Pathways of Invasive Plant Spread to Alaska: III. Contaminants in Crop and Grass Seed

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Invasive plants disperse to new areas via numerous pathways. Study of these pathways helps to focus limited budgets toward prevention and early detection. This study examined potentially invasive seed contaminants in imported crops and grass seed as pathways for plant dispersal to Alaska. Crop and grass seed were purchased from 13 Alaska retail outlets representing 14 seed suppliers. Seed bags were sampled using federally mandated protocols and were analyzed for crop seeds that were not supposed to be included and for weed contaminants. Ninety-five weed and 36 contaminant crop taxa were found. Crop seed contained 43 weed taxa and 15 other crop species contaminants, a mean of 6.4 taxa and 3,844 contaminant seed kg^{-1}. Grass seed samples contained 73 weed taxa and 21 crop contaminants, a mean of 3.5 contaminant species and 1,250 seeds kg^{-1}. Two species prohibited by the Alaska seed law were found: Canada thistle was found in a single crop sample, and quackgrass was found in two grass samples. There were no significant relationships between either seed type or supplier and either the number of contaminant species or number of seeds. Labels of 33% of crop samples and 8% of grass samples claimed 0.00% weed seeds, but low (0.007% by weight, 2 species) to high (1.18% by weight, 13 species) amounts of weed contaminants were found. Importation of crop seed is a large pathway for seed movement, causing significant propagule pressure and an increased likelihood of establishment by new invasive plant populations. Prevention of spread via this pathway would be enhanced by changes to seed laws, by greater regulatory enforcement, and by including on the label, the names of all weed and contaminant crop species found in the law-required samples. Consumers could then make decisions on whether to purchase seed based on the potentially invasive species that would be planted with the desired seed.

Nomenclature: Canada thistle, *Cirsium arvense* (L.) Scop.; quackgrass, *Elymus repens* (L.) Gould.

Key words: Pathways, Alaska, invasion prevention, crop seed, grass seed, other crop species, seed law, seed contaminants.

Prevention is the most cost-effective, environmentally friendly tool for combating the spread of invasive plant species (Davies and Johnson 2011; Radosevich et al. 1997; Reichard 1997). Prevention strategies often strive to reduce propagule pressure from specific pathways (Davies and Johnson 2011) because propagule pressure has been often found to correlate with the probability of naturalization and invasion (D'Antonio et al. 2001; Pyšek et al. 2009). Prevention strategies include education; use of weed-free crop and revegetation seed, feed, soil, mulches, and equipment; and creation and enforcement of seed and other plant material laws or quarantines (Holt 2004).

Alaska is an obvious place to focus prevention efforts because it is relatively free of nonnative plants (14% of established taxa were exotic in 2006; Carlson and Shephard 2007). In Alaska's remaining pristine ecosystems, it is still possible to avoid wide-scale invasions such as those occurring on Alaskan agricultural lands because of a lack of prevention efforts (Conn et al. 2011).

Invasive species often take predictable pathways to reach new areas (Forcella and Harvey 1988; Mack 2003; Thomas et al. 2007; Van der Muelen and Sindel 2008), and some of those pathways may create more propagule pressure and a higher likelihood of invasive plant establishment than others (Ruiz and Carlton 2003). Identifying pathways of highest propagule pressure can focus early detection surveys on likely vulnerable areas (Ruiz and Carlton 2003).

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Management Implications

Seeds of invasive and other nonnative plants disperse to new areas via numerous pathways. Study of these pathways helps to focus limited budgets on prevention and early detection. This study examined the pathway of seed contaminants traveling to Alaska via imported crop and grass seed. Crop and grass seed were purchased from 13 retail seed outlets in Alaska and included 14 seed suppliers. Eighteen crop samples and 100 grass seed samples were collected and sampled using federally mandated protocols. Seed samples were analyzed for crop and weed contaminants using an approved laboratory. A total of 95 weed and 36 contaminant crop taxa were found. The average number of contaminant taxa was 6.4 for crop seed and 3.5 for grass seed. The average number of contaminant seed per kilogram of seed was 3,844 for crop seed and 1,250 for grass seed. Two species prohibited from transport or sale in Alaska were found in the samples: Canada thistle was found in a single crop sample, whereas quackgrass was found in two grass samples. Seed labels of 33% of crop seed samples and 8% of grass seed samples claimed to have 0.00% weed seeds yet contained numerous weed species. Six percent of crop samples and 8% of grass samples did not contain crop or weed contaminants, showing that it is possible to produce clean seed. Statistical analysis showed no differences between seed suppliers or crop species in the number of contaminant taxa or amounts of contaminant seed. Importation of seed into Alaska is a large pathway for movement of nonnative plants. Contaminant seed using this pathway are likely to establish because they are planted under enhanced conditions for survival with the crop seed. Prevention of spread via this pathway would be aided by revising seed laws, increasing regulatory enforcement, and including on the label the names of all weed and crop species found by the seed testing laboratory. Consumers could make a decision on whether to purchase seed based on the potentially invasive species that would be planted along with desired seed.

Pathways for invading plants are generally known but are little studied.

Alaska invasive plant prevention efforts could be maximized by targeting the pathways providing the greatest propagule pressure and likelihood of invasive plant establishment. For that reason, a series of studies on the pathways for seed movement into Alaska was initiated. The size and nature of the pathways from soil imported with ornamentals in containers or in root balls was determined (Conn et al. 2008b) as well as from imported hay and straw (Conn et al. 2010). Fifty-one nonnative plant species were found in soil from ornamentals and forty-nine species were found in imported hay and straw. Container-grown ornamental soil contained Canada thistle [*Cirsium arvense* (L.) Scop.], a prohibited weed in Alaska, and nine other species listed as invasive in Alaska. Another Alaska-prohibited weed, quackgrass [*Elymus repens* (L.) Gould], was found in hay and straw, as well as downy brome (*Bromus tectorum* L.), ranked as invasive in Alaska (Carlson et al. 2008).

