Assessing fertility in horticultural selections of *Agapanthus*©

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INTRODUCTION

Agapanthus is a genus of herbaceous, perennial, and rhizomatous monocots that are endemic to Southern Africa (Leighton, 1965). There are six currently accepted species, several hybrids, and numerous cultivars especially involving *A. praecox* and its subspecies (Snoeijer, 2004). Collectively, these are known under the common names agapanthus, African lily, and lily of the Nile.

Their low maintenance and abundance of flowers have made agapanthus a deservedly popular garden plant, widely grown throughout warm temperate regions of the world. However, agapanthus have typically high seed production and other undesirable weedy traits. These traits have allowed agapanthus to escape cultivation and become naturalized in several countries.

In a response to demands from the public to have selections they can still buy and grow, and from government agencies and environmental groups for less invasive alternatives, New Zealand and more recently Australian nursery industries have released a range of cultivars marketed under various terms, such as "eco-friendly", "environment safe", "low-fertility", "non-invasive", "self-sterile" and "sterile".

However, these claims of sterility, and associated terms, were rather anecdotal and had not previously been substantiated by underpinning research. This paper outlines several approaches for assessing fertility of horticultural selections of agapanthus.

TAXONOMY AND SPECIES OF AGAPANTHUS

Agapanthus have been placed in several different families including the *Alliaceae*, in their own family the *Agapanthaceae*, and in the old catch-all concept of the *Liliaceae* (the lily family). The Angiosperm Phylogeny Group classification is based on DNA sequencing studies and places *Agapanthus* in the *Amaryllidaceae* family (under a monogeneric subfamily, *Agapanthoideae*; APG IV, 2016).

The most recent revision of *Agapanthus* species and cultivars is by Snoeijer (2004) who accepted Zonneveld and Duncan's (2003) proposal to recognize six species equally divided into two sections:

1) Section *Lilacinipollini*:
   - *A. campanulatus* (subspp. *campanulatus* and *patens*)
   - *A. caulescens* (subspp. *angustifolius*, *caulescens* and *gracilis*)
   - *A. coddii*.
2) Section *Ochraceipollini*:
   - *A. africanus* (subspp. *africanus* and *walshii*)
   - *A. inapertus* (subspp. *inapertus*, *hollandii*, *intermedius*, *parviflorus*, and *pendulus*)
   - *A. praecox* (subspp. *minimus*, *orientalis* and *praecox*).

The Plant List (www.theplantlist.org/tpl1.1/search?q=agapanthus) currently rejects some of the subspecies accepted by Zonneveld and Duncan (2003), and accepts some other

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species in *Agapanthus.* These include *A. dyeri* Leight. (considered by Zonneveld and Duncan (2003) as a synonym of *A. inapertus* subsp. *intermedius* Leight.), *A. nutans* Leight. (considered by Zonneveld and Duncan (2003) as a synonym of *A. caulescens*), and *A. walshii* L.Bolus (reduced to the new combination *A. africanus* subsp. *walshii* (L.Bolus) Zonn. & G.D.Duncan by Zonneveld and Duncan (2003)).

AGAPANTHUS AS A VALUED GARDEN PLANT

Snoeijer (2004) cited a figure of 625 agapanthus cultivars that have been named worldwide, and provided a comprehensive listing of them that included synonyms, origins, descriptions, and notes. Some of the cultivars listed by Snoeijer (2004) are historic and no longer commonly available, others are only available in certain countries, and new cultivars have been raised and released since then.

A range of cultivars are popular and widely available in world markets with mild climates, such as Australia, New Zealand, California, South Africa, and warmer parts of the UK. *Agapanthus* taxa are grown commercially in large quantities. They are easy to propagate through division of clumps and through tissue culture; this clonal propagation is essential for retaining the characteristics of the named selections. *Agapanthus* taxa are also easily propagated from seed, but this method should only be used for bulk production of species and subspecies, and not for cultivar propagation.

Agapanthus possess many horticulturally desirable qualities, including minimal pest and disease issues, low maintenance, hardiness, drought tolerance, able to grow in partial shade or full sun, well-suited for coastal plantings, perennial growth habit, fast growth, lush foliage, showy flowers and long flowering season.

They are useful garden, container and amenity plants used for mass plantings in herbaceous borders, along driveways and roadside banks, and on traffic islands (Figures 1 and 2).

Figure 1. Mass planting of a medium height white-flowered agapanthus cultivar to enhance an industrial street front. Photo: Murray Dawson.

Figure 2. Tall-growing white- and blue-flowered *Agapanthus praecox* subsp. *orientalis* planted between driveways. Photo: Murray Dawson.

Agapanthus has resistance to glyphosate (e.g., Roundup®) so amenity plantings can easily be kept clean of emerging weeds by spraying the ground around them—agapanthus are not bothered by minor overspray.

Their strap-like leaves are usually green or with a blue-green waxy (glaucous) surface and leaves of some selections have purple bases. Several cultivars have green leaves that are variegated with white and/or yellow bands (Figures 3 and 4).

Figure 3. *Agapanthus* 'Goldstrike', a variegated green- and white-leaved cultivar. Photo: Lyndale Nurseries.

Figure 4. *Agapanthus* 'Tigerleaf', a variegated green- and yellow-leaved cultivar. Photo: Barrie McKenzie.

Furthermore, their thick rhizomatous growth makes them useful for stabilising slip-prone land, and their fleshy leaves are fire resistant and can regrow from the base of the plants.

Although blue and white are the two basic flower colors often stated for agapanthus, in reality pure blue is rare and instead comes in numerous tones of violet, purple, and lavender. Flowers can also be pure white or off-white. Flowers are usually six-tepaled (The term tepal is used when petals and sepals are relatively indistinguishable from each other.), although some selections have more numerous tepals—those flowers are loosely referred to as "double" or "semi-double". Agapanthus flowers are sometimes used in the cut flower market (Burge et al., 2010).

As a general guide, selections range in stature from about (100-)200 to 500 mm for the low-growing (so-called "dwarf") selections; from 600 mm to 1.2 m for medium-sized selections; and up to 1.8(-2) m, including height of flower stems, for the tallest cultivars. Over time, many of the dwarf selections will exceed the ranges stated here and in nursery catalogues, but their foliage always remains narrow, linear, and held relatively close to the ground.

The great majority of tall-growing cultivars are selections or hybrids of *A. praecox* subsp. *orientalis*. Most narrow-leaved and low-growing cultivars are selections of *A. praecox* subsp. *minimus*. These dwarf cultivars are well-suited to smaller garden areas and have become more popular than the taller growing selections.

