Insights from Southeastern US Nursery Growers Guide Research for Sterile Ornamental Cultivars [1]

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Abstract

Some ornamental plants important to the nursery and landscape industries escape cultivation, spread to natural areas, and become invasive, outcompeting native plants in those ecosystems. Development of sterile cultivars of these problematic species can be one way to continue their sales yet limit their invasive potential and protect natural areas. To maximize the economic (and ecological) impact of this approach, sterile cultivar research and development should directly address grower needs. We conducted a survey of southeastern US growers to quantify sales of five popular yet invasive ornamentals (Coral ardisia, Chinese privet, Japanese honeysuckle, Heavenly bamboo, and Mexican petunia). Firms ranged from small businesses to large operations with up to $30M in gross annual sales. Respondents expressed a largely positive opinion of sterile cultivar research (74%) and a willingness to sell the sterile cultivars once created. Most (40%) recommended that sterile cultivar research on Heavenly bamboo was most critical, while 30% suggested that Chinese privet was the most important research target of the five species. The industry's willingness to adopt sterile cultivars documented in this survey positions the southeastern US to lead development of sterile cultivars and reduce invasiveness of economically important plants; research and development will be most effective if guided by industry input revealed here.

Index words: Invasive species, invasive ornamental, sterile cultivar, ornamental plants, non-invasive, non-native, survey, nursery production, economic impacts.

Species used in this study: Coral ardisia (*Ardisia crenata* Sims); Chinese privet (*Ligustrum sinense* Lour.); Japanese honeysuckle (*Lonicera japonica* Thunb.); Heavenly bamboo (*Nandina domestica* Thunb.); Mexican petunia (*Ruellia simplex* C.Wright).

Significance to the Horticulture Industry

Despite profound and widespread negative ecological impacts caused by invasive plants, there are few procedures in place to prevent potentially problematic introductions and spread of these species. The risk of ornamental species becoming invasive is particularly high in the southeastern region of the United States (US), where specifically the state of Florida is the second largest producer of ornamental plants nationwide. Phasing out the sale of invasive ornamentals, facilitated by adoption of the non-invasive cultivars, could greatly reduce this source of invasion. As part of planned breeding programs at multiple institutions, sterile cultivars of invasive species that have much reduced or eliminated invasive potential are under development for commercial use. Sterile cultivar development research will have the greatest utility if guided specifically by grower needs and attitudes. In this project, survey responses from participating southeastern nursery and landscape professionals revealed significant sales of four popular invasive ornamentals (sales of one study species was not reported). Accordingly, sterile cultivar research on all species investigated is viewed as productive, with Heavenly bamboo and Chinese privet as the most immediate research needs. The availability of sterile cultivars was viewed as important, and as having a positive impact on businesses. We conclude that focused work on development of cultivars is a promising approach to reducing ornamental contributions to plant invasions, largely due to likely adoption of this technology, facilitated by positive attitudes towards sterile cultivars held by growers in this region.

[1]Received for publication January 8, 2019; in revised form March 29, 2019. This research was supported by a grant from the Horticultural Research Institute (“HRI”). Its contents are solely the responsibility of the authors and do not necessarily represent the views of HRI. We are grateful to those who provided feedback on earlier drafts of this survey: Ben Bolusky, Alan Hodges, and Laura Warner. We are also grateful to the administrators of the professional associations that promoted our survey: Ben Bolusky with Florida Nursery Growers and Landscape Association, Karen Summers with Southern Nursery Association, and Donna Foster with International Plant Propagators Society (Southern Region). We thank Bart Schutzman and Gary Knox (both University of Florida, Environmental Horticulture Department) for helpful reviews prior to submission.

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Introduction

While the majority of introduced ornamental plants do not escape cultivation, some grow to be exceptionally adaptable, reproduce prolifically, and eventually invade natural areas. As a result, the ornamental horticulture industry is a source for invasive species (Barton et al. 2004, Bradley et al. 2011, Dehnen-Schmutz et al. 2007, Hulme et al. 2018, Peters et al. 2006, van Kleunen et al. 2018), especially for invasive woody plant species (Reichard and White 2001). Invasive species negatively impact ecosystems and cost millions annually, not only in terms of control and management (Adams et al. 2011, Pimentel et al. 2005), e.g. $26M in the state of Florida alone during 2010-2011 (FWC 2011a, FWC 2011b), but also services lost from invaded ecosystems. Preventing the spread of

invasive plants is considerably less costly than control after an invader has become established (Mack et al. 2000). If control is postponed until a later stage of widespread infestation, it is on average 40 times more expensive to control than early removal (Harris and Timmins 2009). To prevent invasion associated with the horticultural industry, there is national pressure on growers to stop selling invasive ornamental plants, especially herbaceous perennials, shrubs, and trees (Coats et al. 2011, Wirth et al. 2004). Surveys of growers indicate that most (80%) have a sense of duty to protect the environment (Cronin et al. 2017) and are willing to modify business models to limit the spread of potentially invasive crops. However, there will be a considerable cost of product loss to the green industry if high market value species are not saleable (Coats et al. 2011, Gagliardi and Brand 2007, Wirth et al. 2004).

