Invasive Plant Species Response to Climate Change in Alaska
Bioclimatic models of current and predicted future ranges

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Abstract. Sustainable management efforts are limited by a lack of basic information about species behavior in a changing climate. Species may be limited by climate, dispersal limitations, or a combination of the two. Range map scenarios are a valuable tool for decision-making by land managers with limited resources for invasive plant control. Current and future range map scenarios were created for sixteen invasive plant species in Alaska. Selected species represent primarily aquatic, riparian, or wetland habitats and have a high to extremely high invasion potential. Selected species either occur in Alaska (9 species) or are currently absent (7 species). Species were modeling using two different predictive models (DIVA-GIS and MaxEnt), two different future climates (Hadley and CCC), two emissions scenarios (A2, high and B2, low), for current climate plus three time steps (2020, 2050, 2080). Models were assessed with test data, and then evaluated for accuracy in range prediction. All models showed that the 16 species have current potential range in the state that exceeds their known occurrence. MaxEnt models performed best, using Hadley future climate data with the B2 emissions scenarios, to produce the least conservative, most accurate current and future range maps. All species showed an increase in range over time, particularly aquatic species including hydrilla, Eurasian watermilfoil, and white waterlily. Appropriate control actions are listed for each species based on current and potential future range. An existing vegetation cover map was used to spatially assign ecotype categories (Arctic Alpine, Boreal Interior, and South Coastal) to assess species fidelity to assigned types. Species occurred mainly within assigned types with exceptions that limit the use of ecotype as a predictive tool.

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Introduction

Sustainable management efforts are limited by a lack of basic information about species behavior in a changing climate. An understanding of how invasive plant species are likely to behave in a changing climate will allow land managers with limited time or budgets to make better-informed decisions about what type of management is appropriate for a particular species, a suite of species, or a specific land area. Invasive plants are thought to have the potential to disrupt ecosystem function on a widespread scale in Alaska (Carlson et al. 2008). The spread of invasive species in Alaska may be due to climate, dispersal limitations, or a combination of these factors. Certain aquatic, riparian, wetland, and coastal species are a primary threat to native fish and wildlife populations. Invasive plants are frequently spread through activities associated with the transportation of goods and personnel (e.g., construction, maintenance, and permittee or staff field visits). The activities of the US Fish and Wildlife Service (USFWS), its partners, and permittees could therefore play a significant role in the expansion of invasive species ranges in Alaska. Targeted prevention, detection, and monitoring are the most effective invasive species management tools at this time. The USFWS and its many partners in Alaska currently lack the basic information needed to target the use of these tools. Effective planning is needed that recognizes which species are most likely to spread, where they are likely to spread to, and how these factors may change in a warming climate.

Maps created from models provide land managers with a visual tool for quickly assessing an invasive species' potential range in today's climate and in future climate scenarios. Current potential range maps can direct scouting, research, and planning efforts to areas most likely to be subject to invasion. Future range predictions provide insight on which species are likely to spread rapidly, allowing managers with limited budgets to focus prevention, detection, and rapid response efforts on key species in focal areas today to avoid future large-scale problems. Comparison of current and future range maps will also indicate locations of potential change in the vicinity of planned USFWS construction, restoration, or visitation activities and associated nearby wildlife habitats. This will allow managers to incorporate adaptability into long-term operational planning under climate change. Mapping output can guide decision-making for actions that maximize USFWS accountability for the ecological safety of its own operations. At the same time, using these predictions will help the USFWS maintain critical ecosystem services and the social and cultural structure of Alaskan communities that depend on native fish and wildlife resources.

Methods

Sixteen invasive plant species were selected to represent highly invasive species of interest to the USFWS and other land managers. Species are primarily associated with riparian, wetland, or coastal habitats. Nine of the species have known populations in Alaska, and seven are not present in Alaska (Table 1). All species received a score of 75 or greater in the Alaska Natural Heritage Program's (AKNHP) Invasiveness Ranking project and are considered to be either highly invasive (scores of 70 to 79) or extremely invasive (scores above 80) (Carlson et al. 2008). Closely related species with ecological similarity and taxonomic complexity (including cordgrass, hawkweed, and knotweed) were aggregated into complexes for modeling purposes.

Scenario Maps

Global occurrence data was collected from the Global Biodiversity Information Facility (GBIF 2008). Points with incomplete information were removed (e.g., location or name) and then filtered the retained entries to remove duplicate coordinates. Species occurrence data was imported into ArcGIS version 9.2 (ESRI 2007) to sub-sample occurrences using Hawth's Analysis Tools (Beyer 2007) to prevent oversampling effects in areas with high occurrence reporting. Ten percent of the occurrence points were randomly selected by filtering locations at least 10 km from one another.

BIOCLIM (using the DIVA-GIS platform) and MaxEnt were chosen for our two separate biogeoclimatic predictive models. DIVA-GIS is a GIS supported platform of the BIOCLIM model (Hijmans et al. 2004) which fits a minimal species habitat envelope in a multidimensional climate space. MaxEnt is a program developed for maximum entropy modeling of species geographic distributions (Phillips et al. 2004) which expresses the suitability of each grid cell as a function of the environmental variables at that grid cell. High value of functions indicates predicted suitable conditions for a species. These models were selected to accommodate the presence-only data and span a range of modeling platforms (Elith et al 2006).

WORLDCLIM current climate data was used to capture estimates of current climate. WORLDCLIM is mapped at a 2.5 minute arc scale. Current climate data are available from the WORLDCLIM data site for nineteen environmental parameters. Future climate data are available for different GCMs. The Canadian Climate Centre for Modeling and Analysis (CCCma) and the Hadley Centre datasets were selected for both a higher emission (A2) scenario, and a lower emission (B2) scenario. Hadley Centre data are one of the least conservative future predictions, while CCCma data are one of the most conservative future predictions. Both future climate datasets have been tested for use in Arctic regions, and ranked in the top five of tested climate datasets (Walsh et al. 2008). Scenarios represent different storylines for possible emission output with different societal choices and technological changes (IPCC 2007, Nakicenovic & Swart 2000). Using different datasets and scenarios allows us capacity to bracket predicted futures based on an ensemble of models that capture the extremes.

The selected future climate datasets and scenarios were available for the years 2020, 2050, and 2080. Each species was modeled for current climate as well as the three future time steps to present a transient dynamic series of scenarios. Static distribution modeling has been the predominant approach for studying the possible consequences of a changing environment on species distributions (Guisan and Zimmermann 2000). Only a limited number of species have been studied in terms of dynamic response to climate change.

All models were assessed for accuracy in predicting Alaskan climate landscapes. Receiver-Operating Characteristic (ROC) curves were applied to obtain Area Under the Curve (AUC) scores for each model. ROC plots the fraction of true positive occurrences (the model predicts suitable habitat where known occurrences are located) versus the fraction of false positives (the model predicts suitable habitat where model-generated pseudo-absence points indicate that no data points occur). AUC scores greater than 0.500 indicate that a model performs better than random chance; higher AUC scores indicate better model performance. For ecological data, scores of 0.5 to 0.7 are considered weak; 0.7 to 0.8 are considered marginal, and 0.8 to 1.0 are considered strong. 25% of the data was chosen to reserve for training, with 75% reserved for testing.

