The distribution and abundance of the endemic vascular plant taxa of the Athabasca Sand Dunes of northern Saskatchewan

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Executive Summary

An extensive occupancy survey of the Athabasca Sand Dunes endemic flora was conducted in 2009 and 2010. This report is a summary of the findings of that survey.

The Athabasca sand dune region is of high conservation value due to the presence of ten endemic vascular plant taxa. These endemics include two composites: *Achillea millefolium* var. *megacephala* and *Tanacetum huronense* var. *floccosum*, one grass: *Deschampsia mackenzieana,* four willows: *Salix brachycarpa* var. *psammophila*, *Salix silicicola, Salix turnorii*, and *Salix tyrrellii*, one pink: *Stellaria arenicola* and one leadwort: *Armeria maritima ssp*. *interior* All of these taxa have been assessed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). All of the Athabasca endemics are listed under the Species at Risk Act (SARA) as "Species of Special Concern" with the exceptions of *Salix tyrrellii* and *Stellaria arenicola* (Not at Risk) and *Lechea intermedia* (not listed). The 2009 and 2010 occupancy surveys were initiated to provide baseline data on the endemic populations and to provide data for potential status reassessment.

Eighty-three prelocated 250m transects were surveyed in the Cantara Lake, Thompson Bay, and William River dune fields in 2009 and 141 prelocated transects were surveyed in the Thompson Bay, William River, MacFarlane River and Archibald lake dune fields in 2010. Extensive populations of *Deschampsia mackenzieana, Salix brachycarpa, Salix silicicola, Salix turnorii, Salix tyrrellii, Stellaria arenicola,* and *Tanacetum huronense* were encountered. Very limited populations of *Achillea millefolium* and *Armeria maritima* were surveyed, and no individuals of *Lechea intermedia* were found. Details of the habitat affinities, relative abundance, and community patterns of these species are presented in this report. Key findings of this study with respect to each endemic species include:

Achillea millefolium **var.** ***megacephala***

1) Present in very low abundance in the dune fields with only 592 individuals recorded in survey transects. Patchily distributed in the Cantara Lake, Thompson Bay, and William River dune fields and absent from the Archibald Lake and MacFarlane River fields.
2) *Achillea* was most frequently encountered and most abundant in wet interdune slacks, which clearly represent the critical habitat for this species.
3) *Achillea's* very smal*l* population size and limited distribution is cause for significant concern.

Armeria maritima **ssp.** ***interior***

1) The least abundant endemic species observed during the occupancy survey with only 272 individuals identified. *Armeria maritima* was concentrated in the northeastern sector of the William River dune field, patchily distributed in the Thompson Bay and MacFarlane River fields, and was absent from the Archibald lake field.
2) *Armeria* was most frequently encountered in gravel pavement habitats with most other observations occurring in low slope Gravel pavements appear to be the critical habitat for this species.
3. *Armeria's* very small population sizes, physically vulnerable growth form, and preferred habitat make this species of significant concern. In particular this species' germination habit on sandy substrates stabilized by gravel pavements likely makes seedlings vulnerable mortality if acid precipitation impairs root growth.

Deschampsia mackenzieana

1. One of the most widely distributed and frequently encountered endemic species in this study, present in all habitat types, and sectors of the dune fields. Flowering individuals and seedlings of *Deschampsia mackenzieana* were frequently encountered.
2. The wide distribution of *Deschampsia* within the dune environment suggests that the Athabasca sand dunes as a whole should be considered critical habitat for this species. No obvious threats to *Deschampsia mackenzieana* populations were noted during this survey. The robust populations suggest that continued efforts to minimize human impacts on the sand dune environment should ensure the continued healthy population size of this species.
3. *Deschampsia* is extremely common in unstable surface environments, suggesting that it is likely to be minimally affected by surface disturbance (i.e. ATVs.) The open sand germination environment is potentially vulnerable acid deposition, as an impairment of root growth could likely lead to substantial seedling mortality.

Lechea intermedia* var. *depauperata

1) No individuals of *Lechea intermedia* were observed during this study, even at sites where herbarium specimens had been previously collected. It is important to note, however, that *Lechea* is primarily found in habitats distinct from the other endemics, and thus survey efforts in potential *Lechea* habitats were limited.
2) Efforts to resolve the data deficiency for *Lechea intermedia* should be a priority.

Salix brachycarpa* var. *psammophila

1) Commonly encountered in dune slack habitats, widely distributed in the Thompson Bay dune field and common around the margins of the William River, MacFarlane River, and Archibald Lake dune fields.
2) The concentration of *Salix brachycarpa* in wet dune slacks suggests that that habitat should likely be designated critical habitat for the species. No obvious threats to *Salix brachycarpa* populations were identified, however as with many of the other endemic species the concentration of the population in the dune slacks represents a potential limiting factor for this species.

Salix silicicola

1) Frequently encountered in all habitats except gravel pavements and woodlands. *Salix silicicola* was widely distributed in the Thompson Bay and MacFarlane River dune fields and common around the margins of the William River and Archibald Lake dune fields.
2) The wide distribution of *S. silicicola* within the dune environment suggests that the Athabasca sand dunes as a whole should be considered critical habitat for this species. The distribution of *S. silicicola* populations suggests that the species primarily germinates and establishes in wet interdune slacks, with mature individuals persisting as large clumps in other habitats following the burial of old slacks by moving sand.
3) No obvious threats to *Salix silicicola* populations were identified. The robust populations suggest that continued efforts to minimize human impacts on the sand dune environment should ensure the continued healthy population size of this species.

Salix turnorii

1) Frequently encountered in all habitats except lichen-crowberry heaths and woodland. *Salix turnorii* was widely distributed in the Thompson Bay and MacFarlane River dune fields, common around the margins of the William River dune field, but present only on beaches at the margin of the Archibald Lake dune field.
2) The wide distribution of *S. turnorii* within the dune environment suggests that the Athabasca sand dunes as a whole should be considered critical habitat for this species. As with *S. silicicola* and *S. tyrrellii* the distribution of *S. turnorii* is consistent with a species that primarily germinates and establishes in wet interdune slacks, with mature individuals persisting as large clumps in other habitats following the burial of old slacks by moving sand.
3) No obvious threats to *Salix turnorii* populations were observed in these surveys. The robust populations suggest that continued efforts to minimize human impacts on the sand dune environment should ensure the continued healthy population size of this species.

Salix tyrrellii

1. Frequently encountered in lichen-crowberry heath, wet interdune slack, and woodland habitats, less commonly encountered in low and high slope dunes and saline slacks, and least frequent on gravel pavements. *Salix tyrrellii* was widely distributed in all of the dune fields.
2. The wide distribution of *S. tyrrellii* within the dune environment suggests that the Athabasca sand dunes as a whole should be considered critical habitat for this species. As with *S. silicicola* and *S. turnorii* the distribution of *S. tyrrellii* is consistent with a species that primarily germinates and establishes in wet interdune slacks, with mature individuals persisting as large clumps in other habitats following the burial of old slacks by moving sand.
3. No obvious threats to *Salix tyrrellii* populations were observed in these surveys. The robust populations suggest that continued efforts to minimize human impacts on the sand dune environment should ensure the continued healthy population size of this species.

Stellaria arenicola

1. Frequently encountered in wet and saline interdune slacks and high slope dunes, less frequent in low slope dunes, and least frequent in lichen heaths, gravel pavements, and woodlands. *Stellaria arenicola* was widely distributed in the Thompson Bay and MacFarlane River dune fields and common around the margins of the William River and Archibald Lake dune fields.
2. The wide distribution of *S. tyrrellii* within the dune environment suggests that the Athabasca sand dunes as a whole should be considered critical habitat for this species.
3. No obvious threats to *Stellaria arenicola* populations were observed. The robust populations suggest that continued efforts to minimize human impacts on the sand dune environment should ensure the continued healthy population size of this species.
4. *Stellaria* is common in unstable surface environments, suggesting that it is likely to be minimally affected by surface disturbance (i.e. ATVs.) The open sand germination environment is potentially vulnerable acid deposition, as an impairment of root growth could likely lead to substantial seedling mortality.

Tanacetum huronense* var. *floccosum

1. Most frequently encountered in high slope dunes and interdune slacks. *Tanacetum huronense* was widely distributed in all of the dune fields.
2. The wide distribution of *Tanacetum huronense* within the dune environment suggests that the Athabasca sand dunes as a whole should be considered critical habitat for this species. As with *S. silicicola* and *S. turnorii* the distribution of *T. huronense* is consistent with a species that

primarily germinates and establishes in wet interdune slacks, with mature individuals persisting as large clumps in other habitats following the burial of old slacks by moving sand.

3. No obvious threats to *Tanacetum huronense* populations were observed in this survey. Flowering individuals were frequently encountered, as were seedlings and juvenile plants in wet interdune slacks. The robust populations suggest that continued efforts to minimize human impacts on the sand dune environment should ensure the continued healthy population size of this species.

The present survey covered all of the major sand dune complexes within the Athabasca Sand Dunes Provincial Park. Consistent transect coverage was achieved and this survey thus provides a comprehensive picture of the current distribution and abundance of the Athabasca endemics. Future research should be largely focused on narrower questions linked to the conservation of particular species. The following should be considered priorities for future research:

1. Acid deposition represents the most likely short to medium term threat to the Athabasca endemic species. This threat is likely most acute for species including *Armeria maritima, Deschampsia mackenzieana,* and *Stellaria arenicola* that frequently germinate and establish on open sand. Investigations are needed to evaluate the germination ecology of these species and the potential threat that acid deposition may pose to the future viability of these populations. This research is most urgent for *Armeria maritima* given the low population sizes and non-clonal habit of that species.
2. A general effort to understand how climate changes in the Athabasca region are likely to result in long-term trends toward dune stabilization and related changes in the dune environment is important for the conservation of all of the Athabasca endemic species. Of particular importance are investigations of the ecology and hydrology of wet dune slacks, an important habitat for all of the endemics and critical habitat for *Achillea millefolium* and *Salix brachycarpa*.
3. Investigations into the seed and seedling ecology of all of the Athabasca endemic species as it is likely that the seedling life stage and regeneration niche is a primary determinant of adult population sizes, particularly for long-lived clonal species such as the willows and *Tanacetum*. Understanding species' life histories is particularly important for *Achillea millefolium* and *Armeria maritima*, given their low population sizes.
4. A general landscape classification of the Athabasca Sand Dunes region with particular emphasis on delineating gravel pavements and wet dune slacks. Such a classification would provide a strong tool to identify the extent of critical habitat for many of the Athabasca endemic species.
5. The continued lack of data on *Lechea intermedia* is of immediate concern and a barrier to any objective status reassessment. Extended surveys of potential habitat for this species should be considered.

The data presented in this report represent the most comprehensive survey conducted to date on the Athabasca endemic populations. These data represent a strong foundation for a status reassessment for all of these species with the exception of *Lechea intermedia*. Status reassessment to a higher level of concern may be justified given 1) the endemic status of all of these taxa, 2) the limited population sizes and distributions within the dune complex of some taxa, particularly *Achillea millefolium, Armeria maritima*, and *Salix brachycarpa*, and 3) potential threats to the dune environment including acid deposition and climate change.

Contents

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Cover Photo by Digit Guedo. *Armeria maritima* on a gravel pavement in the William River Dunes.

Introduction

The Athabasca sand dunes are a unique landscape in northern Saskatchewan characterized by large regions of active sand dunes and a unique flora (Hermesh 1972, Smith 1978, Mackenzie River Basin Committee 1981, Raup and Argus 1982, Jonker and Rowe 2001). This landscape is the largest complex of active sand dunes in Canada and contains a wide array of sand dune forms including very large longitudinal dunes with crests more than 30m above the surrounding landscape. The region is currently protected as part of the Athabasca Sand Dunes Provincial Wilderness Park.

The Athabasca sand dune region is of high conservation value due to the presence of ten endemic vascular plant taxa (Raup 1936, Mackenzie River Basin Committee 1981, Raup and Argus 1982). These endemic taxa, variously classified as species, subspecies, or varieties (Table 1) (Harms 2003). In general these species are characterized by traits necessary to survive in an environment dominated by moving sand. Traits to cope with burial include vertical growth forms and aggressive adventitious rooting. Traits including thick epidermises and densely hairy leaves are likely adaptations to water stress and abrasion by sand.

Table 1: Endemic plant taxa recognized in the Athabasca sand dunes. Nomenclature follows Harms (2003). In the remainder of the report variety names are not used.

Family	Species	Common name
Asteraceae	*Achillea millefolium* var. *megacephala* (Raup) Boivin	Large headed woolly yarrow
	Tanacetum huronense Nutt. var. *floccosum* Raup	Floccose Tansy
Caryophyllacae	*Stellaria arenicola* Raup	Sand starwort; Sand stitchwort
Cistaceae	*Lechea intermedia* Leggett ex. Britt. var. *depauperata* Hodgdon	Impoverished pinweed
Plumbaginaceae	*Armeria maritima* (P.Mill) Willd. ssp. *interior* (Raup) Pors.	Athabasca thrift
Poaceae	*Deschampsia mackenzieana* Raup	Mackenzie hairgrass
Salicaceae	*Salix brachycarpa* Nutt. var. *psammophila* Raup	Sand-loving or Sand-dune short-capsuled willow
	Salix silicicola Raup	Blanket-leaf or felt-leaf willow
	Salix turnorii Raup	Turnor's willow
	Salix tyrrellii Raup	Tyrrell's willow

All of the Athabasca sand dunes endemics have been assessed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (Environment Canada 2010). Years indicate the date of assessment. *Lechea intermedia* var. *depauperata* (1997) is designated as "Data Deficient". *Achillea millefolium* var. *megacephala* (2000), *Armeria maritima ssp*. *interior* (2002), *Deschampsia mackenzieana* (2001), *Salix brachycarpa* var. *psammophila* (2000), *Salix silicicola* (2000), *Salix turnorii* (2000), and *Tanacetum huronense* var. *floccosum* (2000) are listed as of "Special Concern". *Salix tyrrellii* (2000), and *Stellaria arenicola* (1992) are listed as "Not at Risk". The Species at Risk Act (SARA) came into effect in 2004 with all of the Athabasca endemics listed as "Species of Special Concern" with the exceptions of *Salix tyrrellii* and *Stellaria arenicola* ("Not at Risk") and *Lechea intermedia* (not listed).

A range of potential threats to the Athabasca sand dunes endemic flora have been recognized (Mackenzie River Basin Committee 1981, Environment Canada 2010). Climate change has the potential to alter the distribution and extent of dune habitats, and may favour the invasion of sand-adapted species from the south. Local disturbance by ecotourism, all-terrain vehicles (ATVs), and mineral exploration has the potential to injure or kill individual plants, and may alter habitats to favour of undesirable species. Gravel pavement habitats in particular may be vulnerable to even light foot traffic. Exotic species invasions pose a particularly significant threat because of the potential for hybridization between native sand dune species and closely related invasive species. Finally, the Athabasca sand dunes are subject to acid deposition largely originating with oil and gas and uranium mining activity (Aherne 2008, Whitfield et al. 2010). Current deposition is not estimated to exceed critical loads (Aherne 2008), however given the ongoing expansion of resource extraction in northern Alberta and Saskatchewan, acid deposition is likely to remain a significant potential threat.

Evaluation of the potential threats to the Athabasca sand dunes requires both a detailed understanding of the population sizes and habitat affinities of the endemic taxa, and long-term monitoring of selected populations. Little is known about the full range extent or population sizes of the Athabasca endemics. Extensive botanical research has been conducted in the sand dunes into the taxonomic relationships and habitat affinities (Raup 1936, Hermesh 1972, Mackenzie River Basin Committee 1981, Raup and Argus 1982, Macdonald et al. 1987, Macdonald and Chinnappa 1989, Purdy et al. 1994, Purdy and Bayer 1995b, a, Purdy and Bayer 1996) of the endemic species, but only limited quantitative ecological data on the populations exist. The only widespread quantitative data available were collected in 1979 and 1980 as part of the Mackenzie River Basin baseline assessment (Mackenzie River Basin Committee 1981). In that study the relative abundance of vascular and non-vascular plant species were estimated in representative areas including the Cantara lake, Thompson Bay, and MacFarlane river dune fields. No data were collected from the William river dune field in that study. These data were used to produce detailed plant community classifications and descriptions, but are insufficient for projections of the population sizes of the endemic species in the region.

