A Network Model to Help Land Managers Predict and Prevent Spread of Invasive Plants from Roads to River Systems in Alaska

Matthew J Macander[1]
Tricia L. Wurtz[2]
1. Remote Sensing & GIS Specialist, ABR Inc.—Environmental Research & Services, Box 80410, Fairbanks AK 99708 USA, mmacander@abrinc.com.
2. Research Ecologist, USDA Forest Service, Pacific Northwest Research Station, Box 756780, University of Alaska Fairbanks, Fairbanks, AK 99775 USA, twurtz@fs.fed.us.

ABSTRACT

Alaska has relatively few invasive plants, and most of them are found only along the state's limited road system. *Melilotus alba*, or sweetclover, is one of the most-widely distributed invasives in the state. *Melilotus* has recently moved from roadsides to the floodplains of at least three glacial rivers. We developed a network model to examine the spatial relationships between roads, river crossings and downstream public lands of high conservation significance in interior and south-central Alaska. In 2005 and 2006 we documented the distribution of *Melilotus* on roadsides and near river crossings in interior and south-central Alaska. Considered together, the distribution data and the network model identify road-river interfaces that potentially expose public land downstream to invasion. We have developed the GIS data layers and compiled our results into summary tables so that land managers may execute queries to extract relevant information for their conservation unit. For example, a land manager may query a list of crossings upstream from a particular wildlife refuge. A transportation manager can extract a list of crossings with *Melilotus* on the roadside and adjacent floodplain along a particular stretch of road. We hope to partner with spatial data infrastructure providers in order to make these attribute queries, as well as customized maps, more widely available. Our work to date is focused on a single invasive species, but is intended to provide a general modeling framework to address the spread of invasive species along arctic and subarctic roads, and onto adjoining wild lands.

KEYWORDS: Invasive species, NHD, *Melilotus*

1. Introduction

Alaska has relatively few invasive plants. The state's isolation, lack of development and cold climate limit the introduction and success of many invasive species. Invasive species often disperse along road networks (Gelbard and Belnap 2003, Koch and Smith this volume, Lugo and Gucinski 2000, Parendes and Jones 2000), and Alaska has only 0.01 km of road per km^2 of land area, compared to California's 0.67 km (Alaska DOT 2002).

Melilotus alba, or sweetclover, has recently become a species of concern in Alaska. *Melilotus* is widely distributed along roadsides around the state, a result of both intentional sowing as a roadside stabilization species, and unintentional transport of seed via contaminated soil and gravel. *Melilotus* has been grown as a crop in some parts of the state and used in a number of reclamation efforts in mining and industrial areas. *Melilotus* has been found on roadsides in Denali National Park and Preserve and near several other National Parks in Alaska, lands of unquestionably high conservation value (Densmore and others 2001). Notably, *Melilotus* has aggressively colonized the floodplain of the lower Stikine River in southeast Alaska, the lower Matanuska River is south-central Alaska, and portions of the upper Nenana River in interior Alaska. While the sources of these populations aren't known for certain, it's likely that *Melilotus* spread onto the floodplains from roads, mines, and agricultural developments upstream. Though many of Alaska's most valuable public lands are located off the road system, they may be vulnerable to invasion by species that gain access to river floodplains from upstream roadside environments.

2. Data

The network model examines spatial relationships between invasive plants, roads, river networks, and public land in interior and south-central Alaska (Figure 1). Our analysis is supported by several GIS data layers. The invasive plant distribution data is based on field surveys we conducted (Wurtz et al. in press), as well as several additional surveys (Alaska Natural Heritage Program, n.d.). The river network is modeled using the National Hydrography Dataset (NHD, USGS 1999); the Alaska Department of Transportation GPS centerline dataset provides a detailed road network (Alaska DOT 2006); and the boundaries of federal and state land designations were obtained from an Administrative Boundaries dataset (Alaska DNR 2001) (Figure 2).