The green industry is particularly important in the southeastern United States, where favorable weather conditions promote growing nearly year-round. In 2007-2008, it was estimated that there were 19,803 nursery and greenhouse firms in the United States producing over $27B in sales and employing nearly 472,000 workers (Hodges et al. 2011). Nursery and greenhouse production, specifically, in the southeastern region produced an estimated $3.7B in sales and over 109,000 jobs, or 14% of national sales and 23% of the country's horticulture workforce (Hodges et al. 2011). For growers throughout the US, ornamental invasive species are an economically significant portion of sales, though the species differ by region (Coats et al. 2011, FLEPPC 2017, Gagliardi and Brand 2007, Wirth et al. 2004). Typically, invasive ornamental plants grow readily under widely varying conditions, which makes them appealing to both growers and consumers (Mack 2005, Reichard 2011). Growers move these plants quickly through production, resulting in high profit margins, and rapid growth makes them desirable to consumers as the plants fill in landscape areas faster than other ornamentals and do not require many added inputs, such as water and fertilizer (Li et al. 2004). Unintentionally, the qualities that make these plants profitable to growers also make them strong competitors with native flora (Drew et al. 2010, Knapp et al. 2012). While green industry professionals are becoming more informed as a group about the issue of sale and distribution of invasive species (Gagliardi and Brand 2007), there is little information available to them on what economically feasible alternatives are suitable and feasible to purchase (Stack et al. 2007). The southeastern region's respectable proportion of national production makes it an important area for research to determine what types of plants are being produced and whether those plants have the potential to become invasive.

Since the late 1990's to early 2000's, researchers have developed genetic and molecular techniques to reduce the fecundity of plants, leading to the ability to produce sterile cultivars, or, cultivars that do not produce viable seed (Freyre et al. 2016). The processes are complex and employ forms of genetic mutation and traditional breeding to create sterile male and female plants as well as plants with sterile seed (Li et al. 2004). Nationally, there are still a limited number of ornamental invasive species for which sterile cultivars have been developed, as breeders have not long been involved in creating plants with reduced invasive properties (Burt et al. 2007). An opportunity exists for universities to further research and produce sterile cultivars for species that are particularly profitable and widely produced. Previous efforts by Wirth et al. (2004) suggest that nursery professionals can provide valuable revenue information to focus research on the most economically impactful species, but their study focused only on Florida, and no subsequent studies have gathered more recent information.

Select groups of growers have indicated their willingness to sell and distribute alternatives to invasive species and to share information about alternatives to invasive species with their customers (Burt et al. 2007, Gagliardi and Brand 2007, Peters et al. 2006). Growers have indicated that being able to classify their business as "environmentally-friendly" could increase sales (Gagliardi and Brand 2007). Consumers have also become more informed about how plants add value to their lives in the form of environmental well-being, and are willing to purchase products that increase their overall quality of life (Hall and Dickson 2011). In this highly competitive market of ornamental plant production, growers can advertise their products to highlight the aspect of environmental well-being which will not only interest consumers but will also elevate the industry standards to a greater level of responsibility.

Development of sterile cultivars provides a logical approach to continuing to sell ornamentals while limiting problems caused by their invasive potential and may allow growers to meet consumer demand for "environmentally-friendly" products while maintaining the traits that are responsible for the popularity of these ornamentals. Research and support toward the development and utilization of non-invasive cultivars demonstrate the industry's commitment to sustainability, which is relevant given increasing pressures from federal, state, and local governments to avoid environmental damage, and preferences of environmentally conscious key market consumers. The potential gains from sterile cultivar development to the horticultural industry could be significant if the technology is widely accepted by growers and consumers.

To support development of sterile cultivar technology, UF research programs have assessed the invasive potential of over 60 cultivars or forms in ornamental grasses, herbaceous ornamentals, and woody shrubs (Czarnecki et al. 2012, Wilson et al. 2012). These developments illustrate the feasibility of sterile cultivar research and the need for improved breeding, not only for novel plant characteristics that are highly marketable, but for non-invasiveness. Connections between UF and growers facilitate more effective development of sterile cultivars for the most economically important species, e.g. UF programs are supported by industry-driven funding initiatives from the Horticulture Research Institute (HRI), the Florida Nursery Growers and Landscape Association (FNGLA), and the Center for Applied Nursery Research (CANR). Examples

of development for economically important species are provided here.