To select the highest performing yet most accurate predictive model, each species was tested in both model platforms (BIOCLIM and MaxEnt) in current climate in a series of runs with (a) all parameters, (b) all parameters with neutral or greater AUC score (0.500), or (c) a limited number of high AUC scoring, non-covarying parameters. To reduce effects of covariance in constructing test models, parameters were tested for covariates. Values for all 19 parameters in a worldwide raster dataset were extracted from a 2.5 degree grid using Hawth's Analysis Tools in ArcGIS. A principle components analysis (PCA) was performed in JMP ver. 7.0.2 (SAS Institute 2008). A Spearman's ρ test was applied to measure the strength of the linear relationship between each pairwise combination of variables. A value of zero indicates no linear relationship. Values of 1 or -1 indicate an exact linear relationship, depending on whether the variables are positively or negatively related. Variables were selected to represent different principle component axes. Variables with a significant strong relationship ($\rho > +/-0.9$, $p>0.0001$) were not used in the same species model.

Predicted habitat, as well as mean AUC scores, improved with using fewer, better-performing parameters. For each species, least three parameters were selected to include in the 75% reserve data test model. For the BIOCLIM (DIVA-GIS platform) model, three non-covarying parameters with AUC scores greater than 0.5 were selected. For the MaxEnt model, all non-covarying parameters with AUC scores greater than 0.8 were selected. In addition, parameters were evaluated in a jackknife test in the MaxEnt program to assess individual parameter contribution, which had to be positive to include the parameter. Final models were run with all the data. The final selection criteria for BIOCLIM (DIVA-GIS platform) were (a) location on different PCA axes, (b) lack of significant strong relationships, and (c) AUC value of >0.5. The final selection criteria for MaxEnt were (a) location on different PCA axes, (b) lack of significant strong relationships, (c) AUC value of >0.8, and (d) positive contribution to the model outcome in an internal jackknife test procedure.

Table 1: Species of Interest

Common Name	Scientific Name	Unique Alaska Occurrence Points[1]	Unique Worldwide Occurrence Points[2]	Sub-Sampled Worldwide Occurences[3]	Present in Alaska	AKNHP Ranking	Ecoregion[4] South Coastal	Ecoregion[4] Interior Boreal	Ecoregion[4] Arctic Alpine
cheatgrass	*Bromus tectorum* L.	3	5,569	557	X	78	X	X	X
spotted knapweed	*Centaurea stoebe* L. ssp. *micranthos* (Gugler) Hayek	22	224	224	X	86	X	X	
Canada thistle	*Cirsium arvense* (L.) Scop.	222	12,265	1,227	X	76	X	X	X
leafy spurge	*Euphorbia esula* L.	0	3,689	369		84	X	X	
giant hogweed	*Heracleum mantegazzianum* Sommier & Levier	0	3,223	322		81	X	X	X
hawkweed complex (orange, meadow, narrow-leaf)	*Hieracium aurantiacum* L., *H. caespitosum* Dumort., *H. umbellatum* L.	1,347	11,137	1,114	X	79	X	X	X
hydrilla	*Hydrilla* spp. Rich., mainly *H. verticillata* (L. f.) Royle	0	655	655		80	X	X	X
ornamental jewelweed	*Impatiens glandulifera* Royle	18	4,963	496	X	82	X	X	
purple loosestrife	*Lythrum salicaria* L.	8	15,131	1,513	X	84		X	
sweetclover, yellow or white	*Melilotus officinalis* (L.) Lam.	1,563	8,626	863	X	80	X	X	X
Eurasian watermilfoil	*Myriophyllum spicatum* L.	0	5,993	599		90	X	X	
white waterlily	*Nymphaea alba* L.	0	6,644	664		80	X		
reed canarygrass	*Phalaris arundinacea* L.	5,206	15,595	1,556	X	83	X	X	X

Table 1, Continued

Common Name	Scientific Name	Unique Alaska Occurrence Points[1]	Unique Worldwide Occurrence Points[2]	Sub-Sampled Worldwide Occurences[3]	Present in Alaska	AKNHP Ranking	South Coastal	Interior Boreal	Arctic Alpine
knotweed complex (giant, bohemian, Japanese)	*Polygonum sachalinense* F. Schmidt ex Maxim., *P. ×bohemicum* (J. Chrtek & Chrtkovß) Zika & Jacobson [*cuspidatum* × *sachalinense*], *P. cuspidatum* Siebold & Zucc.	286	7342	734	X	87	X	X	
Himalayan blackberry	*Rubus armeniacus* Focke	0	1247	1247		77	X		
cordgrass complex (smooth, Atlantic, saltmarsh grass)	*Spartina alterniflora* Loisel., *S. anglica* C.E. Hubbard, *S. densiflora* Brongn., *S. patens* (Ait.) Muhls	0	971	971		86	X		

[1] AKEPIC database, 10/10/08. http://akweeds.uaa.alaska.edu

[2] GBIF database, 10/10/2008. http://www.gbif.org/

[3] Includes 10% of all distribution points if species had over 1,000 occurrence points

[4] Assigned by Alaska Natural Heritage Program

Distribution Maps

A current distribution map for all species of interest was created using AKEPIC data with an elevation background and showing infrastructure features and other major invasion vectors (Figure 1 in Mapbook). The Alaska Vegetation Map (Fleming 1996) was imported into ArcGIS version 9.2 (ESRI 2007). Each raster band representing a vegetation type was crosswalked to an assigned ecotype (South Coastal, Interior Boreal, and Arctic Alpine) from the AKNHP system (Appendix A). Species occurrence points were used to extract ecotype values by species. Percent fidelity of assigned type to spatially derived type was calculated. A distribution map was created to illustrate distribution of occurrence points of species of interest within ecotype (Figure 2 in Mapbook). These are called Distribution Maps.

Assessment Maps

Assessments maps were created to identify areas of potential rapid change. MaxEnt models, using the Hadley climate dataset, in the B2 scenario, were the least conservative predictions of future range. For each time step, including current, maps were created by overlaying areas of excellent habitat for all 16 species. Areas where more than three new species appeared over time were identified by drawing a polygon around the area. These maps are called Assessment Maps.

Results

Scenario Mapping

All modeled species showed a potential invasion range within the state of Alaska in current and in future predicted scenarios. Known current populations indicate that species are not yet filling their current predicted potential range. However, some known occurrences already extend beyond the predicted range for that species in the current climate.

Mean AUC scores from the DIVA-GIS model are given for each species in Table 2, along with the parameters included in the final species model. A higher AUC score represents higher confidence in the predicted range. For DIVA-GIS, all species have scores above .600. Five species had scores between 0.6 and 0.7, indicating weak models. Ten species had scores between 0.7 and 0.8, indicating marginal models. One score is above 0.8 (knotweed complex) indicating a strong model. Selected parameters for each species are given. All BIOCLIM parameter descriptions are given in Appendix A.