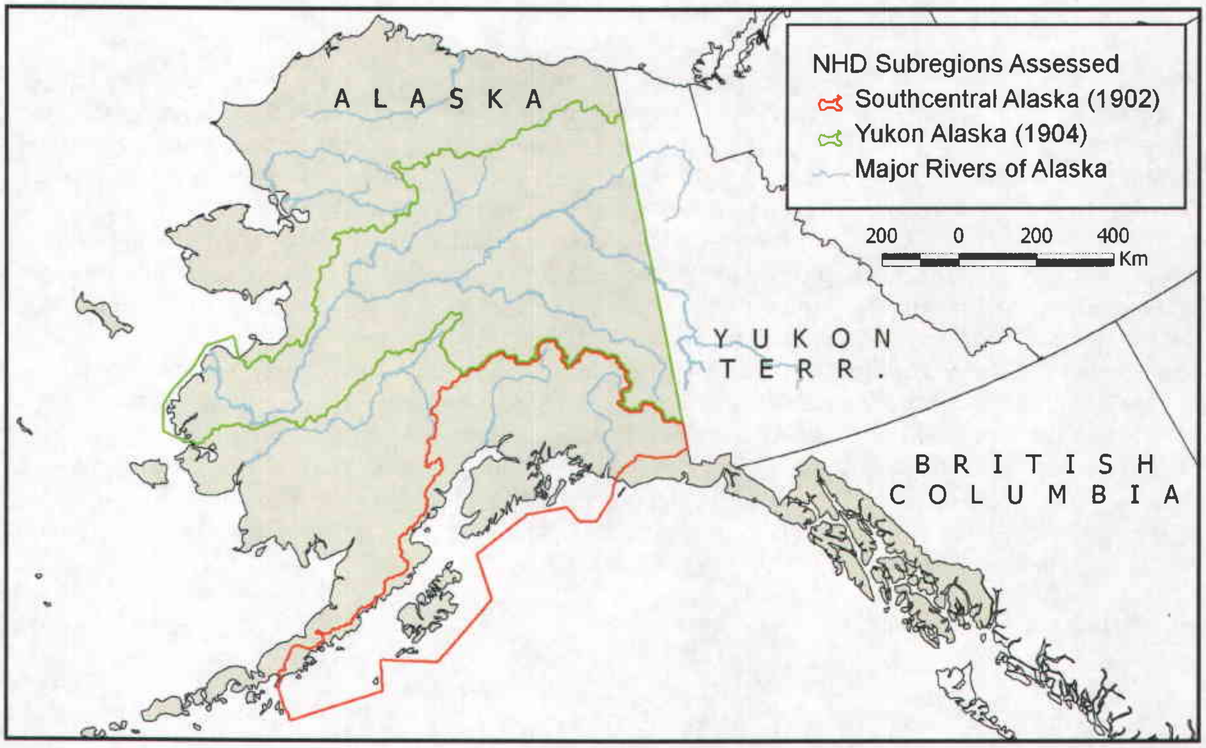

Figure 1. The current spatial extent of our network model is subregions 1902 and 1904 of the US National Hydrography Dataset (NHD).

2.1 Invasive Plant Distribution

In 2005 and 2006, we surveyed 1780 miles of eight major highways in interior and south-central Alaska for *Melilotus alba*. We surveyed for the presence or absence of *Melilotus* at 192 major crossings along these highways. We did not survey the other types of road-river interfaces (see below). At each crossing, we recorded the presence or absence of *Melilotus* on the roadside immediately adjacent to the bridges, and on natural floodplain surfaces below and in the vicinity of the bridge. We considered both upstream and downstream floodplain surfaces in making the floodplain assessments. In addition, we acquired *Melilotus* distribution data for several additional highways (though not crossings) from the Alaska Exotic Plant Information Clearinghouse database (Alaska Natural Heritage Program, n.d.).