A major pathway for the movement of invasive plant species is in seed of agricultural crops and grain commodities. Mack (1986) identified invasive plant propagule contaminants in crop seed as being the most important means for spread of nonindigenous plant species to and within the United States. Souminen (1979) reported that 370 nonindigenous plant species reached and established in Finland via this pathway.

To mitigate this pathway, many countries have enacted seed laws that require testing for, and set limits on, seed contaminants. The Federal Seed Act (7 U.S.C. 1551–1611) and *U.S. Code of Federal Regulations* (title 7, section 201) provides the legal framework in the United States for regulating the types and amounts of weed seeds allowed in crop seed that is transported or sold. The federal noxious weed seed regulations (7 *CFR* 201.16) set forth a list of plant species that cannot be contained in seeds that are transported between states. The law allows states to develop their own laws and regulations that restrict the total weight of weed seed, prohibit certain weed seed (the prohibited species list), and create lists of restricted noxious weed species that cannot be present in more than a specified number of seeds per pound if they are to be transported to or sold within the state (see USDA-AMS 2010 for state lists of prohibited and restricted species). The federal law requires that seeds being transported and sold be tested for crop seed contaminants and weed seeds and that a label be placed on the crop seed container stating: the percentage (by weight of crop seed) of other crop seed and weed seed and the number of seeds of restricted noxious weed species per pound of crop seed.

Despite the effectiveness of better seed-cleaning techniques and seed laws in reducing seed contaminants, extraneous crop and weed seeds are still common contaminants in the seed trade (Mack 1991, 2003). Because of the large volumes of seed contaminants moving in this pathway, even a small percentage of contaminants amounts to a lot of seed (Shimono and Konuma 2008) and, hence, to propagule pressure.

The objectives of this of the study were to determine the sources and amounts of weed and crop seed contaminants imported to Alaska in crop and grass seed.

Materials and Methods

Seed Purchases. Bags (0.5 to 22.7 kg [1 to 50 lb]) of all available types of crop and grass seed were purchased from large chain warehouse stores, feed stores, and garden centers in Anchorage, AK, and Fairbanks, AK (13 stores). Samples were also made of bulk grain and grass at feed stores. According to labels affixed to bags or bulk bins, the suppliers of crop seed were: Alaska Garden and Pet Inc. (Anchorage, AK 99510), DF Marks Co. (Woodinville, WA 98072), and Holm Town Nursery Inc (Fairbanks, AK 99701). Suppliers of grass seed were: Alaska Feed Co. (Fairbanks, AK 99709), Alaska Garden and Pet Inc.,

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Coldspot Feed Co. (Fairbanks, AK 99701), Denali Seed Co. (Anchorage, AK 99515), DF Marks Co., Holm Town Nursery Inc., Irwin and Sons Ag Supply Inc. (Cheshire, OR 97419), Landmark Seed Co. (Spokane, WA 99201), Lilly Miller Brands (Walnut Creek, CA 94597), Mountain View Seeds Ltd. (Salem, OR 97305), Pennington Seed Inc. (Lebanon, OR 97355), The Scotts Company LLC (Marysville, OH 43041), Sun Mountain Natives Seed Co. (Eagle, ID 83616), and Turf-Seed (Gervais, OR 97026). Suppliers of crop and grass seed raise or buy seed from growers, but individual farms are not shown on seed labels.

Sampling. Sampling methods and sample sizes listed in U.S. federal code *CFR* 201 were followed for each seed type. For crop seed, five samples were taken and composited from each bag using a 51 cm by 1.3 cm (20 in by 0.5 in) trier (Bag trier 235; Seedburo Equipment Co., 2293 S. Mt. Prospect Rd., Des Plaines, IL 60018). For analysis, 20 g (0.7 oz) of seed for white clover (*Trifolium repens* L.) and alsike clover (*Trifolium hybridum* L.) and 50 g of seed for red clover (*Trifolium pratense* L. 'Kenland') and yellow sweetclover [*Melilotus officinalis* (L.) Lam.] seed were obtained from the composite samples. Samples for oats (*Avena sativa* L. 'Athabascan'), cereal rye (*Secale cereale* L.), smooth bromegrass (*Bromus inermis* Leyss. 'Manchar'), timothy (*Phleum pratense* L. 'Engmo'), and reed canarygrass (*Phalaris arundinacea* L.) were obtained by hand grab samples from bulk containers. Sample weights sent for analysis were 500 g for oats and cereal rye, 70 g for smooth bromegrass, and 10 g for timothy and reed canarygrass.

For grass seed the following individual species were analyzed for weed seed contaminants: Italian ryegrass [*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot], perennial ryegrass (*Lolium perenne* L.), red fescue (*Festuca rubra* L.), Kentucky bluegrass (*Poa pratensis* L.), roughstalk bluegrass (*Poa trivialis* L.), tufted hairgrass [*Deschampsia cespitosa* (L.) Beauv.], and crested wheatgrass [*Agropyron cristatum* (L.) Gaertn.]. Twenty-seven grass-seed mixtures were also analyzed. Most grass seed mixtures contained Kentucky bluegrass, red fescue, and Italian or perennial ryegrass, but a few mixtures also contained crested wheatgrass, timothy, smooth bromegrass, tufted hairgrass, hard fescue (*Festuca brevipila* Tracey), tall fescue [*Lolium arundinaceum* (Schreb.) S.J. Darbyshire], or blue wildrye (*Elymus glaucus* Buckley). Small bags of seed (0.45 to 9.07 kg) were sampled with a Seedburo 235 trier (Seedburo Equipment Co., 2293 S. Mt. Prospect Rd., Des Plaines, IL 60018) five times in different directions and were then composited. Large bags of seed (11.34 to 22.68 kg) were sampled five times with a large trier (107 cm by 3.5 cm, bag trier 39-OH; Seedburo Equipment Co.). Seeds were then placed in a bag and were sampled five to seven times with the small trier. Samples sent for analysis weighed 50 g for Italian or perennial ryegrass and crested wheatgrass, 10 g for roughstalk and Kentucky bluegrass, 30 g for red fescue and tufted hairgrass. Grass mixture sample weights employed the highest required analysis weight of those species within the mix.

