IS THE SPREAD OF NON-NATIVE PLANTS IN ALASKA ACCELERATING?

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ABSTRACT

Alaska has remained relatively unaffected by non-native plants; however, recently the state has started to experience an influx of invasive non-native plants that the rest of the U.S. underwent 60–100 years ago. With the increase in population, gardening, development, and commerce there have been more frequent introductions to Alaska. Many of these species, such as meadow hawkweed (*Hieracium caespitosum*), Canada thistle (*Cirsium arvense*), and spotted knapweed (*Centaurea biebersteinii*), have only localized populations in Alaska. Other species such as reed canary grass (*Phalaris arundinacea*) and white sweetclover (*Melilotus officinalis*), both formerly used in roadside seed mixes, are now very widespread and are moving into riparian areas and wetlands. We review the available literature and Alaska's statewide invasive plant database (AKEPIC, Alaska Exotic Plant Clearinghouse) to summarize changes in Alaska's non-native flora over the last 65 years. We suggest that Alaska is not immune to invasion, but rather that the exponential increase in non-native plants experienced elsewhere is delayed by a half century. This review highlights the need for more intensive detection and rapid response work if Alaska is going to remain free of many of the invasive species problems that plague the contiguous U.S.

KEYWORDS: Alaska, invasion patterns, invasive plants, non-native plants, plant databases.

INTRODUCTION

Most botanists and ecologists thought Alaska was immune to the invasion of non-native plants the rest of the United States had experienced, and continue to experience, given the great distances from source populations, relative lack of agriculture, low levels of human disturbance, and cold climates. Non-native plants are well known to compose significant components of all the other states' floras and biomass. Their presence as naturalized members of most communities is generally accepted; however, numerous non-native species are recognized for serious ecological and economic damage and targeted for control. Habitats in Alaska are extremely unique in this regard, being nearly free from the presence of non-native plants. Recently, however, populations of many non-native species appear to be expanding and most troubling, a number of species are spreading into natural habitats. The same fate of degraded ecological communities, damaged ecosystem function, endangerment of rare species, and lost economic revenue may be at the doorstep of the 49th state.

The process of species introductions and establishment are quite varied and complex (Pimm 1991, D'Antonio 1993, Williamson 1996) and, despite our fragmented understanding, it informs our comprehension of patterns in Alaska. In general, only a small proportion of total introductions results in the establishment of self-sustaining populations, a smaller proportion expands into natural areas,

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and an even smaller proportion causes significant ecological damage (the familiar Ten's Rule, Williamson 1996). The reasons why an introduction fails may be due to the plant's inability to tolerate the new physical and ecological conditions or because of stochastic events. Short summers, cold winters, and permafrost dominated habitats, among other things, clearly preclude many temperate species from establishing in Alaska. However, successful introductions are known to occur beyond species' expected climatic zones. Plants from temperate Europe have established as far north as 78º N in Svalbard, for example (Elven and Elvebakk 1996). The frequency and size of introductions (i.e., propagule pressure) is well-accepted to be a primary determinant of the success of introductions (Colautti et al. 2006). Low propagule pressure is likely one of the major reasons why Alaska has remained relatively free from non-native plants.

Once populations have been established they generally persist for some time without dramatic growth (i.e., lag phase) and are very susceptible to local extirpation. As population sizes begin to grow they may enter a more dramatic phase of increase (i.e., exponential growth phase; cf. Kinlan and Hastings 2005). Numerous cases, such as purple loosestrife (*Lythrum salicaria* L.) in the Midwest and starlings (*Sturnus vulgaris* L.) in New York, illustrate that a non-native species may appear to be relatively benign and restricted to a few small populations for many decades before expanding dramatically.

Here we review changes in the exotic flora of Alaska since the publication of the state's first flora in 1941 (Hultén 1941). Specifically, we explore whether species of exotics are entering exponential growth phases, if species considered invasive differ in population expansion from exotics as a whole, and what the geographic patterns of exotic establishment have been.

Historic background

Between 1941 and 1950 Eric Hultén published the first comprehensive flora of Alaska, which in many cases included non-native species and discussions of their origins. In 1968 the single volume, *Flora of Alaska and Neighboring Territories*, was published (Hultén 1968), and in it Hultén reported he used over three times the source material than in the earlier volumes. We use these pioneering and comprehensive works as a baseline to gauge changes in the region's non-native flora.

More recently federal and state agencies in Alaska have initiated non-native plant surveys to develop an understanding of the scope of the problem. In 1997 the USDA Forest Service began conducting surveys (Duffy 2003) and in 2000 the National Park Service launched basic inventory work (Densmore et al. 2001). Likewise the Alaska Department of Transportation was concerned about the spread of several species such as bird vetch (*Vicia cracca* L.) along highways (Nolen 2002). The Bureau of Land Management and the Fish and Wildlife Service are now active in collecting information about non-native plants on lands they manage (Cortés-Burns and Carlson 2006). The state's public is also contributing to our understanding of non-native species occurrences as they are becoming increasingly involved in invasive species issues in general, such as impacts of rats on seabird colonies and competition between Pacific salmon species and Atlantic salmon. Non-native plant impacts have even been addressed in recent legislation, whereby the selling of purple loosestrife (*Lythrum salicaria* L.) and orange hawkweed (*Hieracium aurantiacum* L.) would be prohibited (Alaska State House Bill 324).

After reviewing inventory data across the country it became apparent that data management and sharing of information lagged well behind actual infestations. In 2002, an Alaskan statewide invasive plant database, AKEPIC, was developed after many different land management agencies came together in 2002 (see http://akweeds/uaa.alaska.edu). We hoped that this statewide database, modeled after the Southwest non-native plant clearinghouse, would further encourage information exchange concerning invasive plant species. Indeed, the presence of a current database that incorporates information from across the state offers an opportunity to explore the patterns of non-native plant establishment and contrast it with the baseline conditions of 1941.

Based on data present in floras and the statewide database, we show that Alaska is entering a phase of both

increased introductions and establishment of non-native species. While only a handful of non-native species were distributed widely in 1941 and 1968, many more have become naturalized and are spreading rapidly across the state, posing a serious threat to community integrity and ecosystem function.

METHODS

We surveyed the literature, building on a list initiated by M. Duffy and A. Batten (unpublished), to compare the number of non-native species known today to what was reported by Hultén (1941, 1968), and assigned each taxon as naturalized (or not) based on whether self-perpetuating populations were known by the authors or other experts. We also used a single taxonomic system (Integrated Taxonomic Information System, ITIS) to resolve synonymy (Table 1). Taxa known from neighboring territories that have not been recorded for Alaska were removed from the list.