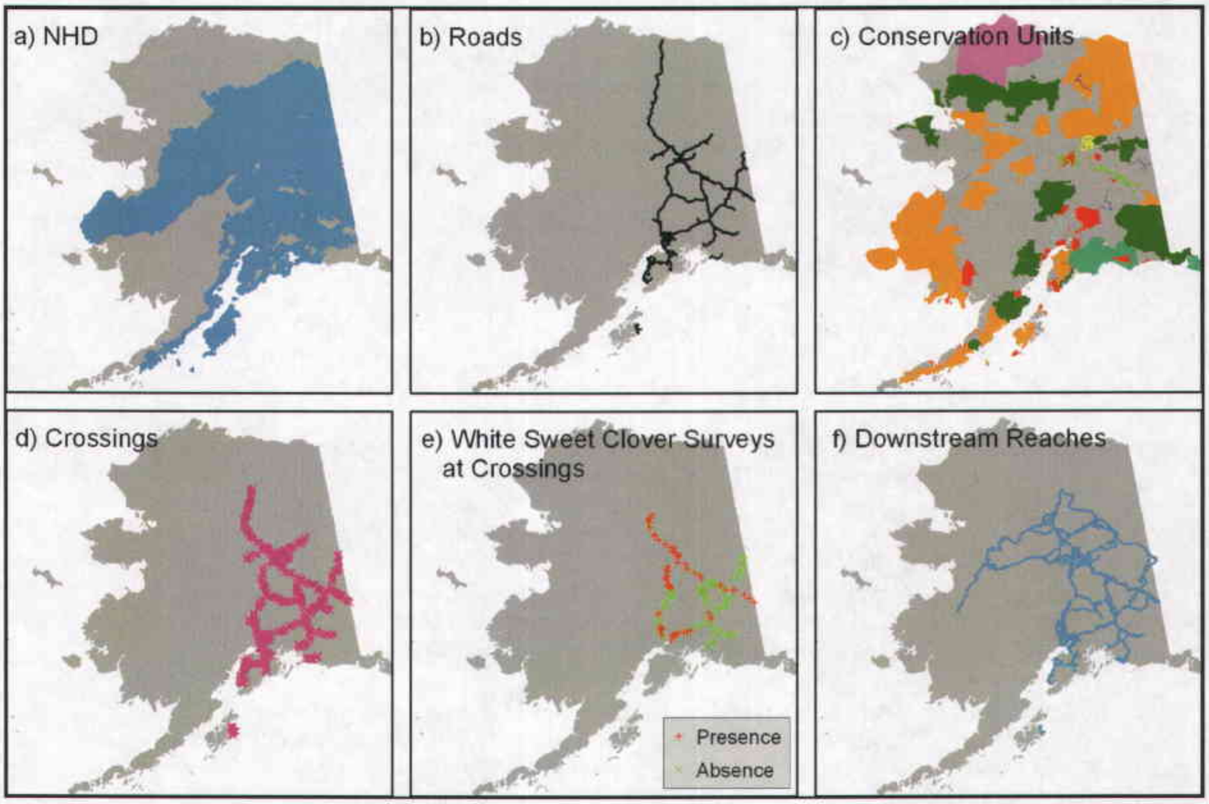

Figure 2. GIS data layers used in the network model. NHD data for other regions of the state does exist, but has not been included in our model. As a result, the crossings dataset we used (tile d) is also restricted in extent.

2.2 National Hydrography Dataset (NHD)

The NHD is managed by the USGS and EPA: "[The NHD] is a comprehensive set of digital spatial data that contains information about surface water features such as lakes, ponds, streams, rivers, springs and wells. Within the NHD, surface water features are combined to form "reaches," which provide the framework for linking water-related data to the NHD surface water drainage network. These linkages enable the analysis and display of these water-related data in upstream and downstream order" (USGS 1999). We started with the assumption that all migration of invasive plants on the river system would be downstream. We then utilized the NHD as our base layer for river networks, since it covers the entire state at a fine scale (1:63360), and also incorporates flow network information allowing us to efficiently identify all river reaches that were downstream from a particular road crossing.

2.3 Road Network

There is no comprehensive road network dataset available for Alaska, but the Alaska Department of Transportation (ADOT) provided a draft version of a new GPS road centerline network. It covers the contiguous highway system plus Kodiak and Cordova. Some roads are not included in this dataset—for example, the Denali National Park road, State of Alaska-administered logging roads, private roads, and many local roads—but these road data are the best currently available.

2.4 Public Conservation Units

We began with the land classification boundaries identified on the Administrative Large Parcel Boundaries dataset from December 20, 2001, produced by the Alaska Department of Natural Resources (Alaska DNR 2001). We selected parcel types to include in our model by reviewing the agency affiliations of land managers who have been active in Alaska's Committee for Noxious and Invasive Plant Management (CNIPM) over the last few years. Managers who are already aware of and concerned about invasive plants on the public lands they manage may be most likely to benefit from the information provided by this work. We refer to that list of parcel types in aggregate as "conservation units." A total of 98 such conservation units occur in Alaska within the NHD subregions we assessed. Land management objectives, as well as agency attitudes and approaches toward invasive species vary widely among these conservation units.