Heavenly bamboo (Nandina domestica Thunb.*)*. Knox and Wilson (2006) and Wilson et al. (2014b) found that landscape performance and fruit production varied widely among selections in north and south Florida. From this work, three cultivars, 'Harbour Dwarf', 'Firepower' and 'Gulf Stream' have been approved for use by the UF IFAS Infraspecific Taxon Protocol (ITP). Four additional cultivars merit ITP assessment approval and are slated for submission ('AKA' Blush Pink, 'Firehouse', 'Firestorm', and 'Monfar' Sienna Sunrise). The sterile Heavenly bamboo (such as the Fire series) has vivid fall color which offsets the lack of fruit in sterile forms. New sterile cultivars of heavenly bamboo are being continually introduced, some through tissue culture, though the invasive potential of some cultivars ('Bonfire', 'Colerno', 'Seika Obsession', 'Flirt', 'Lemon Lime', 'Sassy Lady', 'Twilight', and 'Sunset in Paradise') warrant research and assessment prior to recommendation. UF researchers have produced tetraploid Heavenly bamboo lines for potential production of sterile triploid cultivars[7].

Lantana (Lantana camara L.*)*. A breeding program initiated in 2004 by Z. Deng to sterilize lantana has since developed and evaluated hundreds of triploid lantana breeding lines. Czarnecki et al. (2012) evaluated lantana pollen viability, fruit production and ploidy level, resulting in development of male and female sterile triploid plants for further landscape assessment. Most recently, Deng et al. (2017) released two sterile, triploid cultivars that are now commercially available, 'Bloomify Red' (UF-1013A-2A) and 'Bloomify Rose' (UF-1011-2). On-going efforts focus on adding more flower colors to the sterile 'Bloomify' series. Simultaneously, UF researchers are working with commercial breeding companies to evaluate new lantana varieties for their potential introduction.

Chinese privet (Ligustrum sinense Lour.*)*. Wilson et al. (2014a) evaluated the green wildtype form which produced substantially more fruit with viable seed than the variegated cultivars. However, at 72 weeks, the variegated cultivar showed some reversion to the invasive green form. Two cultivars,

'Swift Creek' and 'Sunshine', will be submitted for ITP assessment. FDACS has exempted 'Variegatum' and 'Sunshine' from their noxious plant list. Fetouh et al. (2016) generated stable tetraploids of Japanese privet (*Ligustrum japonicum*), giving promise for future breeding of Chinese privet with this protocol.

Mexican petunia (Ruellia simplex C. Wright*)*. Wilson and Mecca (2003) evaluated commercially available cultivars and reported that 'Purple Showers' did not set seed. The UF ITP determined that 'Purple Showers' can be recommended for use with caution (UF IFAS 2018). The first Mexican petunia breeding program was initiated in 2007 at UF intending to create sterile cultivars for the landscape industry. In 2012, Freyre et al. released two sterile forms with improved flowering and form and in 2016 released a dwarf sterile cultivar, providing novelty along with sterility. To date, seven UF cultivars ('Mayan Pink', 'Mayan Purple', 'Mayan White', 'Mayan Dwarf Purple', 'Aztec Pink/White', 'Aztec Purple' and 'Aztec Pink') are now recommended for use with caution (UF IFAS 2018).

To investigate the potential use of sterile cultivars, we sought stakeholder input regarding development of this approach. Our objective was to identify which of five selected plant species will likely be sold broadly in the southeastern US as sterile cultivars by collecting information in an extensive survey of nursery professionals (nursery owners, growers, landscape professionals, and retail garden center managers) in this region. Another aim for our study was to characterize grower business in this region and assess attitudes towards development and sale of sterile non-invasive cultivars.

Materials and Methods

Selected study species. The five ornamental species surveyed in this project (Coral ardisia [*Ardisia crenata* Sims], Chinese privet [*Ligustrum sinense* Lour.], Japanese honeysuckle [*Lonicera japonica* Thunb.], Heavenly bamboo [*Nandina domestica* Thunb.], Mexican petunia [*Ruellia simplex* C.Wright]) were chosen based on the following criteria: 1) the species has substantial sales and current availability in the southeast market, 2) the species has been designated as an ornamental invasive in one or more southeastern states, and 3) the biology of the species indicates potential for sterile cultivar development. More information on the invasive assessment of each species is found in Table 1.

Survey. A survey (approved as exempt by the University of Florida Institutional Review Board ID number IRB201601264) was developed to anonymously collect information from nursery professionals to: 1) evaluate business size and scope, 2) estimate current sales of the five study species and 3) evaluate the attitudes of these horticulture professionals towards sterile cultivar research and development. The resulting survey document comprised 13 questions regarding the business' annual sales, business size, plant products sold, percentage of sales of the five potentially invasive species, and their opinions of sterile cultivars to replace the potentially invasive species currently on the market (Table 2).

Survey Distribution. To maximize participation in the survey, we utilized existing networks of horticulture professionals by administering the survey through professional associations that have strong relationships with the horticultural industry. To ensure that potential survey respondents would be familiar with the study species chosen, we selected professional associations in regions appropriate for sales of the study species (USDA zones 6, 7, 8, or 9; U.S. Department of Agriculture, Agricultural Research Service, 2012). Selected associations included: The Southern Nursery Association (SNA), International

[7]Personal communication, Gary Knox/University of Florida, Zhanao Deng/University of Florida.