AGAPANTHUS AS A WEED

Agapanthus is reported to have naturalized in countries including Australia, New Zealand, Jamaica, Mexico, Ethiopia, and the UK.

Wild populations of agapanthus can threaten remnant indigenous ecosystems, and flourish in coastal, frost-free (or lightly frosted) warm temperate climates. Agapanthus is tolerant of a wide range of soil types and growing conditions—from dry exposed environments to damp, lightly-shaded sites. Among other habitats, it has naturalized in coastal areas (Figure 5), along roadsides, and in wasteland. There is no biocontrol available, and (as previously mentioned) it is relatively resistant to herbicides.

Figure 5. Blue- and white-flowered *Agapanthus praecox* subsp. *orientalis* naturalized at Opito Bay on the Coromandel Peninsula. Photo: Trevor James.

Agapanthus can spread by vigorous rhizomatous growth eventually forming dense and robust monocultures. Its rhizomes are extremely difficult to dig out and remove, and any left behind may regrow. It can also spread by the illegal dumping of garden waste (Figure 6).

Figure 6. Roadside dumping of *Agapanthus praecox* subsp. *orientalis*. Photo: Murray Dawson.

Agapanthus typically produces abundant seed (Figure 7) that germinates readily. This seed can spread by wind and water—particularly along drains and waterways (Figure 8). Deadheading (removing seed heads before the capsules split open) to reduce seed dispersal is timing dependent, and for large areas tedious and impractical.

Figure 7. Mature head of a typical high seed set, tall-growing *Agapanthus praecox* subsp. *orientalis*. Photo: Murray Dawson.

Figure 8. *Agapanthus* spreading along a drainage ditch, outside of a lifestyle block, north of Auckland city. Photo: Murray Dawson.

Furthermore, agapanthus sap causes severe ulceration of the mouth and is also a skin irritant (NPPA TAG, 2006). *Agapanthus praecox* is among the New Zealand National Poisons Centre's top 10 poisonous plants and regularly involved in childhood poisonings (Popay et al., 2010).

In New Zealand, *A. praecox* subsp. *orientalis* was first cultivated from about the mid-1800s, and, some 100 years later, was first recorded as naturalized in 1952 (Ford and Dawson, 2010; Dawson and Ford, 2012).

In recent years, there has been increasing concern about the spread and invasiveness of *A. praecox* subsp. *orientalis*, especially in the Auckland Region. In 2008, Auckland Council (then as Auckland Regional Council) banned large-growing forms of agapanthus from sale, propagation, distribution and exhibition in their municipal region. Also in 2008, *A. praecox* was added to the consolidated list of environmental weeds in New Zealand (Howell, 2008). There have also been recent submissions to include it as a National Pest Plant Accord (NPPA) species (NPPA TAG, 2006).

FERTILITY ASSESSMENTS IN NEW ZEALAND

The nursery industry responded to the Auckland Council ban of large-growing forms (*A. praecox* subsp. *orientalis*) by selling existing low-growing cultivars (dwarf selections with *A. praecox* subsp. *minimus* parentage) considered to be less invasive. Various terms have been applied to them, with various degrees of accuracy, including "Auckland safe", "eco-friendly", "environment safe", "low-fertility", "non-invasive", "self-sterile" and "sterile".

While some of these dwarf cultivars subjectively set less seed, others such as *A.* 'Streamline' are obviously highly fertile, and, with a shorter history of cultivation in New Zealand, may have similar weedy potential to the banned tall-growing forms.

Consequently, Auckland Council funded Manaaki Whenua Landcare Research to independently study and quantify fertility of agapanthus. Sterility and low fertility claims made of two dwarf cultivars, *A*. 'Finn' PVR (Figure 9) and *A*. 'Sarah' PVR (Figure 10), were used as exemplars and studied in detail. They were compared against tall-growing *A. praecox* subsp. *orientalis* and the fertile dwarf cultivar *A*. 'Streamline'. A wide range of techniques were used, to determine the levels of both male and female fertility, including pollen staining, pollen-tube germination, artificial crossing experiments (self, sib and outcrosses), seed counts and germination rates.

Figure 9. *Agapanthus* 'Finn' PVR, a low fertility cultivar with white flowers. Photo: Lyndale Nurseries.

Figure 10. *Agapanthus* 'Sarah' PVR, a low fertility cultivar with soft blue flowers. Photo: Lyndale Nurseries.

These techniques quantified male (pollen) and female fertility (seed set and germination), and confirmed low seed set in *A.* 'Finn' PVR and *A*. Sarah' PVR. However, as both were found capable of producing germinable seed neither could be described as sterile or seedless. The results of this work were presented as a technical report (Ford and Dawson, 2010) and popular articles (e.g., Dawson and Ford, 2012), and pointed the way to future research and fertility assessments.

In 2012 an Agapanthus Working Group (AWG) was established to co-ordinate activities of Auckland Council Biosecurity, Auckland Botanic Gardens, Manaaki Whenua Landcare Research, Plant & Food Research, New Zealand Plant Producers Incorporated, and the nursery production industry.

This partnership provides an excellent example of a council/regulator, botanic garden, researchers, and the commercial plant production industry all collaboratively working together. The AWG are seeking a "win-win", to resolve an environmental weeds issue by identifying true low fertility (ideally sterile) cultivars that the public and amenity sector can continue to buy, grow, and enjoy, and to support the plant production industry.

Drawing from the intensive fertility assessments made on relatively few exemplars by Ford and Dawson (2010), the AWG considered which techniques were easy, effective and scalable for assessing the full range of cultivars available on the market.

The AWG agreed that low female fertility (low seed set and seed viability) is more significant for reducing the weed risk to the environment than low male fertility (pollen viability). Low female fertility decreases propagule pressure and effectively restricts new plants escaping from cultivation into the wider environment via seed dispersal.

The AWG advocated in the first instance for a common garden experiment—a rapid non-quantitative screen to detect which of the commercially available cultivars have low seed set when grown together for comparison. The results would provide a shortlist of low seed setting candidates suitable for formal quantitative fertility assessments.

Field trials were initiated at the Auckland Botanic Gardens (ABG; Figure 11) in 2012 to assess natural (open-pollinated) seed set of existing cultivars planted together in a common garden environment (in contrast to Ford and Dawson's 2010 artificial crossing experiments in a glasshouse). In addition to the gardens staff (led by Emma Bodley and Rebecca Stanley), Ian Duncalf contributed his expertise to the outdoor trials. ABG are well-placed to conduct these agapanthus trials as they regularly run trials on other horticultural plant groups to determine superior cultivars to recommend for the Auckland region.