3. Methods

3.1 Crossings (Road/River Interfaces)

The NHD Flowline layer for each subregion was intersected with the ADOT road centerline layer, resulting in a set of over 2000 points corresponding to potential crossings. We filtered out spurious crossings, such as those on the ocean shore, or on river segments with undefined flow (manmade features such as water pipelines and areas with incomplete or erroneous river networks). 1948 crossings remained after this cleanup. There are a few limitations to this GIS-derived crossings layer, but we consider it to be a very useful first approximation of the road-river interfaces. The dataset's main weakness involves places where a road adjoins a river or terminates at a river. In such locations, an intersection may not have been generated in our data layers, despite obvious opportunity for invasive plant movement from road to river. In practice, however, roads that adjoin rivers usually cross feeder tributaries, and so crossings occur and the adjacent rivers are extracted as downstream from these crossings. Including road-river interfaces other than crossings would be a logical extension of the network model.

We then linked the *Melilotus* surveys at bridges to the set of crossings points based on proximity. Based on the GPS locations of each of the 192 bridges where *Melilotus* distribution data had been collected, the nearest crossing was determined. In this way each of the bridge surveys was assigned to the closest GIS-derived crossing. The bridge survey crossings were then categorized as "major crossings". Crossings that were not surveyed, though they were on roads that had been surveyed, were termed "minor crossings." Finally, crossings which occurred on roads that we had not surveyed were termed "unclassified crossings". After reviewing the data, 186 of the 192 major crossings were associated with a GIS-derived crossing. The location of these associated major crossings was updated to the GIS-derived intersection.

3.2 Downstream Reaches

The ArcMap Utility Network Analyst (ESRI, 2006) was used to select only those NHD reaches that were downstream from crossings. This involved manually placing graphic flags just upstream of each crossing, then running the "Trace Downstream" function. All of the downstream reaches were then merged into a single line layer. This line layer was filtered to remove duplicate segments. The resulting lines were then reprojected into the Alaska Albers projection from the original decimal degrees (a requirement if meaningful segment lengths were to be calculated). These flowlines were then split by the road lines, and by the conservation unit boundaries, using the ET Geowizards Split Line by Layer tool (ET Spatial Techniques, 2007). The network was rebuilt using ArcCatalog (ESRI, 2006). The Length_Km field was recalculated for each segment, based on the built-in Shape_Length field (which records the length of each segment, in meters). Network weights were assigned to the flowline edges based on the Length_Km attribute. Finally, the flow directions were re-assigned using the ArcHydro set direction command (ESRI, 2007).

The Fortymile River flows from Alaska into Canada, and empties into the Yukon River in Canada (Figure 3). The Yukon River then flows east to west across Alaska and empties into the Bering Sea. Because the NHD only covers the United States, there was a gap in the river network where the Fortymile leaves Alaska. We filled in this gap by tracing the Canadian portion of the Fortymile and Yukon Rivers necessary to complete the network.