To estimate how changes in the number of populations have occurred over time, we compared the collection

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Table 1—Non-native species found in Alaska (continue)

ITIS scientific name with authors	Naturalized	1941 Hulten	1968 Hulten	Extirpated	Source
Achillea ptarmica L.	-	Yes	Yes	-	1, 2, 3
Achnatherum hymenoides (Roemer & J.A. Schultes) Barkworth	-	-	-	-	3
Agropyron cristatum (Linnaeus) Gaertn.	-	-	-	-	4
Agropyron desertorum (Fisch. ex Link) J.A. Schultes	-	-	-	-	5
Agropyron fragile (Roth) P. Candargy	Nat	-	-	-	4
Agrostemma githago L.	-	Yes	Yes	Ext	1, 2, 3
Agrostis capillaris L.	Nat	Yes	Yes	-	1, 2, 3
Agrostis gigantea Roth	Nat	-	Yes	-	2, 4, 6
Agrostis stolonifera L.	-	Yes	Yes	-	1, 2, 4
Alchemilla monticola Opiz	-	-	-	-	3
Alliaria petiolata (Bieb.) Cavara & Grande	Nat	-	-	-	4
Alopecurus geniculatus L.	Nat	Yes	Yes	-	1, 2, 3, 6
Alopecurus pratensis L.	Nat	Yes	Yes	-	1, 2, 3, 4
Alyssum alyssoides (L.) L.	-	-	-	-	7
Amaranthus albus L.	-	Yes	Yes	Ext	1, 2, 3
Amaranthus retroflexus L.	-	Yes	Yes	-	1, 2, 3, 4
Amsinckia lycopsoides Lehm.	Nat	Yes	Yes	-	1, 2, 3
Amsinckia menziesii (Lehm.) A. Nels. & J.F. Macbr.	Nat	Yes	Yes	-	1, 2, 6
Anthemis cotula L.	Nat	Yes	Yes	-	1, 2, 4
Anthemis tinctoria L.	Nat	Yes	Yes	-	1, 2
Anthoxanthum odoratum L.	Nat	Yes	Yes	-	1, 2
Anthriscus sylvestris (L.) Hoffmann	Nat	-	-	-	3
Arabis glabra (L.) Bernh.	Nat	Yes	Yes	-	1, 2, 6
Arctium lappa L.	-	-	-	-	12
Arctium minus Bernh.	-	-	-	-	13
Arrhenatherum elatius (L.) Beauv. ex J.& K. Presl	Nat	Yes	Yes	-	1, 2
Artemisia biennis Willd.	Nat	-	Yes	-	2, 10
Artemisia vulgaris L.	Nat	-	-	-	8
Asparagus officinalis L.	Nat	-	-	-	7
Asperugo procumbens L.	Nat	-	-	-	3, 10
Astragalus cicer L.	Nat	-	-	-	3, 10
Atriplex hortensis L.	-	Yes	Yes	Ext	1, 2
Atriplex patula L.	Nat	Yes	Yes	-	1, 2, 6
Avena fatua L.	-	Yes	Yes	-	1, 2, 4
Avena sativa L.	-	Yes	Yes	-	1, 2
Bellis perennis L.	Nat	Yes	Yes	-	1, 2
Berteroa incana (L.) DC.	Nat	-	-	-	3, 4, 7
Bidens cernua L.	Nat	Yes	Yes	-	1, 2

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Bidens frondosa L.	Nat	-	Yes	-	2, 6
Borago officinalis L.	Nat	-	-	-	3
Brassica juncea (L.) Czern.	-	Yes	Yes	Ext	1, 2
Brassica napus L.	-	Yes	Yes	-	1, 2, 3, 4
Brassica rapa L.	-	Yes	Yes	-	4
Bromus hordeaceus L.	Nat	Yes	Yes	-	1, 2, 4, 6
Bromus inermis ssp. *inermis* Leyss.	Nat	Yes	Yes	-	1, 2, 4, 6
Bromus secalinus L.	Nat	Yes	Yes	-	1, 2,
Bromus tectorum L.	Nat	Yes	Yes	-	1, 2, 4
Calystegia sepium (L.) R. Br.	Nat	-	-	-	4
Camelina sativa (L.) Crantz	-	Yes	Yes	Ext	1, 2
Campanula glomerata L.	-	-	-	-	3
Campanula rapunculoides L.	Nat	-	-	-	3
Capsella bursa-pastoris (L.) Medik.	Nat	Yes	Yes	-	1, 2, 3, 4
Caragana arborescens Lam.	Nat	-	-	-	3, 4
Cardamine oligosperma Nutt.	Nat	-	-	-	6
Carthamus tinctorius L.	-	-	-	-	12
Castilleja tenuis (Heller) Chuang & Heckard	-	Yes	Yes	Ext	1, 2
Centaurea biebersteinii DC.	Nat	-	-	-	4
Centaurea montana L.	-	-	-	-	3
Cerastium fontanum ssp. vulgare (Hartman) Greuter & Burdet	Nat	Yes	Yes	-	1, 2, 3, 4
Cerastium glomeratum Thuill.	Nat	Yes	Yes	-	1, 2, 3, 4
Cerastium tomentosum L.	-	-	-	-	6
Chenopodium album L.	Nat	Yes	Yes	-	1, 2, 3, 4
Chenopodium berlandieri var. *berlandieri* Moq.	Nat	Yes	Yes	-	1, 2, 3, 4
Chenopodium rubrum L.	Nat	-	Yes	-	3, 7
Chrysanthemum segetum L.	-	-	Yes	Ext	2, 3
Cichorium intybus L.	-	-	-	-	4, 8
Cirsium arvense (L.) Scop.	Nat	Yes	Yes	-	1, 2, 3, 4
Cirsium vulgare (Savi) Ten.	Nat	Yes	Yes	-	1, 2, 3, 4
Clinopodium douglasii (Benth.) Kuntze	-	-	Yes	Ext	2, 3
Collomia linearis Nutt.	Nat	Yes	Yes	-	1, 2, 3, 4
Convallaria majalis L.	-	-	-	-	6
Conyza canadensis (L.) Cronq.	Nat	-	-	-	3, 4
Coronilla varia L.	Nat	-	-	-	14
Cotula coronopifolia L.	Nat	Yes	Yes	-	1, 2, 3
Crepis capillaris (L.) Wallr.	-	-	Yes	-	2, 3, 7
Crepis tectorum L.	Nat	-	Yes	-	2, 3, 4
Cryptantha torreyana (Gray) Greene	-	Yes	Yes	Ext	1, 2, 6
Cytisus scoparius (L.) Link	Nat	-	-	-	3, 4
Dactylis glomerata L.	Nat	Yes	Yes	-	1, 2, 3, 4
Deschampsia danthonioides (Trin.) Munro	-	Yes	Yes	Ext	6
Deschampsia elongata (Hook.) Munro	Nat	Yes	Yes	-	1, 2, 3, 4
Descurainia sophia (L.) Webb ex Prantl	Nat	-	Yes	-	4
Dianthus barbatus L.	-	-	-	-	3
Dianthus plumarius L.	-	-	-	-	4
Digitalis purpurea L.	Nat	Yes	Yes	-	1, 2, 4
Digitaria ischaemum (Schreb.) Schreb. ex Muhl.	-	-	-	-	3
Digitaria sanguinalis (L.) Scop.	-	-	-	-	5
Echium vulgare L.	-	-	-	-	3
Elodea canadensis Michx.	-	-	-	-	3
Elymus canadensis L.	-	-	-	-	5
Elymus repens (L.) Gould	Nat	Yes	Yes	-	1, 2, 3, 4
Elymus sibiricus L.	Nat	Yes	Yes	-	1, 2, 3, 4

Table 1—Non-native species found in Alaska (continue)

