from the maternal plant (Trueman & Wallace, 1999; Benson & McDougall, 2000; Wallace et al., 2002; Weston, 2003; Rymer et al., 2005; Chia et al., 2015). It has been reported that *Persoonia pinifolia* embryo maturation is significantly slower than other Proteaceae genera such as *Macadamia*, and the endosperm is almost completely replaced by the embryo at 34 weeks post-anthesis (Strohschen 1986).

Fruit dispersal

Seed dispersal beyond the maternal plant environment may be limited to fruit-drop from the maternal plant (Rice & Westoby, 1981), but the fleshy *Persoonia* fruits are also likely to be consumed and dispersed by birds and

mammals (Weston, 2003; Auld et al., 2007). In one study, 90% of *Persoonia lanceolata* fruits were consumed by Swamp Wallabies (*Wallabia bicolor*) with 98% of these still being viable after being collected from scats (Auld et al., 2007). *Persoonia longifolia* fruits have been reported to be consumed by Brush Tail Wallabies (*Macropus irma*), Western Grey Kangaroos (*Macropus fuliginosus*) and Bobtail Lizards (*Tiliqua rugosa*) (Chia et al. 2015). Many native birds consume *Persoonia* fruits, including the Olive-backed Oriole (*Oriolus sagittatus*), Silver-eye (*Zosterops lateralis*), Pied Currawong (*Strepera graculina*), Regent Bowerbird (*Sericulus chrysocephalus*), Satin Bowerbird (*Ptilonorhynchus violaceus*), Red Wattlebird (*Anthochaera carunculata*) and Lewin's Honeyeater (*Meliphaga lewinii*) (Barker & Vestjans, 1990). However, it is not known whether these vertebrates facilitate dispersal of viable seeds in their scats. *Persoonia longifolia* fruits are commonly found in Emu (*Dromaius novaehollandiae*) scats, but the germinability of these remains very low (Mullins et al., 2002). Cockatoos and other parrots have also been observed to predate on immature *Persoonia* fruit (Weston 2003; K. Chia, pers. comm. 2016). The removal of *Persoonia* seeds may correlate with the rarity and size of plants, as macropods were found to remove significantly more fruits of two common *Persoonia* species (*Persoonia lanceolata* and *Persoonia mollis* subsp. *maxima*) compared with two rare species (*Persoonia glaucescens* and *Persoonia mollis* subsp. *nectens*) (Rymer, 2006). Furthermore, seed removal was significantly positively correlated with plant height in common species only, although plant population size was not reported to be influencing removal (Rymer, 2006).

Seed biology

Within the fleshy *Persoonia* exocarp and mesocarp is the woody endocarp (Fig. 2), which restricts germination as a form of mechanical dormancy. In *Persoonia longifolia* laboratory trials, germination only occurred when all or half of the endocarp was removed (78% and 68% success, respectively - Chia et al. 2016). Norman and Koch (2008) determined that *Persoonia longifolia* endocarps were permeable to water, (increasing in weight by 10-30% following 30 hours of imbibition), but the permeability and hardness of buried endocarps did not significantly differ from the controls after a 2-year soil burial trial, suggesting that endocarp weakening over time is slow. A recent study on *Persoonia longifolia* noted that the removal of the endocarp lid did not increase the rate of imbibition (Chia et al., 2016).

Coupled with the mechanical dormancy mechanism imposed by the endocarp is the physiological dormancy of the embryo, which may require treatment using a chemical stimulant such as gibberellic acid (GA_3), or a combination of warm and cold stratification to improve overall germination success (Mullins et al., 2002; Chia et al., 2016). Mullins et al. (2002) suggested that *Persoonia longifolia* seeds required an unknown period of cold temperatures over winter to maximise overall germination. By contrast, *Persoonia myrtilloides* and *Persoonia levis* seeds showed significantly reduced and no germination, respectively, following a chilling pre-treatment

(Nancarrow 2001). A recent study on *Persoonia longifolia* suggested that the environmental conditions the endocarps are exposed to are more important than the actual burial time. Specifically, germination was highest when endocarps were treated with two simulations of summer rainfall events and a constant summer temperature of 30°C (Chia et al. 2016). Adding more complexity, a heat spike treatment (50°C) improved germination when moisture was limiting, but germination was significantly reduced if long wet cycles were introduced.

It is possible that the proportion of physiologically dormant seeds may be species-specific or vary among years depending on conditions during fruit maturation. Some studies have found that the addition of GA_3 made no difference or had highly variable results, to overall germination (Ketelhohn et al., 1996; Nancarrow, 2001; Chia et al., 2016). For example, GA_3 increased germination of *Persoonia virgata* seeds by at least 50% (Ketelhohn et al., 1996; Bauer et al., 2004). Similarly, it increased germination of *Persoonia levis* seeds, whereas *Persoonia myrtilloides* seeds were unaffected (Nancarrow, 2001). As seeds from *Persoonia myrtilloides* only germinated after 4 months in storage, it is possible that a period of after-ripening or stratification is required to alleviate physiological dormancy. Furthermore, as no indication of viability was given, it is also possible that viable embryos of both species were damaged during the removal of the endocarp.

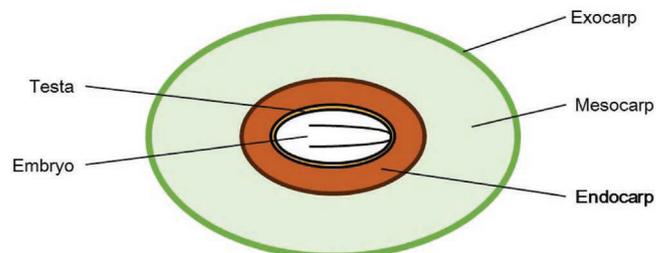


Fig. 2. Diagrammatic cross-section of a typical *Persoonia* fruit (not to scale), comprising mostly a fleshy mesocarp behind a leathery external layer (exocarp). The mesocarp covers the woody stone (endocarp), which protects the seed. *Persoonia* seeds are predominately made up of a testa and non-endospermic embryo, and may contain one or two seeds within the endocarp. The endocarp is the key structure that prevents germination from occurring.