An extensive occupancy survey was conducted in August 2009 in the Cantara lake, Thompson Bay, and William River dune fields. A second survey was conducted in 2010 covering the same areas and in addition the Archibald Lake and MacFarlane River dune fields. The primary purpose of this report is to quantitatively document the distribution and abundance of the endemic vascular flora of the Athabasca sand dunes. This report supersedes the report on the 2009 field survey (Lamb 2010) as all data included in that report are also summarized here.

Field Survey Methods

A field survey of pre-located 250m transects (Figure 1 - Figure 3) was conducted between August 18 and August 27, 2009 by a team of 12 people and between August 10 and August 18, 2010 by a team of 12 people. The transect selection and sampling procedures are described in this section. Initial pre-trip and on-site training was conducted in both years to ensure that all survey team members were familiar with the survey methodology and able to accurately identify the target taxa. Taxonomic experts George Argus and Anna Leighton were present on site in 2009 and led the species identification training. They provided ongoing advice on uncertain specimens as needed. Digit Guedo and Jessus Karst were members of the field teams in both years and led the identification and survey method training in 2010. All survey teams were provided with a laminated booklet containing photos of all target taxa, and were encouraged to take photographs of uncertain specimens for later confirmation. All survey teams participated in the on-site survey of a training transect under the supervision of Eric Lamb and Rob Wright (2009) or Digit Guedo and Jessus Karst (2010) prior to beginning work. All data were recorded on preprinted sheets, and each team carried a reminder sheet listing the definitions all habitats and habitat modifiers and other codes.

A set of 400 pre-located 250m transects were generated in the Cantara Lake, Thompson Bay, and William River dune fields (Figure 1) by CWS staff Sarah Lowe and Darcy Henderson using ArcGIS 9.3 as described by Henderson (2009). A set of 500m transects was also prepared but were not used (see below). Transects were located on the dune landscape in a stratified random fashion. The study area was first divided into ecological strata based on 1) forest stand and dune type boundaries identified in a 1979-1980 air photo interpretation by Rob Wright and 2) additional boundaries identified in aerial photos around small forest stands within the dune fields. Polygons were drawn from these boundaries to separate four major landscape types including: gravel pavements and lichen-crowberry heaths, low parabolic dune fields interspersed with gravel pavements, wet sand slacks, and crowberry flats, high linear dune fields interspersed with gravel pavements and wet sand slacks, and mid-height linear dune fields interspersed with wet sand slacks, but without pavements. Distance strata representing the walking distance from likely access points to the dune fields were also developed. Overlaying the ecological and distance strata created a large number of polygons inside which the sampling transects were randomly located. Each transect ran east to west on a constant northing. Two areas of primarily gravel pavement habitat representing less than 5% of the total dune area were excluded from the transect selection process at the request of Saskatchewan Parks staff.

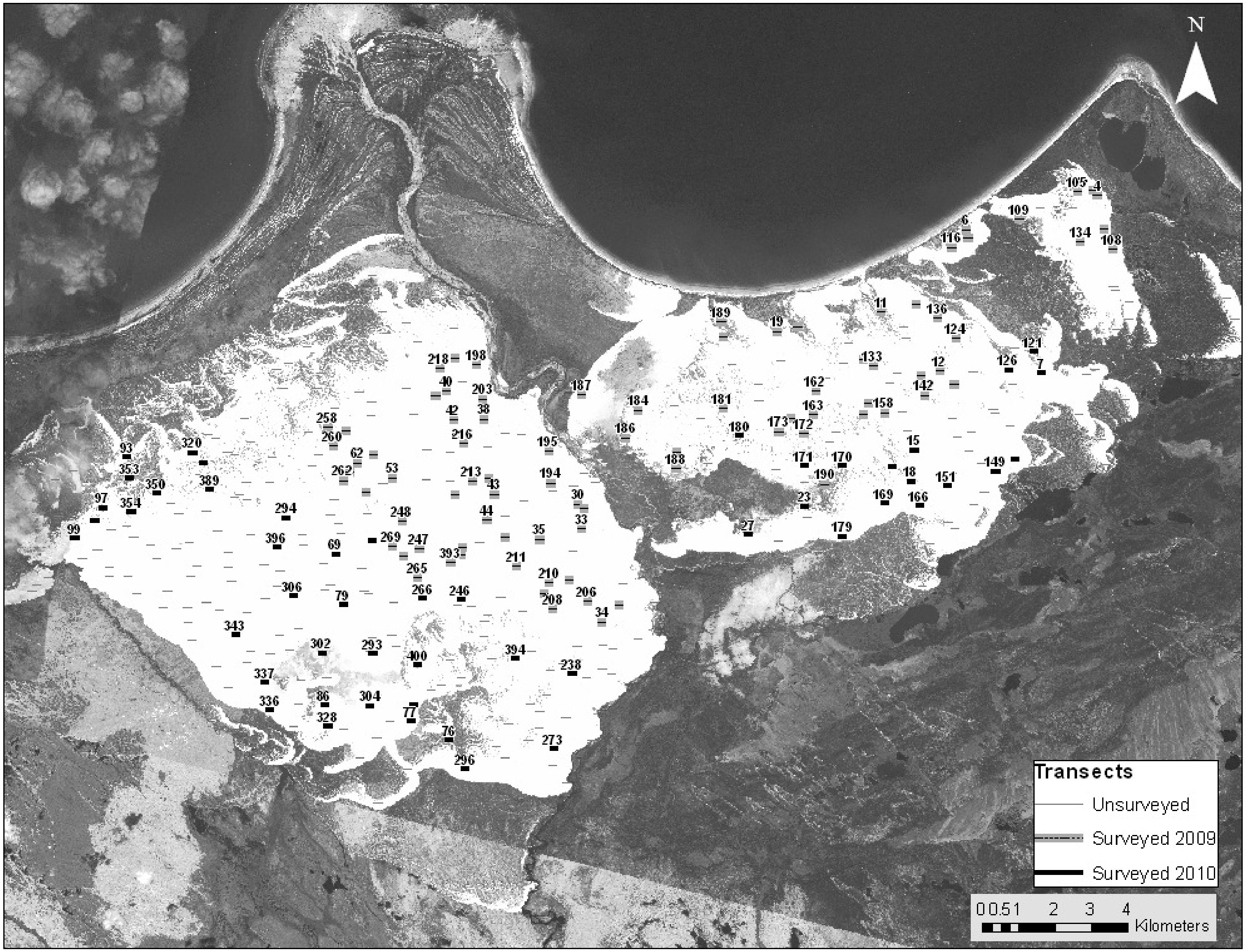


Figure 1: Prelocated transects in the William River, Thompson Bay and Cantara Lake dune fields with surveyed transects marked.

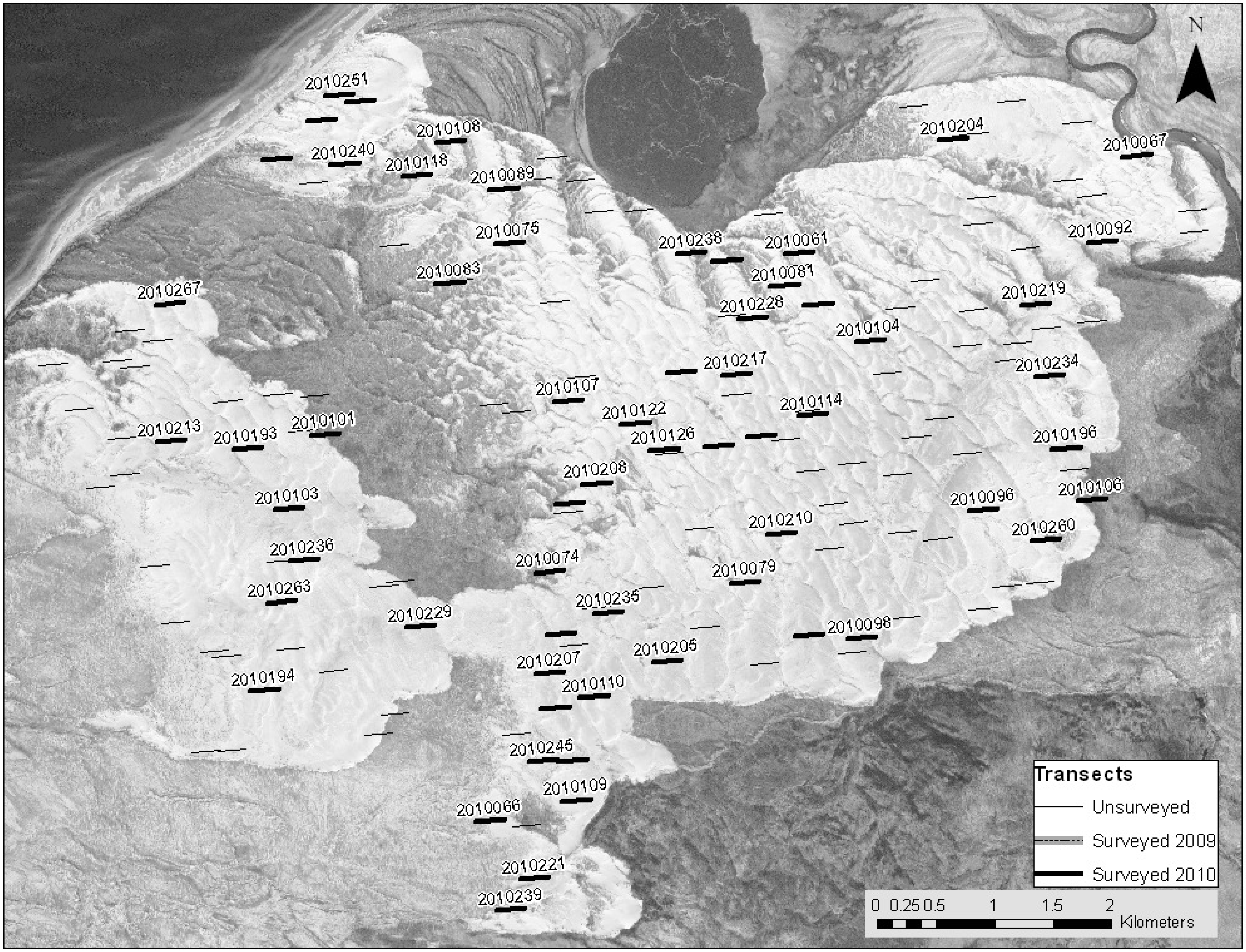


Figure 2: Prelocated transects in the MacFarlane River dune field with surveyed transects marked.

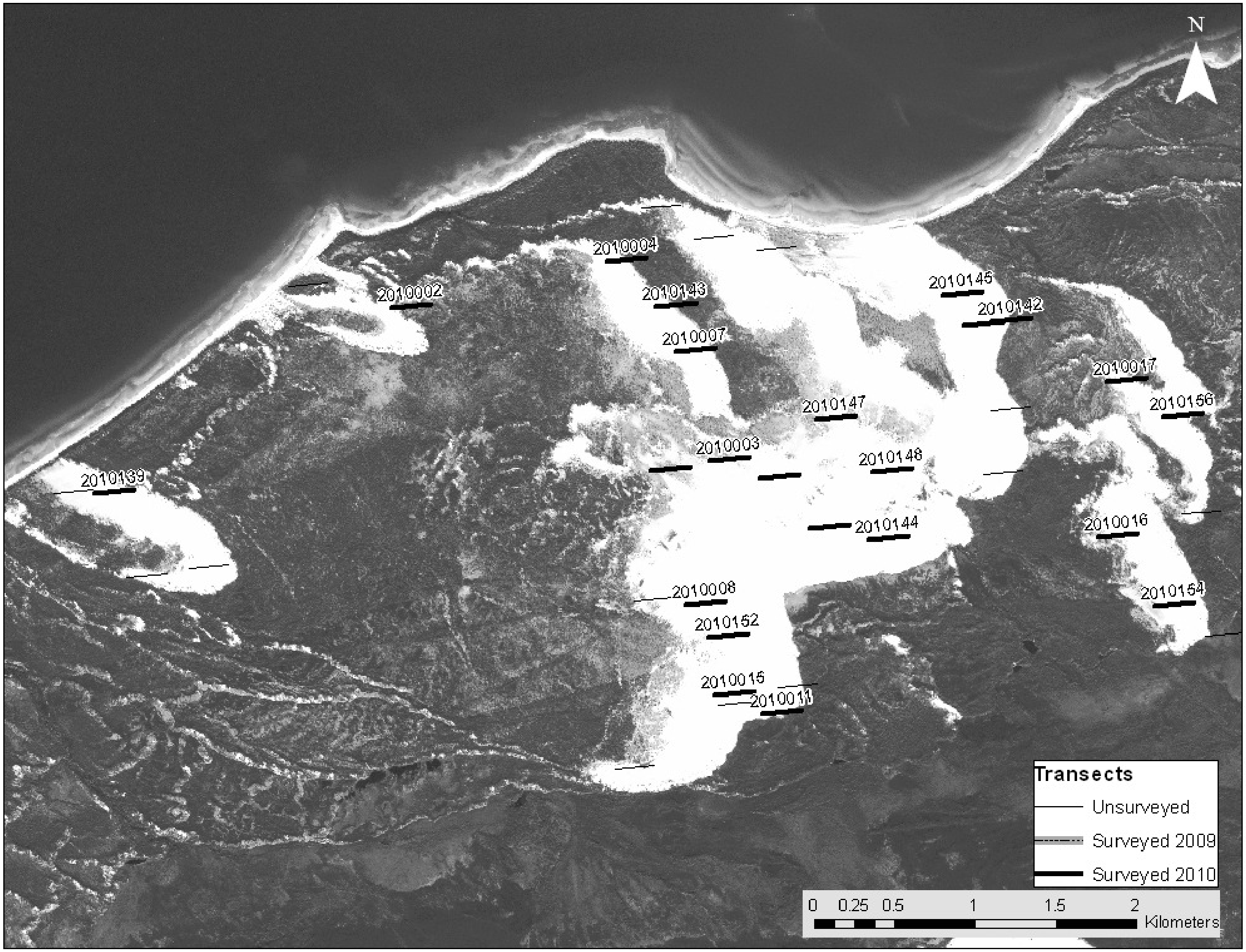


Figure 3: Prelocated transects in the Archibald Lake dune field with surveyed transects marked.

A set of 276 pre-located transects were generated for the Archibald Lake and MacFarlane River dune fields by Saskatchewan Parks staff Jessus Karst (Figure 2; Figure 3). Transects were located within the dune complexes in a random fashion. Unlike the set of 400 transects above, there were no sampling or distance strata used in locating transects. Each transect ran east to west on a constant northing.

Transects were selected for sampling on a daily basis based on a balance between accessibility and areal coverage. Each day each two-person survey team was assigned an area of dunes within walking distance (generally 2-7km from camp) and a list of potential transects in that area. Teams selected transects from the list for survey (typically 2-4 per day) based on accessibility (for example the need to walk around large gravel pavements) and available time. Teams were assigned areas with the goal of maximizing both the overall area of survey coverage and the range of habitat types surveyed. The necessity of accessing sites on foot in 2009 resulted in much heavier survey coverage in locations close to Cantara Lake, Lake Athabasca, and the William River. Helicopter support was available in 2010 permitting much broader survey coverage. Survey teams made extensive efforts to avoid walking on gravel pavements while moving between transects. In consultation with the Saskatchewan Parks staff on the survey team it was determined that transects on gravel pavements would be surveyed. When travel on pavements was necessary teams took steps (for example walking in each other's footsteps) to minimize the disruption of the pavements.

Transect length and width were determined at the beginning of the field survey program in 2009. It was clear from trial transects that a large majority of 250m transects would have at least one endemic species record. Given the greater survey extent possible and the statistical benefits of surveying more shorter transects, the 250m pre-located transects were selected over the alternative 500m transects. Transect widths were set at 10m for willow species and 4m for grasses and forbs. While accurate detection was possible in open dunes at distances from the transect center greater than 5m for shrubs and 2m for forbs, detection distances were much shorter in dense dune slack or woody vegetation.

Transect surveys started with team members locating one end of the transect using a handheld GPS. One member would navigate to the other end and plant a 2m range pole. That individual would then return to the beginning of the transect planting pin flags on the transect center line at intervals. Both team members would then survey the length of the transect recording the habitat types and endemic species encountered. In a limited number transects (typically transects with a high percentage of gravel pavements and very low plant cover) field crews with access to a GPS with advanced navigation features (the ability to display and follow the transect line on an on-screen map at a scale of less than 10m) would not flag the transect. Rather they would walk the transect only once using the GPS to locate the transect center line. This was done to speed the surveying of a habitat with relatively few endemic occurrences and to minimize the disruption to the gravel pavements being surveyed. With the exception of the addition of opportunistic transects (below) there were no changes in field methods between the two survey years.