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Eragrostis intermedia A.S. Hitchc.	-	-	-	-	5
Erodium cicutarium (L.) L'Hér. ex Ait.	- 3, 4	Yes	Yes	-	1, 2,
Erucastrum gallicum (Willd.) O.E. Schulz	-	-	-	-	4
Eschscholzia californica Cham.	-	-	-	-	3
Euphorbia peplus L.	-	-	-	-	7
Euphrasia nemorosa (Pers.) Wallr.	Nat	-	-	-	8
Fagopyrum esculentum Moench	-	-	-	-	7
Festuca trachyphylla (Hack.) Krajina	-	-	-	-	7
Gaillardia pulchella Foug.	-	-	-	-	3
Galeopsis bifida Boenn.	Nat	Yes	Yes	-	1, 2, 3, 4
Galeopsis tetrahit L.	Nat	Yes	Yes	-	1, 2, 3, 4
Geranium bicknellii Britt.	-	-	-	-	6
Geranium carolinianum L.	-	-	-	-	7
Geranium robertianum L.	Nat	Yes	Yes	-	1, 2, 3, 7
Geranium sanguineum L.	-	-	-	-	7
Gilia achilleifolia Benth.	-	Yes	Yes	Ext	1, 2, 3
Gilia capitata Sims	-	Yes	Yes	Ext	1, 2, 3
Glechoma hederacea L.	-	Yes	Yes	Ext	1, 2, 3
Gnaphalium uliginosum L.	Nat	Yes	Yes	-	1, 2, 3, 4
Gypsophila elegans Bieb.	Nat	-	-	-	7
Gypsophila paniculata L.	Nat	-	-	-	12
Hackelia micrantha (Eastw.) J.L. Gentry	-	-	Yes	Ext	6
Helianthus annuus L.	-	Yes	Yes	-	1, 2, 3, 4
Hesperis matronalis L.	Nat	Yes	Yes	-	1, 2, 3
Hieracium aurantiacum L.	Nat	-	Yes	-	1, 2, 3, 4
Hieracium caespitosum Dumort.	Nat	-	-	-	4
Hieracium lachenalii K.C. Gmel.	Nat	-	-	-	14
Hieracium pilosella L.	Nat	-	-	-	4
Hieracium umbellatum L.	Nat	Yes	Yes	-	1, 2, 6
Holcus lanatus L.	Nat	Yes	Yes	-	1, 2, 3, 4
Hordeum comosum J. Presl	-	-	-	-	5
Hordeum jubatum L.	Nat	Yes	Yes	-	1, 2, 3, 4
Hordeum murinum L. ssp. *leporinum* (Link) Arcang.	-	-	-	-	4, 12
Hordeum vulgare L.	-	Yes	Yes	-	1, 2, 4, 8
Hypericum perforatum L.	Nat	-	-	-	4, 6
Hypochaeris radicata L.	Nat	Yes	Yes	-	1, 2, 3, 4
Iberis amara L.	-	-	-	-	3
Impatiens glandulifera Royle	Nat	-	-	-	4
Lactuca serriola L.	Nat	-	-	-	4
Lactuca tatarica (L.) C.A. Mey.	Nat	Yes	Yes	-	8
Lamium album L.	Nat	Yes	Yes	-	3
Lamium maculatum L.	-	-	-	-	7
Lappula squarrosa (Retz.) Dumort.	Nat	Yes	Yes	-	1, 2, 3, 4
Lapsana communis L.	Nat	Yes	Yes	-	1, 2, 3, 4
Lathyrus pratensis L.	-	-	-	-	3
Leontodon autumnalis L.	Nat	-	Yes	-	2, 3, 4
Lepidium densiflorum Schrad.	Nat	Yes	Yes	-	1, 2, 6
Lepidium ramosissimum A. Nels.	Nat	-	-	-	4, 12
Lepidium virginicum L.	-	Yes	Yes	Ext	1, 2
Leucanthemum vulgare Lam.	Nat	Yes	Yes	-	1, 2, 3, 4
Levisticum officinale W.D.J. Koch	-	-	-	-	12
Linaria dalmatica (L.) P. Mill.	-	-	-	-	11
Linaria pinifolia (Poir.) Thellung	-	-	-	-	4, 12

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Linaria vulgaris P. Mill.	Nat	Yes	Yes	-	1, 2, 3, 4
Lolium arundinaceum (Schreb.) S.J. Darbyshire	Nat	Yes	Yes	-	1, 2, 3, 4
Lolium perenne ssp. *multiflorum* (Lam.) Husnot	Nat	Yes	Yes	-	1, 2, 3, 4
Lolium perenne ssp. perenne L.	Nat	Yes	Yes	-	1, 2, 3, 4
Lolium pratense (Huds.) S.J. Darbyshire	-	-	-	-	6
Lonicera tatarica L.	-	-	-	-	8
Lotus corniculatus L.	Nat	-	-	-	4, 14
Lupinus polyphyllus Lindl.	Nat	Yes	Yes	-	1, 2, 4, 6
Lychnis chalcedonica L.	Nat	-	-	-	4
Lychnis coronaria (L.) Desr.	-	-	-	-	8
Lythrum hyssopifolium L.	-	-	-	-	7
Lythrum salicaria L.	Nat	-	-	-	4
Malva neglecta Wallr.	-	-	-	-	4
Marrubium vulgare L.	-	Yes	Yes	Ext	1, 2, 3
Matricaria discoidea DC.	Nat	Yes	Yes	-	1, 2, 3, 4
Medicago lupulina L.	Nat	Yes	Yes	-	1, 2, 3, 4
Medicago minima (L.) L.	-	-	-	-	4
Medicago polymorpha L.	-	Yes	Yes	Ext	1, 2, 3
Medicago sativa L. ssp. *falcata* (L.) Arcang.	Nat	Yes	Yes	-	1, 2, 4, 12
Medicago sativa L. ssp. *sativa*	Nat	Yes	Yes	-	1, 2, 3, 4
Melilotus alba [officinalis (L.) Lam.]	Nat	Yes	Yes	-	1, 2, 3, 4
Melilotus officinalis (L.) Lam.	Nat	Yes	Yes	-	1, 2, 3, 4
Mentha ×piperita L. (pro sp.) [*aquatica* × *spicata*]	Nat	Yes	Yes	-	1, 2
Mentha spicata L.	Nat	Yes	Yes	-	1, 2, 3, 4
Microsteris gracilis (Hook.) Greene	-	Yes	Yes	Ext	1, 2, 3
Misopates orontium (L.) Raf.	Nat	-	Yes	-	1, 2, 3
Mycelis muralis (L.) Dumort.	Nat	-	-	-	4
Myosotis scorpioides L.	Nat	Yes	Yes	-	4, 6
Nemophila menziesii Hook. & Arn.	-	Yes	Yes	-	1, 2, 3
Nepeta cataria L.	-	Yes	Yes	Ext	1, 2, 3
Neslia paniculata (L.) Desv.	-	Yes	Yes	-	1, 2, 3, 4
Nymphaea odorata Ait. ssp. *odorata*	-	-	-	-	6
Onobrychis viciifolia Scop.	-	-	-	-	3
Panicum miliaceum L.	-	-	-	-	5
Papaver nudicaule L.	Nat	Yes	Yes	-	1, 2, 3, 4
Papaver rhoeas L.	-	Yes	Yes	Ext	1, 2, 3
Pascopyrum smithii (Rydb.) A. Löve	Nat	Yes	Yes	-	1, 2, 6
Pastinaca sativa L.	-	Yes	Yes	Ext	1, 2, 3
Phalaris arundinacea L.	Nat	Yes	Yes	-	1, 2, 3, 4
Phalaris canariensis L.	Nat	Yes	Yes	-	1, 2, 3, 4
Phalaris minor Retz.	-	-	Yes	Ext	2, 3
Phleum pratense L.	Nat	Yes	Yes	-	1, 2, 3, 4
Plagiobothrys figuratus (Piper) I.M. Johnston ex M.E. Peck ssp. *figuratus*	-	Yes	Yes	Ext	1, 2, 3
Plantago lanceolata L.	-	Yes	Yes	-	1, 2, 3, 4
Plantago major L.	Nat	Yes	Yes	-	1, 2, 3, 4
Poa annua L.	Nat	Yes	Yes	-	1, 2, 3, 4
Poa compressa L.	Nat	Yes	Yes	-	1, 2, 3, 4
Poa pratensis L. ssp. *irrigata* (Lindm.) Lindb. f.	Nat	Yes	Yes	-	1, 2, 3, 4