Early studies on *Persoonia pinifolia* and *Persoonia longifolia* noted that germination was negatively affected by microbial contamination (McIntyre 1969; Mullins et al. 2002), but the recommended disinfecting and germinating of seeds under aseptic conditions, has produced mixed results for germination success (Bauer et al., 2004; Chia et al., 2016). Interestingly, contamination of *Persoonia longifolia* seeds was most prevalent in those treated with the smoke stimulant karrikinolide (Chia et al., 2016). *Persoonia pauciflora* seeds treated with GA_3 also suffered from severe contamination despite being surface-sterilised (N. Emery, unpublished data). Microbial growth within the seed could be promoted by both GA_3 and karrikinolide as similar chemical derivatives have a microbial origin (Brian et al., 1954; Light et al., 2009).

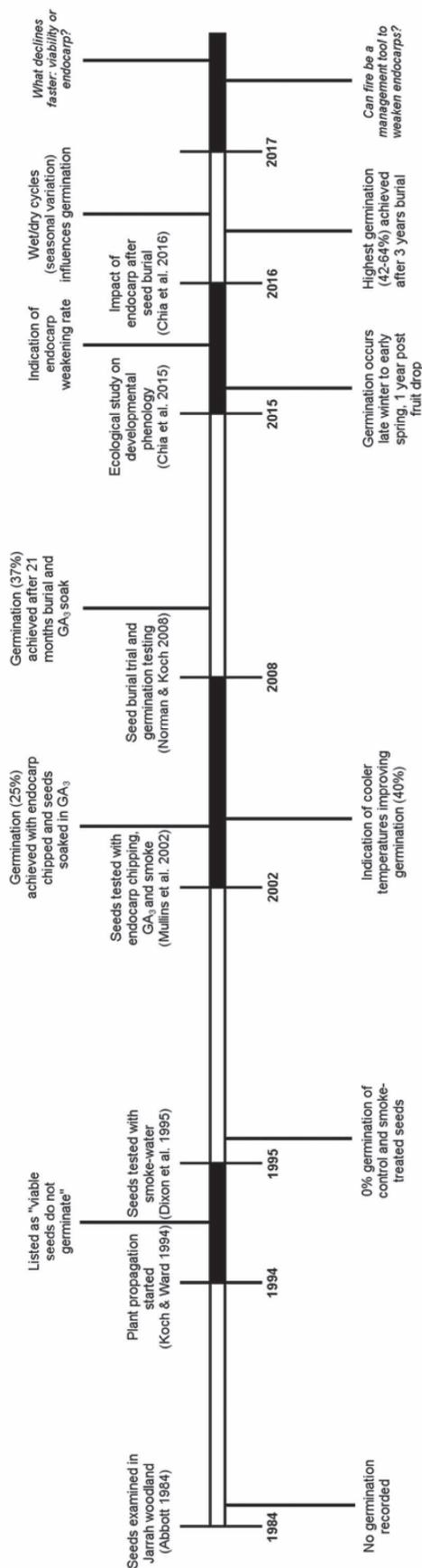


Fig. 3. An example of the framework for *Persoonia longifolia* seed ecology research. Seeds have been tested for germination as part of large mining rehabilitation projects (Abbott 1984; Koch & Ward 1994), conservation studies (Dixon et al. 1995; Norman & Koch

2008), and propagation studies (Mullins et al. 2002; Norman & Koch 2008). Successful germination was not achieved until 2002, when endocarps were physically compromised and seeds were treated with gibberellic acid (GA₃). Germination remained low (25 – 40%); however, there was an indication from direct sowing that germination was higher following cooler temperatures. This link with climate was then rigorously examined in recent studies on the developmental phenology and the endocarp (Chia et al. 2015; Chia et al. 2016). Seed germination was reported to be highest following three years of soil burial, and, moreover, wet and dry cycle length interacted with the rate of endocarp weakening. These results now raise the possibility of fire or heat being used as a management tool for endocarp weakening, and whether endocarps degrade at a faster rate than seed viability *in situ*.

Soil seedbank persistence

In the soil seedbank the endocarp is expected to decompose over time, thereby increasing the rate of oxygen and water reaching the embryo, and allowing the embryo to ‘push out’ of the weakened endocarp. Previous research has reported mixed results of recruitment success in *Persoonia* and, therefore, long-term persistence of seeds in the soil (Auld et al. 2007; Ayre et al. 2009; McKenna, 2007; Chia et al., 2015). *Persoonia pinifolia* fruit, for example, were estimated to have a half-life of one year in the soil seedbank (Auld et al., 2000). The viability of *Persoonia elliptica* seeds in the soil seedbank declined from 39% to 5% after one year (Nield et al., 2015). *Persoonia longifolia* seeds showed a comparatively smaller decline in viability from 93% to 68%, recorded after three years (Chia et al. 2016). In contrast, four *Persoonia* species (two rare and two common) experienced a significant decline in viability to around 30% following a 1-2 year soil burial (McKenna 2007). Interestingly, viability decline also significantly varied among populations, which could indicate local variation due to genetic or environmental factors. However, such a decline in viability might not adversely affect recruitment success where annual fruiting events produce an accumulating seedbank. For example, 476 *Persoonia mollis* subsp. *nectens* seedlings emerged following a wildfire from a population of 25 adult plants (Ayre et al. 2009). An additional 381 seedlings emerged following a second wildfire four years later, and before the first seedling cohort reached reproductive maturity (Ayre et al. 2009). These results suggest that the population had a large and persistent soil seedbank, capable of withstanding multiple fires. Auld et al. (2007) estimated that although the number of *Persoonia lanceolata* seedlings that emerged post-fire was 6-7 times greater than the pre-fire adult numbers, there was at least 72% of available soil seedbank that did not germinate.