Table 1. Species selected for research in the grower survey, and their status according to relevant state and federal level invasiveness assessments.

Species selected for this research	IFAS assessment (Florida based)[z]	State regulated Noxious Weed (Florida based FDACs)[x]	Unregulated State Listing (state EPPCs)[v]	Federally Regulated Noxious Weed (USDA)[u]
Coral ardisia	Prohibited (N, C, S)[y]	Yes	Yes: AL, FL, GA	No
Chinese privet	Prohibited (N, C, S)	Yes[w]	Yes: AL, FL, GA, MS, NC, SC, TN, VA	No
Japanese honeysuckle	Invasive (N, C, S)	No	Yes: AL, FL, GA, MS, NC, SC, TN, VA	No
Heavenly bamboo	Invasive (N, C) Caution (S)	No	Yes: AL, FL, GA, SC, TN	No
Mexican petunia	Invasive (N, C, S)	No	Yes: FL	No

[z]University of Florida, Institute of Food and Agricultural Sciences (IFAS). 2018. "Assessment of Non-native Plants in Florida's Natural Areas" (https://assessment.ifas.ufl.edu) Accessed July 20, 2018. Gainesville, FL, 32611, USA.

[y]Recommendations are specified by region: N=north, C=central, S=south.

[x]Florida Department of Agriculture and Consumer Services (FDACS). 2018. Florida noxious weed List. (www.freshfromflorida.com). Accessed June 16, 2018. Tallahassee, FL, 32399, USA.

[w]Two cultivars are exempted from this regulated list (see Introduction).

[v]Southeast Exotic Plant Pest Council (SEPPC). 2017. (https://www.se-eppc.org). Accessed May 12, 2017. AL=Alabama, FL=Florida, GA=Georgia, MS=Mississippi, NC=North Carolina, SC=South Carolina, TN=Tennessee, VA=Virginia.

[u]United States Department of Agriculture Animal and Plant Health Inspection Service (USDA APHIS). 2018. The PLANTS Database (https://aphis.usda.gov). Accessed June 16 2018. Riverdale, MD, 20737, USA.

Plant Propagators Society (IPPS) – Southern Region, and Florida Nursery, Growers, and Landscape Association (FNGLA).

To quantify our surveyed population, we used reports from professional associations of numbers of members and their activity in the association. Our target audience was nursery professionals growing and/or selling plants. FNGLA is a statewide association for Florida, while SNA and IPPS serve the entire southeastern US region. Their reported "member-growers" from Florida were removed from the total membership of the regional organization so as not to duplicate members counted from FNGLA. In total, 987 "member-growers" from the southeastern US were contacted about the survey.

We designed and implemented surveys through Qualtrics (Qualtrics© 2017, Provo, UT) online survey service. Online surveys were used for their efficiency and low cost compared to standard mail surveys (Schaefer and Dillman 1998). The survey was disseminated by the administrative staff of the professional associations through email newsletters. A total of 2,500 email newsletters with our study information and a hyperlink to the Qualtrics survey were sent to growers, landscape professionals and retail garden centers in the southeastern US from August through October 2017. Qualtrics tracked individual survey responses allowing sales of each species to be calculated from the self-reported annual gross sales figures (responses remained anonymous). Multiple opportunities to complete the survey were provided to optimize participation (Schaefer and Dillman 1998). Administrative staff of each professional association sent subsequent reminders to their members following dissemination, providing three opportunities to complete the survey.

Results and Discussion

Once we controlled for redundancy in participant membership in multiple associations, we determined that the 2,500 surveys sent reached 987 individual "member-growers" through the four combined selected professional associations. Respondents participating in the survey totaled 135, yielding a 14% participation rate. This response rate is lower than typical for surveys of green industry, e.g. a survey of the Illinois nursery industry on basic employment numbers yielded a 48% response rate (Waliczek et al. 2002). Other surveys of the industry regarding invasive species have also found lower response rates (Wirth et al. [2004] response rate = 20%) that are possibly affected by the controversies associated with sales of invasive ornamental plants in this region.

Description of the survey population (sales and size). Most survey respondents indicated that they were either nursery or greenhouse growers (68%) or landscape professionals (27%). Other groups identified included retail garden center professionals (15%), brokers (6%), and allied suppliers (2%). Businesses were located largely in Florida (64% of respondents), while Georgia and Alabama were represented by 10% and 6% or responses, respectively. The participants were asked to report their gross annual sales for 2015. Small businesses were a large component of the overall respondents; 19% responded that they owned a small business that sold $49,000 or less, and 28% reported the slightly higher sales brackets of $100k – 500k. Twenty-two percent of respondents indicated their business sold higher sales figures from $1M - $5M worth of plants in 2015. Annual sales from $11M - $30M was indicated by 7% of respondents. To further characterize business magnitude, survey participants reported the size of their staff during peak season. Most respondents reported 1-9 employees (46%); 19% and 15% of respondents indicated 10-24 and 25-49 employees, respectively.