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Poa trivialis L.	Nat	Yes	Yes	-	1, 2, 3, 4
Polygonum aviculare L.	Nat	-	Yes	-	2, 3, 4
Polygonum convolvulus L.	Nat	Yes	Yes	-	1, 2, 3, 4
Polygonum cuspidatum Sieb. & Zucc.	Nat	Yes	Yes	-	1, 2, 3, 4
Polygonum hydropiper L.	-	Yes	Yes	-	8
Polygonum hydropiperoides Michx.	-	Yes	Yes	Ext	1, 2, 3
Polygonum lapathifolium L.	Nat	Yes	Yes	-	1, 2, 3, 4
Polygonum persicaria L.	Nat	Yes	Yes	-	1, 2, 3
Polygonum ramosissimum Michx. var. *prolificum* Small	-	Yes	Yes	Ext	8
Polygonum sachalinense F. Schmidt ex Maxim.	Nat	-	-	-	14
Polygonum ×bohemicum (J. Chrtek & Chrtkovß) Zika & Jacobson [*cuspidatum* x *sachalinense*]	Nat	-	-	-	14
Polypogon monspeliensis (L.) Desf.	Nat	-	Yes	-	2, 3
Prunus padus L.	Nat	-	-	-	3, 4
Prunus virginiana L.	Nat	-	-	-	14
Ranunculus acris L.	Nat	-	Yes	-	2, 3, 4
Ranunculus repens L.	Nat	Yes	Yes	-	1, 2, 4, 6
Raphanus sativus L.	-	Yes	Yes	-	1, 2, 3, 7
Rorippa nasturtium-aquaticum (L.) Hayek	-	Yes	Yes	-	1, 2, 7
Rosa rugosa Thunb.	Nat	-	-	-	3
Rubus discolor Weihe & Nees	-	-	-	-	4
Rubus idaeus ssp. idaeus L.	Nat	-	-	-	7
Rudbeckia hirta L.	-	-	-	-	3
Rumex acetosa ssp. acetosa L.	-	Yes	Yes	-	1, 2, 3
Rumex acetosella L.	Nat	Yes	Yes	-	1, 2, 3, 4
Rumex crispus L.	Nat	Yes	Yes	-	1, 2, 3, 4
Rumex longifolius DC.	Nat	Yes	Yes	-	1, 2, 3, 4
Rumex maritimus L.	Nat	Yes	Yes	-	1, 2, 3
Rumex obtusifolius L.	Nat	Yes	Yes	-	1, 2, 3, 4
Sagina procumbens L.	Nat	-	-	-	6
Salix X *pendulina* Wenderoth	-	-	-	-	3
Saponaria officinalis L.	-	-	-	-	4
Schedonorus pratensis (Huds.) Beauv.	Nat	-	-	-	3
Secale cereale L.	-	Yes	Yes	-	1, 2, 3
Senecio eremophilus Richards.	-	-	Yes	Ext	2, 7
Senecio jacobaea L.	Nat	-	-	-	4, 6
Senecio sylvaticus L.	-	-	-	-	4
Senecio viscosus L.	-	-	-	-	4
Senecio vulgaris L.	Nat	Yes	Yes	-	1, 2, 3, 4
Setaria viridis (L.) Beauv.	-	-	-	-	3, 4
Silene armeria L.	-	-	-	-	3
Silene dioica (L.) Clairville	Nat	-	-	-	4, 12
Silene latifolia Poir. ssp. *alba* (P. Mill.) Greuter & Burdet	-	-	-	-	3, 4
Silene noctiflora L.	Nat	Yes	Yes	-	1, 2, 3
S*ilene vulgaris* (Moench) Garcke	Nat	-	-	-	3, 7
Sinapis arvensis L.	-	Yes	Yes	Ext	1, 2, 3, 4
Sisymbrium altissimum L.	Nat	Yes	Yes	-	1, 2, 3, 4
Sisymbrium officinale (L.) Scop.	-	Yes	Yes	-	1, 2, 3
Solanum nigrum L.	-	Yes	Yes	Ext	1, 2, 3
Solanum physalifolium Rusby	-	-	-	-	7

Table 1—Non-native species found in Alaska

ITIS scientific name with authors	Naturalized	1941 Hulten	1968 Hulten	Extirpated	Source
Sonchus arvensis L.	Nat	Yes	Yes	-	1, 2, 3, 4
Sonchus arvensis ssp. *uliginosus* (Bieb.) Nyman	Nat	-	-	-	3, 4
Sonchus asper (L.) Hill	Nat	Yes	Yes	-	1, 2, 3, 4
Sonchus oleraceus L.	Nat	Yes	Yes	-	1, 2, 3, 4
Sorbaria sorbifolia (L.) A. Braun	Nat	-	-	-	3, 4
Sorbus aucuparia L.	Nat	Yes	Yes	-	1, 2, 3, 4
Spergula arvensis L.	Nat	Yes	Yes	-	1, 2, 3, 4
Spergularia rubra (L.) J.& K. Presl	Nat	Yes	Yes	-	1, 2, 3, 4
Spinacia oleracea L.	-	Yes	-	Ext	1
Stellaria media (L.) Vill.	Nat	Yes	Yes	-	1, 2, 3, 4
Symphytum asperum Lepechin	-	-	-	-	3
Symphytum officinale L.	-	-	-	-	4
Tanacetum vulgare L.	Nat	Yes	Yes	-	1, 2, 3, 4
Taraxacum laevigatum (Willd.) DC.	Nat	Yes	Yes	-	1, 2, 3, 7
Taraxacum officinale ssp. *officinale* G.H. Weber ex Wiggers	Nat	Yes	Yes	-	1, 2, 3, 4
Thlaspi arvense L.	-	Yes	Yes	-	1, 2, 3, 4
Tragopogon dubius Scop.	Nat	-	-	-	3, 4
Trifolium aureum Pollich	Nat	-	Yes	-	2, 3, 4, 7
Trifolium campestre Schreb.	-	-	Yes	Ext	2, 3, 7
Trifolium dubium Sibthorp	-	Yes	Yes	Ext	1, 2, 3
Trifolium hybridum L.	Nat	Yes	Yes	-	1, 2, 3, 4
Trifolium lupinaster L.	-	Yes	Yes	-	1, 2
Trifolium microcephalum Pursh	-	Yes	Yes	Ext	1, 2, 3, 7
Trifolium pratense L.	Nat	Yes	Yes	-	1, 2, 3, 4
Trifolium repens L.	Nat	Yes	Yes	-	1, 2, 3, 4
Trifolium variegatum Nutt.	-	Yes	Yes	Ext	1, 2, 3
Tripleurospermum perforata (Merat) M. Lainz	Nat	Yes	Yes	-	1, 2, 3, 4
Triticum aestivum L.	-	Yes	Yes	-	1, 2, 3, 4
Urtica urens L.	-	Yes	Yes	Ext	1, 2, 3
Vaccaria hispanica (P. Mill.) Rauschert	-	Yes	Yes	Ext	1, 2, 3
Veronica anagallis-aquatica L.	-	Yes	Yes	Ext	1, 2, 3
Veronica arvensis L.	-	Yes	Yes	-	1, 2, 3
Veronica chamaedrys L.	-	Yes	Yes	-	1, 2, 3
Veronica longifolia L.	Nat	-	-	-	3
Veronica persica Poir.	-	Yes	Yes	Ext	1, 2, 3
Veronica serpyllifolia ssp. *serpyllifolia* L.	Nat	Yes	Yes	-	1, 2, 3, 4
Viburnum opulus L.	-	-	-	-	4
Vicia cracca L.	Nat	Yes	Yes	-	1, 2, 3, 4
Vicia sativa ssp. nigra (L.) Ehrh.	Nat	Yes	yes	-	1, 2, 3
Vicia villosa Roth	Nat	Yes	Yes	-	1, 2, 3
Viola tricolor L.	-	-	-	-	1, 2, 3, 4
Zea mays L.	-	-	-	-	12