Natural recruitment: the role of fire and smoke

It was originally reported that seedling recruitment of *Persoonia* is most likely to occur following a disturbance such as fire (McIntyre, 1969). Fire was thought to be a crucial factor for the recruitment of *Persoonia elliptica* seedlings in jarrah woodlands in Western Australia, with only one seedling observed in plots that had not been burnt (Nield et al. 2015). With fire comes the risk of seeds being destroyed by the combustion (Chia et al., 2015); fire intensity is likely

to be an important factor influencing seed survival, but has not yet been investigated for *Persoonia*.

Auld et al. (2007) remarked that since most *Persoonia lanceolata* fruits were found in the top 5 cm of soil, contact with smoke during or shortly after a fire was a distinct possibility. However, smoke has not been commonly used in *Persoonia* germination experiments or shown to have a positive benefit on germination success. In a comprehensive study of the effect of smoke water on the germination of plants in Western Australia, *Persoonia longifolia* seeds did not germinate when treated with smoke water (Dixon et al., 1995). However, this study used fresh, non-aged seed which would not reflect the ecological priming of soil-stored seed in nature and the post-fire germination found in this species. A subsequent study also found no change in germination success of *Persoonia longifolia* when smoke was applied at different times prior to sowing; however, again non-aged seed was used (Mullins et al., 2002). Similarly, there was no additive effect when smoke water was applied with GA₃. This could be due to both smoke and GA₃ having a similar mode of catalysing germination, through opening the respiration pathway by stimulating the conversion of oxygen to superoxide in the seed (Sunmonu et al., 2016). Furthermore, it is known that smoke catalyses the production of enzymes such as amylase, mobilising starch compounds from the endosperm to other parts of the seed (Cembrowska-Lech & Kępczyński, 2016; Sunmonu et al., 2016). Whether the application of smoke stimulates other mechanisms, particularly for species with non-endospermic seeds, remains unknown. However, this might explain why using smoke as a pre-treatment has no additive effect on the germination of *Persoonia* as the seeds lack an endosperm at maturity (Strohschen 1986).

The variability in germination success reported in *Persoonia* species means that further testing is required to determine the environmental and population factors needed for optimal seed collection, storage and germination conditions. We consider that while a disturbance such as fire may be required to break the mechanical dormancy in *Persoonia* seeds (i.e. the woody endocarp), smoke water provides no greater benefit for overall germination success of fresh seed than GA₃. However, if the role of smoke on germination is to be examined in an ecologically relevant manner, then trialling a possible interactive effect on soil-aged or seasonally-stratified seeds would be an appropriate future study.

Discussion

Much of our knowledge of *Persoonia* seed biology is derived from *ex situ* propagation research, be it for seed germination, dormancy status or viability. However, we also need to understand how the plants interact with their local environment *in situ*, i.e. their ecology. Once the main factors driving fruit set and dormancy are determined, we can use this knowledge to include particular species in propagation and restoration programs. An example demonstrating the relative benefits to 'progress' upon changes from *ex situ* germination testing to *in situ* ecological requirement studies

can be seen in our synopsis of *Persoonia longifolia* research (Fig. 3). Following on from this and other *Persoonia* species research efforts, we outline the major knowledge gaps for restoration practice and, therefore, the research priorities for future work on this taxon.

Climate and phenology

A major omission in many *Persoonia* studies to date is a quantifiable link between phenological events and climatic factors, namely temperature and rainfall. For example, changes in the timing and duration of flowering can have flow-on effects for other phenological events. In several Proteaceae species, a decline in mean daily germination (due to enforced seed dormancy) correlating with an increase of 1.4°C and 3.5°C during seed incubation has been reported (Arnolds et al. 2015). Below-average rainfall was postulated to cause the mortality of several *Persoonia* species following fire (McKenna, 2007). If the flowering phenology of *Persoonia* can be linked with climate, then this could provide better predictions of the species niche, as well as determine appropriate growing conditions and the adaptive timing for fruit set and maturation. Since *Persoonia* species have a breeding system that preferences outcrossing and are predominately pollinated by native and exotic bee species, the effect of the timing of flowering on interactions with pollinators warrants further investigation.

Recent work on *Persoonia longifolia* illustrated the importance of climatic events on both *in situ* and *ex situ* seed burial. For example, brief wet events over summer, such as a thunderstorm, were reported to greatly improve overall germination by breaking mechanical dormancy in the endocarp (Chia et al. 2016). As *Persoonia longifolia* seeds are physiologically dormant, this means that an interactive effect, in the sense of warm and cold stratification, is also required to alleviate dormancy in the seed. Furthermore, as post-fire germination is not always immediate, it is possible that heat exposure, rather than smoke, weakens or cracks the endocarp allowing germination to commence sooner (McKenna, 2007; Chia et al., 2015).

Rethinking the role of fire

If endocarp degradation commences in the soil after fruit drop and follows wet and dry cycles (Chia et al., 2016), then the timing of fire could have a significant effect on seed germination and viability. For example, seeds from populations of *Persoonia glaucescens* and *Persoonia bargoensis* (both obligate seeders) that had been burnt, declined in viability over 12 months (McKenna 2007). By contrast, seed viability in unburnt populations did not vary over the same time. Auld et al. (2000) reported that seed viability in *Persoonia pinifolia* (an obligate seeder) declined to 28–40% following 2 years of soil burial, and suggested that a prescribed burn midway through the experiment may have contributed to seed death. However, seed death did not significantly increase post-burning when compared with pre-burning, and it was thought that seed ageing was the main factor contributing to viability loss (Auld et al., 2000).