Gross sales figures of study species. The next portion of the survey gathered information about the types of plants sold by each business to determine differences in market specialties, and current sales of the five potentially invasive species in our study. Specialties were evenly represented, though most (17%) businesses specialized in ornamental shrubs and trees (also known as woody ornamental species), followed by those specializing in herbaceous perennials (14%), groundcovers (13%), and ornamental

Table 2. Questions included in the online survey implemented through Qualtrics (Qualtrics© 2017, Provo, UT) online survey service. Questions provided a multiple-choice response format (questions #2-9, 11, and 13), with an option for open response by choosing 'other.' One question requested the participants write in their opinion of sterile cultivars (question #11). A Likert-type item scale was used for the attitude assessment question (question #10).

1. Are you over the age of 18?
2. Which of these describe you: Grower (Nursery/Greenhouse), Landscape Professional, Broker, Retail Garden Center Professional, Allied Supplier?
3. What state is your business located in?
4. What were your gross annual sales for 2015?
5. How many employees did your business have at peak in 2015?
6. What are the primary product types sold by your company?
7. Which of the following of our study species does your business currently sell: Coral ardisia, Chinese privet, Japanese honeysuckle, Heavenly bamboo, Mexican petunia?
8. What are the percentages of your 2015 gross annual sales for each of the study species?
9. Are the majority of sales of the study species sold to customers in-state, out-of-state, or both?
10. If there were sterile cultivars available for the study species, how likely would you be to sell them?
11. What impact do you see the availability of sterile cultivars of popular invasive ornamental species having on your business?
12. Please tell us about your opinions of the availability of sterile cultivars and how it pertains to your business.
13. Please rank the study species in the order of importance for availability of sterile cultivars for your business.

grasses and bamboo (13%). Participants were asked whether they carried each of the five potentially invasive species studied; Heavenly bamboo was sold by 70% of respondents, followed by Mexican petunia (41%), Chinese privet (38%), and Japanese honeysuckle (34%) (Fig. 1). We note that far more growers are selling these species than reported in Wirth et al. (2004), in which 15% or less were selling any of these species in Florida. Participants were asked what percentage of the 2015 annual gross sales was accounted for by each of the species (Fig. 2). Heavenly bamboo was reported to be the largest grossing species in the region with $15.7M - $22.8M in sales for 2015. Chinese privet was the next largest grossing species, amounting to $4.7M - $7.1M in 2015. The next species was Japanese honeysuckle, with reported earnings of $1.4M - $1.6M in 2015. Mexican petunia sales were not reported to reach over $1M in 2015. The value of 2015 sales of Coral ardisia were not reported at all, perhaps related to state regulation of this species as a noxious weed; this response contrasts with the 50% of Florida respondents reporting sales of this species previously (Wirth et al. 2004). To summarize, the reported gross sales of each species validated the choice of Chinese privet as a candidate for sterile cultivar development and provided further guidance for cultivar development of Heavenly bamboo, the other economically important species.

Attitudes towards sterile cultivar research. The last portion of the survey was designed to capture the attitudes of the growers, landscape professionals and retail garden centers towards sterile cultivar research being performed in the university setting. In general, 70% of respondents

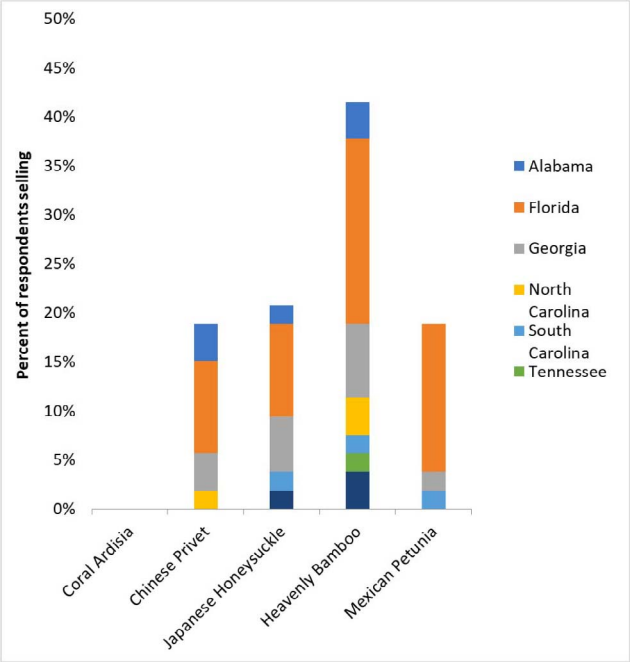

Fig. 1. Percentage of survey respondents, by state, that reported selling each of the selected study species.