In addition to the pre-located transects, in 2010 field crews had the opportunity to partially survey transects or to opportunistically locate transects to increase the coverage of rare habitats. These methods were included as a key recommendation following the 2009 surveys because only limited coverage of habitats including wet-interdune slacks, saline-interdune slacks, lichen heaths, and woodlands were achieved (Lamb 2010). Partial and opportunistic transects were generally only surveyed when one or more nearby complete transects have been surveyed. Partial transects normally involved the survey of a segment of priority habitat on a pre-located transect and at least one segment of non-priority habitat to each side of the priority habitat. Opportunistic (non-prelocated) transects were generally surveyed when a rare habitat was encountered by selecting a starting UTM northing and easting at least 100 away from the survey team's location that bisected the rare habitat. Setting the starting point some distance from the team was done to reduce potential bias (i.e. sampling an unusually dense population of endemics). The team would then survey a full or partial transect along the northing of the starting location, ensuring at least one habitat segment to the east and west of the rare habitat was also sampled. Opportunistic transects were generally only undertaken if teams had already sampled an adequate number of pre-determined transects in the area to ensure efficient and representative sampling of those areas.

Habitat conditions were recorded along each transect. A general habitat code (Table 2), and three habitat description modifiers: aspect (the nearest cardinal direction when facing downslope or "flat" in level terrain), Erosional status (Table 3), and landscape position (Table 4) were recorded for each habitat segment. Habitat conditions were recorded at the start of the transect. At any point along the length of the transect where either the general habitat or one of the modifiers changed an easting was recorded using the GPS. Habitat changes were generally not recorded if the change involved less than 3-5m of transect. This sampling procedure broke each 250m transect into one or more habitat segments consisting of a contiguous stretch with similar environmental conditions.

Table 2: Habitat descriptors used in the occupancy survey. Note that PEBC (Pebbly beach) and SABE (Sandy beach) habitats were also available for teams, but no sampling in those habitats was carried out.

Code	Description
WIDS	Wet inter-dune slack. A level or nearly level habitat with a high groundwater table and moist soils. Open water is occasionally present. May have sandy substrate or more or less extensive herbaceous or bryophyte ground cover.
SIDS	Saline inter-dune slack. As for WIDS but with evidence of salt deposits on the soil surface.
GRPV	Gravel pavement. Dominant surface cover is rocks or pebbles lying on a sandy substrate.
LSDN	Dry low-slope gradient dune. Dominant substrate is open sand with slopes generally less than 15-20 deg. Relatively level areas between dunes without evidence of a high water table were included in this category.
HSDN	Dry high-slope gradient dune. Dominant substrate is open sand with slopes generally greater than 15-20 deg.
LICH	Lichen-crowberry heather. Dry areas with well developed layers of lichens, bryophytes, and low-growing ericaceous shrubs over the soil surface, but without extensive tall shrub or tree cover.
WOOD	Extensive woody vegetation (generally jackpine forest or birch scrub). Substrates between trees generally similar to LICH habitat.

Table 3: Erosional status descriptors used as a habitat modifier.

Code	Description
ER	Erosional Feature. Evidence of sand removal in the recent past (e.g. exposed roots of plants)
DP	Depositional Feature. Evidence of sand deposition in the recent past (e.g. burial of plants, mini-dunes downwind of obstacles)
ST	Static Feature. No evidence of recent deposition or erosion. Gravel pavements were generally considered static.

Table 4: Landscape position descriptors used as a habitat modifier. Boundaries between landscape positions were normally placed approximately midway through the transition.

Code	Description
U	Hilltop or crest
M	Sloped surface with distinct aspect
L	lower lying land without a distinct aspect

Survey crews walked the length of the transect searching for all individuals of the target taxa. In open dunes and gravel pavements with low plant cover surveyors typically walked the center line of the transect. In dense vegetation such as dune slacks a slower search pattern where the surveyors walked out to the transect edges was adopted. Survey teams each carried a 2m pole which was used to confirm whether species occurrences lay within the transect boundaries (2m from the center line for forbs, and 5m from the center line for willows). All endemic species occurrences within the transect area were recorded. No records were made, however, of incidental occurrences outside transects.

When a patch of one of the target species was encountered a GPS easting for the first point where the patch intersected the transect was recorded, as was the size of the patch and the number of individuals in the patch. A patch was defined as a group of individuals of a species where the maximum distance between two individuals was less than 2m. Individuals in the patch that were outside the transect area but within 2m of individuals within the transect were not counted. The size of the patch was estimated by measuring both the longest axis of the patch and the length of a second axis perpendicular to the first axis. Only the part of a patch within a transect was measured. If a patch contained only one individual patch size was recorded as 0.2m by 0.2m. Table 5 lists the definitions of an “individual” used for each species.

The number of individuals in each patch was generally determined by a direct count. In very dense patches, rather than attempting to count hundreds of individuals, the survey team would identify a representative square meter of area within the patch and count the individuals in that area. Patch area (calculated assuming an ellipse-shaped patch) was used to estimate the total number of individuals. In cases where the shorter axis of the patch was the same as the transect width (4m for forbs or 10m for willows) it was assumed that the patch was shaped as a rectangle with the length of the long axis and width of the transect. Patches were recorded separately for each of the target species, even though patches of different species frequently overlapped.

Table 5: Growth forms and definitions of an individual used in the occupancy survey. Note that with the exception of *Armeria maritima* many of the "individuals" in a patch likely belonged to the same genet or genetic individual.

Species	Growth Form	"Individual" Definition
Achillea millefolium	Rhizomatous forb	Ramet with a distinct stem emerging from the ground surface
Armeria maritima	Sub-shrub growing from erect rootstock	Clump from the same rootstock
Deschampsia mackenzieana	Tussock grass	Tussock separated from other tussocks by at least 20cm
Salix brachycarpa	Clonal shrub: multiple aerial stems linked belowground	A distinct live stem emerging from the soil surface
Salix silicicola	Clonal shrub: multiple aerial stems linked belowground	A distinct live stem emerging from the soil surface
Salix turnorii	Clonal shrub: multiple aerial stems linked belowground	A distinct live stem emerging from the soil surface
Salix tyrrellii	Clonal shrub: multiple aerial stems linked belowground	A distinct live stem emerging from the soil surface
Stellaria arenicola	Forb producing numerous tightly clumped ramets through layering	A clump of ramets separated from other clumps by at least 20cm
Tanacetum huronense	Rhizomatous forb with numerous ramets emerging in close proximity	Cluster of ramets separated from other clusters of ramets by at least 20cm

Most transects were surveyed only once, however four transects in 2009 (123, 133, 195, 217) and four transects (97, 166, 400, 2010009) in 2010 were surveyed twice to permit estimates of survey error rates. These transects are recorded in the datafiles as 123.1 and 123.2 etc. In all cases the summary data in this report contains only the ".1" transects. The ".2" transects were only used in the estimates of error rates (see page 59).

A set of beach transects were surveyed in 2010 in addition to the formal transects surveyed in the sand dune complexes. These transects were surveyed as a key recommendation of the report on the 2009 surveys (Lamb 2010). Pre-determined locations for beach transects were developed by Saskatchewan Parks Service staff prior to sampling. Beach transect locations were based on maximizing the amount of area sampled. As such, areas of focus were in close proximity to camp locations. At each pre-determined location a group of 1-4 transects were sampled to allow for flexibility in maximizing area sampled while teams moved to different dune field locations. Transects within groups were separated by a minimum distance of adjacent transect length. Beach transects start points were located in forest fringe, and ran perpendicular to the beach line. As such, transect UTMs did not always follow a constant northing or easting. Habitats encountered along the transect generally followed an order from forest fringe, dynamic slopes, pebble beach, backswamp then active beach. However, the order and number of habitat types varied with each transect, and it was common to have multiple pebble beach, backswamp or active beach habitats. Beach transects were ended when Lake Athabasca was encountered. Sampling of endemic species along beach transects was done using the same methodology as dune field sampling.

Table 6: Habitat codes used for beach transects in 2010

Code	Description
BASW	Beach backswamp - wet depressions immediately upshore from the active, wave-washed beach
DYSA	Dynamic sand slopes – moving slopes adjacent to the forest fringe sand beach
FFSB	Forest fringe sand beach - flat sand benches immediately adjacent to the shore forest
PEBE	Pebble beach - beaches with an armour of beach pebbles varying from small (i.e., 1 cm) to larger (i.e., 20 cm or more in diameter) pebbles
SABE	Sandy active beach - zone in which wave action prevents plant growth

Data Handling

This study resulted in a large dataset with a total of 1580 habitat records and 5295 species records from 224 transects and a further 106 habitat records and 186 species records from 19 beach transects. Raw data including full metadata are stored in the Microsoft Excel file "Athabasca Sand Dunes data_2009_2010.xlsx" appended to this report. The procedures in this section describe how the raw data file was manipulated to produce the analysis-ready file "Athabasca Sand Dunes data_analyzed.xlsx".

For analytical purposes unique habitat segments within each transect were considered to be the sample unit. This approach was used because, while individual patches were determined by arbitrary rules (i.e. 2m separation between patches), the density of individuals within a unit of habitat has direct ecological meaning. The species patches were overlain on the habitat data and total counts of individuals of each species in each habitat segment were calculated. Thus a habitat segment that contained several distinct patches of a species would be recorded as containing the sum total number of individuals from all patches. Some large patches overlaid more than one habitat segment. In those cases the count of individuals from that patch was apportioned to each habitat segment in proportion to the patch area that fell into each segment. The density of individuals of each species in each habitat segment was calculated based on the above counts and total habitat segment area.

Statistical Analyses

Statistical analyses were conducted to investigate species – habitat affinities and community patterns in the species records collected from the major dune complexes. There were too few transects (19) to conduct statistically robust analyses of the beach data, thus only summary data are presented from those transects.

The breadth of habitats that can support a rare species across habitats (i.e. the likelihood that particular species will be present in a particular habitat), and the relative abundance within habitats (i.e. when present how abundant the species is) are both critical elements of a rare species distribution (Rabinowitz et al. 1986). Generalized linear mixed models with a binomial distribution (Crawley 2007) were used to assess whether the probability of at least one occurrence of the species being present in a particular habitat segment differed depending on the habitat type. These models included habitat segment length as a covariate to account for the effect of area searched on the chance of encountering a species. General linear mixed models were used to assess whether the relative abundance of species in occupied habitat segments differed between habitat types. Density was only examined in occupied segments because of the large number of zeros (segments unoccupied by a species) in the full dataset. In all of these models density was log-transformed to normalize the distribution of the residuals, and transect was used as a random factor to account for the nesting of multiple habitat segments within each transect.

Model selection procedures (Crawley 2007) were used to identify groups of habitats that did not differ significantly in the above models. Best models were identified by sequentially taking a pair of habitats with very similar values for a response variable and combining them into a single habitat category. If combining two habitats resulted in a non-significant drop in variance explained (assessed using a χ^2 test) then the simpler model was retained and another combination of habitats evaluated. Finally, the best model was compared to a null model (a model containing only the length covariate and random terms). Significantly higher deviance explained by the best model confirmed that the habitat classification(s) retained in the best model represented significant differences in species distributions between those habitats. All models were fitted using the lmer function (Bates 2005) in the R 2.11.1 statistical package (R Development Core Team 2006).

The patterns of endemic community richness were also examined using generalized linear mixed models. Models with a poisson distribution were used to assess whether endemic species richness differed between habitat types. These models also included habitat segment length as a covariate to account for the effect of area searched on the chance of encountering species. In these models transect was used as a random factor to account for the nesting of multiple habitat segments within each transect.

Species co-occurrence patterns were analyzed using a non-metric multidimensional scaling ordination (McCune and Grace 2002). NMDS is the preferred ordination method for community data because it requires few assumptions about the distributions underlying these data. All habitat segments with at least one endemic occurrence were included in the ordination, with endemic species recorded as presences or absences. Presence absence data was used because the variable definitions of an individual (Table 5) make density estimates difficult to compare between species. Empty cells (habitat segments with no species occurrences) cannot be used in an ordination. The ordination was conducted using PC-ORD 5.0 (McCune and Mefford 1999) with Sorenson distance, An initial ordination was conducted with 250 runs with real data stepping down from 6 to 1 axes. This analysis did not meet instability criteria, but identified an optimal 3 axis solution. A second analysis was carried out requesting a 3 axis solution with 500 runs with real data, a maximum of 500 iterations per run, and a stability criterion of 0.00001 standard deviations in stress over the last 100 iterations. A randomization test was not used because preliminary NMS runs indicated that the reshuffling procedure produced empty rows in too many cases.

Summary of Field Observations

Field Survey Extent

Eighty-three 250m transects in the Cantara Lake, Thompson Bay, and William River dune fields were surveyed in 2009 and 141 transects in the Thompson Bay, William River, MacFarlane River and Archibald lake dune fields were surveyed in 2010 (Figure 1 - Figure 3). The lengths of transect surveyed in each major habitat type are summarized in Table 7. Extensive areas of gravel pavement and high and low-slope dunes were surveyed. More limited coverage of lichen-crowberry heaths, wet dune slacks, and woodland was achieved, and only minimal coverage (only 257m of transect) of saline dune slacks. The proportion of the total area surveyed in each habitat type should not be used as an indicator of the proportion of the total dune mass in each habitat type for two reasons. 1) Restrictions in the pre-survey transect layout procedure (pg. 11) likely contributed to small underestimates of the proportions of the landscape made up by gravel pavements, lichen – crowberry heaths and small woodlands. 2) A key recommendation of the 2009 report (Lamb 2010) was for field crews to increase sampling of less represented habitats. This was achieved by crews concentrating efforts in areas likely to contain priority habitats, and in the use of opportunistic transects. Regardless, wet dune slacks clearly represent only a small proportion of the total area within the sand dunes complex.

Table 7: Summary of survey extent including transect length (km) and number of habitat units in each major habitat type.

Habitat	Km Surveyed	# habitat units	Average unit length (m ± SD)	Total area surveyed for Willows (ha)	Total area surveyed for forbs and grasses (ha)
Gravel Pavement (GRPV)	10.778	171	63 ±62.5	10.78	4.31
High Slope Dune (HSDN)	3.841	159	24.2 ±22.8	3.84	1.54
Lichen – crowberry heath (LICH)	3.520	106	33.2 ±42.6	3.52	1.41
Low slope dune (LSDN)	32.473	925	35.1 ±32.7	32.47	12.99
Saline Inter-dune slack (SIDS)	0.257	8	32.1 ±31.1	0.26	0.10
Wet inter-dune slack (WIDS)	1.204	45	26.8 ±15.4	1.20	0.48
Woodland (WOOD)	3.239	87	37.2 ±40.3	3.24	1.30
Total	55.312	1501	36.9 ±38.6	55.31	22.13

The distribution of other habitat descriptors within each of the major habitat types are summarized in Table 8 (slope position), Table 9 (aspect), and Table 10 (erosional status).

Table 8: Distribution (total km surveyed and % of total within a habitat) of slope positions (Crest, Midslope, Lower Slope) in each major habitat type.

Habitat	Crest	Mid-Slope	Lower Slope
Gravel Pavement (GRPV)	0.953 (8.8)	3.057 (28.4)	6.768 (62.8)
High Slope Dune (HSDN)	0.858 (22.3)	2.415 (62.9)	0.568 (14.8)
Lichen – crowberry heath (LICH)	0.455 (12.9)	0.894 (25.4)	2.171 (61.7)
Low slope dune (LSDN)	5.528 (17.0)	19.773 (60.9)	7.172 (22.1)
Saline Inter-dune slack (SIDS)	0 (0)	0.033 (12.8)	0.224 (87.2)
Wet inter-dune slack (WIDS)	0 (0)	0.045 (3.7)	1.159 (96.3)
Woodland (WOOD)	0.061 (1.9)	1.025 (31.6)	2.153 (66.5)

Table 9: Distribution (total km surveyed and % of total within a habitat) of aspects (no slope and each cardinal direction) in each major habitat type.