Figure 11. *Agapanthus* cultivar trials at Auckland Botanic Gardens, January 2017. Photo: ABG.

Open-pollinated seed set observations from the ABG trials were complemented by Murray Dawson who made separate observations for an agapanthus collection grown in glasshouses and shade-houses at Manaaki Whenua Landcare Research, Lincoln, Canterbury. Observations from both locations (Auckland and Canterbury) were made each fruiting season from 2012 until the present time (2017).

DEFINITIONS OF STERILITY AND MARKETING TERMS USED IN AGAPANTHUS

In 2016, the Agapanthus Working Group began re-evaluating definitions of infertility and criteria for "acceptable" levels of fertility for agapanthus cultivars. A workable definition was required for updating Auckland Council's Regional Pest Management Plan (RPMP), in light of the shortcomings of their previous RMPM, banning sale of all large-growing forms while still allowing all dwarf forms of agapanthus, irrespective of their fertility.

A biological definition of reproductive sterility in plants, for both female and male gametes, is to consistently have no seed capable of germination and no viable pollen produced. In other words, if the term "sterile" is being applied to agapanthus without qualifiers, this should refer to full female and male infertility. Full sterility could be considered the "gold-standard" to achieve in agapanthus selections, although of the two, female sterility is more significant when considering weedy potential.

For plants that never produce viable seed, but may have viable pollen, the following terms are appropriate: "seedless" (where all fruit capsules abort early in their development, or they persist but are either empty or with obviously undeveloped seed; Figure 12) or "female sterile" / "seed sterile" (where there can be a few apparently fully developed seed produced, but they are not capable of germination). Seed sterility of agapanthus cultivars restricts their dispersal and, like full sterility, is highly desirable.

Although these definitions may appear to be obvious, they have not been applied accurately or consistently in the trade. Furthermore, a distinction should be made between these biological definitions of infertility and marketing terms such as "Auckland safe", "eco-friendly", "environment safe", and "non-invasive". These marketing terms have also been used inconsistently and it's confusing to the consumer to have multiple terms with similar meanings.

To provide a straightforward marketing term for certified low fertility and/or sterile agapanthus, the name "Ecopanthus™" was trademarked in 2013 by the Nursery and Garden Industry Association of New Zealand Inc. (New Zealand Intellectual Property Office—967291—Trade Mark—Ecopanthus: https://app.iponz.govt.nz/app/Extra/IP/Mutual/Browse.aspx?sid=636523084468057031) (now the New Zealand Plant Producers Inc.). "Ecopanthus™"(or "Ecopanthus™ Series") may well be useful (main label) marketing terms, but for accuracy a fine-print qualifier such as "Seedless agapanthus" or "Produces less than 2% viable seed" could be considered for mandatory labelling purposes.

Figure 12. Undeveloped seed in *Agapanthus* is easy to recognize: upon maturity of the fruit capsule, inviable seed is lighter colored, smaller, and flattened (top row). In contrast, filled, "viable" seed is black / dark brown and broader (bottom row). Photo: Murray Dawson.

Adoption of "Ecopanthus™" for certified low fertility agapanthus cultivars would rely on agreement within the nursery industry and availability of the NZPPI trademarked name to all growers. There would also need to be agreed exemptions for certified low fertility agapanthus from regulatory authorities (such as exemptions within regional councils' RPMP's and potentially in the New Zealand Ministry of Primary Industries NPPA listings) that may ban propagation, sale, and distribution of the fertile counterparts.

FIELD TRIAL RESULTS: OPEN-POLLINATED SEED SET OBSERVATIONS OF EXISTING CULTIVARS

The natural (open-pollinated) seed set results at Auckland Botanic Gardens were compared with seed set observations made at Manaaki Whenua Landcare Research in Lincoln. The results were relatively consistent for each cultivar between locations and field sites (outdoor evaluation trial beds in Auckland, and glasshouses and shade-houses at Lincoln), and between years (2012-2017). The results were also reasonably consistent with earlier observations made by Jennifer Barrett from plants growing in Auckland Botanic Gardens (unpubl. data, June 2010). This consistency confirmed that open-pollinated seed set observations were a useful screening technique, and our combined results are summarized in Tables 1-3.

Collectively, Table 1-3 lists a broad range of 40 named cultivars currently available in New Zealand and assessed in this paper. Synonyms and brief descriptions are provided for each cultivar, to help confirm their identity. Descriptions based on our living material were closely compared to those published by Snoeijer (2004) and in Plant Variety Rights databases. This information helps resolve instances where the same selection is sold under different names and different selections are sold under the same name.

Although the female fertility descriptors (putative sterile, very low, low, medium, high, very high) are not quantified here with seed set percentages, they do provide an effective coarse screen of the best candidates for more critical evaluation.

Many of the stated plant heights in Tables 1-3 for foliage and flower heads (inflorescences) were measured from well-established plants at Lincoln and Auckland, and thus may be greater than descriptions in nursery catalogues and the size classes given earlier in this paper (dwarf, medium, tall), especially those of the dwarf cultivars. Cultivars have the usual six tepals unless otherwise stated in Tables 1-3 for the multi-tepaled / semi-double / double-flowered cultivars (Figures 13-16). Six-tepaled flowers produce the usual three-locular seed capsules, whereas flowers with eight tepals go on to develop four-locular seed capsules.

Table 1. Putative seedless and confirmed lowest female fertility cultivars of agapanthus based on completed open-pollinated seed set observations.