Table 2: Mean AUC Values and Environmental Parameters for DIVA-GIS Model

Species	Mean AUC	Selected BIOCLIM Parameters
cheatgrass	0.716	19-Precipitation of Coldest Quarter 17-Precipitation of Driest Quarter 12-Annual Precipitation
spotted knapweed	0.723	14-Precipitation of Driest Period 19-Precipitation of Coldest Quarter 12-Annual Precipitation
Canada thistle	0.786	14-Precipitation of Driest Period 19-Precipitation of Coldest Quarter 12-Annual Precipitation
leafy spurge	0.725	14-Precipitation of Driest Period 19-Precipitation of Coldest Quarter 12-Annual Precipitation
giant hogweed	0.689	19-Precipitation of Coldest Quarter 12-Annual Precipitation 6-Min Temperature of Coldest Period
hawkweed complex	0.794	14-Precipitation of Driest Period 19-Precipitation of Coldest Quarter 12-Annual Precipitation
hydrilla	0.764	16-Precipitation of Wettest Quarter 12-Annual Precipitation 6-Min Temperature of Coldest Period
ornamental jewelweed	0.716	17-Precipitation of Driest Quarter 12-Annual Precipitation 18-Precipitation of Warmest Quarter
purple loosestrife	0.670	14-Precipitation of Driest Period 18-Precipitation of Warmest Quarter 6-Min Temperature of Coldest Period
sweetclover	0.747	19-Precipitation of Coldest Quarter 18-Precipitation of Warmest Quarter 6-Min Temperature of Coldest Period 11-Mean Temperature of Coldest Quarter
Eurasian watermilfoil	0.704	19-Precipitation of Coldest Quarter 12-Annual Precipitation 6-Min Temperature of Coldest Period
white waterlily	0.693	12-Annual Precipitation 18-Precipitation of Warmest Quarter 6-Min Temperature of Coldest Period
reed canarygrass	0.680	19-Precipitation of Coldest Quarter 12-Annual Precipitation 6-Min Temperature of Coldest Period
knotweed complex	0.812	14-Precipitation of Driest Period 19-Precipitation of Coldest Quarter 12-Annual Precipitation
Himalayan blackberry	0.670	19-Precipitation of Coldest Quarter 12-Annual Precipitation 6-Min Temperature of Coldest Period

cordgrass complex	0.732	19-Precipitation of Coldest Quarter 13-Precipitation of Wettest Period 6-Min Temperature of Coldest Period

Test AUC scores from the MaxEnt model are shown in Table 3, along with the parameters included in the final species model. AUC scores for the MaxEnt model are all above 0.900, indicating strong model performance.

Table 3: Test AUC Values and Parameters for MaxEnt Model

Species	Test AUC	Selected BIOCLIM Parameters
cheatgrass	0.9233	1-Annual Mean Temperature 3-Isothermality (P2/P7) 4-Temperature Seasonality (Coefficient of Variation) 6-Min Temperature of Coldest Period 11-Mean Temperature of Coldest Quarter
spotted knapweed	0.9695	1-Annual Mean Temperature 6-Min Temperature of Coldest Period 7-Temperature Annual Range (P5-P6) 9-Mean Temperature of Driest Quarter 10-Mean Temperature of Warmest Quarter 11-Mean Temperature of Coldest Quarter 15-Precipitation Seasonality(Coefficient of Variation)
Canada thistle	0.9443	1-Annual Mean Temperature 6-Min Temperature of Coldest Period 7-Temperature Annual Range (P5-P6) 9-Mean Temperature of Driest Quarter 10-Mean Temperature of Warmest Quarter 11-Mean Temperature of Coldest Quarter 12-Annual Precipitation 15-Precipitation Seasonality(Coefficient of Variation) 17-Precipitation of Driest Quarter
leafy spurge	0.9172	1-Annual Mean Temperature 6-Min Temperature of Coldest Period 9-Mean Temperature of Driest Quarter 10-Mean Temperature of Warmest Quarter 15-Precipitation Seasonality(Coefficient of Variation)
giant hogweed	0.9508	1-Annual Mean Temperature 4-Temperature Seasonality (Coefficient of Variation) 9-Mean Temperature of Driest Quarter 10-Mean Temperature of Warmest Quarter 11-Mean Temperature of Coldest Quarter 15-Precipitation Seasonality(Coefficient of Variation) 17-Precipitation of Driest Quarter
hawkweed complex	0.9324	1-Annual Mean Temperature 4-Temperature Seasonality (Coefficient of Variation) 9-Mean Temperature of Driest Quarter 10-Mean Temperature of Warmest Quarter

		11-Mean Temperature of Coldest Quarter 14-Precipitation of Driest Period 15-Precipitation Seasonality(Coefficient of Variation)
hydrilla	0.9829	1-Annual Mean Temperature 3-Isothermality (P2/P7) 4-Temperature Seasonality (Coefficient of Variation) 10-Mean Temperature of Warmest Quarter 12-Annual Precipitation 17-Precipitation of Driest Quarter 18-Precipitation of Warmest Quarter
ornamental jewelweed	0.9494	1-Annual Mean Temperature 3-Isothermality (P2/P7) 4-Temperature Seasonality (Coefficient of Variation) 10-Mean Temperature of Warmest Quarter 11-Mean Temperature of Coldest Quarter 15-Precipitation Seasonality(Coefficient of Variation) 17-Precipitation of Driest Quarter
purple loosestrife	0.9224	1-Annual Mean Temperature 9-Mean Temperature of Driest Quarter 10-Mean Temperature of Warmest Quarter 11-Mean Temperature of Coldest Quarter 14-Precipitation of Driest Period 15-Precipitation Seasonality(Coefficient of Variation)
sweetclover	0.9091	1-Annual Mean Temperature 3-Isothermality (P2/P7) 11-Mean Temperature of Coldest Quarter
Eurasian watermilfoil	0.9321	1-Annual Mean Temperature 4-Temperature Seasonality (Coefficient of Variation) 9-Mean Temperature of Driest Quarter 10-Mean Temperature of Warmest Quarter 11-Mean Temperature of Coldest Quarter 15-Precipitation Seasonality(Coefficient of Variation) 17-Precipitation of Driest Quarter
white waterlily	0.9454	1-Annual Mean Temperature 2-Mean Diurnal Range (Mean (period max-min)) 4-Temperature Seasonality (Coefficient of Variation) 9-Mean Temperature of Driest Quarter 10-Mean Temperature of Warmest Quarter 11-Mean Temperature of Coldest Quarter 14-Precipitation of Driest Period 15-Precipitation Seasonality(Coefficient of Variation)
reed canarygrass	0.9259	1-Annual Mean Temperature 3-Isothermality (P2/P7) 9-Mean Temperature of Driest Quarter 11-Mean Temperature of Coldest Quarter 15-Precipitation Seasonality(Coefficient of Variation) 17-Precipitation of Driest Quarter
knotweed complex	0.9454	1-Annual Mean Temperature