Sources cited are coded as follows: 1- Hultén 1941-50, 2- Hultén 1968, 3- UAF Herbarium database, 4- AK Exotic Plant Clearinghouse -Sept 2006, 5- Jeff Conn unpublished- search of Palmer Herbarium, 6- Mary Stensvold unpublished, 7- Welsh, S. Anderson's Flora of Alaska, 8- Al Batten unpublished work, 9- Bruce Bennett unpublished -Yukon weeds Oct 2004, 10- Mike Duffy unpublished work, 11- Jeff Heys personal communication, 12-Carlson, M., I. Lapina 2004, 13- Jeanne Standley personal communication, 14-Michael Shephard personal communication

history of three groups of Alaskan plants: native, non-native, and non-native species considered to be invasive. The collection history of native species serves as a null expectation of overall collection intensity through time. Rather than comparing the actual number of records, we standardized the records to a proportion of total records for each group for a given year, thus allowing for comparisons among rare and common species or groups of species. For example, 36% (i.e., 488 collections) of the total 1,344 collections of the native plants were recorded by 1941, while 30% (i.e., 90) out of 305 total collections of the invasive plants were recorded by the same year.

From the updated list of non-native species, we selected 15 that are considered to be invasive or very widespread non-native species in the state, and contrasted their history of collections with their closest native relatives (phylogenetically and ecogeographically). Additionally, we compared the 15 species considered invasive with 15 randomly chosen non-native species. The number and location of collections from the earliest record to 2006 were examined. We tallied the number of herbarium samples collected within the following: Hultén (1941), Hultén (1968), and the University of Alaska, Herbarium (ALA – online database current up through 2003; see http://arctos.database.museum/SpecimenSearch.cfm). To explore how Alaska might differ from the Pacific Northwest, we compared the collection history of the chosen 15 invasive species with records in the Oregon State University Herbarium (see http://ocid.nacse.org/cgi-bin/qml/herbarium/ plants/vherb.qml). Three of these species were removed because of too few records. We conducted a second analysis combining these data with those of AKEPIC to contrast the relative proportion of all records for the species at three landmark years: 1941, 1968, and 1985 (Table 2). Differences in proportion of total records in the three years were tested using a non-parametric test (Kruskal-Wallis) since the data did not meet normality assumptions. An experiment-wide Bonferroni correction was made to maintain significance at $p \leq 0.05$.

We attempted to reduce potential bias among the datasets regarding what constitutes a population record by filtering the AKEPIC inventory points through a 25 x 25 mile grid. We chose 25 mile grid cells because this is roughly the size of the 'dots' used by Hultén (1968), where a single dot may represent one or more individual collections. Additionally, this makes AKEPIC data comparable to ALA, which has not entered all collections into their database from a single location (A. Batten, pers. comm.).

The grid cells produce a maximum of a single collection point per grid cell. For example, although there are 209 current points of *Cirsium arvense* (L.) Scop. in the AKEPIC database, most occur within Anchorage and Haines, so when filtered through the grid there are 16 'sites,' which are then comparable to ALA.

RESULTS

Reviewing the literature indicates there have been 283 non-native plant taxa recorded in Alaska to date, relative to a total flora of approximately 2,100 taxa. In 1941 Alaska had 154 non-native plant taxa, and 174 in 1968 (Hultén 1941, 1968); of the latter, 110 have since naturalized; i.e., formed self-perpetuating populations. By 2006 an additional 109 new species were added to Alaska's flora, 47 of which have naturalized (Table 1). Thus, from 1941 to 1968 roughly one non-native plant taxon was added per year, while from 1968 to 2006 nearly three taxa were annually added to the flora. We find that 36 species listed in 1941 and 1968 have not been recorded since and are presumed extirpated (Table 1).

The pattern of plant collections in Alaska through time suggests that the number of herbarium collections has increased steadily for both native and non-native plants (fig. 1). There is a trend for a greater proportion of collections known by 1941 in native plants than in non-native or invasive plants. Relative to native plants, the proportion of collections for the non-native and invasive plants increases more quickly from 1985 to the present. In 1985 roughly 50% of the total collections had been made for invasives and non-natives, contrasting with 68% for the native species. Interestingly, the data of the same invasive species in Oregon show a very different relationship, with a significantly higher proportion of total collections having been made by 1968 and 1985 ($p < 0.001$, Kruskal-Wallis). This suggests that in Oregon collection frequency is declining over time, while in Alaska it is increasing, especially for invasive and non-native species.

Table 2—List of 15 native and non-native Alaskan plant taxa used in the analysis. The number of records is presented prior to 1941, 1941–1967, 1968–1984, 1985–2006, and the 2002–2006 AKEPIC records filtered through a 25 x 25 mile grid.

Native Species	<1941	1941–1967	1968–1984	since 1985	AKEPIC Grid	TOTAL
Cerastium arvense L.	0	15	9	19	0	43
Cirsium kamtschaticum Ledeb. ex DC.	0	3	3	6	0	12
Crepis elegans Hook.	4	30	15	10	0	59
Descurainia sophioides (Fisch. ex Hook.) O.E. Schulz	10	33	20	28	0	91
Scutellaria galericulata L.	1	32	6	10	0	49
Hieracium triste Willd. ex Spreng.	1	43	23	59	0	126
Impatiens noli-tangere L.	4	29	7	7	0	47
Penstemon gormanii Greene	1	20	11	12	0	44
Lupinus arcticus S. Wats.	6	95	48	42	0	191
Phleum alpinum L.	0	170	10	45	0	225
Polygonum caurianum B.L. Robins.	2	28	5	5	0	40
Ranunculus occidentalis Nutt.	5	31	32	67	0	135
Tephroseris palustris (L.) Fourr.	7	95	33	31	0	166
Taraxacum phymatocarpum J. Vahl	0	13	10	68	0	91
Lathyrus palustris L.	1	60	26	21	0	108
Invasive or widely distributed species						
Cerastium fontanum Baumg.	8	4	7	21	30	70
Cirsium arvense (L.) Scop.	2	2	1	5	16	26
Crepis tectorum L.	0	1	4	14	59	78
Descurainia sophia (L.) Webb ex Prantl	5	0	0	3	8	16
Galeopsis bifida Boenn. (combined with G. tetrahit)	5	0	0	0	31	36
Hieracium aurantiacum L.	0	5	4	1	19	29
Impatiens glandulifera Royle	0	0	0	0	3	3
Linaria vulgaris P. Mill.	1	2	7	10	54	74
Melilotus alba Medik.	2	2	2	4	55	65
Phleum pratense L.	25	1	3	12	65	106
Polygonum aviculare L.	8	17	10	22	55	112
Ranunculus acris L.	4	3	2	10	4	23
Senecio jacobaea L.	0	0	0	0	6	6
Taraxacum officinale ssp. *officinale*	29	0	4	18	139	190
Vicia cracca L.	1	4	5	5	27	42
Randomly selected non-native species						
Agrostis stolonifera L.	12	2	4	1	6	25
Caragana arborescens Lam.	0	0	1	3	3	7
Conyza canadensis (L.) Cronq.	0	0	1	3	2	6
Erodium cicutarium (L.) L'Hér.Ait.	1	0	1	3	1	6
Geranium robertianum L.	1	0	1	0	0	2
Hesperis matronalis L.	1	0	1	1	0	3
Lamium album L.	1	0	1	0	1	3
Leontodon autumnalis L.	0	0	0	1	10	11
Lolium perenne L. ssp. *multiflorum*	1	0	0	4	18	23
Nemophila menziesii Hook. & Arn.	2	0	0	1	0	3
Neslia paniculata (L.) Desv.	3	0	0	0	1	4
Polygonum cuspidatum Sieb. & Zucc.	0	0	2	2	16	20
Rumex longifolius DC.	0	0	6	1	5	12
Secale cereale L.	1	1	0	0	0	2
Silene vulgaris (Moench) Garcke	0	0	1	0	1	2