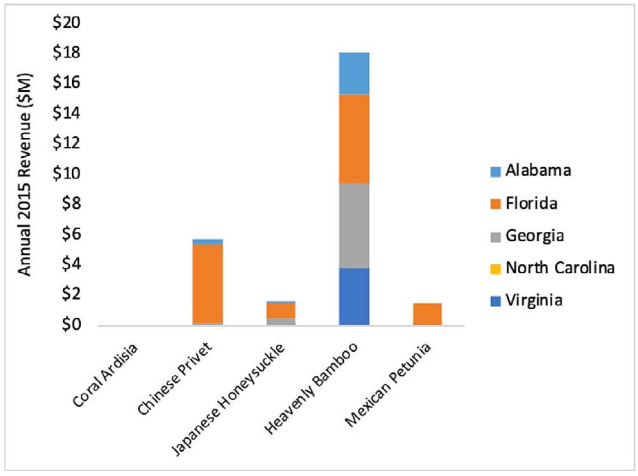

Fig. 2. Self-reported revenue, by state, from sales of each study species for the 2015 calendar year.

indicated that they were likely (slightly to extremely) to sell sterile cultivars overall. However, when asked to assess their willingness to sell sterile cultivars of the five potentially invasive species individually if available, answers varied from species to species (Fig. 3). For Coral ardisia, 28% of participants indicated that they were extremely unlikely to sell any sterile cultivars of the species, and the responses were similar for Japanese honeysuckle (24%) and Mexican petunia (33%). Regarding Coral ardisia, development may also be limited because sterility could preclude formation of ornamentally valuable red berries (though sterile berry formation may be possible). However, we note this same limitation has not restricted development of Heavenly bamboo cultivars, perhaps because the ornamental value of their attractive foliage may compensate for alteration in berry production. Many cultivars and hybrids of *Lonicera* exist (Whitehouse 2012), but there are few cultivated forms of Japanese honeysuckle, and none have been reported in the literature as sterile. Consequently, sterile cultivar development may not limit invasiveness for this species because it spreads aggressively by vegetative climbing. On the other hand, cultivated sterile forms of Mexican petunia have been developed in a breeding program at UF. It remains to be understood why nursery professionals are unlikely to sell sterile forms of Mexican petunia even though sterility does not affect plant growth and ornamental value of this species at all. Our results suggest that availability of these sterile cultivars alone may not be enough to encourage widespread adoption of the technology for some of the studied species.

Conversely, larger percentages of respondents indicated they would be extremely likely to sell sterile cultivars of Heavenly bamboo and Chinese privet (40% and 30%, respectively). Clearly, other factors beyond a general acceptance of the technology itself influence the willingness to sell sterile cultivars of individual species. Research programs should focus on developing sterile cultivars for species that will make economic sense for the industry, but also those for which adoption of sterile cultivars is also feasible, given other factors that influence the nursery professional's willingness to sell.

Survey participants provided insight with their responses to our question "Please tell us about your opinions of the availability of sterile cultivars and how it pertains to your business." Barriers to adoption of sterile cultivars were a common topic of comments, e.g.:

> "Some states pass broad regulations prohibiting . . .plants they consider invasive without considering the economic impact on growers or . . . sterile cultivars which may be available. If more sterile cultivars do become available, it may be a challenge to persuade states to rewrite their regulations."

The additional landscape maintenance required for invasive ornamental species was mentioned as further motivation for sterile cultivar development:

> "We are a landscaper so we purchase plants primarily spec'd by the Architects. The availability of sterile cultivars on a maintenance level would be beneficial. We spend a lot of time cutting back materials that bleed into other beds and ruin the integrity of the landscape design."

> "Sterile cultivars are definitely desired in the marketplace because consumers don't want weedy, unmanageable plants. Sterile cultivars equal lower maintenance plants in the landscape. That's a good thing. Tree growers grow many sterile varieties now. It's worthwhile to develop and breed sterile cultivars."

Others expressed general support for the approach:

> "too few, glad researchers are working on them"

> "Anytime we can offer a sterile version of a popular plant that is a win for everyone".