Contaminant Seed Analysis. A crop and weed examination was performed for all samples by the Washington State Seed Laboratory (Washington State Department of Agriculture, 21 N. First Avenue, Suite 203, Yakima, WA 98902). Weed seed contaminants were separated from crop seed and were then visually identified using seed reference collections.

The laboratory results were reported as the number of crop and weed seed taxa found per pound of seed. Seed weights from the Royal Botanic Gardens Kew Seed Information Database (2008) were used to determine total weights of weed and crop seed to compare with label values for samples that claimed to have 0.0% weed seed kg^{-1}.

For each contaminant taxa found, data from Carlson and Shephard (2007) and Hulten (1968) were used to determine naturalization status. Species were classified as native, naturalized, casual aliens (collected in Alaska but not naturalized), or never collected in Alaska. Seed contaminant taxa were classified as *weeds* or *other crop seed* using the classification in *Code of Federal Regulations* 201.18.

Statistical Analyses. To determine whether the type of crop seed or the supplier of crop seed was related to the degree of weed seed contamination, the seed bags were classified into seed type and suppliers. Crops were classified as grain ($n = 2$), clovers ($n = 12$), or pasture grass ($n = 4$). Separate ANOVA analyses (PROC GLM in SAS software [SAS Version 9.2, SAS Inc., Campus Drive, Cary, NC 27513]) were performed to test for significant effects of crop type and seed supplier on species richness and the number of seed contaminants. Species richness data were transformed (square root) before analysis to stabilize variance.

A similar ANOVA was performed for grass seed. Grass seed types were Italian ryegrass, perennial ryegrass, red fescue, Kentucky bluegrass, crested wheatgrass, and multiple species mixes ($n = 62$).

Source locations for seed, shown on the labels included Washington, Oregon, Utah, Idaho, Minnesota, and Canada. Analysis of differences between source locations in species and amount of seed contaminants was not possible because many of the seeds were mixtures from different locations.

Results and Discussion

Contaminant Species Richness and Number. Between both crop and grass seed samples, the seed laboratory was

able to identify 131 taxa: 93 to the species level and 38 to the genus level. Crop seed samples contained seed of 43 weed taxa and 15 other crop species that were contaminants (Table 1). The mean contaminant species richness for all crops sampled was 6.4. Common lambsquarters (*Chenopodium album* L.), bedstraw (*Galium* spp.), common chickweed [*Stellaria media* (L.) Vill.], and buckhorn plantain (*Plantago lanceolata* L.) were the most common weed species, occurring in 50, 28, 16, and 11% of samples, respectively. The most common crop contaminants were Sandberg bluegrass (*Poa secunda* J. Presl), alsike clover, red clover, Kentucky bluegrass, fescue spp., and timothy, occurring in 50, 39, 39, 33, 26, and 22% of the samples, respectively. The number of seed contaminants ranged from 0 to 19,916 seeds kg^{-1} of crop with a grand mean of 3,844 seeds kg^{-1}.

Several weed species prohibited or restricted in Alaska were found in crop seed imported to Alaska. Quackgrass, a species prohibited under Alaska seed law, was found in a sample of smooth bromegrass. Wild oats (*Avena fatua* L.) was found above allowed levels (13 seeds lb^{-1} versus 7 seeds lb^{-1} allowed), and this species and buckhorn plantain did not appear on associated seed labels as required by Alaska seed regulations (*Alaska Administrative Code*: title 11, chapter 34). Sweetclover, a species that is ranked as highly invasive in Alaska (Carlson et al. 2008) and has been spreading along roadsides and glacial river floodplains (Conn et al. 2008a), was found to be a contaminant of red clover and smooth bromegrass seed. Downy brome, also ranked as highly invasive in Alaska, was found in a smooth bromegrass sample.

The species richness and mean amount of weed seed found in the Alaska crop seed samples is higher than that found at other locations. In a study of weed seed in farmer planter drill boxes, Dewey and Whitesides (1990) determined that 31% of samples contained weed seed with an average of 690 seed kg^{-1}. The drill box study included seed that was not certified and had been saved by the farmers, whereas this study is of seed that is supposed to conform to seed law. Michael et al. (2010) conducted a study of weed and crop contaminants in wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), and lupine (*Lupinus* spp.) seed that had been grown and conserved for planting by grain farmers in Western Australia. Eleven weed and crop species were found. In cleaned seed, 73% of samples had some level of contamination and an average of six weeds and extraneous crop seed kg^{-1} was found.

Alaska grass seed samples contained a total of 73 weed taxa and 21 agricultural species contaminants (Table 2). The most common weeds were rattail fescue [*Vulpia myuros* (L.) K.C. Gmel.], alkaligrass (*Puccinellia* spp.), ventenata [*Ventenata dubia* (Leers) Coss. in Dur.], shortawn foxtail (*Alopecurus aequalis* Sobol.), mayweed chamomile (*Anthemis cotula* L.), Japanese brome (*Bromus japonicus* Thunb. ex. Murr.), dandelion (*Taraxacum officinale* G.H. Weber ex Wiggers), and henbit (*Lamium amplexicaule* L.), found in 30, 12, 12, 12, 12, 9, 8, and 7% of all samples, respectively. The most common crop contaminants were Kentucky bluegrass, bulbous bluegrass (*Poa bulbosa* L.), Canada bluegrass (*Poa compressa* L.), canarygrass (*Phalaris canariensis* L.), and fescue species, occurring in 21, 13, 8% 7, and 7% of samples, respectively. The mean contaminant species richness was 3.5, and the number of contaminant seed ranged from 0 to 22,936 seeds kg^{-1} with a grand mean of 1,250 seeds kg^{-1}. Seeds of the Alaska-prohibited species Canada thistle were found as a contaminant in two separate grass seed mixes. Wild oats, an Alaska-restricted species, was found in single samples of Italian ryegrass, Kentucky bluegrass, and a grass mixture but was not listed on the seed labels. Two species were found in grass seed samples that are ranked as highly invasive in Alaska (Carlson et al. 2008), that are not listed as prohibited or restricted species in Federal or Alaska seed law. Downy brome was found in 5% of all grass seed samples, and reed canarygrass was found in a single grass seed mix. Reed canarygrass is still used as a pasture grass in Alaska but has been found to be colonizing stream banks of important salmon-spawning streams on the Kenai Peninsula (Spellman 2009).