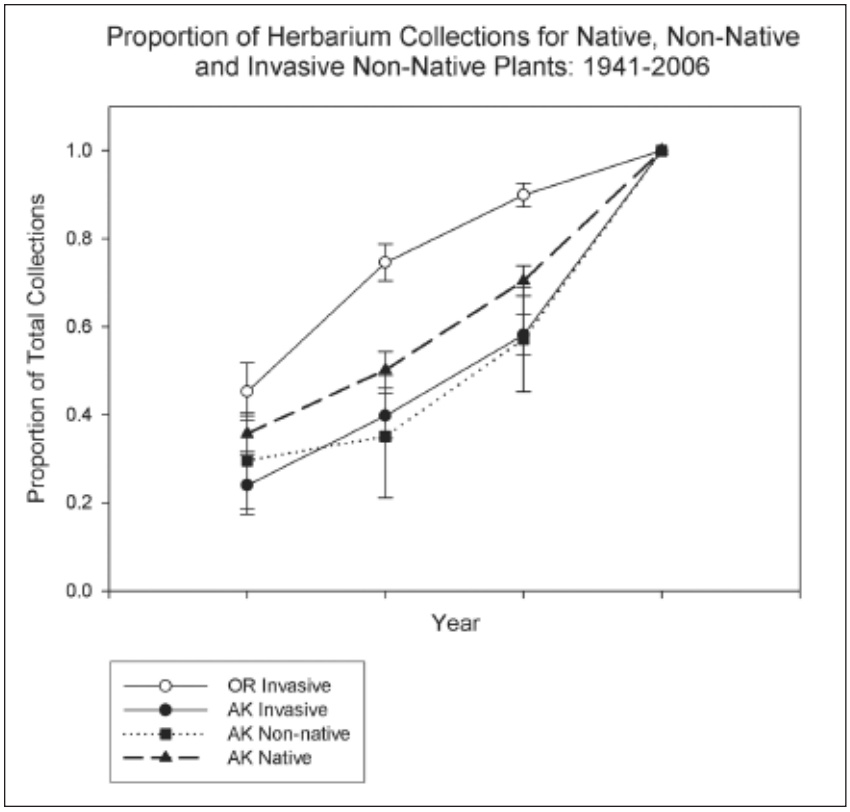

Figure 1—Mean proportion of collections over time relative to the cumulative total in 2006 for 15 invasive, non-native, and native plants in Alaska. Proportion of collections in Oregon is displayed for 12 of 15 of the invasive species. The means of the 15 species in each group are displayed as symbols and standard errors are also included.

If records from the AKEPIC database are added to the herbarium records, a recent and exponential growth pattern is observed for both non-native and invasive species (fig. 2). The two groups began with roughly the same proportion of records in 1941. While the non-natives increased more steadily, displaying a significantly greater proportion by 1985 ($p = 0.024$, Mann-Whitney), the invasive group rose dramatically after 1985, with 81% of all species collections having been made in the last 20 years.

The overall number of records is on average an order of magnitude greater for native species than for non-native and invasive species. When AKEPIC data are included, the number of records of invasive and non-native species is still less than half that of native species for any given year (Table 2).

The pattern of records over time differed for individual species among the three Alaskan species groups (native, non-native, and non-native and invasive). Individual native species differed substantially among one another in 1941, with more than half of the total collections recorded by this time for four of the 15 species (fig. 3). Four native species, including *Taraxacum alaskum* Rydb., the rare *Cirsium kamtschaticum* Ledeb. ex DC., and geographically restricted *Penstemon gormani* Greene had very few of the total collections known until after 1985. Individual invasive species all showed a consistent pattern of exponential growth (fig. 4), while the non-native species differed dramatically from one another in the proportion of records over time (fig. 5). No more than 35% of the total collections had been made for any of the species in the invasive group by 1941, and in two cases no records were known until after 1985. By comparison, five of 15 non-native species had more than 50% of the records made by 1941, while seven species were not known until after 1968.

DISCUSSION

The flora of Alaska, like all other states, is clearly in flux due to introductions of non-native species. A relatively

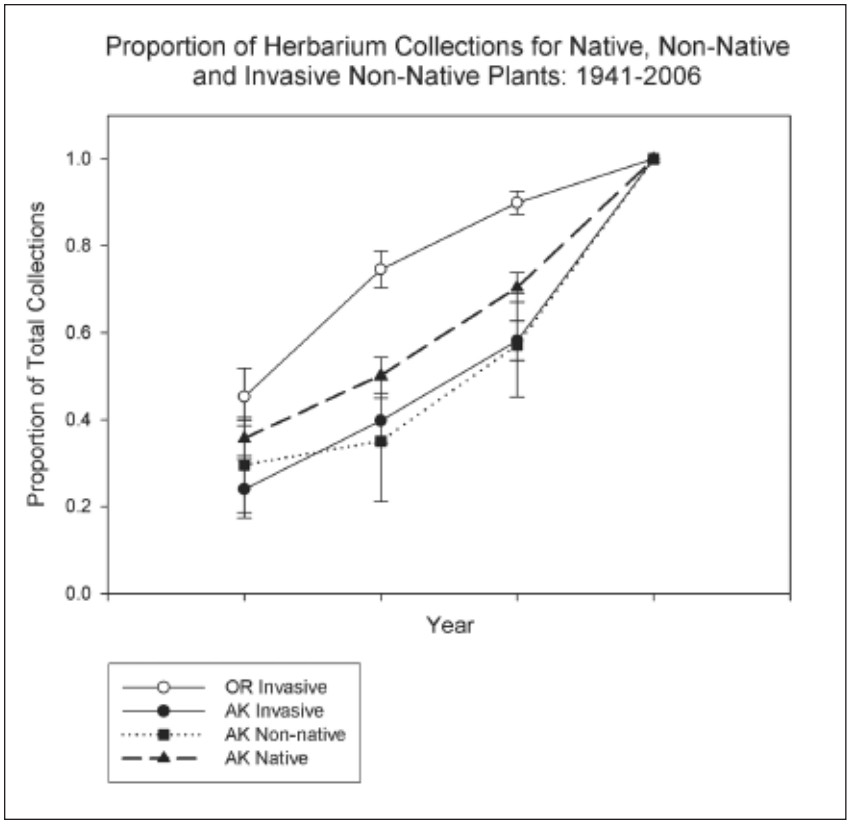

Figure 2—Mean proportion (and standard error) of all records, including the AKEPIC database, over time of 15 invasive, non-native, and native plants in Alaska.

severe climate and low levels of anthropogenic landscape changes have not offered an effective barrier to non-native plants, and a more proactive approach is necessary if the state wishes to maintain its natural ecosystems. While the proportion of non-native to native species is still relatively small (14% vs. *ca.* 30% for Oregon; T. Kaye pers. comm.), a growing number of non-native plants is being collected every year. Further, there is an increase in observations of species moving off of the anthropogenic footprint and into more intact ecosystems, often in habitats with natural disturbance (Carlson and Lapina 2004).

The increase in non-native plants mirrors a similar increase in human population for the state, which has tripled since 1968 (U.S. Census 2000). With it, the amount of ground disturbing activities related to oil development, agriculture, housing, and roads has also dramatically increased. When human disturbance was low, such as the decade after Alaska became a state, the probability that a non-native plant species would find its way to Alaska and become established was small. In this context, it is interesting to note that the majority of non-native plants recorded in Alaska by the mid 20th century were restricted to southeastern Alaska, which was the population center, and is also the region that has seen the greatest proportion of species actually establish. Currently, we are witnessing a geographic shift in the center of introductions, with an increasing number of non-native species establishing in south central and central Alaska, where the human population and development is now greatest.