Habitat	Flat	North	East	South	West
Gravel Pavement (GRPV)	7.003 (65.0)	0.426 (4.0)	1.302 (12.1)	0.346 (3.2)	1.701 (15.8)
High Slope Dune (HSDN)	0.554 (14.4)	0.497 (12.9)	1.722 (44.8)	0.074 (1.9)	0.994 (25.9)
Lichen – crowberry heath (LICH)	2.437 (69.2)	0.331 (9.4)	0.424 (12.0)	0.032 (0.9)	0.296 (8.4)
Low slope dune (LSDN)	6.902 (21.3)	2.387 (7.4)	8.172 (25.2)	2.12 (6.5)	12.892 (39.7)
Saline Inter-dune slack (SIDS)	0.213 (82.9)	0 (0)	0.044 (17.1)	0 (0)	0 (0)
Wet inter-dune slack (WIDS)	0.996 (82.7)	0.029 (2.4)	0.081 (6.7)	0.07 (5.8)	0.028 (2.3)
Woodland (WOOD)	1.625 (50.2)	0.169 (5.2)	0.389 (12.0)	0.502 (15.5)	0.554 (17.1)

Table 10: Distribution (total km surveyed and % of total within a habitat) of erosional status (Static, depositional, erosional) in each major habitat type.

Habitat	Erosional	Depositional	Static
Gravel Pavement (GRPV)	0.731 (6.8)	0.324 (3.0)	9.723 (90.2)
High Slope Dune (HSDN)	0.835 (21.7)	2.703 (70.4)	0.303 (7.9)
Lichen – crowberry heath (LICH)	0.12 (3.4)	0.533 (15.1)	2.867 (81.4)
Low slope dune (LSDN)	10.212 (31.4)	14.766 (45.5)	7.495 (23.1)
Saline Inter-dune slack (SIDS)	0.02 (7.8)	0.084 (32.7)	0.153 (59.5)
Wet inter-dune slack (WIDS)	0 (0)	0.145 (12.0)	1.059 (88.0)
Woodland (WOOD)	0.214 (6.6)	0.026 (0.8)	2.999 (92.6)

Relative Abundance of species at risk

A total of 206138 individuals of 9 of the 10 endemic taxa were observed during the occupancy survey (Table 11). No individuals of impoverished pinweed (*Lechea intermedia*) were observed. *Achillea millefolium* and *Armeria maritima* stand out by their low occurrence rates, while *Deschampsia mackenzieana* and the *Salix* species were very common. Caution should be used in interpreting the relative abundance measures as the number of *Salix* individuals, particularly *S. tyrrellii* and *S. silicicola* were likely inflated due to the counting of stems rather than clumps that likely represent genetic individuals in the field. Table 12 provides a summary of the density of each species in each major habitat type.

Table 11: Count of total observations and the relative abundance (percentage of total number of observations) of each taxa in the occupancy survey. Note that the relative abundance numbers are not adjusted for the wider search area for the willows.

Species	Count
Achillea millefolium	592 (0.29)
Armeria maritima	272 (0.13)
Deschampsia mackenzieana	14213 (6.89)
Salix brachycarpa	28224 (13.69)
Salix silicicola	23740 (11.52)
Salix turnorii	15634 (7.58)
Salix tyrrellii	114025 (55.31)
Stellaria arenicola	3810 (1.85)
Tanacetum huronense	5628 (2.73)

Table 12: Mean density (individuals m-2 ±std. dev) of each taxa in each major habitat type. Blank cells indicate that no observations were made. Note that these estimates included habitat segments with no observations (zero density). Statistical tests were carried out on the probability of species presence in each habitat type (Table 13) and on the density of species within occupied habitat segments (Figure 4 through Figure 12).

Species	GRPV	HSDN	LICH	LSDN	SIDS	WIDS	WOOD
Achillea millefolium		0.0003 ±0.0032	0.0059 ±0.0397	0.0028 ±0.0294		0.0390 ±0.1350	0.0026 ±0.0101
Armeria maritima	0.0050 ±0.0274	0.0005 ±0.0058	0.0002 ±0.002	0.0011 ±0.0122	0.0009 ±0.0027	0.0009 ±0.0039	0.0011 ±0.0080
Deschampsia mackenzieana	0.0446 ±0.2136	0.0310 ±0.0839	0.0027 ±0.0182	0.1126 ±0.4320	0.0741 ±0.1480	0.1018 ±0.4093	0.0003 ±0.0027
Salix brachycarpa	0.0123 ±0.1363	0.0499 ±0.2067	0.0989 ±0.4100	0.0978 ±0.5677	0.3843 ±0.9202	0.3083 ±0.8239	0.0514 ±0.4292
Salix silicicola	0.0058 ±0.0389	0.0648 ±0.2497	0.0177 ±0.0906	0.0820 ±0.5718	0.0075 ±0.0145	0.8189 ±4.1193	0.0011 ±0.0101
Salix turnorii	0.0051 ±0.0378	0.0433 ±0.1985	0.0075 ±0.0427	0.0586 ±0.6159	0.2903 ±0.5718	0.2333 ±0.7808	0.0026 ±0.0154
Salix tyrrellii	0.0002 ±0.0013	0.4728 ±1.8935	0.4086 ±1.4828	0.2219 ±1.1642	0.0048 ±0.0123	4.0976 ±5.7508	0.2356 ±1.1551
Stellaria arenicola	0.0010 ±0.0074	0.0515 ±0.1935	0.0240 ±0.1325	0.0297 ±0.1519	0.2433 ±0.5437	0.0546 ±0.2384	0.0021 ±0.0104
Tanacetum huronense	0.0035 ±0.0181	0.1199 ±0.6938	0.0217 ±0.0678	0.0360 ±0.1130	0.0604 ±0.1675	0.3082 ±0.8550	0.0154 ±0.0474

The mean densities in Table 12 mask a great deal of heterogeneity as the vast majority of habitat segments were unoccupied. Table 13 lists the percentage of the habitat units surveyed that were occupied by at least one individual of each taxa. Generalized linear mixed models were used to analyze the rates of occurrence between habitats for each species. The best *Achillea millefolium* model included low incidence in the combined GRPV, HSDN, and SIDS habitats with progressively higher incidence in the LSDN, LICH, WOOD, and WIDS habitats (best model vs. null model with only habitat length χ^2_4=33.149, p<0.0001). The best *Armeria maritima* model included low incidence in the combined HSDN, LICH, LSDN, and WOOD habitats, and higher incidence in the combined GRPV, SIDS, and WIDS habitats (best model vs. null model with only habitat length χ^2_1=20.414, p<0.0001). The best *Deschampsia mackenzieana* model included low incidence in the WOOD habitat and progressively higher incidence in LICH, and the combined GRPV, HSDN, SIDS, and WIDS habitats, and highest incidence in the LSDN (best model vs. null model with only habitat length χ^2_3=72.092, p<0.0001). The best *Salix brachycarpa* model included low incidence in the combined GRPV, HSDN, and WOOD habitats, moderate incidence in the combined LSDN and LICH habitats, and high incidence in the combined SIDS and WIDS habitats (best model vs. null model with only habitat length χ^2_2=28.368, p<0.0001). The best *Salix silicicola* model included low incidence in the combined GRPV and WOOD habitats, and high incidence in the combined HSDN, LICH. LSDN, SIDS, and WIDS habitats (best model vs. null model with only habitat length χ^2_1=11.346, p=0.0007). The best *Salix turnorii* model had low incidence in the combined LICH and WOOD habitats and high incidence in the combined GRPV, HSDN, LSDN, SIDS, and WIDS habitats (best model vs. null model with only habitat length χ^2_1=6.411, p=0.0113). The best *Salix tyrrellii* model included low incidence in GRPV, moderate incidence in the HSDN, LSDN, and SIDS habitats, and high incidence in the combined LICH, WOOD, and WIDS habitats (best model vs. null model with only habitat length χ^2_2=48.828, p<0.0001). The best *Stellaria arenicola* model had low incidence in the combined GRPV, LICH, and WOOD habitats, moderate incidence in the LSDN, and high incidence in the combined HSDN, SIDS, and WIDS habitats, and all other habitats combined (best model vs. null model with only habitat length χ^2_2=45.787, p<0.0001). The best *Tanacetum huronense* model included low occurrence rates in the combined GRPV and WOOD habitats, moderate occurrence rates in the combined LICH and LSDN habitats, and high occurrence rates in the HSDN, SIDS, and WIDS habitats (best model vs. null model with only habitat length χ^2_2=53.632, p<0.0001).

Table 13: Percentage of habitat units surveyed where at least one individual of the target taxa were observed. Superscripts indicate habitats where the probability of occurrence was not significantly different. Superscript letters are ordered from "a" (lowest probability) and up. Note that the reported occurrence rates in the SIDS habitat are likely very unreliable as only eight habitat units of this type were surveyed.

Species	GRPV	HSDN	LICH	LSDN	SIDS	WIDS	WOOD
Achillea millefolium	0^{a}	1.3^{a}	7.6^{c}	3.0^{b}	0^{a}	17.8^{e}	10.3^{d}
Armeria maritima	8.2^{b}	0.6^{a}	0.9^{a}	1.6^{a}	12.5^{b}	6.7^{b}	2.3^{a}
Deschampsia mackenzieana	34.5^{c}	27.7^{c}	6.6^{b}	45.6^{d}	37.5^{c}	22.2^{c}	1.2^{a}
Salix brachycarpa	5.9^{a}	11.3^{a}	17.9^{b}	14.7^{b}	50.0^{c}	48.9^{c}	11.5^{a}
Salix silicicola	14.0^{a}	18.2^{b}	17.9^{b}	19.4^{b}	37.5^{b}	33.3^{b}	2.3^{a}
Salix turnorii	9.9^{b}	17.0^{b}	6.6^{a}	13.2^{b}	37.5^{b}	17.8^{b}	5.8^{a}
Salix tyrrellii	3.5^{a}	22.6^{b}	33.0^{c}	15.8^{b}	25.0^{b}	60.0^{c}	32.2^{c}
Stellaria arenicola	3.5^{a}	32.1^{c}	4.7^{a}	18.5^{b}	50.0^{c}	33.3^{c}	5.8^{a}
Tanacetum huronense	8.8^{a}	42.8^{c}	26.4^{b}	30.9^{b}	37.5^{c}	64.4^{c}	19.5^{a}
Total number of habitat units surveyed	171	159	106	925	8	45	87

Figure 4 through Figure 12 show the density of individuals of each species per square meter in occupied habitat segments in each habitat type. Note that if unoccupied segments were included in these figures and analyses the median value would be zero density in almost all cases. The best *Achillea millefolium* model included combined HSDN, LICH, and WOOD habitats , with the LICH and WIDS habitats separate (best model vs. null model χ^2_2=11.999, p=0.0025). The best *Armeria maritima* model was not significantly better than a null model (χ^2_1=0.5099, p=0.4752) indicating that there were no significant differences between habitats in *Armeria* density in occupied habitat segments. The best *Deschampsia mackenzieana* model had the lowest density in the combined LICH and WOOD habitats, intermediate density in GRPV, and higher density in the combined HSDN, LSDN, SIDS, and WIDS habitats (best model vs. null model χ^2_2=14.650, p=0.0006). The best *Salix brachycarpa* model had low density in the combined GRPV and WOOD habitats and higher density in the combined HSDN, LICH, LSDN, SIDS, and WIDS habitats (best model vs. null model χ^2_1=19.871, p<0.0001).. The best *Salix silicicola* model included low density in the combined GRPV, LICH, SIDS, and WOOD habitats, moderate density in the HSDN and WIDS habitats, and high density in the LSDN (best model vs. null model χ^2_2=38.680, p<0.0001). The best *Salix turnorii* model included low density in the GRPV, moderate density in the combined HSDN, LICH, LSDN, and WOOD habitats and high density in the combined SIDS and WIDS habitats (best model vs. null model χ^2_2=25.026, p<0.0001). The best *Salix tyrrellii* model included low density in the combined GRPV and SIDS habitats, higher density in the combined LICH and WOOD habitats, and progressively higher density in each of the LSDN, HSDN, and WIDS habitats (best model vs. null model χ^2_4=70.652, p<0.0001). The best *Stellaria arenicola* model included low density in the combined GRPV and WOOD habitats, moderate density in the combined HSDN, LSDN, AND WIDS HABITATS, and high density in the combined LICH and SIDS habitats (best model vs. null model χ^2_2=14.689, p=0.0006). The best *Tanacetum huronense* model included low density in the combined GRPV and SIDS habitats, moderate density in the combined LICH, LSDN, and WOOD habitats and high density in the combined HSDN and WIDS habitats (best model vs. null model χ^2_2=35.508, p<0.0001).

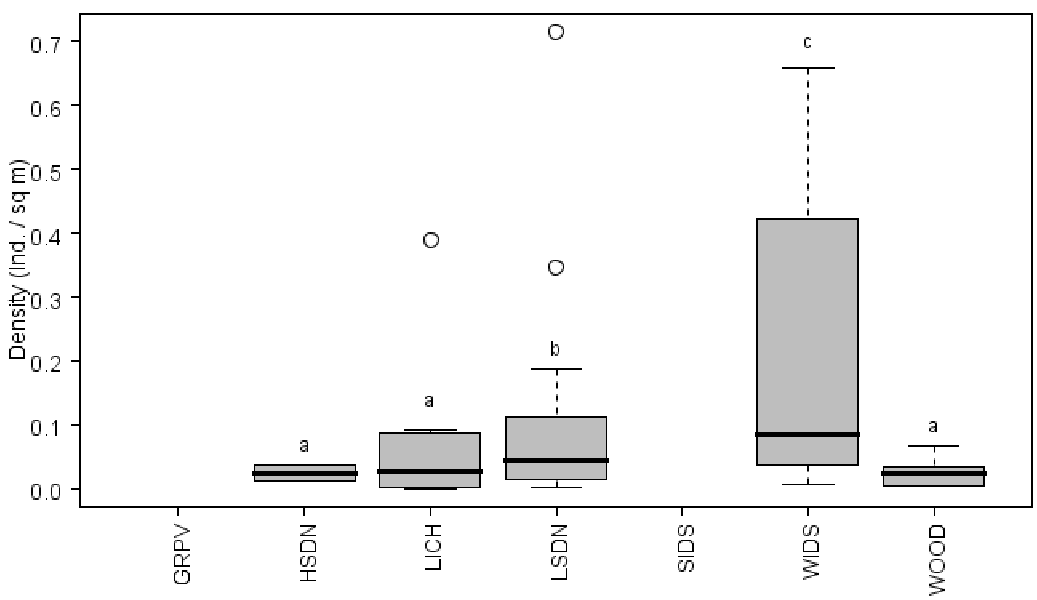


Figure 4: Density of *Achillea millefolium* (individuals m^{-2}) in occupied habitat segments. The superscripts indicate groups that are significantly different from one another. The thick horizontal line is the median, and the lower and upper bounds of the box represent the 25th and 75th percentiles respectively.

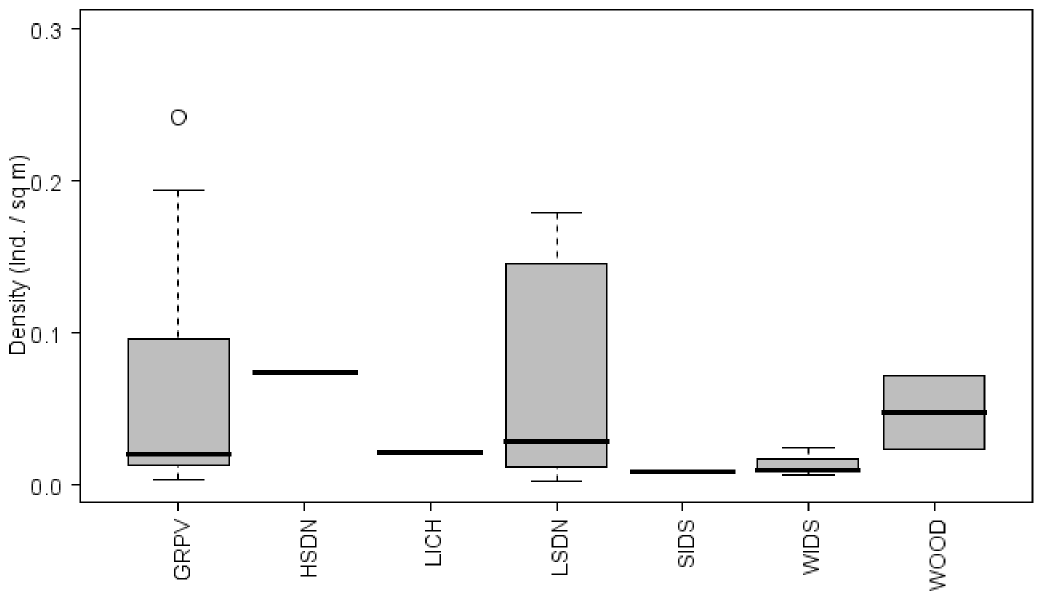


Figure 5: Density of *Armeria maritima* (individuals m^{-2}) in occupied habitat segments. There were no significant differences in mean density between habitats. The thick horizontal line is the median, and the lower and upper bounds of the box represent the 25th and 75th percentiles respectively.