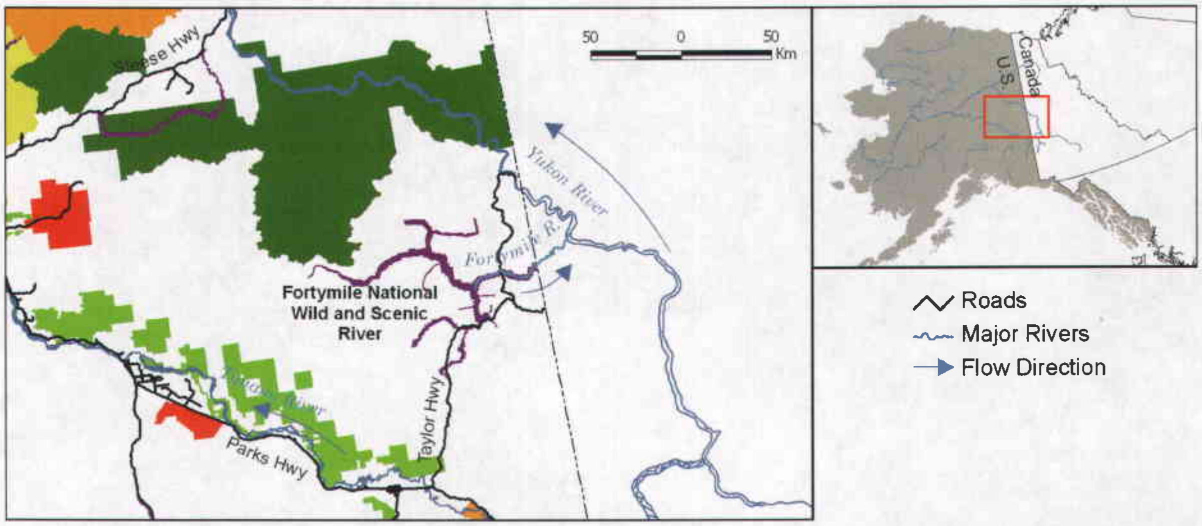

Figure 3. Fortymile River and surrounding areas.

The downstream reaches of the lower Yukon (near and on the Yukon Delta) were not included, because gaps in the NHD network prevented proper selection of these reaches. There are no roads included downstream of this break, so in our analysis we simply treated conservation units downstream of this break as being exposed to the same crossings as the Innoko National Wildlife Refuge, which is also located along the Yukon River upstream from the Yukon Delta, but downstream from all crossings.

The result was a new hydrology network dataset which included all of the downstream reaches for both interior and south-central Alaska. Because it was split at the roads and conservation unit boundaries, accurate distances between crossings and conservation unit boundaries could be calculated. Because stream reaches that were not downstream of any road-river interfaces were excluded, the dataset was much smaller and easier to work with than the full NHD geodatabases. The downstream reaches geodatabase file size was 40 MB, compared to 3.5 GB for the full NHD for subregions 1902 and 1904.

3.3 Populate Link Tables

The crossings and downstream reach data layers provided the basis for developing tabular data useful for queries by land managers. The base tables of the database were based on existing GIS layers: Roads, Crossings, Flowline_Downstream, and Conservation_Units. In addition, three link tables were developed to represent the network linkages between these base tables. Ideally, these link tables would be calculated dynamically (i.e. by querying the spatial network on demand). However, if this is possible, it would require server software and/or programming beyond what we have available. Instead of calculating these linkages on demand, we conducted a series of network queries manually and exported the results to link tables suitable for querying in an ordinary relational database management system (RDBMS). The data tables and the relationships between different tables are summarized in Figure 4.