Cultivar	Female fertility/seed set	Brief description
A. 'Agapetite' PBR, PVR	Sterile?	Very dwarf and compact stature—one of the smallest growing cultivars, foliage to 100 mm tall, short wide blue-green leaves up to 130 mm long and 17 mm wide, white flowers, additional tepals (about 9), 7-23 flowers per inflorescence, flower heads to 270 mm tall.
A. 'Blue Finn' PVR (was provisionally named *A*. 'Ecostorm')	Sterile?	Dwarf stature, foliage to 170 mm tall, short wide green leaves up to 280 mm long and 17 mm wide, blue flowers, 18-20 flowers per inflorescence, flower heads to 350 mm tall.
A. 'Dorothy Edwards'	Sterile?	Medium stature, foliage to 670 mm tall, wide blue-green leaves up to 540 mm long and 40 mm wide, dark blue flowers, numerous additional tepals (24-30), 59-94 flowers per inflorescence, flower heads to 650 mm tall.
A. 'Finn' PVR	Very low	Semi-dwarf stature, foliage to 330 mm tall, narrow light- to mid-green leaves with cream bases and up to 310 mm long and 17 mm wide, white flowers, 18-60 flowers per inflorescence, flower heads to 730 mm tall.
A. 'Golden Drop' PBR, PVR (syn. *A*. 'Gold Drops')	Very low	Dwarf compact stature, foliage to 340 mm tall, narrow mid-green leaves that are variegated light green and golden yellow and up to 350 mm long and 12 mm wide, lavender blue flowers, 5-11 flowers per inflorescence, flower heads to 550 mm tall.
A. 'Goldstrike' (syn. *A*. 'Gold Strike')	Very low (– low)	Semi-dwarf compact stature, foliage 380 to 600 mm tall, green leaves that are variegated golden-yellow (aging to cream as the leaves mature) up to 500 mm long and 20 mm wide, dark blue flowers, 16-22 flowers per inflorescence, flower heads to 670 mm tall.
A. 'Pavlova' PBR, PVR	Very low	Semi-dwarf stature, foliage to 410 mm tall, short wide green leaves with cream bases up to 250 mm long and 30 mm wide, creamy-white flowers, 64-144 flowers per inflorescence, flower heads to 670 mm tall.
A. 'Sarah' PVR	Very low (– low)	Semi-dwarf stature, foliage to 350 mm tall, narrow light- to mid-green leaves with cream bases and up to 200 to 315 mm long and 19 mm wide, soft blue flowers, abnormal stigma and styles, additional tepals (6-12) common, 20-58 flowers per inflorescence, flower heads 570 to 900 mm tall, multi-locular seed capsules.
A. 'Snowdrops' (syn. *A*. 'Snowdrop')	Sterile (– very low?)	Dwarf stature, semi-upright foliage to 300 mm tall, dark blue-green leaves up to 250 mm long and 24 mm wide, white flowers, additional tepals (6-12) common with conversion of inner flower parts, 9-20 flowers per inflorescence, and flower heads to 500 mm tall. This description is based on material growing at Lincoln. Plants currently growing at Auckland Botanic Gardens under the name *A*. 'Snowdrops' are excluded from our assessments as they are not the same selection (they are taller growing, don't have additional tepals, and are moderate seed setters).
A. 'Thunder Storm' PVR (syn. *A*. 'Thunderstorm', *A*. 'DunAga02')	Sterile?	Semi-dwarf stature, foliage to 340 mm tall, relatively broad green leaves that are variegated cream (with a yellow-green basal flush when shaded) and are up to 290 mm long and 20 mm wide, blue flowers, 26-50 flowers per inflorescence, flower heads to 600 mm tall.

Table 2. Suspected low female fertility, borderline results, or uncertain cases where candidate cultivars of agapanthus require further assessments.

Cultivar	Female fertility/seed set	Brief description
'Baby Pete' PBR (syn. *A.* 'Benfran')	Low (– medium)	Semi-dwarf compact stature, foliage to 500 mm tall, mid-green leaves up to 515 mm long and 19 mm wide, pale blue flowers, 37-83 flowers per inflorescence, flower heads to 1030 mm tall.
A. 'Bertsbrook' (was provisionally named A. 'Bertsbrook Blue')	Low	Semi-dwarf compact stature, foliage to 720 mm tall, dark green leaves up to 580 mm long and 19 mm wide, mid-blue flowers, variable number of tepals (5, sometimes 6), 5-12 flowers per inflorescence, flower heads to 900 mm tall.
A. 'Blue Baby'	Low – medium	Dwarf stature, foliage to 200 mm tall, narrow mid-green leaves, light blue flowers, 16-25 or more flowers per inflorescence, flower heads to 600 mm tall.
A. 'Blue Storm' PBR (syn. *A.* 'Bluestorm' and *A.* 'ATIblu')	Very low (– low). Limited observations	Dwarf stature, foliage 150 mm or more tall, narrow mid-green leaves with cream bases up to 200 mm long and 11 mm wide, soft violet blue flowers, additional tepals (6-12) common, 8-33 flowers per inflorescence, flower heads to 610 mm tall. This description is based on a dwarf plant with very low to low seed set. However, there may be two different selections under this one cultivar name and further work is required to confirm the true identity and fertility of *A.* 'Blue Storm'.
A. 'Debbie's Dwarf'	Sterile or low? Limited observations	Very dwarf, compact stature, foliage to 130 mm tall, narrow green leaves up to 110 mm long and 5 mm wide, blue flowers, occasional flowerer, 14-20 flowers per inflorescence, flower heads to 200 mm tall.
A. "Plantlife Var" (unnamed selection, grown at AGB as *A.* 'Variegata')	Low? Limited observations	Semi-dwarf stature, upright foliage to 450 mm tall, relatively broad, sparse grey-green leaves that are variegated yellow and cream and are up to 420 mm long and 26 mm wide, blue flowers, 50-60 flowers per inflorescence, flower heads to 650 mm tall.
A. 'Purple Cloud'	Limited observations	Tall stature, erect foliage 570 mm to 1000 m tall, blue-green leaves with dark purple bases that are long and narrow—up to 620 mm long and 23 mm wide, deep purple-blue flowers, 44-70 flowers per inflorescence, flower heads 1200 to 1800 mm tall. This description is based on relatively young plants—the dimensions of mature plants could be greater than measured here.
A. 'Sea Coral'	Low – high?	Medium stature, foliage to 770 mm tall, green leaves up to 500 mm long and 17 mm wide, white flowers that flush coral pink with age, 45-52 flowers per inflorescence, flower heads 800 to 1040 mm tall. This description is based on material currently growing at Auckland Botanic Gardens under this name. Further work may be required to confirm the true identity and fertility of *A.* 'Sea Coral'.
A. 'Sea Foam' (syn. *A.* 'Seafoam')	Low (– medium)	Medium stature, foliage to 600 mm tall, green leaves up to 520 mm long and 23 mm wide, white flowers, 47-54 flowers per inflorescence, flower heads 870 to 1200 mm tall.
A. 'Senna' PBR	Limited observations. Claimed to be sterile by some nurseries	Medium stature, foliage to 290 mm tall, deciduous even in mild New Zealand conditions, dark blue-green leaves with dark purple bases up to 310 mm long and 23 mm wide, dark purple-blue flowers, 24-55 or more flowers per inflorescence, flower heads 700 to 960 mm tall.
A. 'Surprise Storm'	Sterile? Limited observations	Dwarf stature, foliage to 150 mm tall, blue/green leaves variegated with white margin up to 190 mm long and 15 mm wide, blue flowers, occasional flowerer, 30-40 flowers per inflorescence, flower heads to 290 mm tall.
A. 'Timaru'	Low (–medium). Limited observations. Seems to be one of the few taller cultivars that produce relatively little seed.	Medium/tall stature, foliage to 730 mm tall, mid-green leaves with cream bases up to 700 mm long and 60 mm wide, dark purple-blue flowers, 193-369 flowers per inflorescence, flower heads to 1680 mm tall.
A. 'Tinkerbell'	Low – medium. Irregular flowerer, but can have moderate seed set when it does flower.	Dwarf compact stature, foliage to 200 mm tall, narrow green leaves that are variegated cream up to 220 mm long and 12 mm wide, occasional blue flowers, flower heads 400 to 508 mm tall.