		4-Temperature Seasonality (Coefficient of Variation) 9-Mean Temperature of Driest Quarter 11-Mean Temperature of Coldest Quarter 14-Precipitation of Driest Period 15-Precipitation Seasonality(Coefficient of Variation)
Himalayan blackberry	0.9625	1-Annual Mean Temperature 2-Mean Diurnal Range (Mean (period max-min)) 4-Temperature Seasonality (Coefficient of Variation) 9-Mean Temperature of Driest Quarter 10-Mean Temperature of Warmest Quarter 11-Mean Temperature of Coldest Quarter
cordgrass complex	0.9698	9-Mean Temperature of Driest Quarter 5-Max Temperature of Warmest Period 12-Annual Precipitation 17-Precipitation of Driest Quarter 19-Precipitation of Coldest Quarter

Area calculations provided a quantified measure of percent suitable versus unsuitable habitat in current and future time steps. All species showed changes in total area of suitable habitat from current climate predictions to future climate predictions (Table 4). Hadley climate dataset predictions showed greater increases in total suitable habitat compared to CCC climate dataset predictions. MaxEnt percents show lower percent suitable habitat overall than DIVA-GIS model prediction percents. MaxEnt, with a higher model strength, can be considered to have a higher likelihood of occurrence in all suitable habitat areas. In other words, the confidence in the prediction of suitable habitat is greater for all MaxEnt models.

Table 4: Percent Area of Suitable and Unsuitable Habitat

Species	Model	Climate Dataset	Time Step	Not Suitable (%)	Suitable Habitat (%)
cheatgrass	DIVA-GIS	WORLDCLIM	Current	13	87
		CCC	2020 A2	10	90
			2050 A2	9	91
			2080 A2	8	92
			2020 B2	10	90
			2050 B2	11	89
			2080 B2	8	92
		Hadley	2020 A2	13	87
			2050 A2	13	87
			2080 A2	12	88
			2020 B2	12	88
			2050 B2	10	90
			2080 B2	10	90
	MaxEnt	WORLDCLIM	Current	82	18
		CCC	2020 A2	79	21

			2050 A2	65	35
			2080 A2	56	44
			2020 B2	79	21
			2050 B2	70	30
			2080 B2	65	35
		Hadley	2020 A2	76	24
			2050 A2	69	31
			2080 A2	62	38
			2020 B2	79	21
			2050 B2	74	26
			2080 B2	64	36
spotted knapweed	DIVA-GIS	WORLDCLIM	Current	22	78
		CCC	2020 A2	23	77
			2050 A2	23	77
			2080 A2	22	78
			2020 B2	20	80
			2050 B2	23	77
			2080 B2	17	83
		Hadley	2020 A2	19	81
			2050 A2	23	77
			2080 A2	19	81
			2020 B2	20	80
			2050 B2	19	81
			2080 B2	18	82
	MaxEnt	WORLDCLIM	Current	88	12
		CCC	2020 A2	89	11
			2050 A2	82	18
			2080 A2	72	28
			2020 B2	47	53
			2050 B2	84	16
			2080 B2	80	20
		Hadley	2020 A2	83	17
			2050 A2	83	17
			2080 A2	75	25
			2020 B2	87	13
			2050 B2	83	17
			2080 B2	78	22
Canada thistle	DIVA-GIS	WORLDCLIM	Current	0	100
		CCC	2020 A2	0	100
			2050 A2	0	100
			2080 A2	35	65
			2020 B2	0	100
			2050 B2	0	100
			2080 B2	0	100
		Hadley	2020 A2	0	100
			2050 A2	0	100

			2080 A2	1	99
			2020 B2	0	100
			2050 B2	0	100
			2080 B2	1	99
	MaxEnt	WORLDCLIM	Current	91	9
		CCC	2020 A2	89	11
			2050 A2	79	21
			2080 A2	77	23
			2020 B2	86	14
			2050 B2	82	18
			2080 B2	79	21
		Hadley	2020 A2	86	14
			2050 A2	84	16
			2080 A2	86	14
			2020 B2	89	11
			2050 B2	85	15
			2080 B2	78	22
leafy spurge	DIVA-GIS	WORLDCLIM	Current	33	67
		CCC	2020 A2	34	66
			2050 A2	35	65
			2080 A2	27	73
			2020 B2	33	67
			2050 B2	35	65
			2080 B2	34	66
		Hadley	2020 A2	32	68
			2050 A2	23	77
			2080 A2	23	77
			2020 B2	23	77
			2050 B2	21	79
			2080 B2	20	80
	MaxEnt	WORLDCLIM	Current	82	18
		CCC	2020 A2	81	19
			2050 A2	67	33
			2080 A2	64	36
			2020 B2	78	22
			2050 B2	67	33
			2080 B2	65	35
		Hadley	2020 A2	74	26
			2050 A2	72	28
			2080 A2	60	40
			2020 B2	77	23
			2050 B2	70	30
			2080 B2	62	38
giant hogweed	DIVA-GIS	WORLDCLIM	Current	73	27
		CCC	2020 A2	77	23

			2050 A2	73	27
			2080 A2	75	25
			2020 B2	77	23
			2050 B2	76	24
			2080 B2	73	27
		Hadley	2020 A2	70	30
			2050 A2	64	36
			2080 A2	62	38
			2020 B2	69	31
			2050 B2	65	35
			2080 B2	20	80
	MaxEnt	WORLDCLIM	Current	94	6
		CCC	2020 A2	93	7
			2050 A2	88	12
			2080 A2	86	14
			2020 B2	93	7
			2050 B2	90	10
			2080 B2	88	12
		Hadley	2020 A2	94	6
			2050 A2	93	7
			2080 A2	91	9
			2020 B2	94	6
			2050 B2	93	7
			2080 B2	88	12
hawkweed complex	DIVA-GIS	WORLDCLIM	Current	26	74
		CCC	2020 A2	26	74
			2050 A2	22	78
			2080 A2	23	77
			2020 B2	34	66
			2050 B2	24	76
			2080 B2	25	75
		Hadley	2020 A2	20	80
			2050 A2	18	82
			2080 A2	17	83
			2020 B2	20	80
			2050 B2	15	85
			2080 B2	17	83
	MaxEnt	WORLDCLIM	Current	77	23
		CCC	2020 A2	73	27
			2050 A2	62	38
			2080 A2	58	42
			2020 B2	73	27
			2050 B2	65	35
			2080 B2	63	37
		Hadley	2020 A2	70	30
			2050 A2	66	34