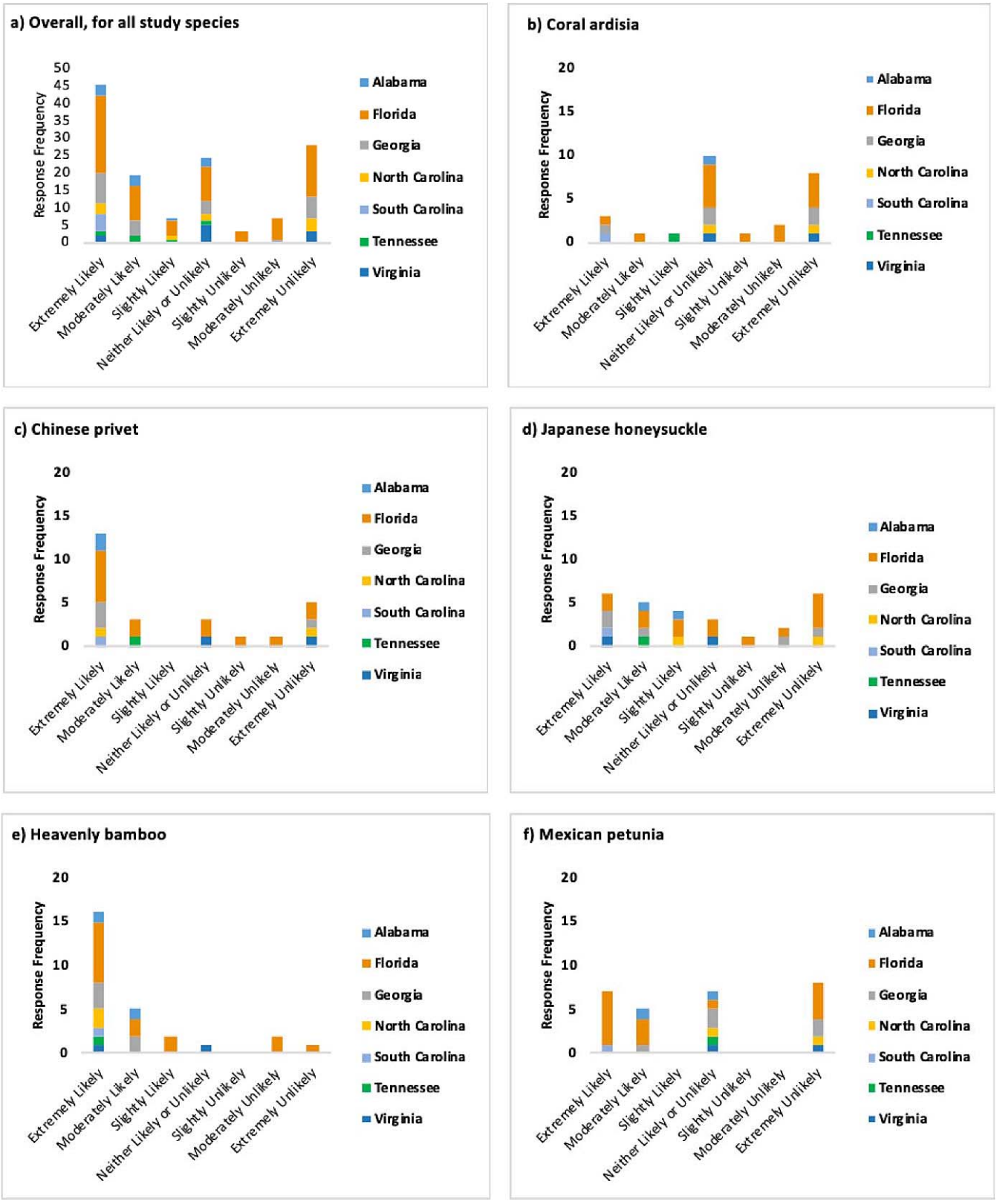

Fig. 3. Frequency tables depicting respondents' likeliness, by state, to sell sterile cultivars (a) of all species, (b) of Coral ardisia, (c) of Chinese privet, (d) of Japanese honeysuckle, (e) of Heavenly bamboo, and (f) of Mexican petunia. Note: scale is different in (a).

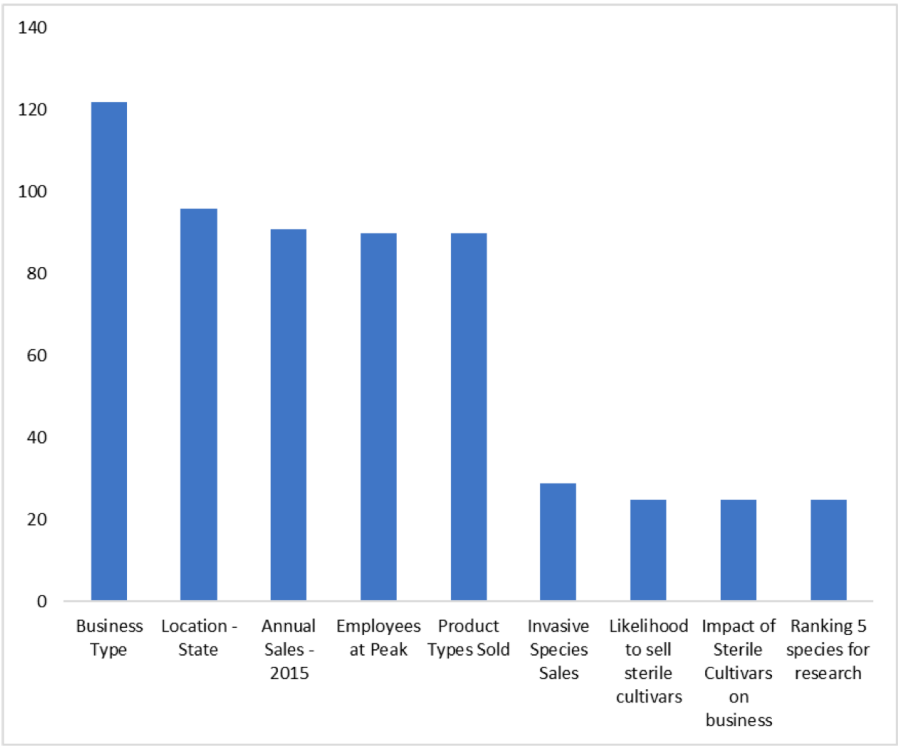

Fig. 4. The number of respondents providing a response to subsequent survey questions (questions that addressed a second level of detail or required a written answer are omitted here). See Table 2 for full description of survey questions.