Persoonia endocarps are water-permeable, and poorly-timed fires could essentially pressure-cook any partially imbibed seeds (Norman & Koch, 2008; Chia et al., 2016). While fire may hasten the relaxing of mechanical dormancy, if a portion of the soil seedbank has already experienced some level of degradation, a fire could then scorch and kill the more water-permeable seeds. This outcome could be the underlying reason for significantly higher germination of *Persoonia mollis* subsp. *nectens* seeds following a medium-intensity burn, compared to a high-intensity burn (McKenna, 2007). Chia et al. (2015) suggested that fire had killed *Persoonia longifolia* seeds in the seedbank, as recruitment events only occurred following post-fire fruit set. Taken together, these results suggest a fine balance for endocarp degradation through wet and dry cycles and fire. This raises the question of whether endocarps require a fire and, if so, when should a fire occur relative to fruit drop? It is also plausible that a low-intensity burn following seed-sowing might lead to a shorter time to recruitment.

To determine whether either the prescribed burning of *Persoonia* soil seedbanks or *ex situ* ‘priming’ of seeds by burning is likely to be important, the *in situ* seed longevity must be known. Previous evidence indicates that seed longevity varies among *Persoonia* species (Auld et al. 2000; Norman & Koch, 2008) and suggests that seed longevity and endocarp degradation might be intimately linked. If seeds lose viability before the endocarp breaks down in the seedbank sufficiently to allow germination to commence, an early controlled burn could shorten the time for endocarp weakening.

However, some obligate-seeding *Persoonia* species require an interval of at least 8 years between fires to allow juvenile plants to reach reproductive maturity (Weston, 2003). This part of the life-cycle is still poorly understood; the length of the primary juvenile period for only six *Persoonia* species is known (Appendix 1).

Seed production areas

The goal for any species being re-introduced to an ecosystem is to produce self-sustaining populations. Genetic variation in local provenances is also an important consideration for restoration practices. For example, non-locally sourced material could have negative consequences for persistence due to factors such as maladaptation, where the non-local material is selected against local genotypes, leading to higher mortality rates (Bischoff et al., 2010). However, there may be occasions when non-local material is required, such as providing sufficient genetically-diverse material to buffer rare species from future environmental change (Broadhurst et al., 2008). It is not our intention to discuss the various merits of local vs. non-local material. Rather, we describe a more immediate requirement of generating a source of high quality seed.

Seed is often sourced from the wild in large quantities for restoration projects (Broadhurst et al. 2015) but issues including reproductive failure, low abundance, plant age and phenological variation can hamper the availability of large seed collections. Rare species often have life-history

traits that can create barriers to fecundity and survival (Abeli & Dixon, 2016; Reiter et al., 2016). Rare or threatened *Persoonia* species, including *Persoonia pauciflora* and *Persoonia bargoensis*, have poor seed-production years. Successful translocations of rare species (and, indeed, other restoration practices) rely on an understanding of the ecological requirements of the species (Abeli & Dixon 2016). Tellingly, in an analysis of 249 plant species worldwide a lack of species biology knowledge was found to be a main cause of reintroduction failure (Godefroid et al., 2011). A lack of data on the pollination biology was concluded to have caused failure in previous orchid reintroduction attempts (Reiter et al. 2016) and there is strong evidence that an understanding of pollination ecology is also important for rare *Persoonia* species (Rymer et al., 2005).

Plants from known sources can be established in seed production ‘orchards’ to provide seed that is genetically diverse and representative of a robust population, and as an alternative to overharvesting wild populations (Nevill et al. 2016). This requires an agronomic approach for maintaining and harvesting and the ecological requirements of a species can be implemented to produce large quantities of high-quality seed for collection. In *Persoonia*, for example, manually hand-pollinating flowers to promote outcrossing could result in a higher fruit set of large quantities of seeds for restoration programs. Many situations may also require short- or long-term *ex situ* seed storage prior to restoration projects. In this regard, *ex situ* seedbanks provide an important supportive role. High-quality collections ensure that seeds are more robust for *ex situ* storage conditions.

Conclusions

There is great potential for *Persoonia* species to be successfully mass-propagated from seeds and included more widely in restoration and horticulture projects. Research to date has added several pieces to the puzzle; however, the focus on optimising germination success has meant that the ecological factors affecting this process have not been widely tested. We also stress that maximising germination does not necessarily translate into maximum seedling survival. Similarly, assessing one seed batch from a population does not provide any interpretation for that population’s health beyond the collection year. *Persoonia* propagation requires integrated collaboration between the restoration and horticulture industries with rigorous scientific research to achieve successful reintroduction and conservation practices. We have highlighted several key areas for future *Persoonia* seed research (summarised in Fig. 4). The ecological requirements of *Persoonia*, in terms of climate, plant-pollinator interactions, and seed biology, are important for obtaining sufficient quotas of high-quality seed to meet the growing needs of conservation, restoration and horticulture.