			2080 A2	59	41
			2020 B2	72	28
			2050 B2	67	33
			2080 B2	60	40
hydrilla	DIVA-GIS	WORLDCLIM	Current	83	17
		CCC	2020 A2	80	20
			2050 A2	67	33
			2080 A2	55	45
			2020 B2	71	29
			2050 B2	71	29
			2080 B2	65	35
		Hadley	2020 A2	75	25
			2050 A2	74	26
			2080 A2	67	33
			2020 B2	82	18
			2050 B2	74	26
			2080 B2	58	42
	MaxEnt	WORLDCLIM	Current	90	10
		CCC	2020 A2	86	14
			2050 A2	81	19
			2080 A2	78	22
			2020 B2	88	12
			2050 B2	85	15
			2080 B2	81	19
		Hadley	2020 A2	86	14
			2050 A2	79	21
			2080 A2	77	23
			2020 B2	87	13
			2050 B2	79	21
			2080 B2	76	24
ornamental jewelweed	DIVA-GIS	WORLDCLIM	Current	69	31
		CCC	2020 A2	67	33
			2050 A2	66	34
			2080 A2	64	36
			2020 B2	70	30
			2050 B2	67	33
			2080 B2	66	34
		Hadley	2020 A2	66	34
			2050 A2	55	45
			2080 A2	50	50
			2020 B2	66	34
			2050 B2	63	37
			2080 B2	54	46
	MaxEnt	WORLDCLIM	Current	90	10
		CCC	2020 A2	89	11
			2050 A2	81	19

			2080 A2	75	25
			2020 B2	88	12
			2050 B2	83	17
			2080 B2	80	20
		Hadley	2020 A2	88	12
			2050 A2	83	17
			2080 A2	79	21
			2020 B2	90	10
			2050 B2	85	15
			2080 B2	78	22
purple loosestrife	DIVA-GIS	WORLDCLIM	Current	27	73
		CCC	2020 A2	32	68
			2050 A2	27	73
			2080 A2	32	68
			2020 B2	29	71
			2050 B2	28	72
			2080 B2	28	72
		Hadley	2020 A2	27	73
			2050 A2	24	76
			2080 A2	26	74
			2020 B2	27	73
			2050 B2	25	75
			2080 B2	25	75
	MaxEnt	WORLDCLIM	Current	78	22
		CCC	2020 A2	74	26
			2050 A2	75	25
			2080 A2	67	33
			2020 B2	74	26
			2050 B2	76	24
			2080 B2	75	25
		Hadley	2020 A2	66	34
			2050 A2	73	27
			2080 A2	68	32
			2020 B2	68	32
			2050 B2	64	36
			2080 B2	72	28
sweetclover	DIVA-GIS	WORLDCLIM	Current	1	99
		CCC	2020 A2	1	99
			2050 A2	1	99
			2080 A2	1	99
			2020 B2	1	99
			2050 B2	1	99
			2080 B2	1	99
		Hadley	2020 A2	2	98
			2050 A2	2	98
			2080 A2	3	97

			2020 B2	2	98
			2050 B2	3	97
			2080 B2	3	97
	MaxEnt	WORLDCLIM	Current	69	31
		CCC	2020 A2	67	33
			2050 A2	57	43
			2080 A2	46	54
			2020 B2	68	32
			2050 B2	63	37
			2080 B2	55	45
		Hadley	2020 A2	65	35
			2050 A2	61	39
			2080 A2	57	43
			2020 B2	67	33
			2050 B2	62	38
			2080 B2	57	43
Eurasian watermilfoil	DIVA-GIS	WORLDCLIM	Current	71	29
		CCC	2020 A2	63	37
			2050 A2	53	47
			2080 A2	46	54
			2020 B2	69	31
			2050 B2	52	48
			2080 B2	47	53
		Hadley	2020 A2	67	33
			2050 A2	62	38
			2080 A2	60	40
			2020 B2	68	32
			2050 B2	64	36
			2080 B2	54	46
	MaxEnt	WORLDCLIM	Current	47	53
		CCC	2020 A2	83	17
			2050 A2	74	26
			2080 A2	68	32
			2020 B2	82	18
			2050 B2	77	23
			2080 B2	73	27
		Hadley	2020 A2	81	19
			2050 A2	74	26
			2080 A2	70	30
			2020 B2	47	53
			2050 B2	77	23
			2080 B2	71	29
white waterlily	DIVA-GIS	WORLDCLIM	Current	86	14
		CCC	2020 A2	81	19
			2050 A2	66	34
			2080 A2	58	42

			2020 B2	84	16
			2050 B2	67	33
			2080 B2	62	38
		Hadley	2020 A2	81	19
			2050 A2	78	22
			2080 A2	77	23
			2020 B2	86	14
			2050 B2	77	23
			2080 B2	65	35
	MaxEnt	WORLDCLIM	Current	90	10
		CCC	2020 A2	87	13
			2050 A2	76	24
			2080 A2	70	30
			2020 B2	87	13
			2050 B2	79	21
			2080 B2	76	24
		Hadley	2020 A2	86	14
			2050 A2	81	19
			2080 A2	74	26
			2020 B2	87	13
			2050 B2	83	17
			2080 B2	75	25
reed canarygrass	DIVA-GIS	WORLDCLIM	Current	21	79
		CCC	2020 A2	22	78
			2050 A2	22	78
			2080 A2	22	78
			2020 B2	22	78
			2050 B2	24	76
			2080 B2	21	79
		Hadley	2020 A2	24	76
			2050 A2	22	78
			2080 A2	19	81
			2020 B2	22	78
			2050 B2	21	79
			2080 B2	19	81
	MaxEnt	WORLDCLIM	Current	76	24
		CCC	2020 A2	72	28
			2050 A2	61	39
			2080 A2	57	43
			2020 B2	72	28
			2050 B2	67	33
			2080 B2	63	37
		Hadley	2020 A2	67	33
			2050 A2	63	37
			2080 A2	59	41
			2020 B2	70	30

			2050 B2	64	36
			2080 B2	59	41
knotweed complex	DIVA-GIS	WORLDCLIM	Current	15	85
		CCC	2020 A2	21	79
			2050 A2	16	84
			2080 A2	18	82
			2020 B2	19	81
			2050 B2	17	83
			2080 B2	16	84
		Hadley	2020 A2	18	82
			2050 A2	16	84
			2080 A2	17	83
			2020 B2	16	84
			2050 B2	15	85
			2080 B2	14	86
	MaxEnt	WORLDCLIM	Current	88	12
		CCC	2020 A2	87	13
			2050 A2	83	17
			2080 A2	76	24
			2020 B2	87	13
			2050 B2	84	16
			2080 B2	83	17
		Hadley	2020 A2	86	14
			2050 A2	83	17
			2080 A2	77	23
			2020 B2	86	14
			2050 B2	84	16
			2080 B2	77	23
Himalayan blackberry	DIVA-GIS	WORLDCLIM	Current	13	87
		CCC	2020 A2	15	85
			2050 A2	13	87
			2080 A2	23	77
			2020 B2	13	87
			2050 B2	14	86
			2080 B2	13	87
		Hadley	2020 A2	12	88
			2050 A2	11	89
			2080 A2	11	89
			2020 B2	13	87
			2050 B2	13	87
			2080 B2	11	89
	MaxEnt	WORLDCLIM	Current	96	4
		CCC	2020 A2	95	5
			2050 A2	88	12
			2080 A2	79	21
			2020 B2	95	5