Six crop samples (33% of all crop samples) and eight grass seed samples (8% of all grass samples) had labels claiming that they contained 0.00% weed seeds, but sample results showed they actually contained low (1 species, 0.0004% by weight) to high (13 species, 1.18% by weight) amounts of weed contamination. Although determination of weed and agricultural crop contaminants is subject to variability because samples are analyzed instead of the entire seed population (Copeland and McDonald 2001, USDA-AMS 2009), the large quantity of weed seeds found in eight of the samples, compared with the label-stated zero weed content, suggests that sampling error was not the cause of discrepancies.

In contrast to these samples, one crop sample (6% of all crop samples) and eight grass seed samples (8% of total grass seed samples) did not have any extraneous seed contaminants. These zero-contaminant samples may be artifacts of sampling or could be the result of exemplary farm management or seed cleaning or both.

Effects of Seed Type and Supplier. There were no significant effects (ANOVA, $P = 0.5$) of crop or grass seed type or supplier on contaminant species richness or in the mean number of contaminant seeds for both crop and grass seed samples. Although some samples from individual seed suppliers were relatively free of extraneous seeds, there were no suppliers that were significantly better or worse than others in this regard. Crop seed passes through a number of hands, including growers, cleaners, buyers, brokers,

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Table 1. Frequency of occurrence and mean number of seeds of weed and crop contaminants in crop seed imported to Alaska.

Scientific name	Common name	Weed and naturalization status[a]	Frequency of occurrence[b]									Mean number of seeds[b]								
			AC	WC	RC	SC	T	O	R	B	RG	AC	WC	RC	SC	T	O	R	B	RG
			%									No. seeds kg $^{-1}$								
Agrostis spp.	Bentgrass	w	0	0	0	0	50	0	0	0	0	0.0	0.0	0.0	0.0	6,634	0.0	0.0	0.0	0.0
Amaranthus albus L.	Tumble pigweed	w+	0	20	0	0	0	0	0	0	0	0.0	88	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Amaranthus blitoides S. Wats.	Prostrate pigweed	w	0	0	33	0	0	0	0	0	0	0.0	0.0	13	0.0	0.0	0.0	0.0	0.0	0.0
Amaranthus spp.	Pigweed	w	33	0	0	0	0	0	0	0	0	82	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Anthemis cotula L.	Mayweed chamomile	wn	0	40	0	0	0	0	0	0	0	0.0	150	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Asclepias spp.	Milkweed	w	0	0	0	0	0	0	0	100	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.2	0.0
Avena fatua L.	Wild oat	wn	0	0	0	0	0	0	0	100	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.7	0.0
Axyris amaranthoides L.	Russian pigweed	w	0	0	33	0	0	0	0	0	0	0.0	0.0	17.6	0.0	0.0	0.0	0.0	0.0	0.0
Kochia scoparia (L.) Schrad.	Kochia	w	0	0	33	0	0	0	0	0	0	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0
Brassica napus L.	Rapeseed	cn	0	0	0	0	0	100	0	0	0	0.0	0.0	0.0	0.0	0.0	2.2	0.0	0.0	0.0
Brassica rapa L.	Birdsrape mustard	cn	33	0	0	0	0	0	0	0	0	108	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bromus japonicus Thunb. ex. Murr.	Japanese brome	w	0	0	0	0	0	0	0	100	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1204	0.0
Bromus tectorum L.	Downy brome	wn	0	0	0	0	0	0	0	100	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	41.9	0.0
Carex spp.	Sedge	w	0	0	0	0	50	0	0	0	0	0.0	0.0	0.0	0.0	48.5	0.0	0.0	0.0	0.0
Chenopodium album L.	Common lambs-quarters	wn	100	40	67	100	0	0	0	0	0	1,310	137	624	19.8	0.0	0.0	0.0	0.0	0.0
Deschampsia spp.	Hairgrass	w	0	0	0	0	0	0	100	0	0	0.0	0.0	0.0	0.0	0.0	0.0	538	0.0	0.0
Dracocephalum parviflorum Nutt.	American dragonhead	wn	67	0	0	100	0	0	0	0	0	57.3	0.0	0.0	317	0.0	0.0	0.0	0.0	0.0
Eleocharis spp.	Spikerush	w	0	0	0	0	50	0	0	0	0	0.0	0.0	0.0	0.0	48.5	0.0	0.0	0.0	0.0
Elymus repens (L.) Gould	Quackgrass	wn	0	0	0	0	0	0	0	100	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.2	0.0
Eruca sativa P. Mill.	Garden rocket	w	33	0	0	0	0	0	0	0	0	8.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Festuca spp.	Fescue	c	33	0	0	0	50	100	100	100	0	33.1	0.0	0.0	0.0	48.5	2.2	35.3	13.2	0.0
Galium spp.	Bedstraw	w	33	20	33	100	50	0	0	0	0	1,303	474	547	238	344	0.0	0.0	0.0	0.0
Geranium pusillum L.	Smallflower geranium	w	0	20	0	0	0	0	0	0	0	0.0	13.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Glyceria spp.	Mannagrass	w	0	0	0	0	50	0	0	0	0	0.0	0.0	0.0	0.0	48.5	0.0	0.0	0.0	0.0
Hordeum vulgare L.	Barley		0	0	0	0	0	100	0	0	0	0.0	0.0	0.0	0.0	0.0	2.2	0.0	0.0	0.0
Lactuca serriola L.	Prickly lettuce	wn	0	20	0	0	0	0	0	0	0	0.0	11.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lamium amplexicaule L.	Henbit	w	0	20	0	0	0	0	0	0	0	0.0	11.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 1. Continued.