Table 3. Cultivars of *Agapanthus* that set abundant seed.

Cultivar	Female fertility/seed set	Brief description
A. 'Black Pantha' PBR (syn. *A*. 'Black Panther')	High. Has been claimed by some nurseries to be "virtually sterile", but plants growing at ABG sets abundant seed.	Medium/tall stature, foliage to 550 mm tall, mid-green leaves with purple restricted to bases and up to 450 mm long and 55 mm wide, dark purple-blue flowers, 30-55 flowers per inflorescence, flower heads to 1350 mm tall.
A. 'Blue Blazer'	Medium (– high)	Medium stature, foliage to 300 mm or more tall, light green leaves with cream bases up to 390 mm or more long and 25 mm wide, dark blue flowers, 15-60 flowers per inflorescence, flower heads to 1070 mm or more tall.
A. 'Blue Dot'	High	Semi-dwarf stature, foliage to 340 mm tall, narrow light green leaves with cream bases up to 350 mm long and 15 mm wide, mid-blue flowers, 5–33 flowers per inflorescence, flower heads 400 to 770 mm tall.
A. 'Gayle's Lilac'	Low – high	Medium stature, foliage to 240 mm tall, narrow mid-green leaves with cream bases up to 255 mm long and 21 mm wide, soft blue flowers, 27-55 flowers per inflorescence, flower heads to 640 mm tall.
A. 'Gayle's Sapphire'	Medium – high	Medium stature, arching foliage to 370 mm tall, light green leaves with cream bases that are relatively long and narrow—up to 415 mm long and 16 mm wide, dark blue flowers, 8-24 flowers per inflorescence, flower heads 780 to 1000 mm tall.
A. 'Glen Avon' (syn. *A*. 'Glenavon', *A*. 'Fragrant Glen')	High	Medium/tall stature, foliage to 560 mm or more tall, mid-green and broad leaves with cream bases up to 650 mm long and 67 mm wide, rounded flower heads, lilac blue striped flowers, additional tepals (6-8, possibly up to 10) common, 46-185 or more flowers per inflorescence, flower heads 1000 m to 1330 mm tall, capsules commonly 4-locular (instead of the usual 3).
A. 'Lapis' PVR	Medium	Medium stature, dense foliage to 410 mm tall, light- to mid-green leaves with cream bases and up to 430 mm long and 20 mm wide, dark purple-blue flowers, 17-69 flowers per inflorescence, flower heads to 930 mm tall.
A. 'Moonshine'	Medium – high	Medium stature, foliage to 380 mm tall, light green leaves with cream bases and up to 270 mm long and 20 mm wide, very pale lavender (almost white) flowers, 22-63 flowers per inflorescence, flower heads to 690 mm tall.
A. 'Olive Darragh'	High – very high	Tall stature, foliage to 720 mm tall, blue-green leaves with cream bases up to 560 mm long and 46 mm wide, blue flowers, 45-150 flowers per inflorescence, flower heads to 1500 mm tall.
A. 'Peter Pan'	High – very high	Semi-dwarf stature, foliage to 330 mm tall, light- to mid-green leaves with cream bases up to 260 mm long and 17 mm wide, mid-blue flowers, 11-32 flowers per inflorescence, flower heads 500 to 820 mm tall. Some nurseries claim to have a sterile form of this cultivar.
A. 'Regal Beauty'	Medium (– high?)	Medium stature, dense foliage to 650 mm tall, mid-green leaves with cream bases up to 650 mm long and 40 mm wide, dark purple-blue flowers, 10-134 flowers per inflorescence, flower heads to 1180 mm tall.
A. 'Sea Spray'	Medium – high	Semi-dwarf stature, foliage to 240 mm tall, narrow mid-green leaves with cream bases up to 170 mm long and 11 mm wide, white flowers with soft purple blue flush, 20-25 flowers per inflorescence, flower heads to 570 mm tall.
A. 'Silver Baby'	Medium – high	Semi-dwarf stature, foliage to 340 mm tall, narrow blue-green leaves with cream bases up to 300 mm long and 16 mm wide, white flowers flushed pale blue on tepal tips, 18-33 flowers per inflorescence, flower heads to 630 mm tall.
A. 'Snowball' (syn. *A*. 'Snow Ball')	Medium – high	Dwarf stature, foliage to 310 mm tall, white flowers, flower heads 400 to 600 mm tall.
A. 'Snow Storm' (syn. *A*. 'Snowstorm')	High	Semi-dwarf stature, dense foliage to 305 mm tall, narrow yellow-green to mid-green leaves, white flowers, 60 flowers per inflorescence, flower heads 700 to 900 mm tall.
A. 'Streamline'	High – very high	Semi-dwarf stature, foliage 300 to 440 mm tall, narrow blue-green leaves up to 375 mm long and 13 mm wide, abundant mid-blue flowers, 8-33 flowers per inflorescence, flower heads 600 to 850 mm tall.
A. 'Wavy Navy'	High	Medium stature, foliage to 390 mm or more tall, light to dark green leaves up to 370 mm or more long and 32 mm wide, dark blue flowers, 17-78 flowers per inflorescence, flower heads to 990 mm or more tall.

Figure 13. *Agapanthus* 'Glen Avon', showing a flower with six tepals and six anthers. Photo: Murray Dawson.

Figure 14. *Agapanthus* 'Glen Avon', showing a flower with eight tepals and eight anthers. Photo: Murray Dawson.

Figure 15. *Agapanthus* 'Snowdrops', a low fertility cultivar showing pataloid conversion of anthers creating an inner whorl of additional floral parts. Photo: Murray Dawson.

Figure 16. *Agapanthus* 'Sarah' PVR, a low fertility cultivar showing a flower with ten tepals. Photo: Murray Dawson.

Table 1 shows that sterility/very low seed set among the 10 cultivars listed is closely associated with dwarf selections, variegated foliage, and/or abnormal flower parts including multi-tepals (low fertility can occur in plant groups where anthers and other floral parts are converted into additional petal-like structures, disrupting normal functioning) (Figures 15-16) and aberrant stigma/styles (Figure 17).