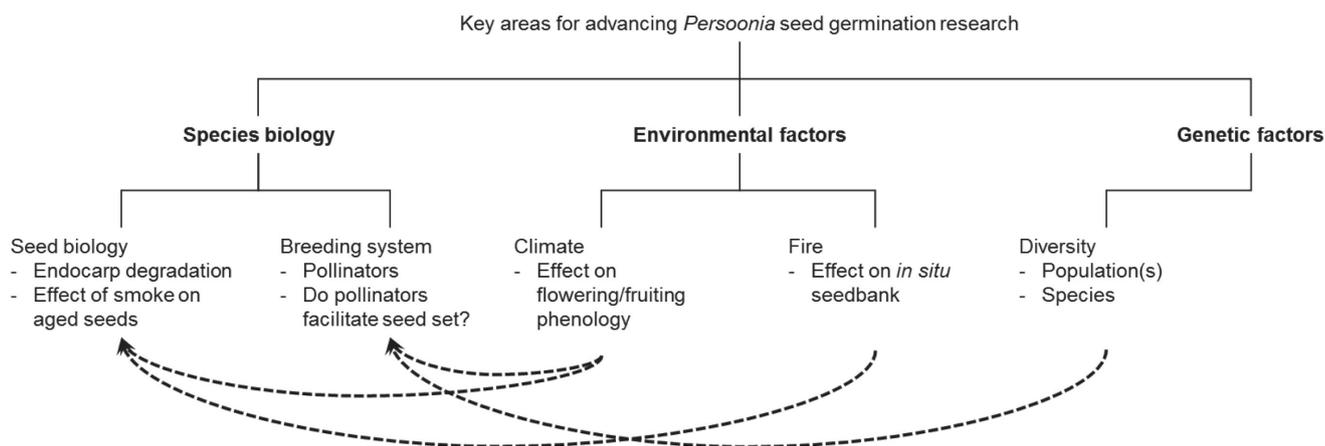


Fig. 4. Key areas that must be addressed for progressing *Persoonia* seed research. This requires an integrative approach, where data from environmental and genetic factors help to inform key questions surrounding seed biology and the breeding system.

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APPENDIX 1
Database table of biological and ecological species characteristics of 115 taxa (including all 99 species) of *Persoonia*.

Species	Distribution (state)	Bioregion ¹	Growth form	Longev (yrs) ²	Juv Period (yrs) ²	Habitat ³	Phylogeny ⁴	Rarity ⁵	Fire resp ⁶	Breed Syst ⁷	Fruit set ⁸	Ovule num ⁹	Germ ¹⁰
<i>Persoonia acerosa</i>	NSW	SEH, SYB	spreading shrub			DSF	Lanceolata	Vu**†	1			1	
<i>Persoonia acicularis</i>	WA	GES, YAL	erect shrub			MH	Quinquenervis	NL	2			1	
<i>Persoonia acuminata</i>	NSW	NET, NNC, SEH	prostrate to spreading shrub			WSF	Lanceolata	NL				1	
<i>Persoonia adenantha</i>	QLD, NSW	SEQ	erect shrub or small tree			DSF, H, RF, WSF	Lanceolata	NL	3			1	
<i>Persoonia amaliae</i>	QLD	BBN, CMC, MGD, SEQ	erect shrub to tree			DSF, VF	Lanceolata	NL	3			2	
<i>Persoonia angustiflora</i>	WA	AVW, COO, GES, JAF, SWA	erect shrub			DW, H	Quinquenervis	NL	2			1	
<i>Persoonia arborea</i>	VIC	AUA, NET, SEH	erect shrub or small tree			WSF	Arborea	NL	1			1	
<i>Persoonia asperula</i>	NSW, VIC	AUA, SEC, SEH	prostrate to erect shrub			H, WSF	Lanceolata	Th*	1			1	
<i>Persoonia baeckeoides</i>	WA	MAL	erect shrub			H	Lanceolata	NL				1	
<i>Persoonia bargoensis</i>	NSW	SYB	erect shrub			DSF, DW	Lanceolata	Er*, Vu†	1	SC		1	
<i>Persoonia biglandulosa</i>	WA	GES, YAL	erect to decumbent shrub			H	Teretifolia	NL	2			2	
<i>Persoonia bowgada</i>	WA	CAR, GES, YAL	erect to spreading shrub			DW, H	Quinquenervis	NL				1	
<i>Persoonia brachystylis</i>	WA	GES	erect to spreading shrub			H	Teretifolia	NL				2	
<i>Persoonia brevifolia</i>	NSW, VIC	SEC, SEH	erect shrub			DSF, WSF	Lanceolata	NL				2	
<i>Persoonia brevithachis</i>	WA	ESP, MAL	erect to spreading shrub			H	Ruffiflora	NL				2	
<i>Persoonia chamaepeuce</i>	NSW, VIC	AUA, NET, NNC, NSS, RIV, SCP, SEC, SEH, SYB, SVP, VIM	prostrate shrub		4	DSF	Lanceolata	NL	2			1	
<i>Persoonia chamaeptyxis</i>	NSW	SCP, SEH, SYB	prostrate shrub			DSF, H	Lanceolata	NL	1			1	
<i>Persoonia chapmaniana</i>	WA	AVW, GES, SWA	erect shrub			DSF	Chapmaniana	NL				2	
<i>Persoonia comata</i>	WA	AVW, GES, JAF, SWA	erect to spreading shrub			DSF, DW, H	Teretifolia	NL	2			2	
<i>Persoonia confertiflora</i>	NSW, VIC	AUA, NSS, RIV, SCP, SEC, SEH	erect to decumbent shrub			DW, WSF	Laurina	NL	2			1	
<i>Persoonia conjuncta</i>	NSW	NNC	erect shrub or small tree			DSF, WSF	Lanceolata	NL	3			1	
<i>Persoonia cordifolia</i>	WA	MAL	erect shrub			H	Dillwynioides	NL	1			2	