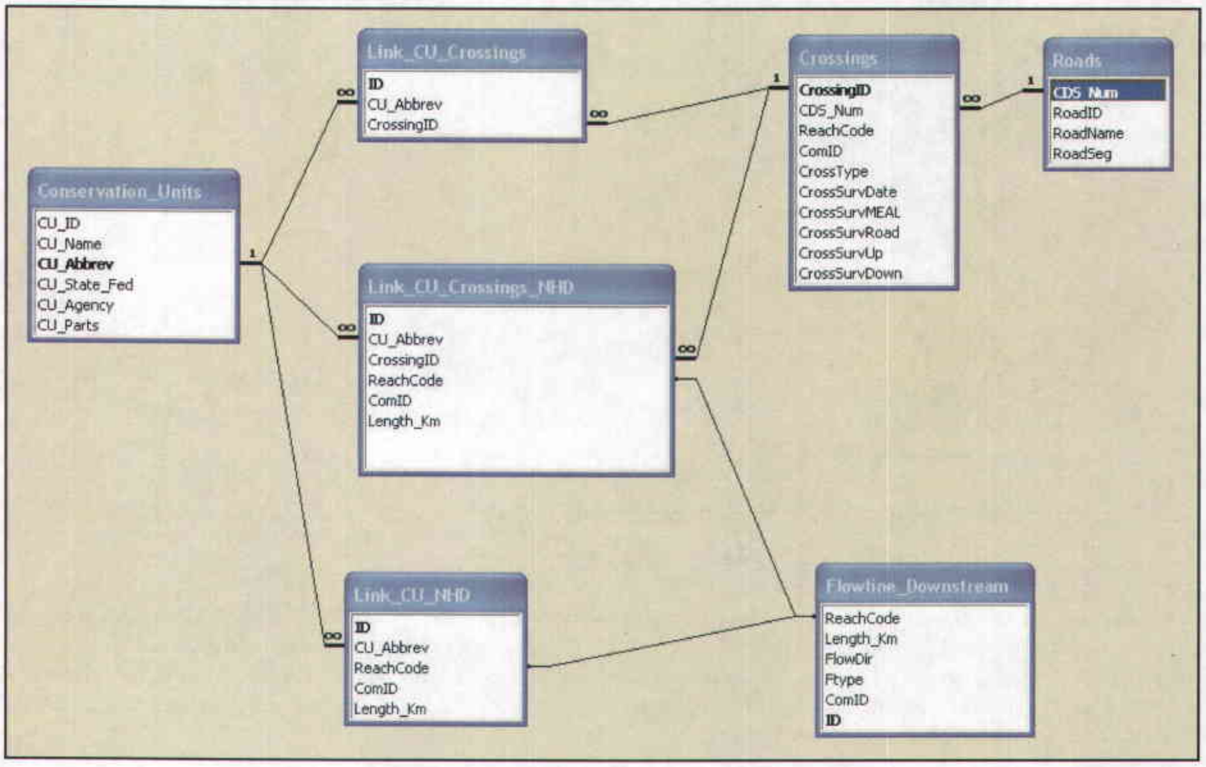

Figure 4. Data tables and relationships between tables for the network model outputs.

The "Link_CU_Crossings" and "Link_CU_NHD" link tables provide the information necessary to answer the questions, "What is upstream of a particular Conservation Unit?" as well as "What conservation units are downstream from a particular crossing?" These two tables are populated by tracing the reduced "downstream NHD" network, upstream from each conservation unit. The river reaches that are downstream from a crossing, and upstream from a particular conservation unit, are selected in this manner. The upstream crossings are then selected based on their proximity to the selected river reaches. Figure 5 presents an example of this procedure, for the Fortymile National Wild and Scenic River. All of the orange reaches (in tile b) and the orange crossings (in tile c) are upstream from the Fortymile National Wild and Scenic River, or are within the borders of the unit. The blue reaches (tile b) and pink crossings (tile c) are not upstream of the Fortymile—they are within other watersheds (the Tanana River to the south, and the Yukon River to the north). The outputs from these operations are compiled to populate the first two link tables. These tables were fully populated for the 98 conservation units in our study area.

The third link table, "Link_CU_Crossings_NHD," provides information required to answer the question, "How far is it downstream from a crossing to a particular conservation unit?" This table explicitly links the NHD river reaches with specific crossings and specific conservation units. To do this, the shortest path along the river system is calculated from a crossing to a downstream conservation unit. In this case, network solutions are calculated with the weight parameter activated (otherwise, the calculation would return the path with the fewest segments, rather than the path with the shortest length). The third link table requires several manual operations for each crossing (one operation for each crossing-to-conservation unit pair). Rather than perform this time-consuming operation for each of 1948 crossings, we performed it for a subset of crossings to demonstrate the functionality. It would be preferable to develop an automated means of performing this calculation and we are investigating this possibility.