Scientific name	Common name	Weed and naturalization status[a]	Frequency of occurrence[b]									Mean number of seeds[b]								
			AC	WC	RC	SC	T	O	R	B	RG	AC	WC	RC	SC	T	O	R	B	RG
Lolium spp.	Ryegrass	c	0	0	0	0	0	0	0	0	100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	48.5
Lycopus spp.	Bugleweed	w	0	0	0	0	50	0	0	0	0	0.0	0.0	0.0	0.0	48.5	0.0	0.0	0.0	0.0
Medicago sativa L.	Alfalfa	cn	0	0	0	0	50	0	0	0	100	0.0	0.0	0.0	0.0	148	0.0	0.0	0.0	48.5
Melilotus spp.	Sweetclover	cn	0	0	33		0	0	0	0	0	0.0	0.0	48.5		0.0	0.0	0.0	0.0	0.0
Phleum pratense L.	Timothy	cn	67	20	33	0		0	0	0	0	33.1	24.3	19.8	0.0		0.0	0.0	0.0	0.0
Plantago lanceolata L.	Buckhorn plantain	w+	0	20	33	0	0	0	0	0	0	0.0	13.2	6.6	0.0	0.0	0.0	0.0	0.0	0.0
Plantago major L.	Broadleaf plantain	wn	33	0	0	0	0	0	0	0	0	33.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Poa palustris L.	Fowl bluegrass	ci	0	0	0	0	50	0	0	0	0	0.0	0.0	0.0	0.0	2934	0.0	0.0	0.0	0.0
Poa pratensis L.	Kentucky bluegrass	cn	67	20	0	0	0	0	100	100	100	123	13.2	0.0	0.0	0.0	0.0	143	13.2	148
Poa secunda J. Presl	Sandberg bluegrass	c	0	20	67	100	50	100	100	100	100	0.0	13.2	13.2	13.2	13.2	13.2	13.2	13.2	13.2
Poa spp.	Bluegrass	w		0	0	0	0	0	0	0	0	0.0	13.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Polygonom persicaria L.	Ladysthumb	wn	0	0	33	0	0	100	0	0	0	0.0	0.0	4.4	0.0	0.0	2.2	0.0	0.0	0.0
Polygonum spp.	Smartweed	w	0	0	100	0	0	0	0	0	0	0.0	0.0	88.2	0.0	0.0	0.0	0.0	0.0	0.0
Potentilla spp.	Cinquefoil	w	33	0	0	0	0	0	0	0	0	141	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rumex acetosella	Red sorrel	wn	0	20	0	0	0	0	0	0	0	0.0	61.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rumex crispus	Curly dock	wn	0	0	33	0	0	0	0	0	0	0.0	0.0	26.5	0.0	0.0	0.0	0.0	0.0	0.0
Rumex spp.	Dock	w	33	0	0	0	0	0	0	0	0	33.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sherardia arvensis L.	Field madder	w	0	20	0	0	0	0	0	0	0	0.0	1,969	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Silene latifolia Poir.	White campion	w+	0	0	33	100	0	0	0	0	0	0.0	0.0	81.6	99.2	0.0	0.0	0.0	0.0	0.0
Silene noctiflora L.	Nightflowering catchfly	wn	33	0	0	0	0	0	0	0	0	57.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sisymbrium officinale (L.) Scop.	Hedge mustard	w+	0	20	0	0	0	0	0	0	0	0.0	24.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Spergula arvensis L.	Corn spurry	wn	33	0	0	0	0	0	0	0	0	397	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stellaria media (L.) Vill.	Common chickweed	wn	33	40	0	0	0	0	0	0	0	183	335	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Stellaria spp.	Chickweed	w	33	0	0	0	0	0	0	0	0	545	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Thlaspi arvense L.	Field pennycress	w+	33	0	0	0	0	0	0	100	0	340	0.0	0.0	0.0	0.0	0.0	0.0	13.2	0.0
Tragopogon spp.	Salsify	w	0	0	0	0	0	0	0	100	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.2	0.0
Triticum aestivum L.	Wheat	c+	0	0	0	0	0	0	0	100	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.2	0.0
Trifolium hybridum L.	Alsike clover	cn		40	67	100	100	0	0	0	0		2,282	805	278	196	0.0	0.0	0.0	0.0
Trifolium pratense L.	Red clover	cn	100	40		100	50	0	0	0	0	81.6	37.5		119	48.5	0.0	0.0	0.0	0.0
Trifolium vesiculosum Savi	Arrowleaf clover	w	0	0	33	0	0	0	0	0	0	0.0	0.0	3126	0.0	0.0	0.0	0.0	0.0	0.0
Vicia spp.	Vetch	c	0	0	33	0	0	100	0	0	0	0.0	0.0	146	0.0	0.0	2.2	0.0	0.0	0.0

Table 1. Continued.

No. of samples	3	5	3	1	2	1	1	1	1
Total No. of contaminant species	18	17	16	7	12	6	4	11	3
Mean No. of contaminant species	10.0	4.4	6.0	7.0	7.0	6.0	4.0	11.0	3.0
Mean No. of contaminant seed kg^{-1}	4,869	5,671	4,696	804	10,520	24	730	1,380	258

[a] w, weed; c, crop; i, native in Alaska; n, not indigenous, naturalized; +, collected in Alaska, not naturalized; −, not collected in Alaska.

[b] Abbreviations: AC, alsike clover; WC, white clover; RC, red clover; SC, sweetclover; T, timothy; O, oats; R, cereal rye; B, smooth brome; RG, reed canarygrass.

packagers, wholesalers, and retailers. Suppliers or wholesalers of seeds often buy and combine seeds from multiple fields and origins (Copeland and McDonald 2001). The variability in the amounts of extraneous seeds in seed samples from the same supplier probably reflects the differences in weed management between fields. Extraneous crop and weed contamination levels in crop seed have been shown to be strongly related to field abundance of weeds (Michael et al. 2010; Shimono and Konuma 2008).