Species	Distribution (state)	Bioregion ¹	Growth form	Longev (yrs) ²	Juv Period (yrs) ²	Habitat ³	Phylogeny ⁴	Rarity ⁵	Fire resp ⁶	Breed Syst ⁷	Fruit set ⁸	Ovule num ⁹	Germ ¹⁰
<i>Persoonia coriacea</i>	WA	AVW, COO, GES, GVD, JAF, MAL, MUR, YAL	erect to spreading shrub			H, MH	Lanceolata	NL	2			2	
<i>Persoonia cornifolia</i>	QLD, NSW	BBS, NAN, NET, NNC, SEQ, SYB	erect to spreading shrub			DSF, DW	Lanceolata	NL	2			1	
<i>Persoonia curvifolia</i>	NSW	BBS, COP, NET, NSS, RIV, SEH, SYB	erect to spreading shrub			DSF, DW	Lanceolata	NL				3	
<i>Persoonia cuspidifera</i>	NSW	BBS	erect shrub			DSF, DW	Lanceolata	NL				1	
<i>Persoonia cymbifolia</i>	WA	ESP, MAL	spreading shrub			H, RO	Lanceolata	NL	2			2	
<i>Persoonia daphnoides</i>	NSW	NET	prostrate shrub			DSF, DW	Lanceolata	NL				1	
<i>Persoonia dillwynioides</i>	WA	ESP	erect to spreading shrub			H	Dillwynioides	NL				2	
<i>Persoonia elliptica</i>	WA	ESP, JAF, SWA, WAR	erect shrub to small tree			DSF, DW	Lanceolata	NL	3		39%	2	
<i>Persoonia falcata</i>	QLD, NT, WA	ARC, ARP, BBN, BBS, CEA, CEK, CMC, CYP, DAB, DAC, DAL, DEU, EIU, GFU, GSD, GUC, GUP, MGD, NOK, OVP, PCK, TIW, VIB, WET	erect shrub to small tree			DSF, DW, H, RO	Teretifolia	NL	3			2	
<i>Persoonia fastigiata</i>	NSW	BBS, NET	erect to spreading shrub			DSF, DW	Lanceolata	NL	2			2	
<i>Persoonia filiformis</i>	WA	GES, SWA	erect shrub			H	Quinquenervis	NL	2			1	
<i>Persoonia flexifolia</i>	WA	ESP	erect to spreading shrub			H	Dillwynioides	NL				2	
<i>Persoonia glaucescens</i>	NSW	SYB	erect shrub			DSF	Lanceolata	En*, Vu†	1	NC	86%	1	
<i>Persoonia graminea</i>	WA	JAF, WAR	erect to decumbent shrub			DSF, H	Graminea	NL	1			2	
<i>Persoonia gunnii</i>	TAS	BEL, TCH, TSR, TWE	erect shrub			AH, RF, WSF	Gunnii	NL				2	
<i>Persoonia hakeiformis</i>	WA	AVW, MAL	erect to spreading shrub			DSF, H, MH	Teretifolia	NL				2	
<i>Persoonia helix</i>	WA	COO, ESP, MAL	erect to spreading shrub			DW, H, MH	Lanceolata	NL	2			2	
<i>Persoonia hexagona</i>	WA	AVW, GES, YAL	erect to spreading shrub			DW	Quinquenervis	NL				1	
<i>Persoonia hindii</i>	NSW	SB	small suckering shrub	indefinite		DSF	Lanceolata	En*	2			1	
<i>Persoonia hirsuta</i> subsp. <i>evoluta</i>	NSW	NSS, SB	spreading decumbant shrub			DSF	Lanceolata	En**†	1			1	

Species	Distribution (state)	Bioregion ¹	Growth form	Longev (yrs) ²	Juv Period (yrs) ²	Habitat ³	Phylogeny ⁴	Rarity ⁵	Fire resp ⁶	Breed Syst ⁷	Fruit set ⁸	Ovule num ⁹	Germ ¹⁰
<i>Persoonia hirsuta</i> subsp. <i>hirsuta</i>	NSW	NSS, SB	spreading decumbent shrub			DSF	Lanceolata	En*†	1			1	
<i>Persoonia inconspicua</i>	WA	AVW, COO	erect to spreading shrub			H, MH	Ruffiflora	NL				2	
<i>Persoonia togyna</i>	QLD	SEQ	erect shrub to small tree			DSF, WSF	Lanceolata	NL				1	
<i>Persoonia isophylla</i>	NSW	SYB	erect to spreading shrub			DW	Lanceolata	NL	1			1	
<i>Persoonia juniperina</i>	NSW, SA, TAS, VIC	BEL, FLB, FUR, KAN, KIN, MDD, NCP, SCP, SEC, SEH, SVP, TCH, TNM, TNS, TSE, TSR, TWE, VIM	erect to spreading shrub			DSF, H	Lanceolata	NL	2	SC	83%	2	
<i>Persoonia kararae</i>	WA	YAL	erect shrub			S	Teretifolia	NL				2	
<i>Persoonia katerae</i>	NSW	NNC	erect shrub or small tree			DSF, H	Lanceolata	NL					
<i>Persoonia lanceolata</i>	NSW	NET, NNC, SEC, SEH, SEQ, SYB	erect to spreading shrub	25–60	6–8	DSF	Lanceolata	NL	1	NC	97%	2	~10%
<i>Persoonia laurina</i> subsp. <i>intermedia</i>	NSW	SEH, SYB	erect to spreading shrub	25–60		DSF	Lanceolata	NL	2			1	
<i>Persoonia laurina</i> subsp. <i>laurina</i>	NSW	NNC, NSS, SEH, SYB	erect to spreading shrub	25–60		DSF	Lanceolata	NL	2			1	
<i>Persoonia laurina</i> subsp. <i>letogyna</i>	NSW	SEH, SYB	erect to spreading shrub	50–100		DSF	Laurina	NL	2			1	
<i>Persoonia laxa</i>	NSW	SYB	ground-dwelling shrub			DSF	Lanceolata	NL				2	
<i>Persoonia leucopogon</i>	WA	COO, MUR	erect to decumbent shrub			H	Lanceolata	NL				2	
<i>Persoonia levis</i>	NSW, VIC	NNC, SEC, SEH, SEQ, SYB	erect shrub or small tree	>60		DSF, DW	Lanceolata	NL	3	NC	55%	2	50%
<i>Persoonia linearis</i>	NSW, VIC	BBS, NET, NNC, NSS, SEC, SEH, SEQ, SYB	erect shrub or small tree			DSF, DW, WSF,	Lanceolata	NL	3			2	
<i>Persoonia longifolia</i>	WA	ESP, JAF, SWA, WAR	erect shrub or small tree			DSF, DW	Longifolia	NL	3		98%	2	95%
<i>Persoonia manotricha</i>	WA	AVW, MUR, YAL	erect shrub or small tree			RO, S	Quinquenervis	NL				2	
<i>Persoonia marginata</i>	NSW	SEH, MDD	spreading to decumbent shrub			DSF	Lanceolata	NL	2			2	
<i>Persoonia media</i>	QLD, NSW	NET, NNC, SEQ	erect to spreading shrub	20	6	RF, WSF	Lanceolata	NL	2			1	