Figure 17. Split styles (arrowed) and deformed stigmas, aberrations typical in the flowers of the low fertility cultivar *Agapanthus* 'Sarah' PVR. Photo: Kerry Ford.

Agapanthus 'Dorothy Edwards' is the only medium height cultivar assessed so far that appears to have low female fertility (no doubt due to its extreme multi-tepals). There are no tall-growing cultivars yet confirmed as sterile or to set very little seed.

Table 2 lists thirteen cultivars that require further assessments. They have not been accepted as seedless or with the lowest seed set; nor have they been rejected as being too fertile.

The variegated cultivar, *A*. 'Tinkerbell' (Figure 18), presents an interesting case in assessing fertility. Like some of the other variegated cultivars, it is an intermittent shy flowerer, and sets little seed per plant on an average season. However, seed set of *A*. 'Tinkerbell' is moderate per flower head when it does flower.

Figure 18. *Agapanthus* 'Tinkerbell', a cultivar with variegated leaves. Photo: Barrie McKenzie.

We uncovered five additional cultivars (currently grown in Australia) that are not yet available in New Zealand. They are claimed to be sterile (*A*. 'Double Diamond' and *A*. 'Little Boy Blue') or of low female fertility (*A*. 'Cloudy Days' PBR, *A*. 'Lilibet' PBR, and *A*. 'Queen Mum' PBR).

Table 3 lists seventeen cultivars that have been consistently observed setting abundant seed. These confirmed high seed-setters are rejected from our low fertility lists.

Interestingly, a few cultivars rejected here (Table 3) have not lived up to low fertility claims made by some in the nursery industry. For example, *A*. 'Black Pantha' PBR was said to be "virtually sterile" but the material we assessed set abundant seed in the outdoor trials in Auckland Botanic Gardens.

Material of *A*. 'Peter Pan' that we studied also demonstrated heavy seed set. However, it seems that there are two selections under the name *A*. 'Peter Pan'; one fertile and one of low fertility, as some nurseries have claimed it to be sterile, self-sterile or with low seed set (e.g., Snoeijer, 2004; Dawson and Ford, 2012).

SEED PRODUCTION ESTIMATES

Seed production is important to estimate when assessing the weedy potential of fertile plants and to provide a comparison against selections with reduced seed production.

Accordingly, we have calculated some actual and theoretical seed production estimates based on mature plants growing in publically accessible sites in Auckland and Canterbury.

The tall-growing "wild-type" (*A. praecox* subsp. *orientalis*) typically has a three-locular seed capsule (and occasionally four-locular; Figure 19). Each typical locule has the capacity to physically house up to eight seeds: 8×3 = up to 24 seeds per capsule.

Figure 19. Dissected four-locular capsule of *Agapanthus praecox* subsp. *orientalis* providing a comparison of the dark, broad, presumed viable seed with light colored, smaller, inviable seed. Photo: Kath Stewart.

The number of seed capsules per flower head (inflorescence) were counted from several plants and multiplied by the number of presumed "viable" seeds (filled and black / dark brown colored) counted; this was compared with the theoretical maximum number of seeds that could be produced per head (based on a maximum of 24 seeds per capsule): 640 ("viable") to 4,200 (theoretical maximum) seeds per flower head. The range we obtained here is a reasonable fit with that provided by Barrett (2011) of "1,500-3,000 mostly fertile seeds per flower head".

The number of seed heads produced in a season ranged from 13-40 per "wild-type" plant and the capsules per head ranged from 64-175.

Because of the rhizomatous and spreading nature of agapanthus, clumps with reasonably defined boundaries between them were chosen and considered to correctly encompass the original plant. This resulted in seed production estimates of: 12,880 ("viable") to 86,160 (theoretical maximum) seeds per "wild-type" plant (clump) per season.

Seed production estimates of the low-growing, narrow-leaved dwarf types (as exemplified by the highly fertile *A*. 'Streamline'), and probably corresponding to *A. praecox* subsp. *minimus* parentage, are different. For these, there are less seeds per capsule (a maximum of 18 physical places), many more seed heads are produced in a season (64-147 per plant), and there are fewer capsules per head (10-25). Using these parameters, seed production estimates for high fertility dwarf selections range from: 19,200 ("viable") to

29,290 (theoretical maximum) seeds per plant per season.

Our estimate here of 19,200 “viable” seeds for a plant of *A*. ‘Streamline’ provides an interesting comparison with an average of 3.15 “viable” seeds produced per plant for *A*. ‘Finn’ PVR over one season (based on 85 dark colored seeds set from 27 young plants). This comparison highlights the relative propagule pressure in the environment of a high female fertility cultivar with a low fertility cultivar.

SEED GERMINABILITY AND LONGEVITY

Observations made at Manaaki Whenua Landcare Research have revealed that seed germinability of high fertility (open-pollinated) plants can approach 100%.

This is supported by Ford and Dawson (2010) who obtained germination rates of 80-100% for controlled outcrossed seed from *A. praecox* subsp. *orientalis* and 61-95% for outcrossed seed of the high fertility cultivar *A*. ‘Streamline’ (as female parents).

Ford and Dawson (2010) reported generally lower outcrossed germination rates for the low fertility cultivars they tested—65% for *A*. ‘Sarah’ PVR (as a female parent) and 25-74% for *A*. ‘Finn’ PVR, depending on what male pollen parent was involved. Auckland Botanic Gardens obtained a range of germination rates from 40-78% for seed collected from five open-pollinated cultivars.

We found that agapanthus seed germinates readily, as soon as it is mature (i.e., when the capsules dry and split open to expose the mature seeds for dispersal), and agapanthus seed appears to lack a dormancy period. Duncan (1998) states: “Seeds of all agapanthus species have a limited viability and are best sown immediately after ripening … Fresh seed normally germinates within 6 to 8 weeks.”

We have not conducted independent seed germination longevity experiments to determine how seed germinability declines over following months or years.

QUANTIFICATION OF A LOW FERTILITY THRESHOLD IN AGAPANTHUS

Determining an “acceptable” boundary for low female fertility in any plant group that has competing weedy and horticultural values is problematic and somewhat arbitrary.

However, practical and clearly stated methods for quantitatively measuring fertility and establishing an “acceptable” threshold becomes important for horticulturally useful but potentially weedy plants subject to regulatory conditions. This is especially true for borderline low fertility cultivars of agapanthus that growers still wish to market in Auckland, in other areas of New Zealand, and potentially in other countries where agapanthus is also becoming weedy.