Pathway Risk. The results of this study indicate that exogenous seed in crop and grass seed is a significant pathway for movement of nonindigenous plants to Alaska. Between crop and grass seed, 95 weed and 36 crop taxa were found as contaminants. Species that are prohibited from being shipped to, or sold in, Alaska are arriving via this pathway. Increasing the risk from this pathway is that weed and crop contaminants are typically planted under enhanced conditions for germination and establishment. Given the number of contaminants arriving and the proximity of planted areas to native ecosystems, this pathway is significantly increasing the risk of invasive plant establishment in Alaska's intact ecosystems.

Current seed laws do not appear to be effective in stopping the movement of extraneous, nonindigenous seed in crop seed. Thirty-three percent of Alaska crop seed and 8% of grass seed claimed to be weed free but actually contained substantial amounts of crop contaminants and weed seed. Whether this degree of departure from label information is just an Alaska phenomenon is unknown. To reduce this pathway, it may be necessary to revise lists of state-prohibited and -restricted weeds to better reflect current and future threats, increase regulatory sampling of seeds for contaminants, and more-rigorously enforce seed laws. Because of the possibility of missing important seed contaminants due to sampling error, it may not be possible to eliminate this pathway, even with enhanced regulatory controls. When it is critical to avoid introduction of invasive species, planting with seed produced on site may be required (Densmore et al. 2000).

Currently, seed labels only list the total weight of weed and extraneous crop species and do not identify the species. Thus, it is not possible for consumers to know which weeds and unwanted crop species they will be planting along with their desired seeds (Christians 2011). Only restricted, noxious weeds on a state's weed list are required to be listed on the label now. These lists only contain a small proportion of a state's weeds, usually those that are the worst weeds in a state's primary crops (Christians 2011) and may not include weeds that are problems in minor crops or wildlands.

Seed-Contaminant Naturalization Status. Of the 95 species of weed and extraneous crop contaminants identified in this study, 8% are currently indigenous to

Table 2. Occurrence frequency and mean number of seeds (kg^{-1}) of weeds and crop contaminants in grass seed imported to Alaska.

Naturalization status and scientific name[a]	Common name	Frequency of occurrence[b]								Mean number of seeds[b]							
		IR	PR	KB	RF	RB	TH	CW	M	IR	PR	KB	RF	RB	TH	CW	M
		%								No. seeds kg^{-1}							
c+*Achnatherum hymenoides* (Roem. & Schult.) Bark.	Indian ricegrass	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.8	0.0
cn*Agropyron cristatum* (L.) Gaertn.	Crested wheatgrass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
w*Agrostis* spp.	Bentgrass	0.0	20.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	28.7	0.0	0.0	0.0	0.0	0.0	1.3
w*Allium* spp.	Wild onion	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.6
wi*Alopecurus aequalis* Sobol.	Shortawn foxtail	0.0	0.0	7.0	0.0	0.0	0.0	0.0	17.0	0.0	0.0	6.6	0.0	0.0	0.0	0.04	10
c−*Alopecurus arundinaceus* Poir.	Creeping meadow foxtail	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
wn*Alopecurus geniculatus* L.	Water foxtail	20.0	0.0	7.0	10.0	0.0	100	0.0	2.0	99.2	0.0	13.2	4.4	0.0	1263	0.0	0.7
cn*Alopecurus pratensis* L.	Meadow foxtail	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4
w−*Amaranthus blitoides* S. Wats.	Prostrate pigweed	0.0	0.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4	0.0	0.0	0.0	0.0
w−*Amaranthus retroflexus* L.	Redroot pigweed	0.0	0.0	7.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	6.6
w*Amsinckia* spp.	Fiddleneck	20.0	0.0	6.0	0.0	0.0	0.0	0.0	2.0	19.8	0.0	13.2	0.0	0.0	0.0	0.0	0.7
w−*Anthriscus caucalis* Bieb.	Bur chervil	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
wn*Anthemis cotula* L.	Mayweed chamomile	0.0	0.0	7.0	0.0	0.0	0.0	0.0	17.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	11.0
cn*Anthoxanthum odoratum* L.	Sweet vernalgrass	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
w−*Apera spica-venti* (L.) Beauv.	Silky windgrass	0.0	0.0	7.0	0.0	0.0	0.0	0.0	7.0	0.0	0.0	22.0	0.0	0.0	0.0	0.0	2.2
wn*Avena fatua* L.	Wild oat	20.0	0.0	7.0	0.0	0.0	0.0	0.0	2.0	4.4	0.0	0.2	0.0	0.0	0.0	0.0	1.1
w*Beckmannia* spp.	Sloughgrass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1
wi*Beckmannia syzigachne* (Steud.) Fernald	American sloughgrass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.7
cn*Brassica napus* L.	Rapeseed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
cn*Brassica rapa* L.	Birdsrape mustard	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8
w*Brassica* spp.	Mustard	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
w+*Bromus briziformis* Fisch. & C.A. Mey.	Rattlesnake brome	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
w+*Bromus commutatus* Schrad.	Hairy chess	20.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	15.4	0.0	0.0	0.0	0.0	0.0	0.0	1.5
cn*Bromus inermis* Leyss.	Smooth brome	0.0	0.0	0.0	10.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	17.6	0.0	0.0	0.0	0.9
w−*Bromus japonicus* Thunb. Ex. Murr.	Japanese brome	20.0	20.0	0.0	10.0	0.0	0.0	0.0	10.0	4.4	4.4	0.0	6.6	0.0	0.0	0.0	37.5
c+*Bromus marginatus* Nees ex Steud.	Mountain brome	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4
wn*Bromus tectorum* L.	Downy brome	0.0	0.0	0.0	0.0	0.0	0.0	50.0	7.0	0.0	0.0	0.0	0.0	0.0	0.0	70.5	8.8
w*Bromus* spp.	Brome	20.0	0.0	0.0	0.0	0.0	0.0	50.0	2.0	108	0.0	0.0	0.0	0.0	0.0	11.0	0.7
wn*Capsella bursa-pastoris* (L.) Medik.	Shepherd's-purse	0.0	0.0	0.0	0.0	0.0	100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	194	0.0	0.0
w*Carex* spp.	Sedge	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	46.3
wn*Cerastium fontanum* ssp. *vulgare* (Hartman) Greuter & Burdet	Mouseear chickweed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
wn*Chenopodium album* L.	Common lambsquarters	0.0	0.0	0.0	0.0	0.0	100	0.0	8.0	0.0	0.0	0.0	0.0	0.0	97.0	0.0	4.4
wn*Cirsium arvense* (L.) Scop.	Canada thistle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
w+*Claytonia perfoliata* Willd.	Miner's lettuce	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
w*Crepis* spp.	Hawksbeard	0.0	0.0	0.0	10.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	4.4	0.0	0.0	0.0	1.3

Table 2. Continued.