The benefits of discussing the approach with consumers was also mentioned:

> "we like to educate people on sterile cultivars of potentially invasive plants, so we would love to use new cultivars for education"

> "it opens dialogue with potential customers on what species of plants are best for the environment."

Most comments express a positive opinion of the impact of cultivars on their business, but two respondents noted the urgency of sterile cultivar development for this technology to have the maximum impact on their business:

> "I really think the sterile cultivars are coming a little late to the game."

> "Sterile cultivars are the best way to ensure the future sales of any of these and other genus that are potentially invasive instead of losing them to governmental regulation. Once banned, it will be too late even if sterile varieties are created to be able to sell them. We must be ahead of the bans in order to keep the genus able to be grown and sold."

Informed direction for future sterile cultivar work. Most directly, the next steps for future sterile cultivar work are to develop sterile cultivars of Chinese privet. Heavenly bamboo represents another economically important species for sterile cultivar development based on the survey responses from the southeastern growers in this study. These species and others identified as economically important are already the subject of sterile cultivar development research in the southeast (Table 2). Results from this work suggest that these existing programs, as well as future work on these species, should be highly prioritized.

Suggestions for future research. We recommend continuing survey work to identify research priorities, but several improvements could increase the utility of results. Participants answered fewer questions over the course of the questionnaire; the most notable drop in participation occurred with 60% abandoning the survey at the mention of invasive species (participation dropped from 90 to 20 participants, Fig. 4). This resulted in fewer data points to inform questions towards the end of the survey and limited our ability to evaluate the growers' opinions of sterile cultivar research. An improved survey instrument could 1) avoid language that implies a negative bias associated with ornamentals and 2) reduce survey fatigue by structuring the survey to include more specific questions first and collect demographic data last.

In our survey, we gathered valuable information to guide research to best benefit the industry, but important questions remain. Most significantly, how can the practice of selling sterile cultivars become more mainstream? Our results suggest that the challenge to obtain acceptance differs with species, and therefore each species may require an individual plan. The large investment in research and development associated with species-specific plans may be justified, given the considerable sales generated by these invasive species, and the promise of acceptance of this technology. We caution that, as survey respondents noted,

the faster the development of sterile cultivars can proceed, the greater their benefit to the green industry.

Further, nursery professionals expressed a willingness to modify stock to limit sale of invasive species, so we assume that there may be other alternative strategies to minimizing profit reliance on invasive species that growers could recommend. Among these options, it would be useful to gauge industry's estimation of several other approaches to reducing sales of invasive species, including 1) providing better information to consumers to place responsibility on the end user, 2) researching alternative avenues of reducing invasiveness that will retain the value of the plant material for growers, and 3) incentivizing phasing out ornamental invasives via replacement with non-invasive alternatives. Given the favorable attitudes toward sterile cultivar technology revealed in our survey, we also recommend researching actions to specifically increase the feasibility of adopting sterile cultivars. Studies have revealed that the lack of an official, centralized list of approved sterile cultivars can be a source of confusion for growers that is a barrier to application of this technology (Cronin et al. 2017). Similarly, we must identify a strategy for facilitating production and sales of the sterile cultivar of a species that is prohibited. We also note that an important part of relying on consumer choice of sterile cultivars includes showing consumers how to recognize sterile forms compared to non-sterile forms when not fruiting, which would likely require a certification and labeling system. These approaches present challenges but do represent alternatives to legislative bans of ornamental species that have been considered and could lead to substantial losses in revenues to the green industry (Li et al. 2004).

In summary, our survey revealed nursery/growers in this region to be primarily smaller businesses, most of which sell Heavenly bamboo (also the largest grossing species), and many of which sell Mexican petunia, Chinese privet, and Japanese honeysuckle. Over 70% of those surveyed would be likely to sell sterile cultivars, showing a high level of acceptance for this technology in general, and a great deal of interest in providing alternatives to potentially invasive species. The green industry is increasingly concerned that valuable crops will be classified as invasive, and sterile cultivar research represents a way to neutralize the invasive characteristics of these economically important species (Li et al. 2004). Sterile cultivar research is particularly urgent for the species in this study because, for most of these species, there are currently no bans against their sale, only recommendations not to plant them. Researchers have an opportunity to develop sterile cultivars to limit the invasive potential of these economically important species, thereby allowing growers to remain profitable and reduce the chance of invasion outbreaks concurrently.

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