			2050 B2	90	10
			2080 B2	87	13
		Hadley	2020 A2	96	4
			2050 A2	91	9
			2080 A2	83	17
			2020 B2	97	3
			2050 B2	95	5
			2080 B2	84	16
cordgrass complex	DIVA-GIS	WORLDCLIM	Current	41	59
		CCC	2020 A2	44	56
			2050 A2	41	59
			2080 A2	38	62
			2020 B2	45	55
			2050 B2	41	59
			2080 B2	41	59
		Hadley	2020 A2	37	63
			2050 A2	35	65
			2080 A2	35	65
			2020 B2	39	61
			2050 B2	36	64
			2080 B2	33	67
	MaxEnt	WORLDCLIM	Current	88	12
		CCC	2020 A2	88	12
			2050 A2	83	17
			2080 A2	83	17
			2020 B2	87	13
			2050 B2	85	15
			2080 B2	84	16
			2020 A2	87	13
			2050 A2	81	19
			2080 A2	71	29
			2020 B2	87	13
			2050 B2	82	18
			2080 B2	75	25

Distribution Mapping by Ecotype

Species occurred mainly within assigned ecotypes during the spatial examination of ecotype fidelity (Figure 2, Mapbook). Assigned ecotypes refer to the designation by the Alaska Natural Heritage Program. Unassigned types include instances where the species occurred outside of assigned type, or occurred within non-vegetated cover types such as rock, ice, glaciers, snowfields, water, ocean, or outside the mapped boundaries (no data). Occurrence points, by the particular latitude and longitude assigned to them, frequently fell within these locations rather than a vegetation cover type to which an ecotype had been assigned (a crosswalk of vegetation cover types to ecotypes is given in Appendix A). The occurrence in unassigned types could be due to GPS location error, or the scale of the raster pixels. Only nine species of interest had presence points occurring in areas designated by one of the three ecotypes (hawkweed species were split out for this exercise). Total N, count per ecotype, and percent occurrence is shown in Table 5, along with totals for each ecotype. The type with the highest percent occurrence is shown in bold. Anomalies in AKNHP designation include spotted knapweed and ornamental jewelweed, with one and three points respectively occurring in an unassigned type. Purple loosestrife had half of its occurrence points occur in an unassigned ecotype, although only eight points are currently recorded for the state in the AKEPIC database.

Table 5: Species Percent Distribution by Ecotype

Species	Assigned Ecotypes	Unassigned Ecotypes	Count	Percent
cheatgrass	Arctic Alpine		0	0.00
N=3	**Interior Boreal**		3	100.00
	South Coastal		0	0.00
		Water/Ice/No Data	0	0.00
spotted knapweed		Arctic Alpine	1	4.55
N=22	Interior Boreal		0	0.00
	South Coastal		5	22.73
		Water/Ice/No Data	16	72.73
Canada thistle	**Arctic Alpine**		69	31.08
N=222	Interior Boreal		56	25.23
	South Coastal		34	15.32
		Water/Ice/No Data	63	28.38
orange hawkweed	Arctic Alpine		87	7.76
N=1121	Interior Boreal		123	10.97
	South Coastal		524	46.74
		Water/Ice/No Data	387	34.52
meadow hawkweed	Arctic Alpine		0	0.00
N=51	Interior Boreal		6	11.76
	South Coastal		43	84.31
		Water/Ice/No Data	2	3.92
narrow-leaf hawkweed	Arctic Alpine		20	11.43
N=175	**Interior Boreal**		83	47.43
	South Coastal		39	22.29
		Water/Ice/No Data	33	18.86
ornamental jewelweed		Arctic Alpine	3	16.67
N=18	**Interior Boreal**		8	44.44
	South Coastal		2	11.11
		Water/Ice/No Data	5	27.78
purple loosestrife		**Arctic Alpine**	4	50.00
N=8	**Interior Boreal**		4	50.00
		South Coastal	0	0.00
		Water/Ice/No Data	0	0.00
sweetclover	Arctic Alpine		118	7.55
N=1563	**Interior Boreal**		1224	78.31
	South Coastal		112	7.17

		Water/Ice/No Data	109	6.97
reed canarygrass	Arctic Alpine		18	0.35
N=5206	Interior Boreal		95	1.82
	South Coastal		4482	86.09
		Water/Ice/No Data	611	11.74
knotweed complex		Arctic Alpine	0	0.00
N=286	Interior Boreal		1	0.35
	South Coastal		65	22.73
		Water/Ice/No Data	220	76.92
		Grand Total	**8675**	
		Arctic Alpine	**320**	**3.69**
		Interior Boreal	**1603**	**18.48**
		South Coastal	**5306**	**61.16**
		Water/Ice/No Data	**1446**	**16.67**

Assessment Mapping

MaxEnt model ranges were used to create assessment maps of potential rapid change areas. Higher suitability habitat was centered on the coastal areas of Alaska (Figures 3 to 6). For current climate, excellent ranked habitat occurs along the Southeast Alaska Coast, around Prince William Sound, across the Kenai Peninsula, Kodiak Island, along the Aleutian chain, the southern part of the Yukon-Kuskokwim Delta, the Bristol Bay coast, and the remote islands to the west of the Alaska shore. The 2020 scenarios reflect a smaller overall excellent habitat range, with extension further into the interior of Southeast Alaska. The 2050 scenario shows an extension of excellent habitat in Southcentral Alaska and parts of Southeast Alaska. Individual species ranges are larger. The 2080 scenario shows increases in excellent range along the Southeast Alaska coastline.

Discussion

This analysis can be considered an initial modeling of the potentially devastating effects of highly invasive species at a coarse scale across Alaska under current and changing climate conditions. Scenarios are representations of potential ranges for all of the species of interest, suitable for a variety of planning purposes. Scenario maps represent the minimum potential habitat that is likely to occur. Actual future ranges may differ from predicted ranges, as predictions are limited by available future climate datasets and, as with all species, these invaders will continue to evolve and adapt in environments that may not share the same limiting factors as in their native range (e.g., pathogens, herbivores, competitors, etc.). Global circulation model datasets offer conservative projections of change.

MaxEnt models performed better. MaxEnt is recommended for future predictive modeling exercises for Alaska. MaxEnt performs better with large scale, general datasets (Elith et al. 2006). Low AUC scores indicate that DIVA-GIS (or other BIOCLIM models) may not work well for Alaska. AUC scores could be improved by selecting the three highest scoring parameters. However, the evaluation process considered the prediction of the highest possibly accurate range in selecting parameters. For example, the highest scoring raw scores for reed canarygrass were parameters 19, 14, and 17. This set of parameters limited the predicted range to a smaller area in the upper south coast. Given current knowledge on reed canarygrass distribution and habitat tolerance, this range is inaccurate. The limiting factors for reed canargygrass are likely different than those that scored highest in the DIVA-GIS model. For each species, all high-scoring parameters were tested to find the limiting factors that worked the best for each species, in order to define the best possible predicted range.