Overall, our study indicates that the number of non-native plant population records (including those considered invasive) follows an exponential growth pattern, in contrast to that of native species, which is linear. The greater increase in non-native plant records is likely due to both an escalation in establishment and a stepped-up survey effort, two factors that are difficult to disentangle with these data alone. However, comparisons of only herbarium records indicate that the number of collections of non-native and

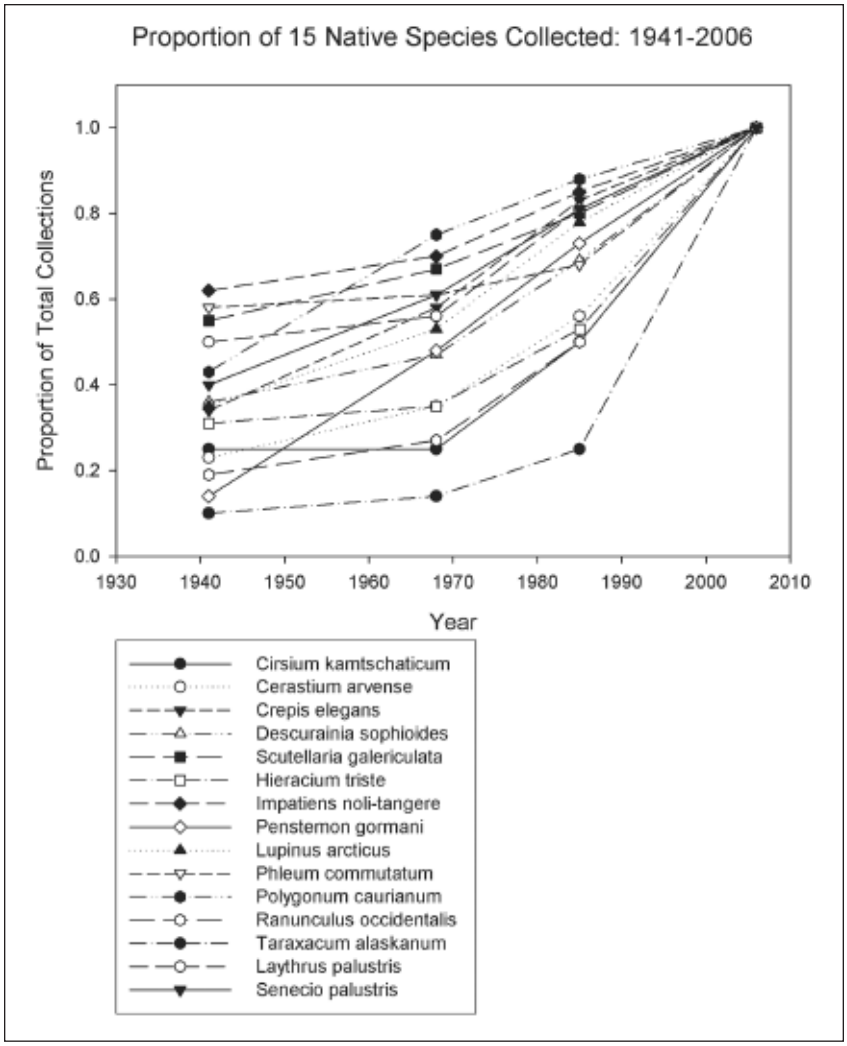

Figure 3—Proportion of all records over time of 15 native plants in Alaska.

invasive taxa is increasing more quickly than those of natives. Additionally, when comparing species considered invasive relative to a random sample of non-native species in the combined data set, we see that the invasives are showing a greater increase in number of populations recorded in recent years. Given these trends, we propose that this increase is not just due to increased survey effort.

Species invasions can be characterized as going through the phases of 1) establishment (when population growth is often highly irregular), 2) rapid population growth and expansion, and 3) reduced growth and slowed spread (Kinlan and Hastings 2005). In Oregon invasive species appear to be in the reduced growth phase. The same species in Alaska, however, are all behaving as populations in the establishment and rapid population growth phases. Taken together, these trends suggest that Alaska is not necessarily less susceptible to invasion, but that the process of invasion has been delayed by a number of decades. We further propose what we are now seeing in Alaska is the establishment of individual foci in various locations of where human disturbance and the propagule pressure are large enough to promote establishment. For example, in Valdez, there is now a large infestation of *Hieracium caespitosum* Dumort. that must have been established some time in the last decade. Otherwise, this species is only known from a few disparate and small populations (M. Shephard pers. obs.).

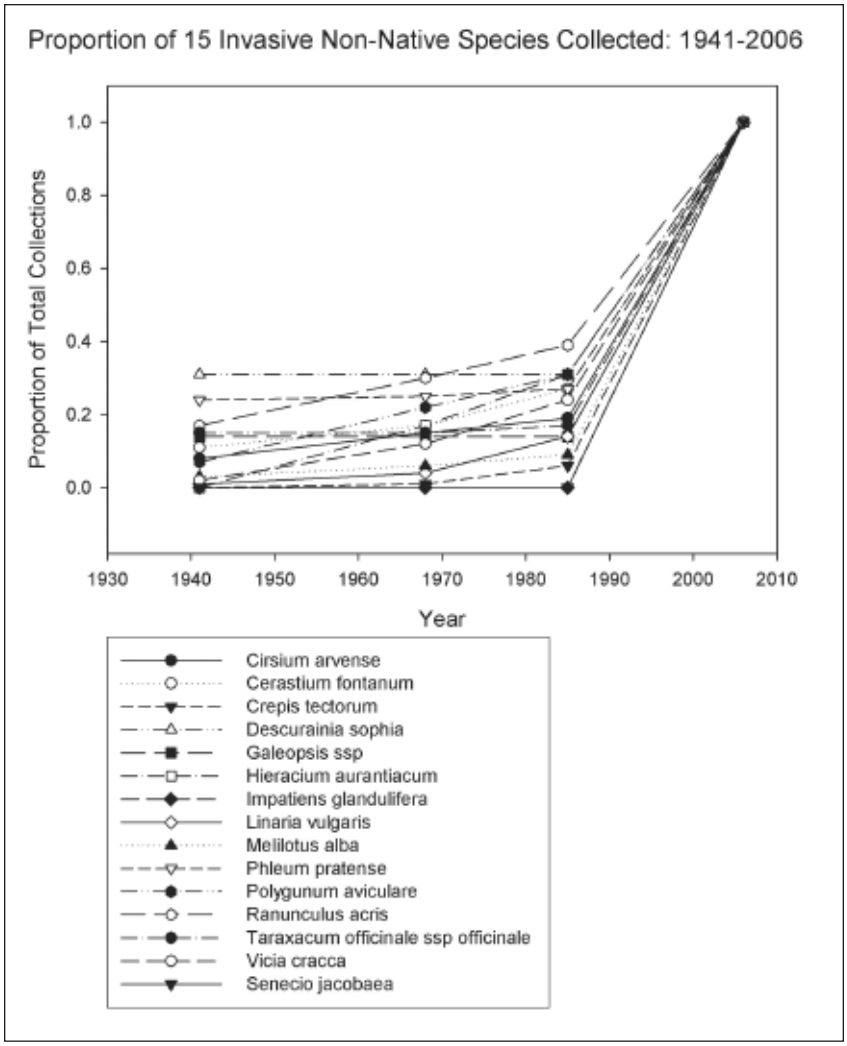

Figure 4—Proportion of all records over time of 15 invasive plants in Alaska.