Ford and Dawson (2010) recommended applying to other purportedly sterile or claimed low fertility cultivars the benchmark they established for *A*. ‘Finn’ PVR, which had substantially reduced pollen viability, was found to be self-infertile, and had <10% outcross seed set (Ford and Dawson, 2010). Ford and Dawson’s (2010) seed set percentages, derived from the results of artificial pollinations, were calculated by dividing the actual yield (number of “viable” seeds produced) by the total potential yield (number of ovules) in a capsule at maturity and did not factor in total seed production potential as shown later in this paper.

Here we advocate following the regulatory precedence set in the State of Oregon for *Buddleja* (a genus that also has competing horticultural and weedy values), which uses the definition “produces less than 2% viable seeds compared to fertile cultivars that were evaluated under the same conditions and location”. Cultivars of *Buddleja* approved by Oregon may be propagated and sold if labelled “Seedless Butterfly Bush*” or “*Produces less than 2% viable seed.” Within the context of their regulations, these are treated as effectively sterile. Otherwise, any plant listed as “butterfly bush” is assumed to be *B. davidii* and is prohibited entry, transport, purchase, sale or propagation in the State of Oregon (http://plants.usda.gov/factsheet/pdf/fs_buda2.pdf). Evaluation parameters for assessing this are described by the Oregon Department of Agriculture and Oregon State University (2011). They provide protocols that could be adapted here for agapanthus.

HOW TO CALCULATE "PRODUCES LESS THAN 2% VIABLE SEEDS COMPARED TO FERTILE CULTIVARS THAT WERE EVALUATED UNDER THE SAME CONDITIONS AND LOCATION" FOR AGAPANTHUS?

Although this sounds like a relatively simple task, several aspects need to be considered, including growing conditions, climate, abundance of pollen sources and pollination vectors, self- and cross-compatibility of plants, seed set, seed germination, seed production, and methods of calculating percentage viability.

As stated in the above definition, plants should be grown together under the same conditions and location. Plants should be well-established before assessing fertility (e.g., at least two years old), and replicate plants (e.g., a minimum of three) of each cultivar being assessed should be grown together, alongside several high fertility reference comparators. These reference comparators (standards) should include different accessions of typical tall-growing agapanthus (*A. praecox* subsp. *orientalis*), *A*. 'Streamline' (likely to be a selection of *A. praecox* subsp. *minimus*) as a low-growing high fertility reference cultivar, and probably *A. inapertus* to cover a range of taxa as pollen sources (e.g., planted at a rate of one fertile cultivar for every three plants under investigation). Flowering times of the reference plants should overlap with the cultivars being assessed to maximize the likelihood of cross-pollination.

Capsules for seed counts should be collected over the course of a season, as each matures but before they split open—to ensure no lost seed which would adversely affect the accuracy of the seed set determinations.

As explained previously, mature, dark colored filled seeds (more-or-less assumed to be "viable") can easily be distinguished from pale aborted seeds that are clearly inviable. Also, the number of ovules that can potentially set seed within a capsule is easy to determine by examining the material.

The difference in growth form and the number of potential seeds/capsule (= number of ovules) means that "like should be compared with like". Tall-growing, broad-leaved 24 seeds/capsule cultivars should be compared against fertile "wild-type" agapanthus, whereas smaller growing, narrow-leaved 18 seeds/capsule selections should be compared to *A*. 'Streamline' which as a known high-fertility cultivar is an ideal standard comparator.

Instead of determining seed viability of the reference plants each season when grown alongside the candidate cultivars, another option is to use a predetermined upper limit for seed viability percentages for the fertile reference standards (such as 95% viability, and to make this publicly available as part of the assessment criteria).

Determining seed set and seed viability per capsule of tall-growing agapanthus

For this calculation, seed from 72 capsules of one open-pollinated tall-growing plant was counted, and 581 seeds were found to be filled and dark colored. Percent seed set per capsule is determined by:

$$\left(\frac{581}{72 \times 24}\right) \times 100 = 33.6\% \text{ seed set/capsule}$$

If, for example, 95% of those dark, filled seeds are capable of germination, then the figure for percent seed viability per capsule would be:

$$0.336 \times 0.95 \times 100 = 31.9\% \text{ seed viability/capsule}$$

Seed set (in this example 33.6%) can be treated as an upper estimate of seed viability (here 31.9%) in the absence of seed germination trials.

Although based on real data, the figure here of 33.6% seed set was derived from a plant examined late in the season (Figure 20), which may have incurred some seed loss through collecting capsules that were well open.

Figure 20. Large plant in seed of *Agapanthus praecox* subsp. *orientalis*, from Diamond Harbour, Canterbury, June 2016. Photo: Murray Dawson.

A more rigorous survey of tall-growing agapanthus was undertaken in Auckland, where 100 open-pollinated seed heads were collected from plants growing around the city, and an average of 10 fully formed (dark colored) seeds in each capsule was obtained. This equates to an average of 41.7% seed set per (24-place) capsule (the range was 33-96%).

When artificially sib-crossed, Ford and Dawson (2010) reported an average of 74% seed set (54-96%) for five tall-growing accessions from Canterbury. Open-pollinated field conditions are likely to produce lower seed sets, as evidenced here.

Determining seed set per capsule of low fertility cultivars against a fertile standard

Using the same approach for determining percent seed set per capsule of a known low fertility cultivar (*A*. 'Finn' PVR), and assuming a maximum potential of 18 seeds/capsule:

$$\left(\frac{85}{43 \times 18}\right) \times 100 = 10.98\% \text{ seed set/capsule}$$

Choosing not to incorporate seed germinability, and using a percentage of 84.3% seed set per capsule for our *A*. 'Streamline' comparator, then to calculate percent seed set per capsule compared to a fertile cultivar:

$$(0.1098 \div 0.843) \times 100 = 13.02\% \text{ seed set/capsule against fertile comparator}$$

These results (10.98% and 13.02%) are well above the <2% threshold that we advocate here, even if we factor in a 74% seed germination rate for *A*. 'Finn' PVR (determined through controlled outcrossing by Ford and Dawson, 2010). Yet clearly *A*. 'Finn' has very low female fertility (Figure 21).

Figure 21. Rare capsule formation on *Agapanthus* 'Finn' PVR, a confirmed low fertility cultivar. Photo: Murray Dawson.

THE PROBLEM WITH THE ABOVE APPROACHES FOR DETERMINING FEMALE FERTILITY

Percentage seed set per capsule is easy to calculate by dividing the actual yield (number of filled, dark colored "viable" seeds produced) by the total potential yield (number of ovules) in a capsule at maturity.

Percentage seed germination is likewise a useful measure of viability, but is usually assessed only on the filled (dark colored) seeds and not the visibly inviable seeds (aborted seeds or unpollinated ovules).