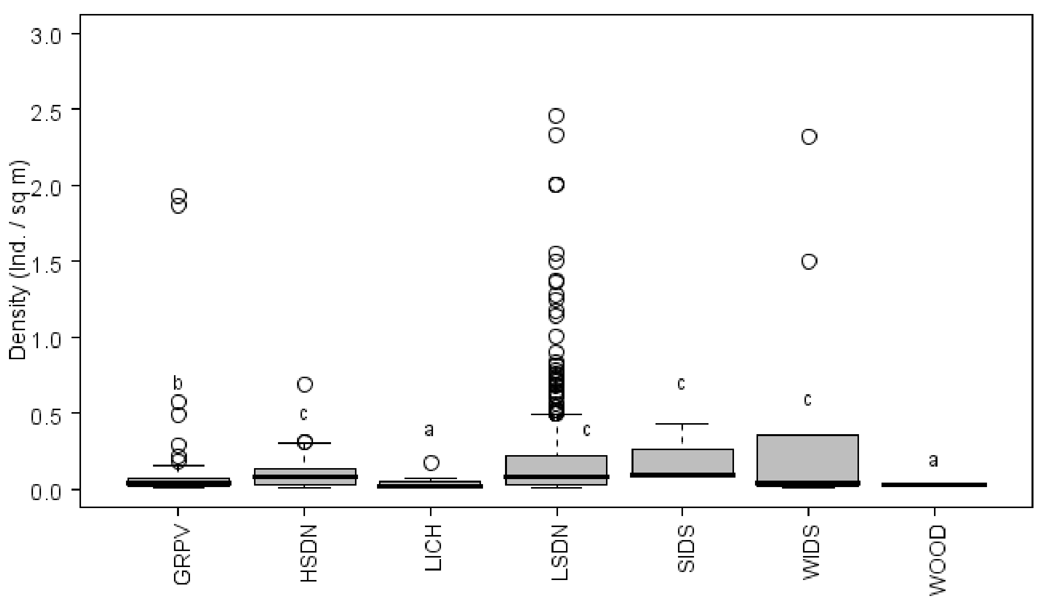


Figure 6: Density of *Deschampsia mackenzieana* (individuals m^{-2}) in occupied habitat segments. Note that five datapoints in the LSDN with densities of 3.40, 5.00, 5.31, 5.67, and 6.02 individuals m^{-2} are not displayed on this figure. The thick horizontal line is the median, and the lower and upper bounds of the box represent the 25th and 75th percentiles respectively.

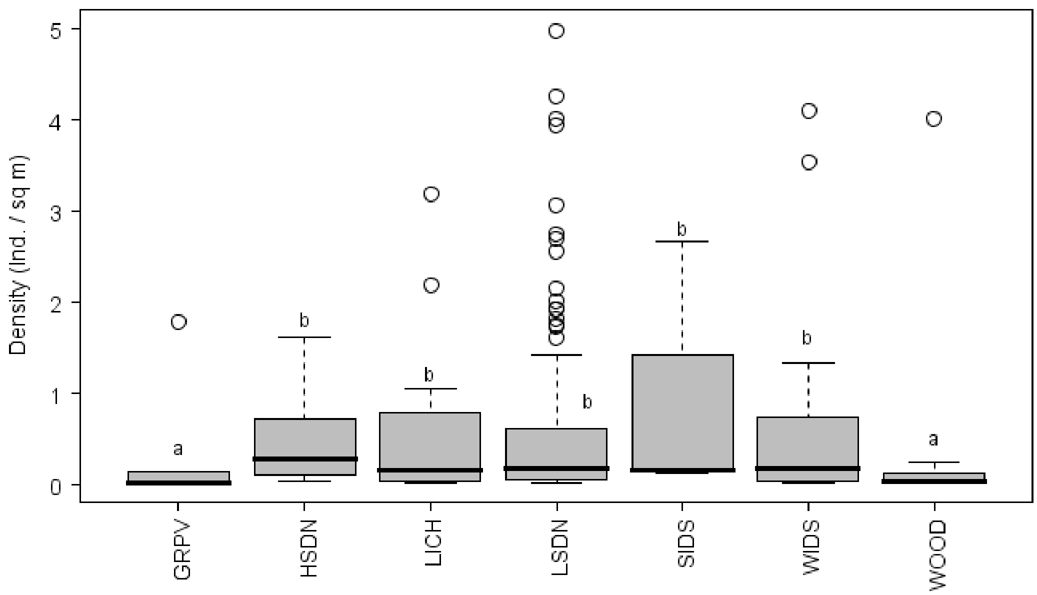


Figure 7: Density of *Salix brachycarpa* (individuals m^{-2}) in occupied habitat segments. Note that two datapoints in the LSDN with densities of 6.26 and 10.59 individuals m^{-2} are not displayed on this figure. The thick horizontal line is the median, and the lower and upper bounds of the box represent the 25th and 75th percentiles respectively.

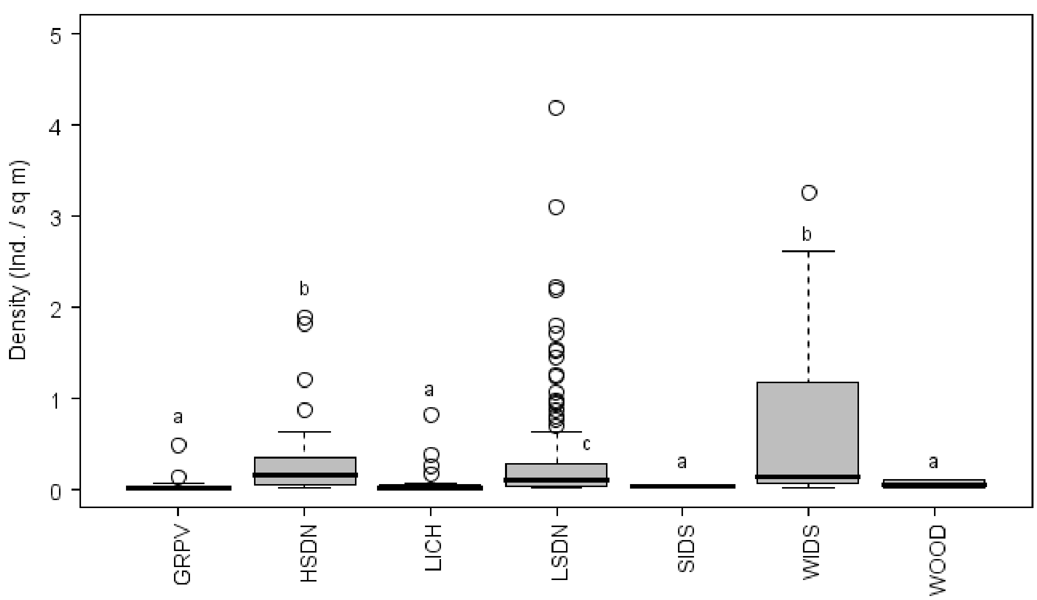


Figure 8: Density of *Salix silicicola* (individuals m^{-2}) in occupied habitat segments. Note that three datapoints in the LSDN with 6.60, 10.00, and 10.00 individuals m^{-2} respectively and one datapoint in the WIDS with 27.5 individuals m^{-2} are not displayed on this figure. The superscripts indicate groups that are significantly different from one another. The thick horizontal line is the median, and the lower and upper bounds of the box represent the 25th and 75th percentiles respectively.

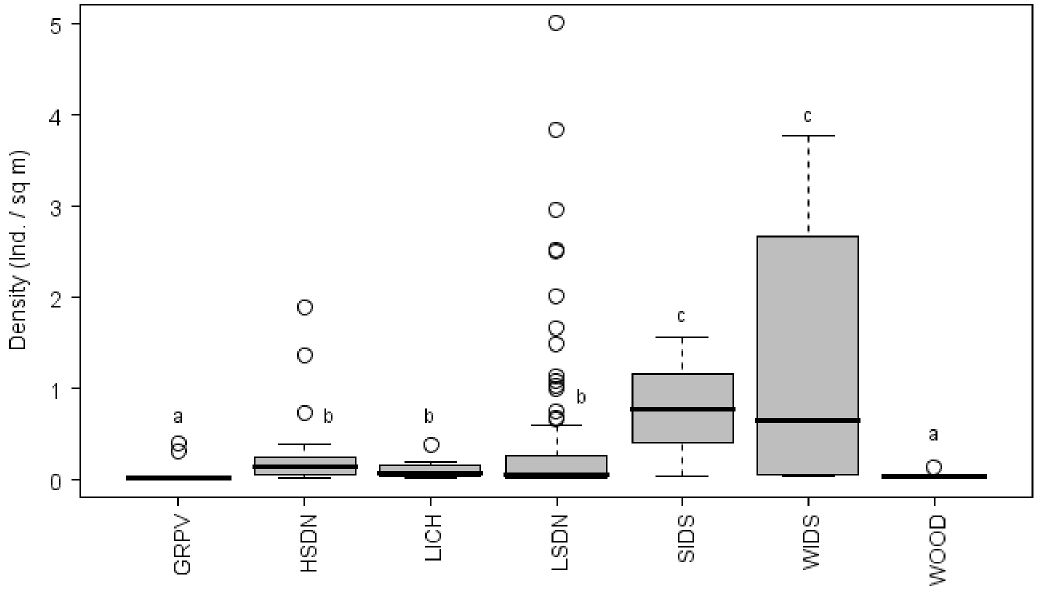


Figure 9: Density of *Salix turnorii* (individuals m^{-2}) in occupied habitat segments. Note that one datapoint in the LSDN with density of 16.59 individuals m^{-2} is not displayed on this figure. The superscripts indicate groups that are significantly different from one another. The thick horizontal line is the median, and the lower and upper bounds of the box represent the 25th and 75th percentiles respectively.

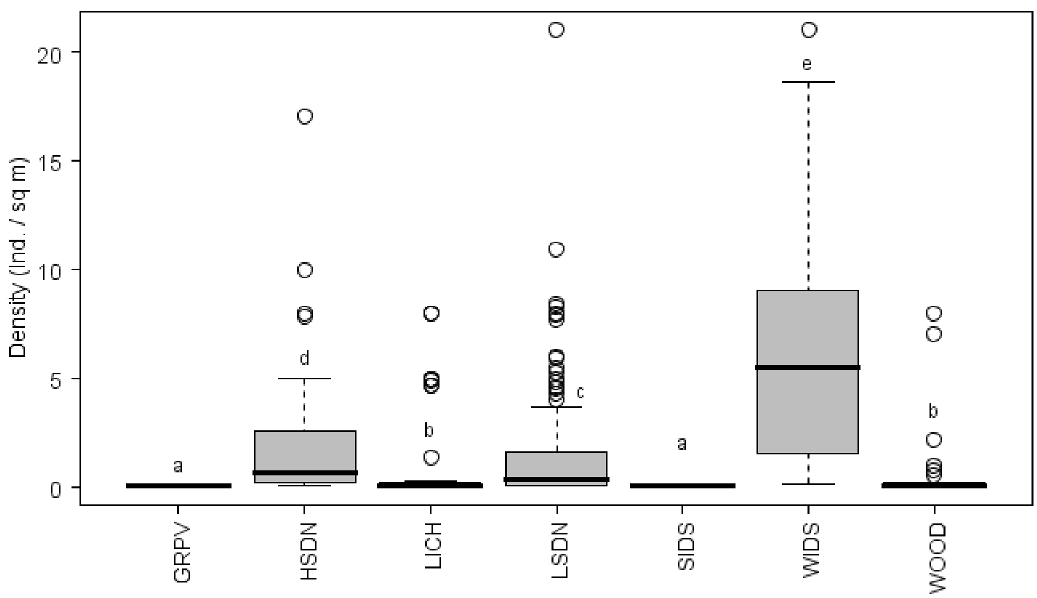


Figure 10: Density of *Salix tyrrellii* (individuals m^{-2}) in occupied habitat segments. The superscripts indicate groups that are significantly different from one another. The thick horizontal line is the median, and the lower and upper bounds of the box represent the 25th and 75th percentiles respectively.

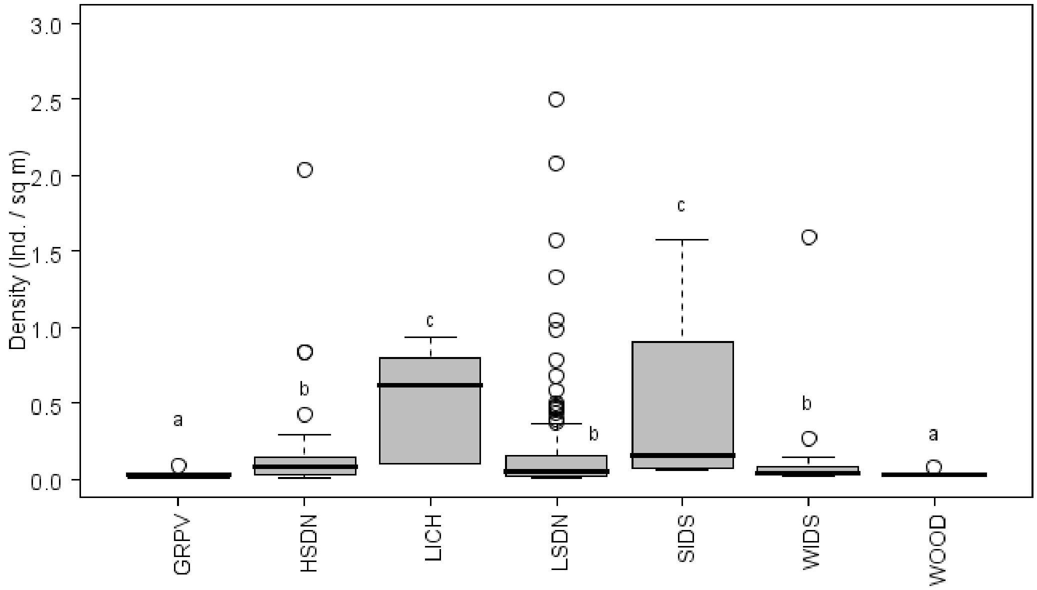


Figure 11: Density of *Stellaria arenicola* (individuals m^{-2}) in only occupied habitat segments. The thick horizontal line is the median, and the lower and upper bounds of the box represent the 25th and 75th percentiles respectively.

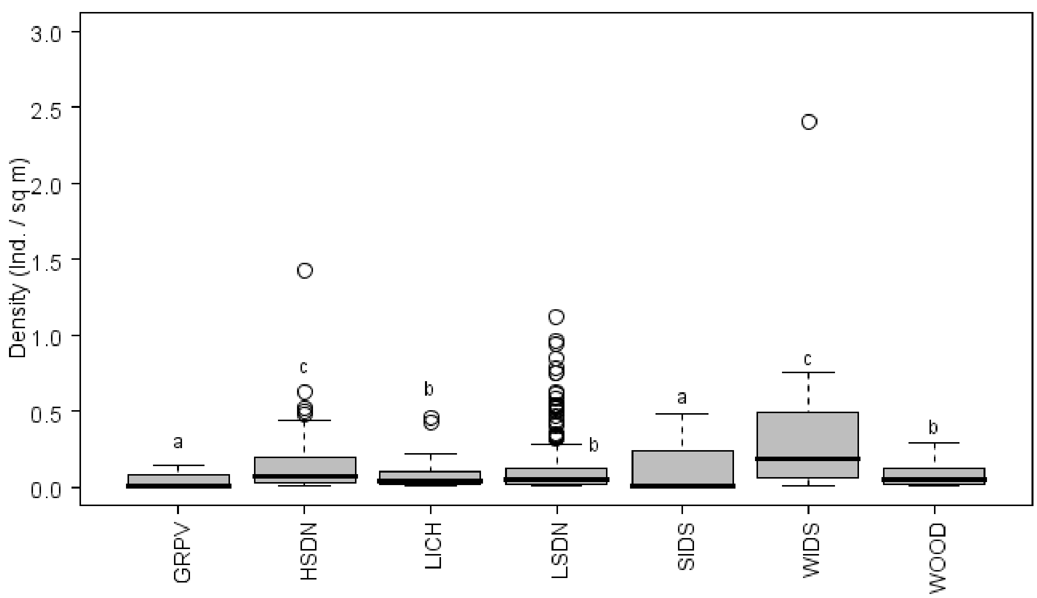


Figure 12: Density of *Tanacetum huronense* (individuals m^{-2}) only in occupied habitat segments. Note that one datapoint in the HSDN with 8.57 individuals m^{-2} and one point in the WIDS with 5.29 individuals m^{-2} are not displayed on this figure. The superscripts indicate groups that are significantly different from one another. The thick horizontal line is the median, and the lower and upper bounds of the box represent the 25th and 75th percentiles respectively.