Species	Distribution (state)	Bioregion ¹	Growth form	Longev (yrs) ²	Juv Period (yrs) ²	Habitat ³	Phylogeny ⁴	Rarity ⁵	Fire resp ⁶	Breed Syst ⁷	Fruit set ⁸	Ovule num ⁹	Germ ¹⁰
<i>Persoonia micranthera</i>	WA	ESP	prostrate to decumbent shrub			H, RO	Graminea	C†* En†	1			2	
<i>Persoonia microphylla</i>	NSW	SEC, SEH, SYB	prostrate to erect shrub			DSF	Lanceolata	NL				1	
<i>Persoonia mollis</i> subsp. <i>calayi</i>	NSW	SEC, SEH, SYB	prostrate to erect shrub			DSF	Lanceolata	NL	1			2	
<i>Persoonia mollis</i> subsp. <i>ledifolia</i>	NSW	SEC, SEH, SYB	erect shrub			DSF	Lanceolata	NL	1			2	
<i>Persoonia mollis</i> subsp. <i>leptophylla</i>	NSW	SEH, SYB	erect shrub			DW	Lanceolata	NL	1			2	
<i>Persoonia mollis</i> subsp. <i>livens</i>	NSW	SEH, SYB	erect shrub			DSF, DW	Lanceolata	NL	1			2	
<i>Persoonia mollis</i> subsp. <i>maxima</i>	NSW	SYB	erect shrub		10	DSF	Lanceolata	En*†	1	NC	89%	2	
<i>Persoonia mollis</i> subsp. <i>mollis</i>	NSW	SEH, SYB	prostrate to erect shrub			DSF	Lanceolata	NL	1			2	
<i>Persoonia mollis</i> subsp. <i>nectens</i>	NSW	SYB	prostrate to erect shrub		>4	DSF	Lanceolata	NL	1	NC	91%	2	~40%
<i>Persoonia mollis</i> subsp. <i>revoluta</i>	NSW	SEC, SEH, SYB	prostrate to decumbent shrub			DSF	Lanceolata	NL	1			2	
<i>Persoonia moscatii</i>	TAS	TWE	prostrate shrub			AH, RF, WSF	Gunnii	NL				2	
<i>Persoonia muelleri</i> subsp. <i>angustifolia</i>	TAS	TCH, TNS, TSR, TWE	erect shrub			AH, RF	Gunnii	NL				2	
<i>Persoonia muelleri</i> subsp. <i>densifolia</i>	TAS	TSR, TWE	erect shrub to small tree			H	Gunnii	NL				2	
<i>Persoonia muelleri</i> subsp. <i>muelleri</i>	TAS	BEL, TCH, TNS, TSE, TSR, TWE	erect shrub to small tree			AH, WSF	Gunnii	NL				2	
<i>Persoonia myrtilloides</i> subsp. <i>cunninghamii</i>	NSW	NSS, SYD	erect to spreading shrub			DSF, DW	Lanceolata	NL	1	NC	70%	2	
<i>Persoonia myrtilloides</i> subsp. <i>myrtilloides</i>	NSW	SEC, SEH, SYD	erect to spreading shrub			DSF, DW, H	Lanceolata	NL	1	NC		2	
<i>Persoonia nutans</i>	NSW	SYB	erect to spreading shrub			DW	Lanceolata	En*†	1			2	
<i>Persoonia oblongata</i>	NSW	NSS, SEH, SYB	erect to spreading shrub			DSF, DW, RO	Lanceolata	NL	1			2	
<i>Persoonia oleoides</i>	NSW	NET, NNC	erect to spreading shrub			DSF, WSF	Lanceolata	NL	2			1	
<i>Persoonia oxycoccoides</i>	NSW	NSS, SEC, SEH, SYB	prostrate to spreading shrub			H, DSF	Lanceolata	NL	2			1	