Naturalization status and scientific name[a]	Common name	Frequency of occurrence[b]								Mean number of seeds[b]							
		IR	PR	KB	RF	RB	TH	CW	M	IR	PR	KB	RF	RB	TH	CW	M
[cn]*Dactylis glomerata* L.	Orchardgrass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
[w]*Deschampsia* spp.	Hairgrass	0.0	0.0	0.0	0.0	0.0		50.0	5.0	0.0	0.0	0.0	0.0		0.0	11.0	4.4
[w+]*Digitaria sanguinalis* (L.) Scop.	Large crabgrass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
[w−]*Echinochloa crus-galli* (L.) Beauv.	Barnyardgrass	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.8	0.0
[w]*Eleocharis* spp.	Spikerush	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8
[ci]*Elymus trachycaulus* (Link) Gould ex Shinners	Slender wheatgrass	0.0	0.0	7.0	0.0	0.0	100	0.0	0.0	0.0	0.0	2.2	0.0	0.0	1,457	0.0	0.0
[w]*Elymus* spp.		0.0	0.0	0.0	0.0	0.0	0.0		2.0	0.0	0.0	0.0	0.0	0.0	0.0		0.7
[c−]*Elytrigia intermedia* (Host) Nevski	Intermediate wheatgrass	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.0	0.0
[c+]*Erodium cicutarium* (L.) L'Hér. Ex Ait.	Redstem filaree	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
[w−]*Erysimum repandum* L.	Bushy wallflower	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
[ci]*Festuca rubra* L.	Red fescue	0.0	0.0	14.0		0.0	0.0	0.0	0.0	0.0	0.0	55.1		0.0	0.0	0.0	0.0
[c]*Festuca* spp.	Fescue	0.0	40.0	7.0	0.0	0.0	0.0	50.0	4.0	0.0	8.8	0.2	0.0	0.0	0.0	30.9	159
[w]*Galium* spp.	Bedstraw	0.0	0.0	7.0	10.0	0.0	0.0	0.0	4.0	0.0	0.0	4.4	4.4	0.0	0.0	0.0	1.1
[w−]*Geranium dissectum* L.	Cutleaf geranium	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
[wi]*Glyceria grandis* Watson	American mannagrass	40.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	1085	0.0	0.0	0.0	0.0	0.0	0.0	2.2
[w]*Glyceria* spp.	Mannagrass	20.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0	15.4	0.0	0.0	0.0	0.0	0.0	0.0	8.8
[w]*Hieracium* spp.	Hawkweed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2
[c]*Holcus* spp.	Velvetgrass	0.0	0.0	0.0	0.0	0.0	100	0.0	2.0	0.0	0.0	0.0	0.0	0.0	194	0.0	1.8
[w]*Hordeum* spp.	Wild barley	0.0	0.0	7.0	0.0	0.0	0.0	0.0	7.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0	2.2
[wn]*Hypochaeris radicata* L.	Hairy cat's-ear	0.0	0.0	0.0	10.0	0.0	100	0.0	4.0	0.0	0.0	0.0	4.4	0.0	97.0	0.0	1.1
[w+]*Lamium amplexicaule* L.	Henbit	0.0	0.0	14.0	0.0	0.0	0.0	0.0	8.0	0.0	0.0	6.6	0.0	0.0	0.0	0.0	6.6
[wn]*Lapsana communis* L.	Nipplewort	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
[w]*Lepidium* spp.	Pepperweed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
[c]*Linum* spp.	Flax	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
[c]*Lolium* spp.	Ryegrass	0.0	0.0	14.0	0.0	0.0	0.0	50.0	0.0	0.0	0.0	231	0.0	0.0	0.0	30.9	0.0
[w]*Lycopus* spp.	Bugleweed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.6
[w+]*Lythrum hyssopifolia* L.	Hyssop loosestrife	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4
[w+]*Malva neglecta* Wallr.	Common mallow	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1
[cn]*Medicago sativa* L.	Alfalfa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
[w]*Papaver* spp.	Poppy	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
[cn]*Phalaris arundinacea* L.	Reed canarygrass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.8
[cn]*Phalaris canariensis* L.	Canarygrass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8
[cn]*Phleum pratense* L.	Timothy	20.0	0.0	0.0	0.0	0.0	100	0.0	7.0	4.4	0.0	0.0	0.0	0.0	2,330	0.0	6.6
[w]*Plagiobothyrus* spp.	Scorpionweed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
[cn]*Poa annua* L.	Annual bluegrass	0.0	0.0	7.0	0.0	0.0	0.0	0.0	8.0	0.0	0.0	6.6	0.0	0.0	0.0	0.0	4.4
[c−]*Poa bulbosa* L.	Bulbous bluegrass	0.0	0.0	14.0	0.0	0.0	0.0	0.0	17.0	0.0	0.0	22.0	0.0	0.0	0.0	0.0	19.8
[cn]*Poa compressa* L.	Canada bluegrass	0.0	0.0	0.0	10.0	0.0	0.0	0.0	12.0	0.0	0.0	0.0	4.4	0.0	0.0	0.0	108

Table 2. Continued.