Distribution of Species at Risk

The distribution of the Lake Athabasca endemics in the surveyed dune fields are shown in Figure 13 through Figure 35. *Achillea millefolium* was patchily distributed in the Cantara Lake, Thompson Bay, and William River dune fields. *Achillea* was absent from the Archibald Lake and MacFarlane River fields. *Armeria maritima* was concentrated in the northeastern sector of the William River dune field, patchily distributed in the Thompson Bay and MacFarlane River fields, and was absent from the Archibald lake field. *Deschampsia mackenzieana* was widely distributed in all of the dune fields. *Salix brachycarpa* was widely distributed in the Thompson Bay dune field and common around the margins of the William River, MacFarlane River, and Archibald Lake dune fields. *Salix silicicola* was widely distributed in the Thompson Bay and MacFarlane River dune fields and common around the margins of the William River and Archibald Lake dune fields. *Salix turnorii* was widely distributed in the Thompson Bay and MacFarlane River dune fields, common around the margins of the William River dune field, but present only on beaches at the margin of the Archibald Lake dune field. *Salix tyrrellii* was widely distributed in all of the dune fields. *Salix tyrrellii* was widely distributed in all of the dune fields with the exception of the Archibald Lake dunes where it was only found on and near Lake Athabasca beaches. *Stellaria arenicola* was widely distributed in the Thompson Bay and MacFarlane River dune fields and common around the margins of the William River and Archibald Lake dune fields. *Tanacetum huronense* was widely distributed in all of the dune fields.

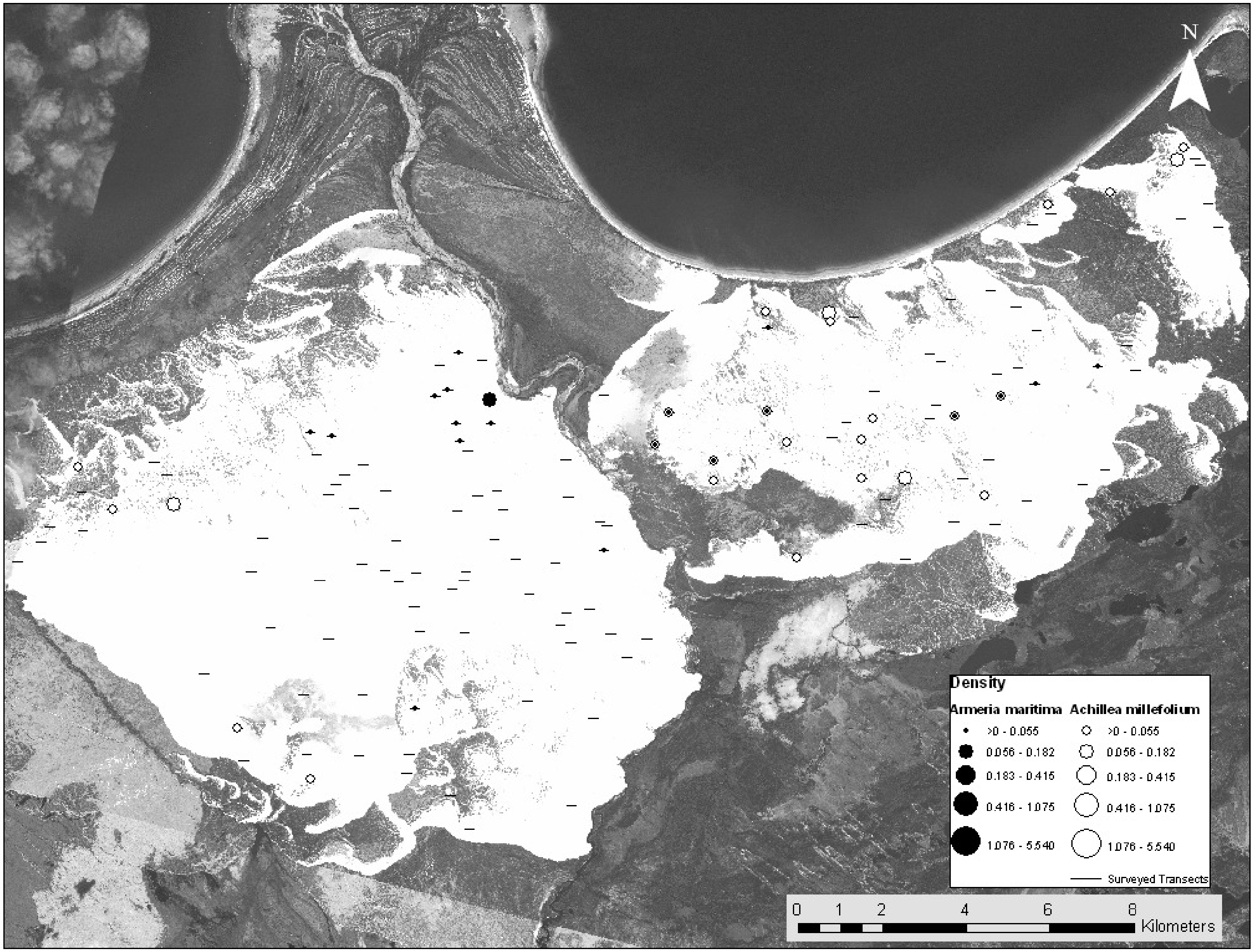


Figure 13: Distribution of *Achillea millefolium* and *Armeria maritima* in the William River, Thompson Bay, and Cantara Lake dune fields. Symbol size reflects species density (individuals m^{-2}) on each transect.

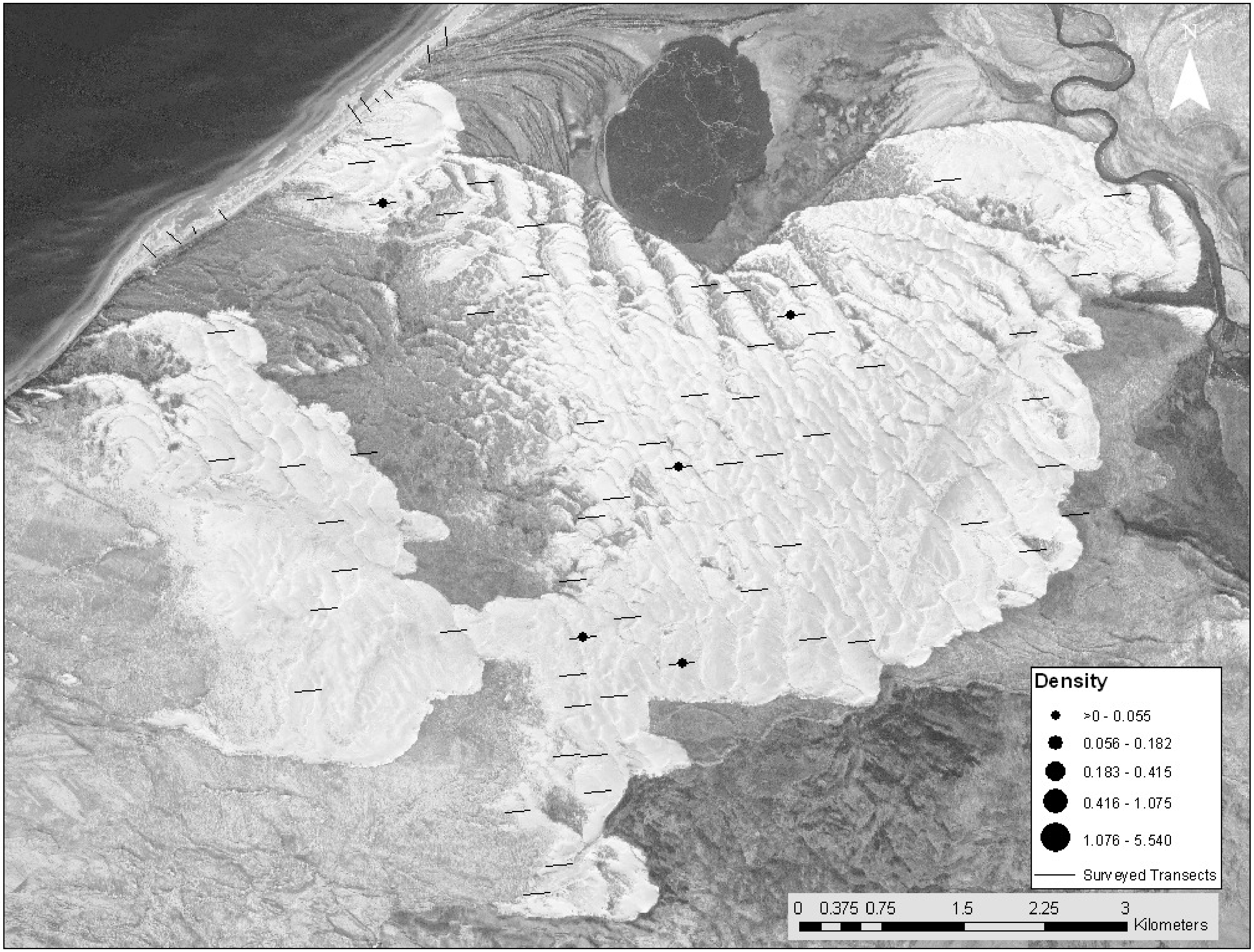


Figure 14: Distribution of *Armeria maritima* in the MacFarlane River dune field. Symbol size reflects species density (individuals m^{-2}) on each transect.

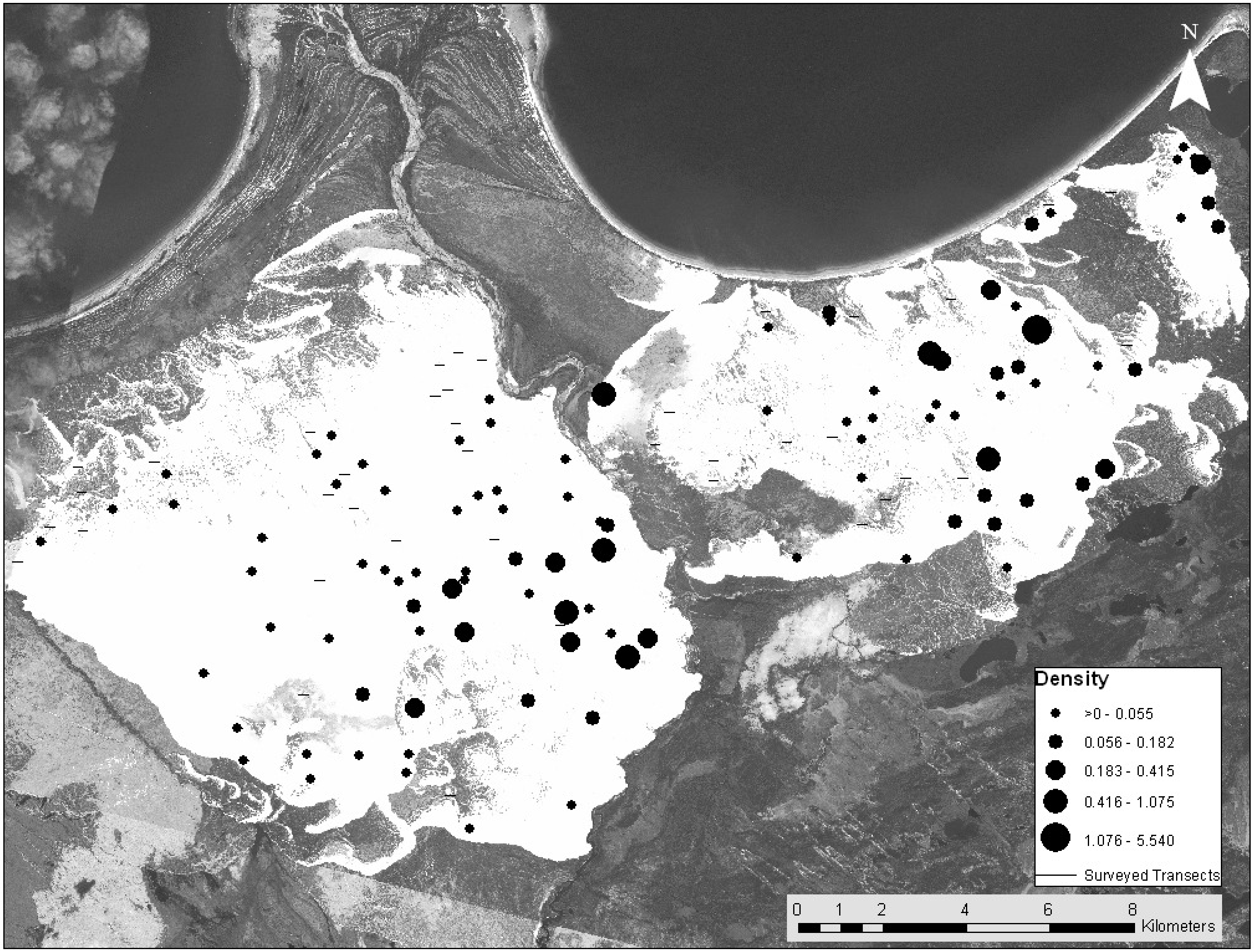


Figure 15: Distribution of *Deschampsia mackenzieana* in the William River, Thompson Bay, and Cantara Lake dune fields. Symbol size reflects species density (individuals m^{-2}) on each transect.

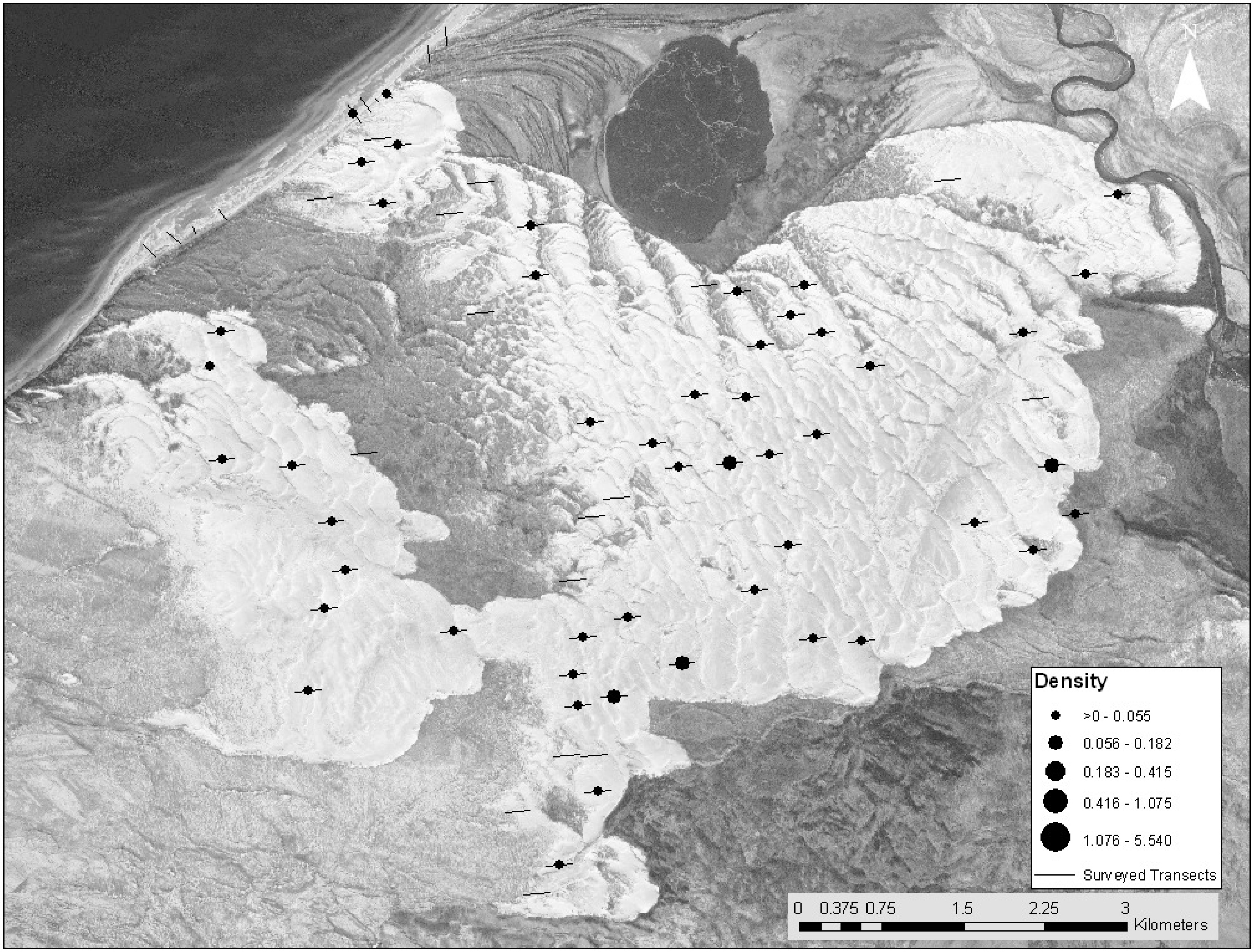


Figure 16: Distribution of *Deschampsia mackenzieana* in the MacFarlane River dune field. Symbol size reflects species density (individuals m^{-2}) on each transect.