Species	Distribution (state)	Bioregion ¹	Growth form	Longev (yrs) ²	Juv Period (yrs) ²	Habitat ³	Phylogeny ⁴	Rarity ⁵	Fire resp ⁶	Breed Syst ⁷	Fruit set ⁸	Ovule num ⁹	Germ ¹⁰
<i>Persoonia papillosa</i>	WA	GES	erect shrub			S	Quinquenervis	NL				1	
<i>Persoonia pauciflora</i>	NSW	SYB	spreading shrub			DSF, DW	Lanceolata	Cr**†	1			1	
<i>Persoonia pentasticha</i>	WA	AVW, GES, MUR, YAL	erect to spreading shrub			H	Chapmaniana	NL	2			2	
<i>Persoonia pertinax</i>	WA	COO, GVD	erect to spreading shrub			DW	Lanceolata	NL				2	
<i>Persoonia pinifolia</i>	NSW	SYB	erect shrub or small tree	25—60	5	DSF	Lanceolata	NL	1			1	
<i>Persoonia procumbens</i>	NSW	NET, NNC	prostrate shrub			DSF, DW	Lanceolata	NL				1	
<i>Persoonia prostrata</i>	QLD	SEQ	prostrate shrub			DSF, DW, H, S	Lanceolata	Ex					
<i>Persoonia pungens</i>	WA	AVW, GES	spreading to decumbent shrub			H	Lanceolata	NL	2			1	
<i>Persoonia quinquenervis</i>	WA	AVW, COO, ESP, GES, JAF, MAL, SWA	erect to spreading shrub			DSF, DW, H, MH	Quinquenervis	NL	2			1	
<i>Persoonia recedens</i>	NSW	SYB	prostrate to spreading shrub			DSF	Lanceolata	NL				1	
<i>Persoonia rigida</i>	NSW, VIC	AUA, BBS, NSS, SEC, SEH, SYB, RIV, VIM	erect to decumbent shrub			DSF	Lanceolata	NL	1	SC	67%	2	
<i>Persoonia rudis</i>	WA	AVW, GES, SWA	erect shrub			DSF	Quinquenervis	NL	1			1	
<i>Persoonia rufa</i>	NSW	NET, NNC	erect to spreading shrub			DSF, RO	Lanceolata	NL	1			1	
<i>Persoonia rufflora</i>	WA	AVW, GES, JAF, MAL, SWA	erect to spreading shrub			DW, H, MH	Rufflora	NL	2			2	
<i>Persoonia saccata</i>	WA	JAF, SWA, WAR	erect to spreading shrub			DSF, DW	Teretifolia	NL	2			2	
<i>Persoonia saundersiana</i>	WA	AVW, COO, GES, MAL, MUR, SWA, YAL	erect to spreading shrub			H, MH	Teretifolia	NL				2	
<i>Persoonia scabra</i>	WA	ESP, MAL	erect to spreading shrub			MH	Quinquenervis	NL	2			1	
<i>Persoonia sericea</i>	QLD, NSW	BBS, DRP, NAN, NET, NNC, NSS, SEQ, SYB	erect to spreading shrub			DSF, WSF	Lanceolata	NL	2			2	88%
<i>Persoonia sivatrica</i>	NSW, VIC	SEC, SEH	erect shrub or small tree			DSF	Laurina	NL	2			1	
<i>Persoonia spathulata</i>	WA	ESP, MAL	erect to spreading shrub			H	Quinquenervis	NL	1			1	
<i>Persoonia stradbrokensis</i>	QLD, NSW	NNC, SEQ	erect shrub to small tree			DSF	Lanceolata	NL	3			1	

Species	Distribution (state)	Bioregion ¹	Growth form	Longev (yrs) ²	Juv Period (yrs) ²	Habitat ³	Phylogeny ⁴	Rarity ⁵	Fire resp ⁶	Breed Syst ⁷	Fruit set ⁸	Ovule num ⁹	Germ ¹⁰
<i>Persoonia stricta</i>	WA	AVW, COO, ESP, JAF, MAL	erect to spreading shrub			H, MH	Quinquenervis	NL	2			1	
<i>Persoonia stricta</i>	WA	AVW, GES, MUR, YAL	spreading shrub			DW	Teretifolia	NL				2	
<i>Persoonia subtilis</i>	NSW	BBN, BBS	spreading to decumbent shrub			DSF, DW	Lanceolata	NL	2			2	
<i>Persoonia subvelutina</i>	ACT, NSW, VIC	AUA, NSS, SEH	spreading shrub or small tree			DW, WSF	Arborea	NL				1	
<i>Persoonia sulcata</i>	WA	AVW, JAF, SWA	erect to spreading shrub			DW, RO	Quinquenervis	NL	2			2	
<i>Persoonia tenuifolia</i>	QLD, NSW	BBS, NAN, NET, NNC, SEQ	erect to decumbent shrub			DSF, H	Lanceolata	NL	2			2	
<i>Persoonia teretifolia</i>	WA	AVW, ESP, JAF, MAL	erect to spreading shrub			H, MH	Teretifolia	NL				2	
<i>Persoonia terminalis</i> subsp. <i>recurva</i>	QLD, NSW	BBS, NET	erect to spreading shrub			DSF	Lanceolata	NL	1			2	
<i>Persoonia terminalis</i> subsp. <i>terminalis</i>	QLD, NSW	NET	erect to spreading shrub			DSF	Lanceolata	NL	1			2	
<i>Persoonia trinervis</i>	WA	AVW, ESP, GES, JAF, MAL, SWA	erect to spreading shrub			DW, H, MH	Quinquenervis	NL	2			1	
<i>Persoonia tropica</i>	QLD	EIU, WET	erect shrub or small tree			DSF, WSF	Lanceolata	NL				2	
<i>Persoonia virgata</i>	QLD, NSW	BBN, BBS, CMC, NNC, SEQ	erect shrub			DSF	Lanceolata	NL	1	NC	49%	2	100%
<i>Persoonia volcanica</i>	QLD, NSW	SEQ	erect shrub			DSF, WSF, RF	Lanceolata	NL				1	

¹ Bioregions were extracted from Australia's Virtual Herbarium (avh.ala.org.au) on 23/04/2018; the list IBRA7 region codes and names are available from <http://www.environment.gov.au/land/nrs/science/ibra/ibra7-codes> (accessed on 23/04/2018)

² Obtained from Benson & McDougall (2000)

³ AH = alpine heath, DSF = dry sclerophyll forest, DW = dry woodland, H = heath, MH = mallee heath, RF = rainforest, RO = rocky outcrops, S = sandplains, WSF = wet sclerophyll forest, VF = vine forest

⁴ Obtained from Weston (2003)

⁵ Cr = critically endangered, En = endangered, Ex = extinct, NL = not listed under state or national legislation, Th = threatened, Vu = vulnerable; * threatened status listed under state/territory legislation; † threatened status listed under the national EPBC Act

⁶ Ability to resprout following fire: 1 = cannot resprout and reliant on seeds, 2 = can resprout from base only, 3 = can resprout from base and stems; Rymer (2006)

⁷ NC = non-compatible breeding system, SC = self-compatible breeding system; reference list available in Appendix 2

⁸ Highest percentage fruit set from open pollination as of 23/04/2018; reference list available in Appendix 2

⁹ Obtained from Rymer (2006)

¹⁰ Highest germination value reported in the literature as of 23/04/2018; reference list available in Appendix 2

Appendix 2

References for the data on *Persoonia* breeding system, fruit set and germination listed in Table 1 and Appendix 1.

Breeding System

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