For invasive plant species in Alaska, the basic limitations to growth are assumed to be temperature and precipitation. The main limiting factors for most of the DIVA-GIS species models are a combination of cold and precipitation. Parameters that combined temperature with precipitation scored highest. Most of northernmost Alaska had no or low predicted habitat suitability, due to cold restrictions. However, habitat suitability for several species (Table 6) expanded from primarily south coastal Alaska well up into the Arctic (as described by the Arctic Council's Program for the Conservation of Arctic Flora and Fauna). Aquatic species' models are currently the most limited by the available parameters. Aquatic species may be improved with a particular variant of this type of model that takes into account specific habitat requirements to perform better.

Parts of Southeast Alaska were not included in several species' predicted ranges. The limited climate data did not indicate suitable habitat in this area, even though the species' are able to grow there. This exclusion is the most serious limitation of this series of models. Available climate data predicts high increases of precipitation for Southeast Alaska. Most recorded occurrence points for species that can grow in Southeast Alaska represent climate conditions that are very different from climate conditions in this area. Because the DIVA-GIS model functions by using climate information from all global occurrence points, regional areas with extreme or particular climate features do not perform as well in BIOCLIM models of coarse areas. MaxEnt operates on different algorithms which process occurrence points by a weighting process rather than direct values, allowing for a less strict representation of potential habitat.

Another climate limitation to this study includes the ability of predictive habitat models to accurately illustrate scenarios at a large scale. Although the selected future climate datasets for Alaska performed well for Arctic climates (Walsh et al. 2008), models are based on a limited number of environmental parameters derived from global weather station data. Specific values for each 2.5 degree arc were extrapolated from available weather station data by WORLDCLIM to cover the entire world. Alaska is only represented by data from three stations, including Fairbanks, Anchorage, and Juneau. While climate data models are constantly improving, many northern regions are limited by the generality of available data. Increases per time step are not obvious for all species at the scale being mapped, and in some cases, species' ranges are reduced in areas in future time steps. The area of range decrease may be experiencing a temperature increase in the future, which may change the area from being suitable to being unsuitable for a species to grow there. In reality, decreases in range are unlikely in the time period represented based on current knowledge of invasive species behavior in new habitats ((Alpert 2006, Callaway & Maron 2006, Blossey & Notzold 1995). The further out the prediction in time, the less reliable the scenario is, which is a universal problem in predictive modeling.

Also, global occurrence data are limited to the data currently entered, which are subject to error (Guisan et al. 2007). Data are concentrated in locations including Europe, parts of Australia, North America, and studies or records from researchers originating in these regions. Through sub-sampling randomly, some of the over sampling effects of available data are reduced, but data output is only as representative as data input. Species with fewer occurrence points (such as white waterlily, purple loosestrife, and spotted knapweed) may have less accurate models because the predictive ability of the model is lowered when the plant's entire potential habitat is not represented by occurrence points. MaxEnt performed better with more limited occurrence data.

Introduced species also are generally known to be able to occur in environmental conditions that are more extreme than in their home environment. The influence of herbivory, competition, or other factors that keep native populations in check may not apply to populations in a new location. Genetic changes and genetic mixing may also occur in the new environment (Blossey & Notzold 2005). Plant life history factors are difficult to quantify for inclusion in modeling at the scale of this exercise, and have not yet been applied in most predictive modeling. Opportunity exists to fine-tune specific species models with detailed information about that particular species' life history and home environment. The scale of modeling in this study prevents detailed investigation of particular regions, instead offering a general picture of change that may occur over time.

More specific modeling, applied to smaller regions of the state, could include detailed parameters such as more refined elevation values; soil type; refined water, ice, rock values; waterway values; plant life history characteristics; monthly or quarterly soil temperatures; average frost free days; satellite derived data; monthly or quarterly average length of daylight; or other specific parameter values. Suggested areas of detailed modeling include areas identified as potentially experiencing larger sized infestations or an increase in the number of invasive species present. This includes much of the coastal areas in Southeast Alaska, Prince William Sound, Kodiak, the Kenai Peninsula, Bristol Bay, the Aleutians, the Anchorage Bowl, and the Matanuska-Susitna Valley. Other suggested areas include major rivers and waterways, the Yukon-Kuskokwim Delta, and the Fairbanks area.

Although the series of scenarios produced for each species are subject to some limitations, the overall product will be a useful tool for USFWS planning efforts. Management priorities should include a program of monitoring for these species in predicted range areas that overlap potential areas of activity for the USFWS (Table 6). Prevention activities can be enhanced by using the predicted scenarios as a guide and having a plan of action in place – for example, a prevention plan generated by using the

Hazard Analysis and Critical Control Points planning process recently called for in the Service Manual (USFWS, 750 FW 1, 2009).

Scenarios can be used as illustrative examples, or as teaching tools, in describing current potential range and future potential ranges. Scenarios also provide a better understanding of limiting factors to invasive species spread. With mild temperature or precipitation increases, species can be expected to fill ranges covering vast portions of the state. The main limiting parmaters include (a) precipitation of the driest period or driest quarter, (b) precipitation of the wettest quarter, and (c) minimum temperature of the coldest quarter. Increased travel, construction, and movement from areas with known populations of invasive plants to potential habitat areas may introduce new populations to currently pristine regions, including USFWS managed lands. Additionally, USFWS habitat restoration, endangered species, fisheries, migratory birds, and conservation planning assistance programs should benefit from this information and also institute measures to prevent the spread of invasive species. Prevention planning is critical to prevent new and potentially large infestations from starting.

Invasiveness ranking scores on all species considered in this analysis are high enough to justify a program of eradication or at least containment for widespread species. All species require appropriate action (Table 6). Species with large predicted ranges but low current distribution are the best candidates for a program of statewide eradication and aggressive prevention tactics. These species include cheatgrass, spotted knapweed, Canada thistle, purple loosestrife, and the knotweed complex. Species with large predicted ranges and no known current occurrences in Alaska should be targeted for prevention, early detection monitoring and rapid eradication if found. Himalayan blackberry, white waterlilly, hydrilla, and Eurasian watermilfoil fall in this category.

Species with a smaller, but still substantial, predicted range and low or no current occurrence are good candidates for eradication in known or found populations. Predicted ranges still cover vast acreages, and in some cases, have a higher proportion of Excellent or Very High suitable habitat. This may indicate that once a threshold of a particular environmental parameter level is crossed, the species may increase more rapidly than is possible to predict with currently available tools. If this is the case, this makes early detection and rapid response all the more critical for such species. These species include leafy spurge, giant hogweed, ornamental jewelweed, and the cordgrass complex.