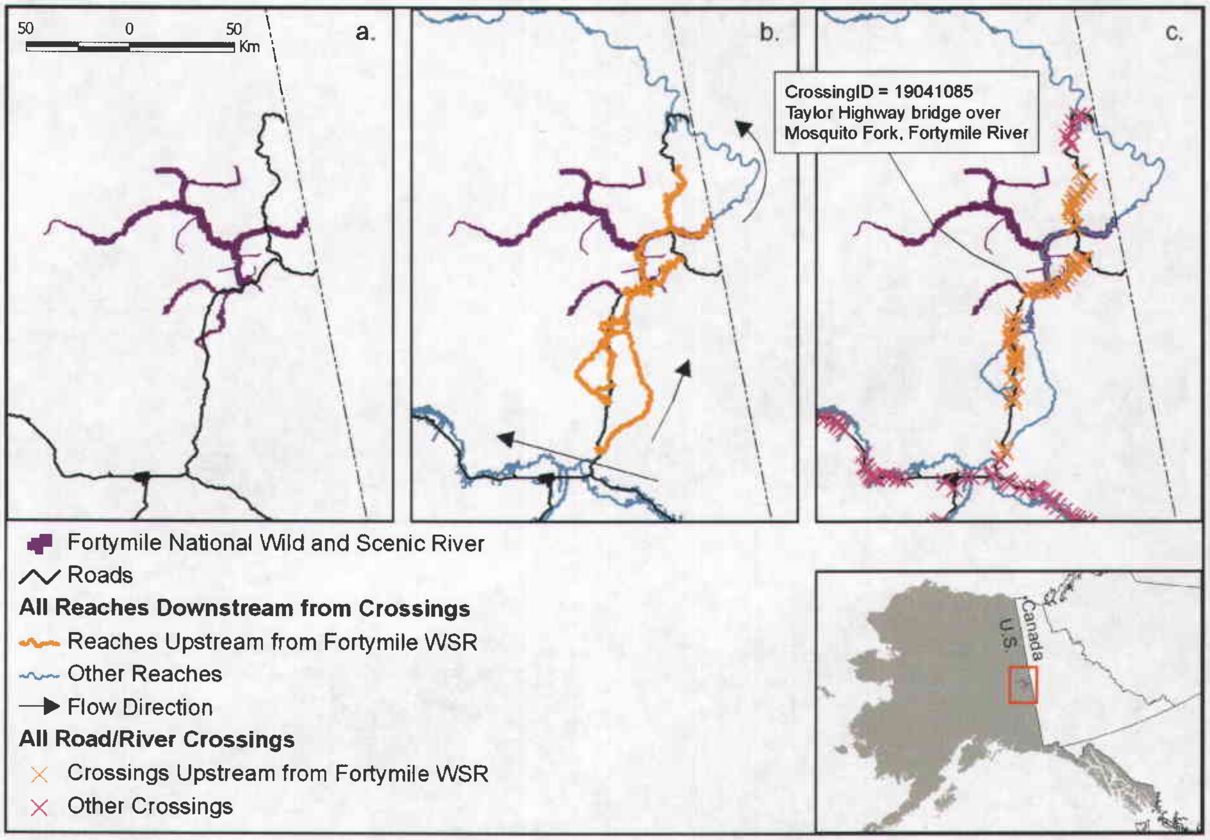

Figure 5. Selection of river reaches (downstream from crossings) and crossings, that are upstream from the Fortymile National Wild and Scenic River, Alaska.

4. Results

Queries and reports were created based on the data tables and the relationships described above. As an example, the 13 major crossings upstream from the Fortymile National Wild and Scenic River are presented in Table 1 (all 60 crossings are displayed in Figure 5, tile c). Fortunately, all of these crossings were free from *Melilotus* infestation, at the time of the survey in summer 2006. Similarly, a list of all the conservation units downstream from a single crossing within the Fortymile National Wild and Scenic River (Table 2) demonstrates the potentially long-range consequences of an invasion at a far upstream location.

Based on our work, we have compiled a report listing all of the crossings upstream for each of the 98 conservation units in our study area. Of the 98, 41 have no crossings upstream (they are upstream of all roads used in our analysis, though there may be crossings in other NHD regions or in Canada that could affect them). For the remaining 47 conservation units, there is a mean of 176.4 crossings upstream (19.8 major crossings, 62.2 minor crossings, 94.4 unclassified crossings). The Innoko and Yukon Delta National Wildlife Refuges in southwest Alaska have the greatest number of upstream crossings (1077), though their actual vulnerability may be lessened by the long distance between the crossings and these refuges.

Table 1. Major crossings in or upstream from Fortymile National Wild and Scenic River