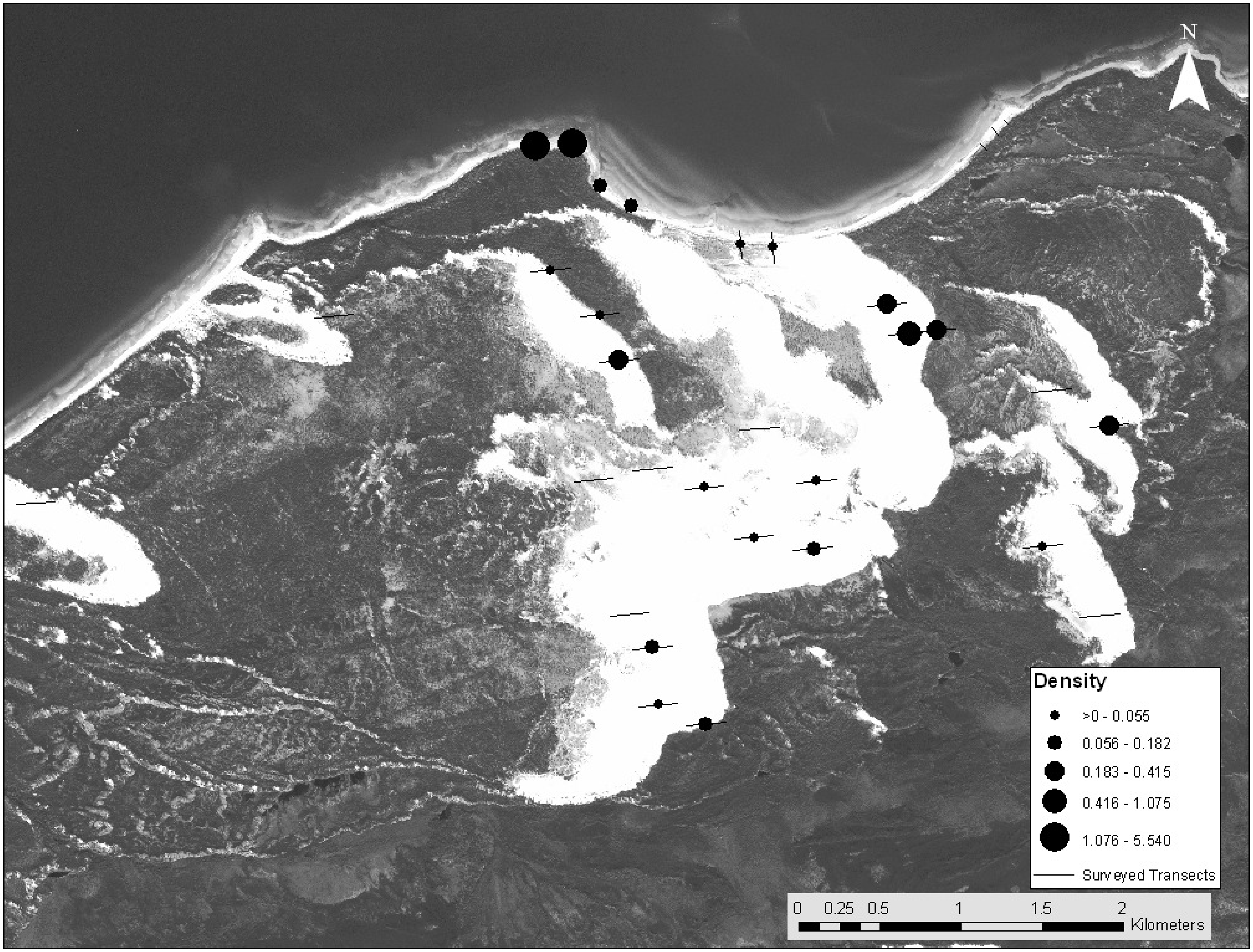


Figure 17: Distribution of Deschampsia mackenzieana in the Archibald Lake dune field. Symbol size reflects species density (individuals m^{-2}) on each transect.

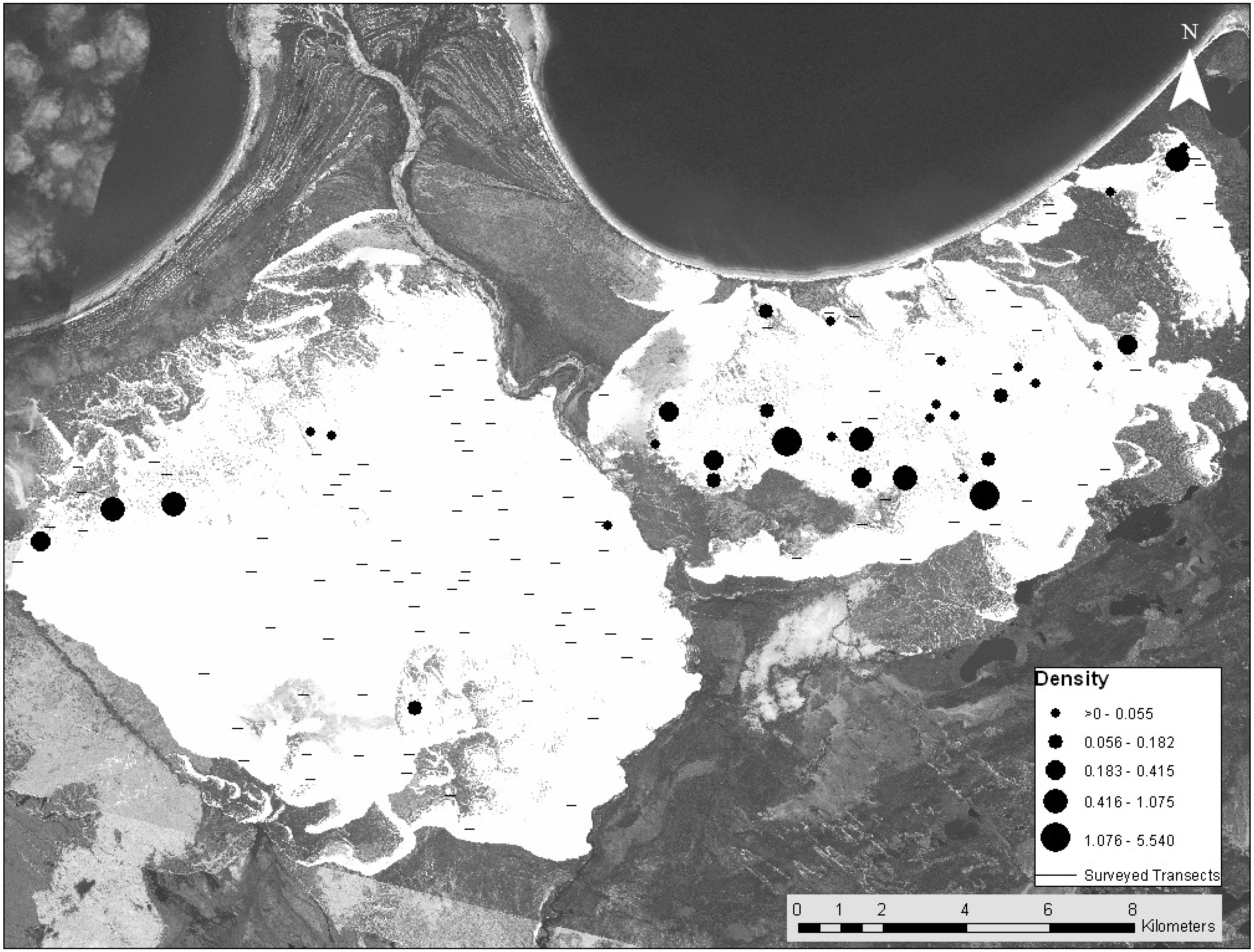


Figure 18: Distribution of *Salix brachycarpa* in the William River, Thompson Bay, and Cantara Lake dune fields. Symbol size reflects species density (individuals m^{-2}) on each transect.

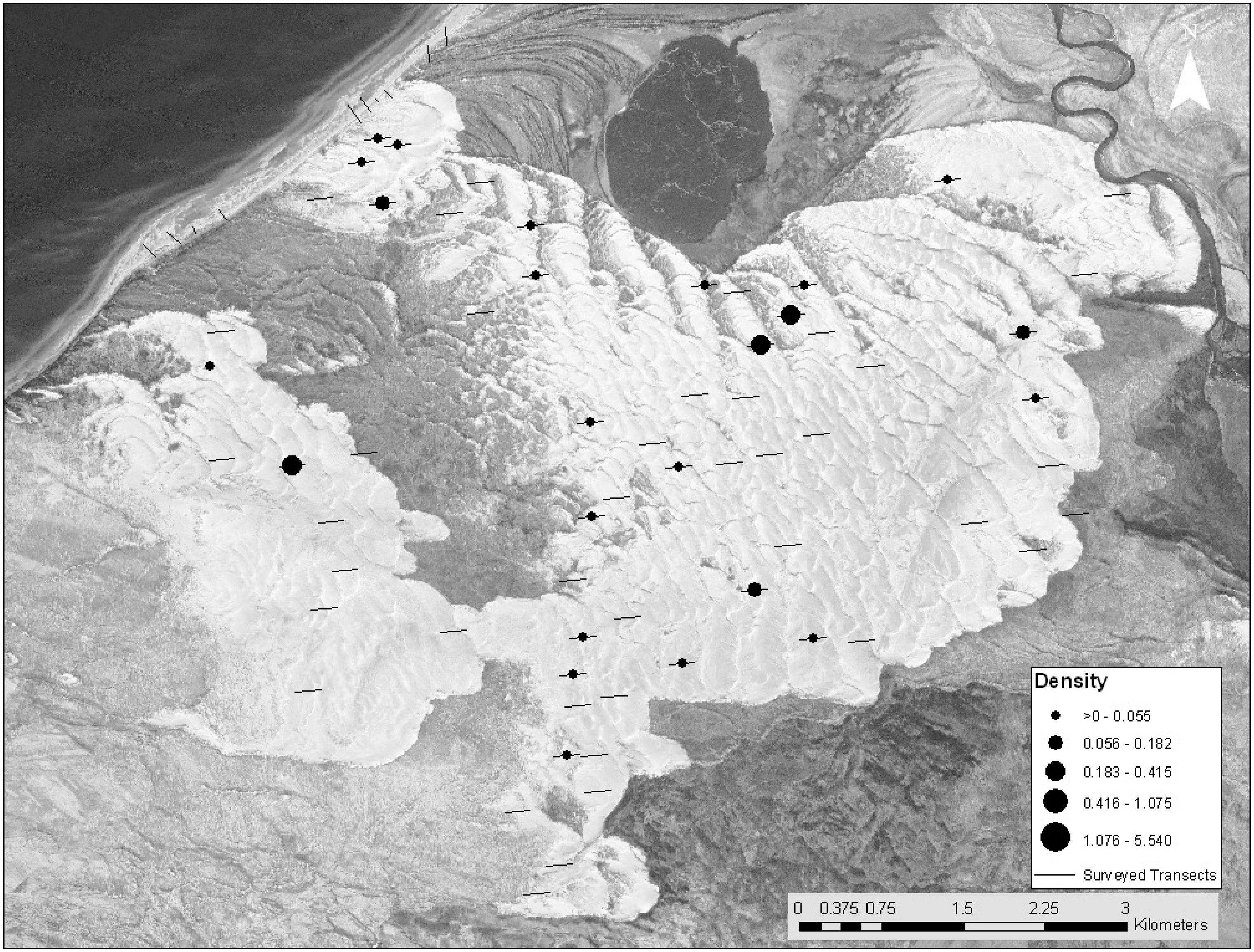


Figure 19: Distribution of *Salix brachycarpa* in the MacFarlane River dune field. Symbol size reflects species density (individuals m^{-2}) on each transect.

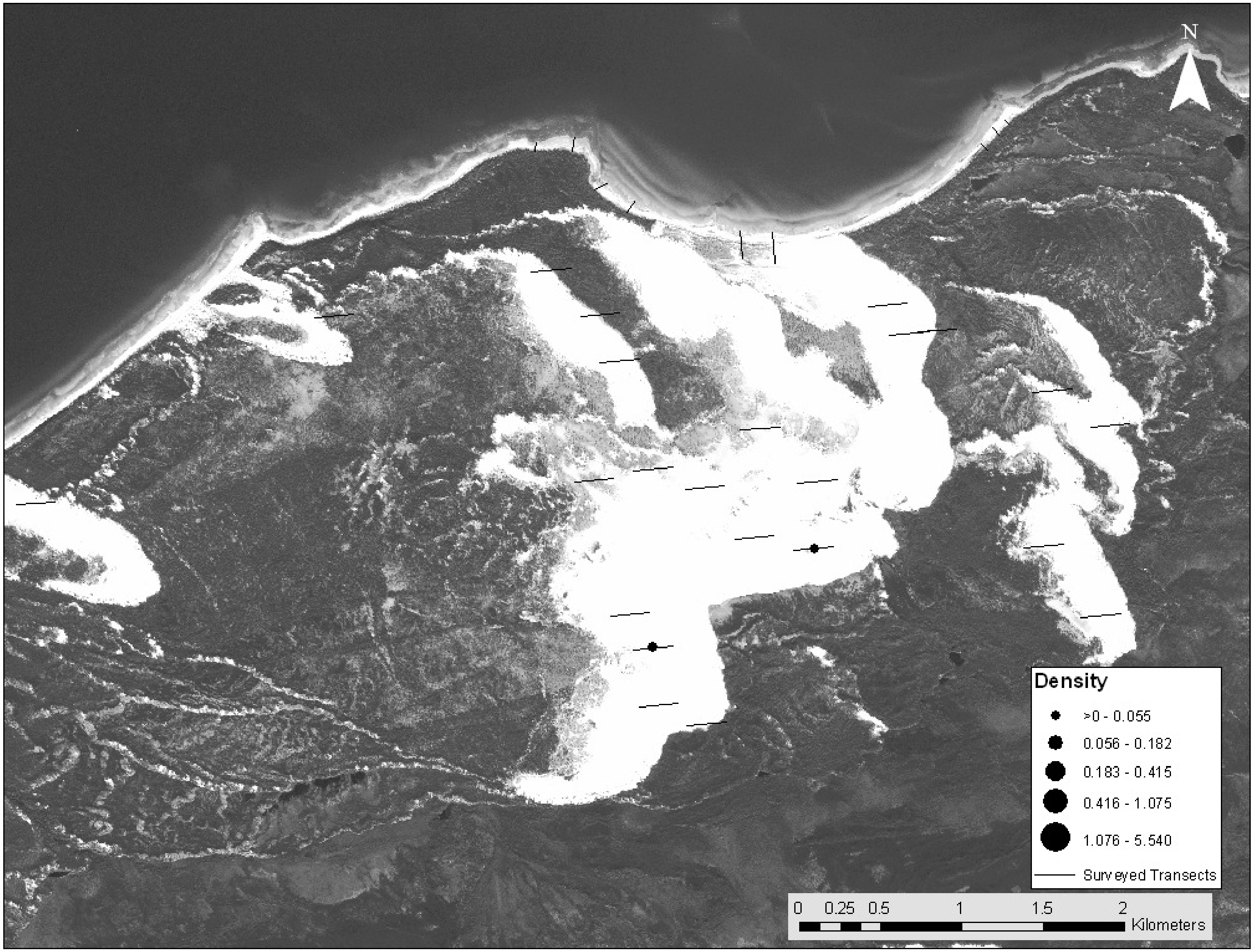


Figure 20: Distribution of *Salix brachycarpa* in the Archibald lake dune field. Symbol size reflects species density (individuals m^{-2}) on each transect.