Species with large predicted ranges and a larger current statewide distribution may not be possible to eradicate. However, programs of containment and spread prevention are still critical, given the amount of uninvaded potential habitat. These species include the hawkweed complex, sweetclover, and reed canarygrass.

Table 6: Current Distribution, Predicted Future Range, and Appropriate Actions

Species	Current Distribution	Predicted Range	Appropriate Actions
cheatgrass	low	Most of Alaska	Eradicate known populations; monitor for new populations
spotted knapweed	low	Most of Alaska	Eradicate known populations;

			monitor for new populations
Canada thistle	moderate	All of Alaska	Eradicate or contain known populations; monitor for new populations
leafy spurge	none	Most of Alaska	Monitor to prevent establishment in Alaska
giant hogweed	none	Most of Alaska	Monitor to prevent establishment in Alaska
hawkweed complex (orange, meadow, narrow-leaf)	high	Most of Alaska	Contain known populations; work towards eradication; take aggressive prevention actions
hydrilla	none	Southeast, Southcentral, Aleutians, Seward Peninsula, Y-K Delta	Monitor to prevent establishment in Alaska
ornamental jewelweed	low	Southern half of Alaska	Eradicate known populations; monitor for new populations
purple loosestrife	low	Most of Alaska	Eradicate known populations; monitor for new populations
sweetclover, yellow or white	high	All of Alaska	Contain known populations; take aggressive prevention actions
Eurasian watermilfoil	none	Southeast, Southcentral, Aleutians, Seward Peninsula, Y-K Delta	Monitor to prevent establishment in Alaska
white waterlily	low to none	Southeast, Southcentral, Aleutians, Seward Peninsula, Y-K Delta	Monitor to prevent establishment in Alaska
reed canarygrass	high	Most of Alaska	Contain known populations; take aggressive prevention actions
knotweed complex (giant, bohemian, Japanese)	moderate	Most of Alaska	Contain known populations; work towards eradication; take aggressive prevention actions
Himalayan blackberry	low to none	Most of Alaska	Monitor to prevent establishment in Alaska
cordgrass complex (smooth, Atlantic, saltmarsh grass)	none	Southeast, Southcentral, Aleutians, Seward Peninsula, Y-K Delta	Monitor to prevent establishment in Alaska

Attachments

Figures 1-6: Distribution Maps and Assessment Maps

Figures 1 - 702: Scenario Mapbook for Current and Future Predicted Ranges, with Index.

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Appendices

Appendix A: Vegetation Cover Code to Ecotype Crosswalk

Vegetation Cover Code[1]	Vegetation Cover Name	Ecotype Code[2]	Ecotype Name
0	Ocean Water	0	None
1	Water	0	None
2	Glaciers & Snow	1	Arctic Alpine
3	Alpine Tundra & Barrens	1	Arctic Alpine
4	Dwarf Shrub Tundra	1	Arctic Alpine
5	Tussock Sedge/Dwarf Shrub Tundra	1	Arctic Alpine
6	Moist Herbaceous/Shrub Tundra	1	Arctic Alpine
7	Wet Sedge Tundra	1	Arctic Alpine
8	Low Shrub/Lichen Tundra	2	Interior Boreal
9	Low & Dwarf Shrub	2	Interior Boreal
10	Tall Shrub	2	Interior Boreal
11	Closed Broadleaf & Closed Mixed Forest	2	Interior Boreal
12	Closed Mixed Forest	2	Interior Boreal
13	Closed Spruce Forest	3	South Coastal
14	Spruce Woodland/Shrub	2	Interior Boreal
15	Open Spruce Forest/Shrub/Bog Mosaic	2	Interior Boreal
16	Spruce & Broadleaf Forest	2	Interior Boreal
17	Open & Closed Spruce Forest	2	Interior Boreal
18	Open Spruce & Closed Mixed Forest Mosaic	2	Interior Boreal
19	Closed Spruce & Hemlock Forest	3	South Coastal
20	1991 Fires	2	Interior Boreal
21	1990 Fires & Gravel Bars	2	Interior Boreal
22	Canada/Russia	0	None
23	Tall & Low Shrub	2	Interior Boreal

[1] From Fleming 1996

[2] Based on ecotype categories assigned by AKNHP (AKNHP website, 2008)

Appendix B: Data and Model Websites

Alaska Natural Heritage Program (AKNHP) Weed Ranking Project:
http://akweeds.uaa.alaska.edu/akweeds_ranking_page.htm

Alaska Exotic Plants Information Clearinghouse (AKEPIC):
http://agdc.usgs.gov/akepic/

Global Biodiversity Information Facility (GBIF):
http://www.gbif.org/

BIOCLIM:
http://cres.anu.edu.au/outputs/anuclim/doc/bioclim.html

Canadian Centre for Climate Modelling and Analysis (CCCma):
http://www.cccma.ec.gc.ca/eng_index.shtml

DIVA-GIS:
http://www.diva-gis.org/

MaxEnt:
http://www.cs.princeton.edu/~schapire/Maxent/

Hadley Centre for Climate Prediction and Research:
http://www.metoffice.gov.uk/research/hadleycentre/

WORLDCLIM climate data:
http://www.worldclim.org/

Appendix C: BIOCLIM Parameters

1 - Annual Mean Temperature
2 - Mean Diurnal Range (Mean (period max-min))
3 - Isothermality (P2/P7)
4 - Temperature Seasonality (Coefficient of Variation)
5 - Max Temperature of Warmest Period
6 - Min Temperature of Coldest Period
7 - Temperature Annual Range (P5-P6)
8 - Mean Temperature of Wettest Quarter
9 - Mean Temperature of Driest Quarter
10 - Mean Temperature of Warmest Quarter
11 - Mean Temperature of Coldest Quarter
12 - Annual Precipitation
13 - Precipitation of Wettest Period
14 - Precipitation of Driest Period
15 - Precipitation Seasonality (Coefficient of Variation)
16 - Precipitation of Wettest Quarter
17 - Precipitation of Driest Quarter
18 - Precipitation of Warmest Quarter
19 - Precipitation of Coldest Quarter

Data Format (from the BIOCLIM website)

These layers (grid data) cover the global land areas except Antarctica. They are in geodetic coordinate system (not projected, i.e., 'GEOGRAPHIC' or 'LATLONG' system). The datum is WGS84. They are available at 4 different spatial resolutions; from 30 seconds ($0.93 \times 0.93 = 0.86$ km^2 at the equator) to 2.5, 5 and 10 minutes ($18.6 \times 18.6 = 344$ km^2 at the equator). The original data were at a 30 second resolution, the other data have been derived through aggregation, by calculating the mean of groups of cells. Cells with 'no data' were ignored. In other words, if some of the original cells were on land, and some cells were on sea, the aggregate cells have data. Only if all original cells have 'no data' then the aggregate cell has 'no data'. Aggregation was done for monthly precipitation, minimum, mean and maximum temperature. The Bioclimatic variables were calculated from these aggregated data.