In many instances, the spatial and temporal patterns of expansion and establishment of non-natives across Alaska mirror those known from the rest of the continent. *Crepis tectorum* L., *Hieracium aurantiacum* L., and *Hypochaeris radicata* L. all are expanding rapidly in the western United States and they appear to be in an exponential growth phase within Alaska. In 1968 there were only one or two collections of these plants in Alaska, whereas now AKEPIC and additional unpublished data suggest these taxa are all spreading rapidly. The Kodiak Wildlife Refuge and the Koniag Native Corporation have been jointly trying to control a large infestation of *H. aurantiacum* within native plant communities across a remote 40 acre island.

Hypochaeris radicata was one of the most common roadside weeds, often exceeding 30% cover, on Prince of Wales Island in southeastern Alaska (unpublished report, for the USDA Forest Service). *Crepis tectorum* is now extremely abundant along roads throughout Alaska, and is beginning to show up on glacial river floodplains.

Other taxa, such as *Phalaris arundinacea* L., *Trifolium repens* L., *T. hybridum* L., and *Melilotus alba* Medikus were previously used for roadside seeding. Today these species visually dominate many road systems across the state, and are known to be spreading into wetlands and riparian areas.

There are still other species such as *Impatiens glandulifera* Royle, *Senecio jacobaea* L., and *Centaurea*

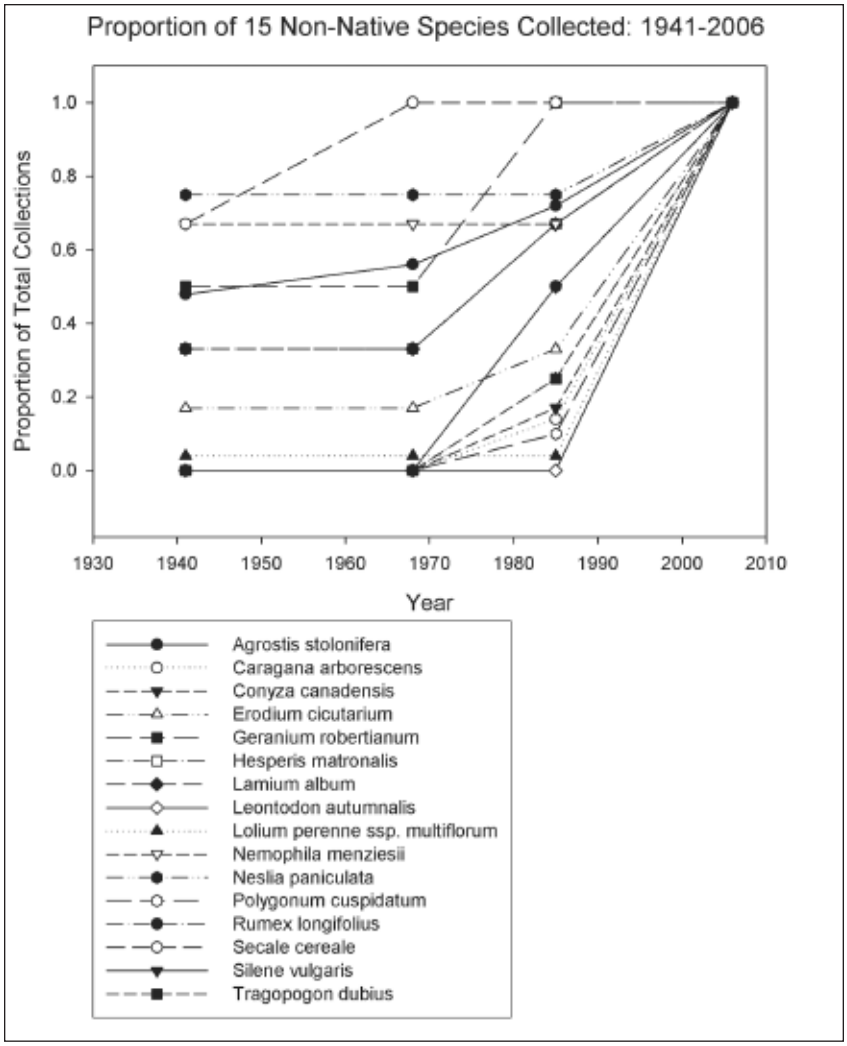

Figure 5—Proportion of all records over time of 15 non-native and invasive plants in Alaska.

bier-bersteinii D.C. that were completely unknown to be naturalized in the state before 1985. *Impatiens glandulifera* was probably planted in gardens, then escaped and is now well entrenched in a beach meadow in southern Alaska. *Senecio jacobaea* likely arrived via road and logging equipment, and is now very widespread in Ketchikan and occurs in small, scattered populations further north. Likewise, *C. bierber-steinii* has probably hitchhiked to Alaska on equipment, and is currently known from at least ten different locations along roads, from Anchorage to Ketchikan (all populations ranged from 1- 50 plants).

Some taxa such as *Descurainia sophia* (L.) Webb ex Prantl, *Ranunculus acris* L., and Lonicera tatarica L. are considered problematic invasive species outside of Alaska. In Alaska *D. sophia*, and *R. acris* are naturalized but populations tend to be small and isolated and are not particularly problematic. *Lonicera tatarica*, which is widely planted in southern and central Alaska, never has naturalized to our knowledge. Perhaps these taxa are in a 'lag phase' or will never become established in Alaska.

Alaska does have some invaders that have not been particularly problematic in the contiguous U.S. states. For example, Siberian rye (*Elymus sibiricus* L.) was introduced at the University of Alaska experimental station in Palmer and is now showing up on sandy soils in south-central Alaska and even relatively remote river bars. Siberian peashrub (*Caragana arborescens*) has been planted as an ornamental shrub and hedge in interior and southern Alaska for

many decades and it is now readily recruiting in undisturbed boreal forests in Alaska. It has also recently found to be quite invasive in Elk Island National Park in Alberta, Canada (Henderson and Chapman 2006).

A number of introductions also appear to have failed, as expected. Species such as *Spinacia oleracea*, *Nepata cataria*, and *Plagiobothrys figuratus* were known only from a few collections 65 years ago and no additional records have been noted since. The majority of the failed introductions are agricultural species or agricultural weeds, which often are not effective competitors outside of cultivation. Nonetheless, it should be noted that even apparently poorly adapted agricultural species have responded quickly to natural selection and are now invading native habitats (e.g. *Melilotus officinalis* and *M. alba*, cf. Klebesadel 1992).

Undoubtedly, many of the current and future introductions in Alaska will go extinct locally, but others will result in establishment and potentially affect habitats and ecosystem functioning. Efforts to identify which of those species will cause greatest ecological harm are currently being undertaken (Carlson et al. manuscript in prep.).

Many land management agencies, as well as the public, are becoming mobilized to reduce potentially negative impacts due to non-native plants. Primarily, the response has been to identify which species are here, where they are located, and how fast they are spreading. This information is critical in designing effective and efficient control measures. Additionally, we need to develop a better understanding of the pathways of dispersal and establishment, and how of ground disturbing activities contribute to invasion.

CONCLUSION

Alaska occupies a unique and advantageous position relative to the rest of the states: the majority of land has not been impacted by human development, and non-native plants are still largely concentrated in high-use areas. However, invasive non-native plants are quickly colonizing undeveloped areas (cf. Conn et al. in press). Once they become established in undeveloped areas, eradication and control efforts will be extremely expensive and logistically challenging, if not impossible. Consequently, the only effective way of maintaining the uniquely native flora of Alaska is by reducing the influx of non-native species into developed areas and by controlling the invasive species before they reach natural systems.

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