Although the calculations thus far combine both of these female fertility measures (i.e., seed set per capsule and seed germination), they overlook overall female reproductive potential (including seed that never formed and whole capsule abortion).

The illustration above (Figure 21) visually reveals the limitations of the calculation methods so far. For low female fertility cultivars such as *A*. 'Finn' PVR, we can see that capsule formation is rare, in stark contrast to the tall "wild-type" agapanthus (cf. Figure 7, where capsules have formed on nearly every peduncle (flower/fruit stalk)—close to 100% capsule formation per head).

Within each capsule that develops to maturity, *A*. 'Finn' PVR has low seed set (a mean of 1.98/capsule, with a range of 1-5 seeds per capsule for 43 capsules that developed), and it is probably these few seeds that help ensure retention of those few capsules on to maturity (Our observations for some cultivars, including *A*. 'Finn' PVR, is that if no seed is set within a capsule, then that capsule is likely to abscise early in development compared to a capsule with viable seed set. Early capsule drop in low fertility selections is a desirable trait as it results in more tidy fruit stalks (peduncles) and highlights the sterility of the plant.). Hence, on a per mature capsule basis, you would never get less than 4.2-5.6% seed set (for one filled, dark colored seed to develop from a maximum of 18 or 24 ovules per capsule). No account is made so far of the early and mass abortion of capsules of low fertility selections such as *A*. 'Finn' PVR, which obviously greatly reduces the overall female reproductive potential.

In other words, per mature capsule estimates alone don't produce fully meaningful female fertility estimates for agapanthus—further calculations are needed.

THE PROPOSED SOLUTION FOR CALCULATING "PRODUCES LESS THAN 2% VIABLE SEEDS COMPARED TO FERTILE CULTIVARS THAT WERE EVALUATED UNDER THE SAME CONDITIONS AND LOCATION"

A more biologically meaningful approach is to determine seed production potential and seed viability together. Results can be expressed on an averaged per seed head basis, which largely overcomes differences in the age of plants (where older and larger plants produce more seed heads).

Although whole plant estimates of female fecundity—viable seeds produced per plant per season—remains a useful metric and one that is easily understood, this is likely to be less reliable than per seed head determinations as per plant counts are more dependent upon age and growing conditions. Furthermore, the rhizomatous nature of agapanthus clumps can make discrimination of old plants problematic when they have been planted closely together and become intermixed.

Determining seed set per head of low fertility cultivars against a fertile standard

Following this revised approach for *A*. 'Finn' PVR data, a working example is provided as follows: 27 (young) plants were counted, with a total of 117 seed heads, and 3,931 peduncles (flower/fruit stalks—an average of 33.6 peduncles per seed head). From the total number of peduncles, only 43 capsules formed—resulting in an incidence of 1.09% of the potential capsule production (and 0.37 capsules formed per head), based on the theoretical assumption that all peduncles have the potential to form fruit.

The final calculation incorporating capsule formation for *A*. 'Finn' PVR (and assuming here an 80% capsule formation rate for the fertile comparator) would then be:

$$[(0.1098 \times 0.0109) \div (0.843 \times 0.8)] \times 100 = 1.6\% \text{ seed set per head against fertile comparator}$$

In other words:

$$\left\{ \frac{\begin{array}{c}\text{Seed set/capsule} \times \text{capsule formation/head} \\ (\times \text{ germination rate if known}) \\ \text{of test cultivar}\end{array}}{\begin{array}{c}\text{Seed set/capsule} \times \text{capsule formation/head} \\ (\times \text{ germination rate if known}) \\ \text{of standard high fertility comparator}\end{array}} \right\}$$

Or more simply stated (and in agreement with Rounsaville et al., 2011), relative female fertility is determined by:

(% seed set × % germination of low fertility test cultivar) ÷ (% seed set × % germination of standard high fertility comparator)

In this example, the 1.6% estimate of seed set per head compared to a more fertile comparator is below the proposed >2% viable seeds threshold.

For cultivars that exceed this 2% threshold, germination rates could be added to the assessment; if below the 2% threshold, germination rate would not need to be factored in.

DISCUSSION

From our agapanthus collections, we have provided a shortlist of ten cultivars that have consistently demonstrated low natural seed set (Table 1). Following the methodology outlined in this paper, a more stringent next step is to quantify the percent seed set of each.

If regulatory authorities adopted the <2% seed viability threshold advocated here that aims to lessen the weed risk of agapanthus on the environment, then a formal legal exemption process would be required to be enacted.

Acceptance of a <2% seed viability threshold will undoubtedly greatly reduce relative propagule pressure in the environment, and the example is given earlier of 19,200 "viable" seeds produced by one plant of the high fertility cultivar *A*. 'Streamline' versus 3.15 "viable" seeds produced for *A*. 'Finn' PVR. However, progeny arising from low fertility selections have the potential to be highly fecund and for sensitive ecological environments "seedless" cultivars should be recommended.

If formal quantitative assessments of agapanthus fertility are to proceed, we recommend that a list of approved cultivars and clear assessment guidelines are made publically available (e.g., on the Auckland Botanic Gardens website for plants regulated by Auckland Council) and promoted by the horticultural industry. This should be a working list where new "certified" low fertility cultivars are added over time.

An example of an online working list is provided by the Oregon Department of Agriculture list of approved cultivars of butterfly bush (*Buddleja*) (www.oregon.gov/ODA/programs/NurseryChristmasTree/Pages/ButterflyBush.aspx).

In New Zealand, there is legislative precedence for exempting sterile cultivars from their weedy counterparts. *Calluna vulgaris* is included in the current National Pest Plant Accord, but double-flowered cultivars of it are excluded.

Similarly, the Government of South Australia have exempted sterile cultivars of *Gazania* as a Declared Plant from their Management Plan (Hunter, 2015). Abell and Layt (2015) document low seed set selections of *Rhaphiolepis*, compare them with weedy *R. indica*, and argue for the exemption of the low fertility cultivars in Australia.

Ford and Dawson (2010) recognized the potential to breed novel low fertility or sterile agapanthus through non-GMO chromosome manipulations (to produce tetraploids and then triploids), and Barrett (2011) successfully induced tetraploids as part of her thesis work. Murray Dawson and Peter Heenan at Manaaki Whenua Landcare Research undertook an independent breeding programme that began in 2012, and a similar approach has been followed by Ed Morgan of Plant & Food Research who began 2010/2011. Several promising candidates have been selected from these programmes, which are in the process of being evaluated. They will be named as new cultivars if or when commercially released to the public.

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