CrossingID	Latitude (WGS84)	Longitude (WGS84)	Road Name	River Name	Year Surveyed	*Melilotus* present on roadside at bridge?	*Melilotus* present on floodplain upstream?	*Melilotus* present on floodplain downstream?
19041751	64.07596513	-141.6315814	Taylor Highway	Walker Fork	2006	NONE	NONE	NONE
19041771	64.35656779	-141.4128561	Taylor Highway	Alder Creek	2006	NONE	NONE	NONE
19041736	63.90703668	-142.2184632	Taylor Highway	Taylor Creek	2006	NONE	NONE	NONE
19041759	64.05821069	-141.7657017	Taylor Highway	South Fork Fortymile River	2006	NONE	NONE	NONE
19041769	64.49204309	-141.1920541	Taylor Highway	King Solomon Creek	2006	NONE	NONE	NONE
19041764	64.4315277	-141.3543651	Taylor Highway	Columbia Creek	2006	NONE	NONE	NONE
19041447	63.88996195	-142.2349536	Taylor Highway	West Fork Dennison Fork	2006	NONE	NONE	NONE
19041084	64.53634298	-141.2549681	Taylor Highway		2006	NONE	NONE	NONE
19041085	64.06588097	-141.9956276	Taylor Highway	Mosquito Fork	2006	NONE	NONE	NONE
19041770	64.31540571	-141.4194887	Taylor Highway	O'Brien Creek	2006	NONE	NONE	NONE
19041442	64.07300703	-141.9320886	Taylor Highway	Chicken Creek	2006	NONE	NONE	NONE
19041445	63.8031193	-142.2124147	Taylor Highway	Logging Cabin Creek	2006	NONE	NONE	NONE
19041449	64.3087938	-141.4087846	Taylor Highway	Fortymile River	2006	NONE	NONE	NONE

Table 2. Conservation units downstream from Crossing #19041085 (Taylor Highway crossing Mosquito Fork, Fortymile River)

Conservation Unit Name	Area (sq. km)	State/Federal	Agency	Distance Downstream (km)
Fortymile Wild & Scenic River	1000	Federal	BLM	0.0
Yukon-Charley Rivers National Preserve	10202	Federal	NPS	258.6
Yukon Flats National Wildlife Refuge	45231	Federal	USFWS	516.7
Nowitna National Wildlife Refuge	8333	Federal	USFWS	1170.6
Innoko National Wildlife Refuge	18488	Federal	USFWS	1402.5

5. Future Directions

The most important next step is to make our results available to land managers. To accomplish this, we hope to partner with specialists in making spatial data accessible. A GIS-enabled web portal, with the ability to execute one of several queries and output results to maps and tables, would be an ideal means of disseminating practical information from our network model. The IPY GeoNorth meeting in Yellowknife may provide the opportunity to locate an appropriate partner. In the meantime, complete reports and maps, and the geodatabase used in our analysis, are available upon request.

In the future we hope to be able to quantitatively assess the most important crossings, and the most vulnerable conservation units. This will require some additional information. First, the third link table should be fully populated so that distances between crossings and conservation units would be fully available. Second, some information on the susceptibility to invasion of different river reaches would be necessary. Finally, it is important to incorporate updated invasive plant survey data as it becomes available, including plant and propagule abundance measurements. The existing framework can be easily adapted to store the data from multiple surveys at each crossing.

More sophisticated capabilities for data extraction would be a major improvement. This would allow us to fully populate the link tables, and would also allow for efficient updates if new information were added (for example, new roads, new surveys, or expansion of the study area to include portions of Canada or Southeast Alaska.

There are several deficiencies in the data used to develop our model. For example, there are some gaps and errors in the NHD, and our road coverage is not complete. There is also a lack of *Melilotus* survey data for some crossings, and the survey data that does exist is dated. The spatial extent of the current model is a limitation—most glaringly, that portion of the Yukon drainage that is in Canada is completely excluded. Also, our model does not consider the possibility of invasive species spread onto wild lands at locations other than at crossings—for example, where roads terminate at rivers, or from roads into adjacent firescars.

We are applying our network data to other modeling tasks. The first task is to assign environmental or physical attributes to river reaches that could then be used to predict the susceptibility to invasion. Substrate type is likely an important variable, but one that is difficult to map. We are investigating the use of proxies such as distance from source, distance from a glacier source, and river slope as a way to predict substrate types. We are also working on a raster-based spread model that uses our downstream reaches as corridors of potential spread. When fully developed, the raster spread model can be extended to scenarios other than road-to-river spread—including spread into firescars.

6. Conclusions

In its current form, our network model provides valuable information to land managers, transportation managers, and groups planning to conduct surveys of invasive plant distribution. More invasive plant survey data is available each year in Alaska. Our model will be a big step in helping managers interpret those data—to determine which sightings are the ones to be concerned about and which are less important. It provides a useful framework for understanding the relationship between invasive species, roads, rivers, and lands of high conservation value. We hope to make the data easily accessible in the near future by collaborating with spatial data infrastructure providers.

7. Acknowledgments

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