Naturalization status and scientific name[a]	Common name	Frequency of occurrence[b]								Mean number of seeds[b]							
		IR	PR	KB	RF	RB	TH	CW	M	IR	PR	KB	RF	RB	TH	CW	M
[wi]*Poa palustris* L.	Fowl bluegrass	0.0	0.0	0.0	0.0	0.0	100	0.0	4.0	0.0	0.0	0.0	0.0	0.0	1,845	0.0	300
[cn]*Poa pratensis* L.	Kentucky bluegrass	60.0	60.0		20.0		100	50.0	17.0	115	223		112		5,049	351	121
[cn]*Poa trivialis* L.	Roughstalk bluegrass	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	39.7	0.0
[wn]*Polygonum pensylvanicum* L.	Pennsylvania smartweed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
[wn]*Polygonom persicaria* L.	Ladysthumb	20.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	4.4	0.0	0.0	0.0	0.0	0.0	0.0	1.8
[w]*Polygonum* spp.	Smartweed	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.6
[w]*Puccinellia* spp.	Alkaligrass	0.0	0.0	14.0	0.0	0.0	0.0	0.0	14.0	0.0	0.0	13.2	0.0	0.0	0.0	0.0	28.7
[w]*Ranunculus* spp.	Buttercup	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
[wn]*Rorippa palustris* (L.) Bess.	Marsh yellowcress	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.2
[wn]*Rumex acetosella* L.	Red sorrel	0.0	0.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4	0.0	0.0	0.0	0.0
[wn]*Rumex crispus* L.	Curly dock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1
[w−]*Salsola tragus* L.	Russian-thistle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
[wn]*Senecio vulgaris* L.	Common groundsel	0.0	0.0	7.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0	1.1
[w+]*Setaria viridis* (L.) Beauv.	Green foxtail	0.0	0.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4	0.0	0.0	0.0	0.0
[wn]*Silene noctiflora* L.	Nightflowering catchfly	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1
[w]*Silene* spp.	Campion	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8
[w+]*Solanum physalifolium* Rusby	Hairy nightshade	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
[wn]*Sonchus asper* (L.) Hill	Spiny sowthistle	0.0	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4	0.0	0.0	0.0	0.0	0.0	0.0
[wn]*Sonchus oleraceus* L.	Annual sowthistle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
[wn]*Spergula arvensis* L.	Corn spurry	20.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
[w]*Spergula* spp.	Spurry	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
[wn]*Stellaria media* (L.) Vill.	Common chickweed	0.0	0.0	14.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.8	0.0	0.0	0.0	0.0	0.0
[wn]*Taraxacum officinale* G.H. Weber ex Wiggers	Dandelion	0.0	0.0	7.0	0.0	0.0	0.0	0.0	14.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0	4.4
[w+]*Thlaspi arvense* L.	Field pennycress	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.0
[c+]*Triticum aestivum* L.	Wheat	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
[cn]*Trifolium hybridum* L.	Alsike clover	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1
[cn]*Trifolium pratense* L.	Red clover	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2
[c]*Trifolium* spp.	Clover	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8
[w−]*Ventenata dubia* (Leers) Coss. in Dur.	Ventenata	0.0	0.0	14.0	0.0	0.0	0.0	0.0	15.0	0.0	0.0	13.2	0.0	0.0	0.0	0.0	13.2
[w+]*Viola tricolor* L.	Pansy	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4
[w+]*Vulpia myuros* (L.) K.C. Gmel.	Rattail fescue	40.0	40.0	29.0	40.0	0.0	0.0	0.0	30.0	13.2	19.8	55.1	545	0.0	0.0	0.0	37.5
[w]*Vulpia* spp.	Fescue	0.0	0.0	7.0	10.0	0.0	0.0	0.0	4.0	0.0	0.0	4.4	132	0.0	0.0	0.0	13.2

Table 2. Continued.

No. of samples	5	5	14	10	1	1	2	62
Total No. of contaminant species	16	6	22	13	0	9	10	87
Mean No. of species	4	1.8	2.6	1.7	0	9.0	5.0	4.2
Mean No. of contaminant seed kg^{-1}	1,546	289	509	833	0	12,526	591	1,398

[a] Weed and naturalization status: w, weed; c, crop; i, native in Alaska; n, not indigenous, naturalized; +, collected in Alaska, not naturalized; −, not collected in Alaska.

[b] Abbreviations: IR, Italian ryegrass (n = 5); PR, perennial ryegrass (n = 5); KB, Kentucky bluegrass (n = 14); RF, red fescue (n = 10); RB, roughstalk bluegrass (n = 1); TH, tufted hairgrass (n = 1); CW, crested wheatgrass (n = 2); M, grass mixes (n = 62).

Alaska, 42% are not indigenous but are recognized as naturalized (Carlson and Shephard 2007), 28% are casual aliens (species that fail to maintain their populations without repeat introduction) that have been collected after germinating and establishing but have not established persistent populations, and 22% have never been collected in Alaska. It is likely that a number of the nonindigenous species that are now naturalized in Alaska were introduced as seed contaminants. Souminen (1979) found that 370 nonindigenous plant species reached and established in Finland via this pathway. Continuing propagule pressure may result in the arrival of genotypes better adapted to Alaska conditions or may increase the probability that enough seeds arrive to find suitable sites for germination and establishment with enough individuals to naturalize.

The number of nonindigenous species that establish in Alaska via this pathway is likely to increase if the climate warms at high latitudes, as predicted by climate models (Meehl et al., 2007), and the growing season lengthens (Carter 1998). Under those more-favorable conditions, casual aliens may be able to complete their reproductive cycle and naturalize, and associated changes in crops and land may introduce new plant species (Hyvonen and Jalli 2011; Hyvonen et al. 2010).

A positive result from this study is that 6% of crop seed and 8% of grass seed was free of extraneous crop and weed seed. By learning what farm management practices were responsible for that outcome, it should be possible to increase the amount of clean seed in the marketplace. Seed suppliers may be able to charge a premium for seed that does not contain extraneous seed.

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