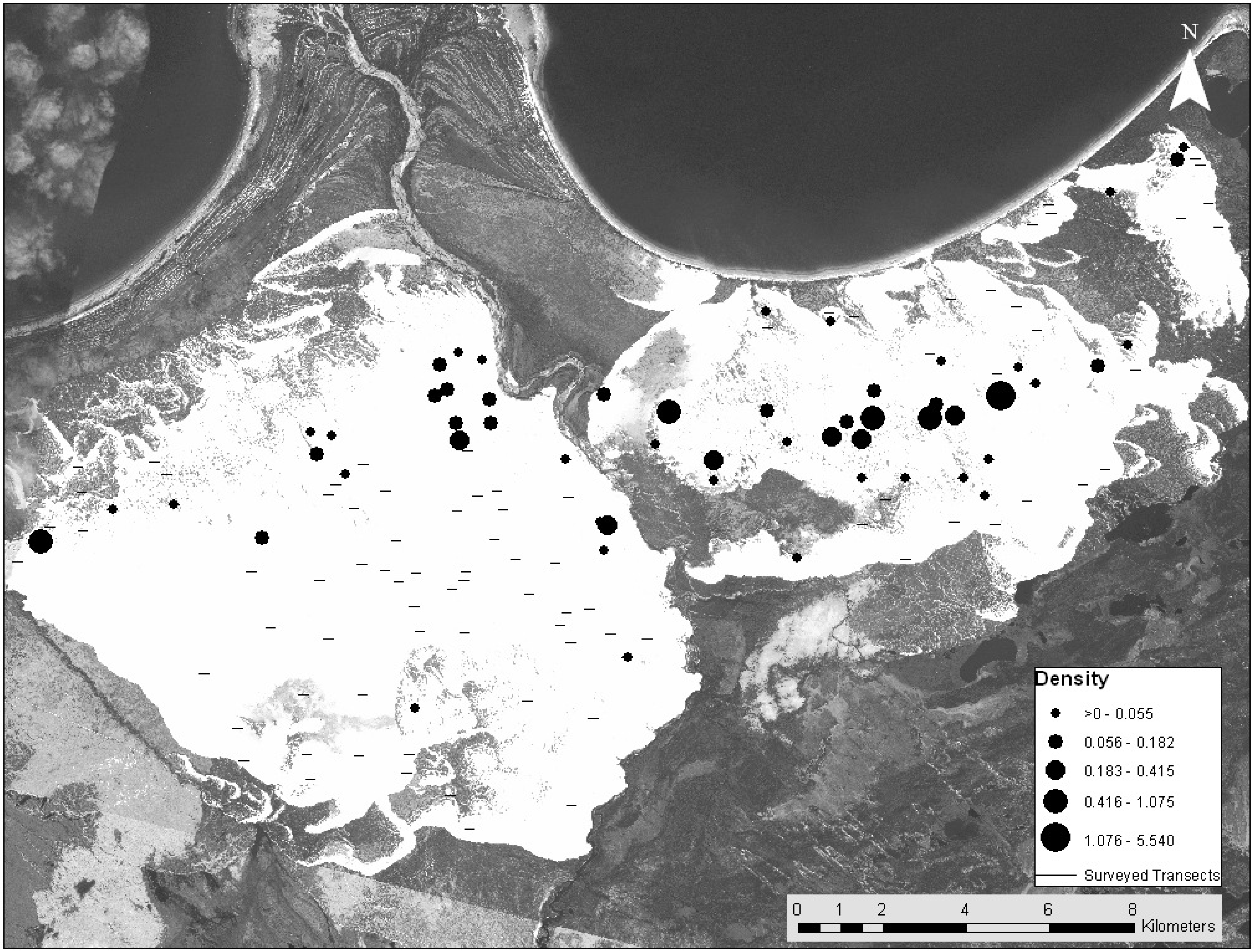


Figure 21: Distribution of *Salix silicicola* in the William River, Thompson Bay, and Cantara Lake dune fields. Symbol size reflects species density (individuals m^{-2}) on each transect.

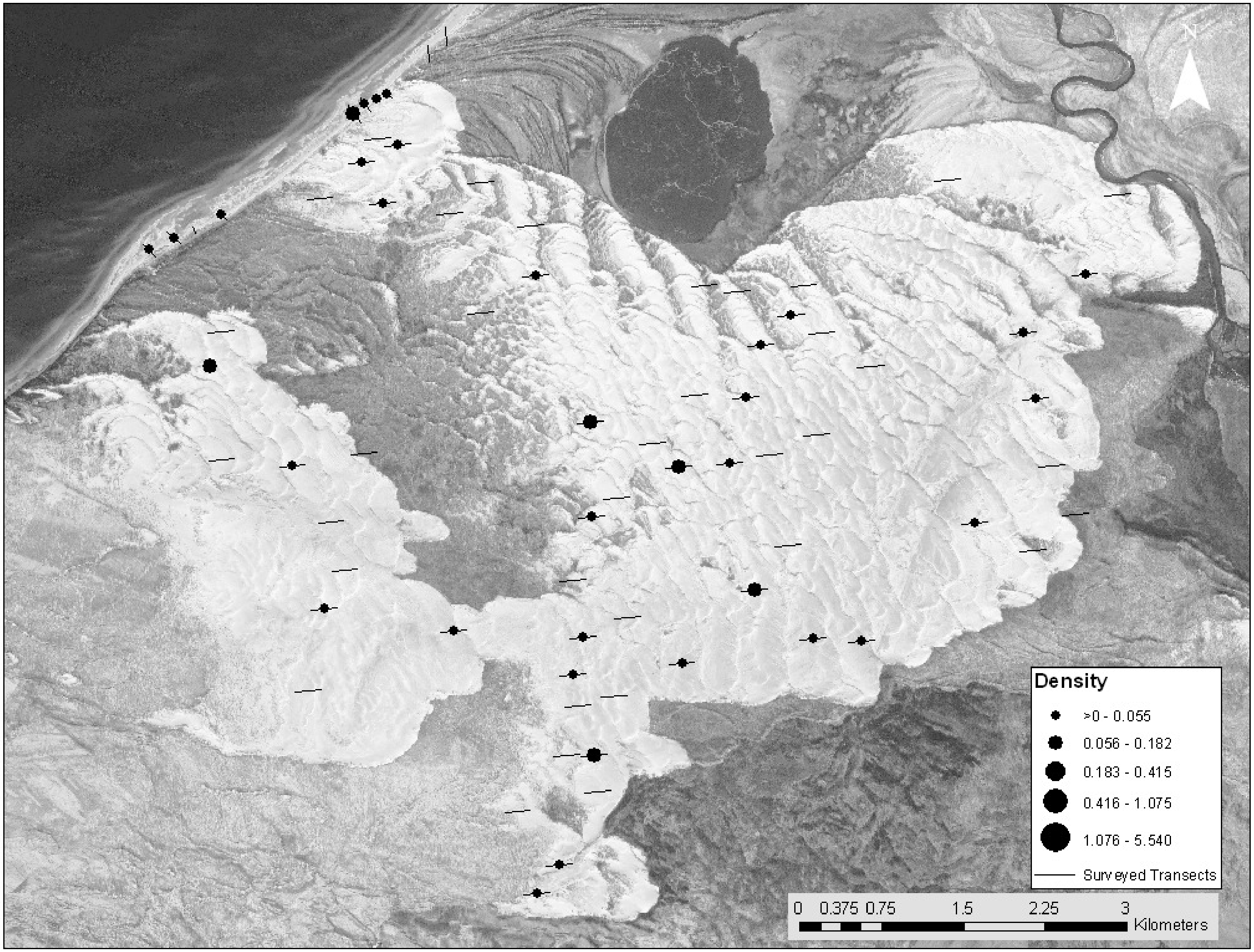


Figure 22: Distribution of *Salix silicicola* in the MacFarlane River dune field. Symbol size reflects species density (individuals m^{-2}) on each transect.

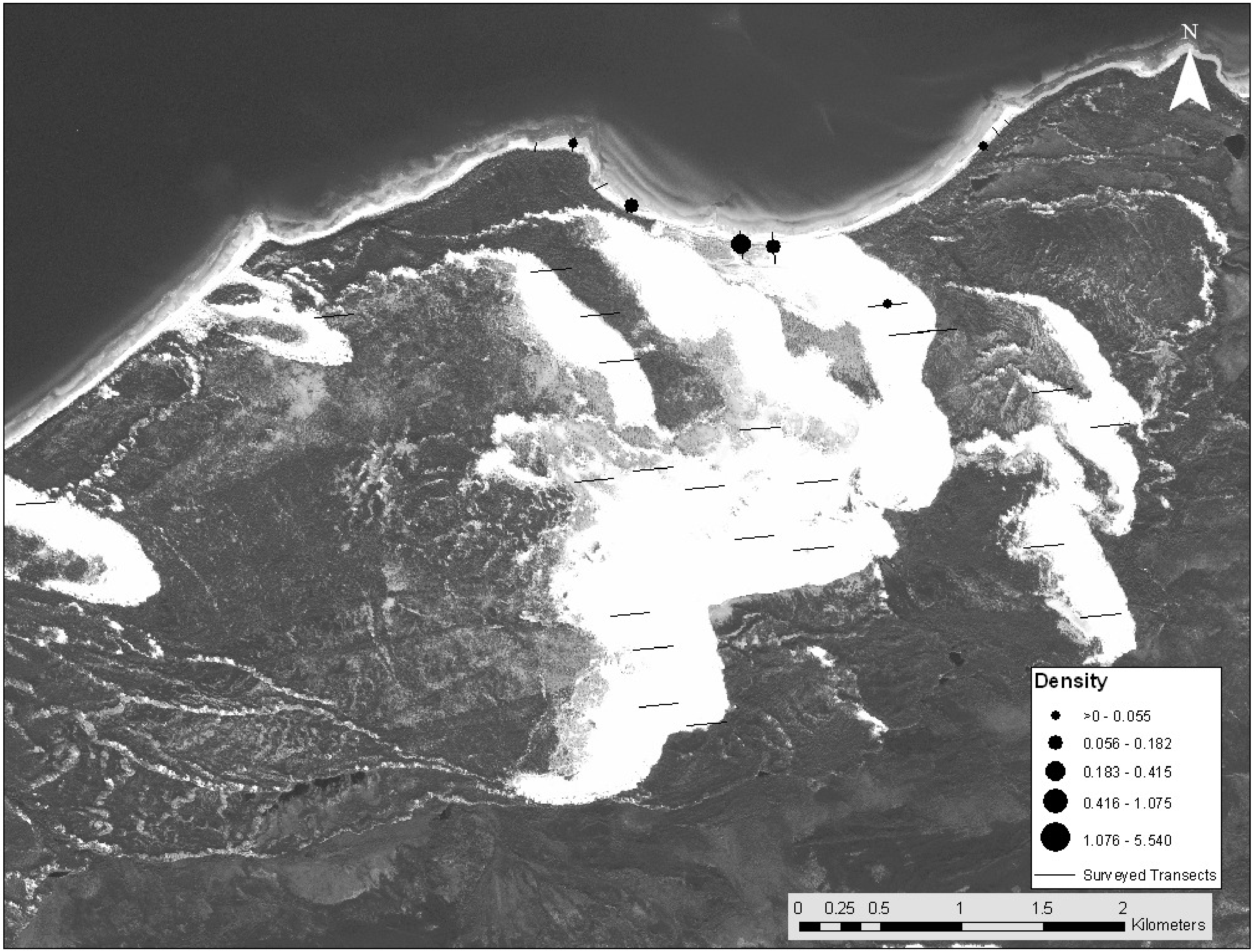


Figure 23: Distribution of *Salix silicicola* in the Archibald Lake dune field. Symbol size reflects species density (individuals m^{-2}) on each transect.

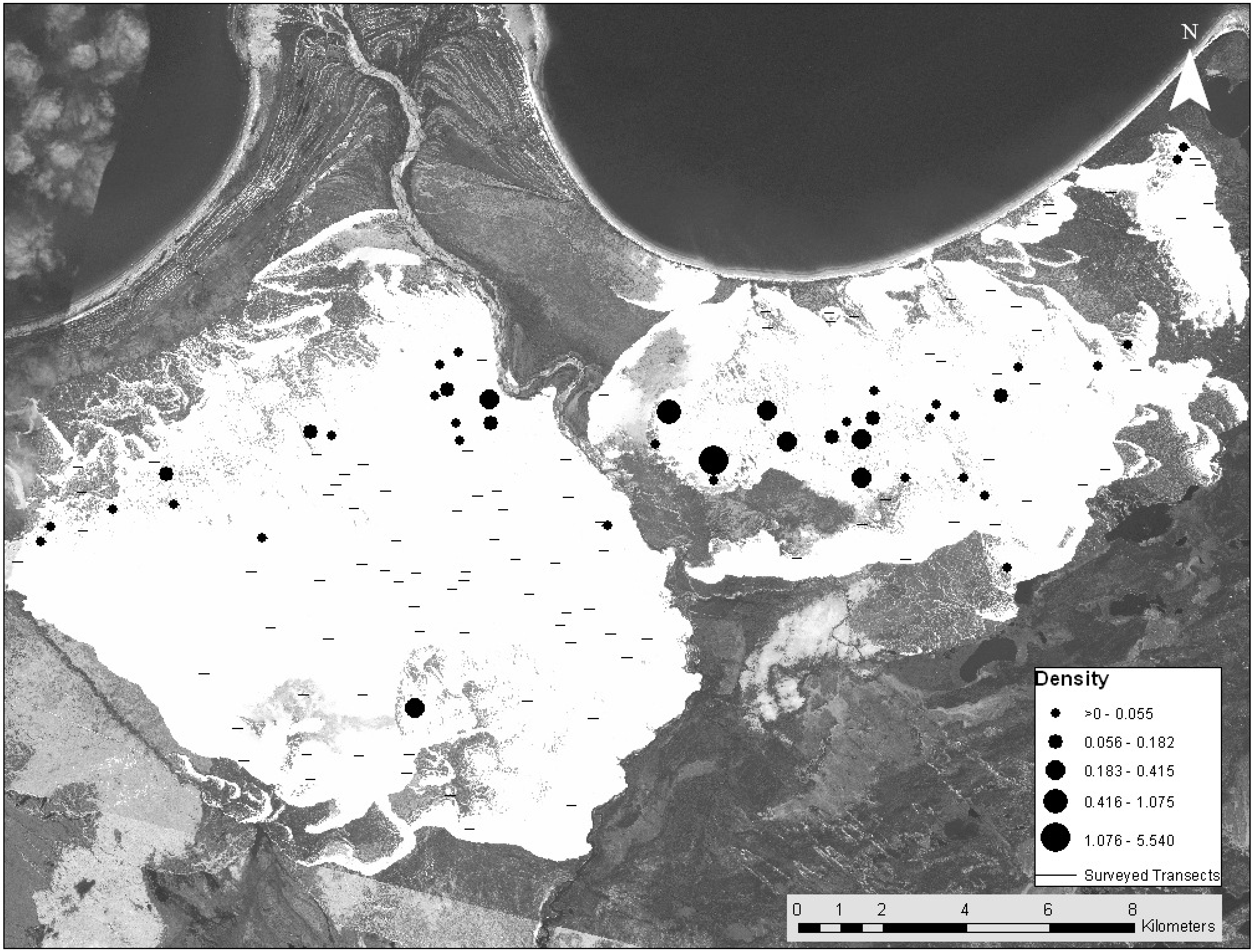


Figure 24: Distribution of *Salix turnorii* in the William River, Thompson Bay, and Cantara Lake dune fields. Symbol size reflects species density (individuals m^{-2}) on each transect.

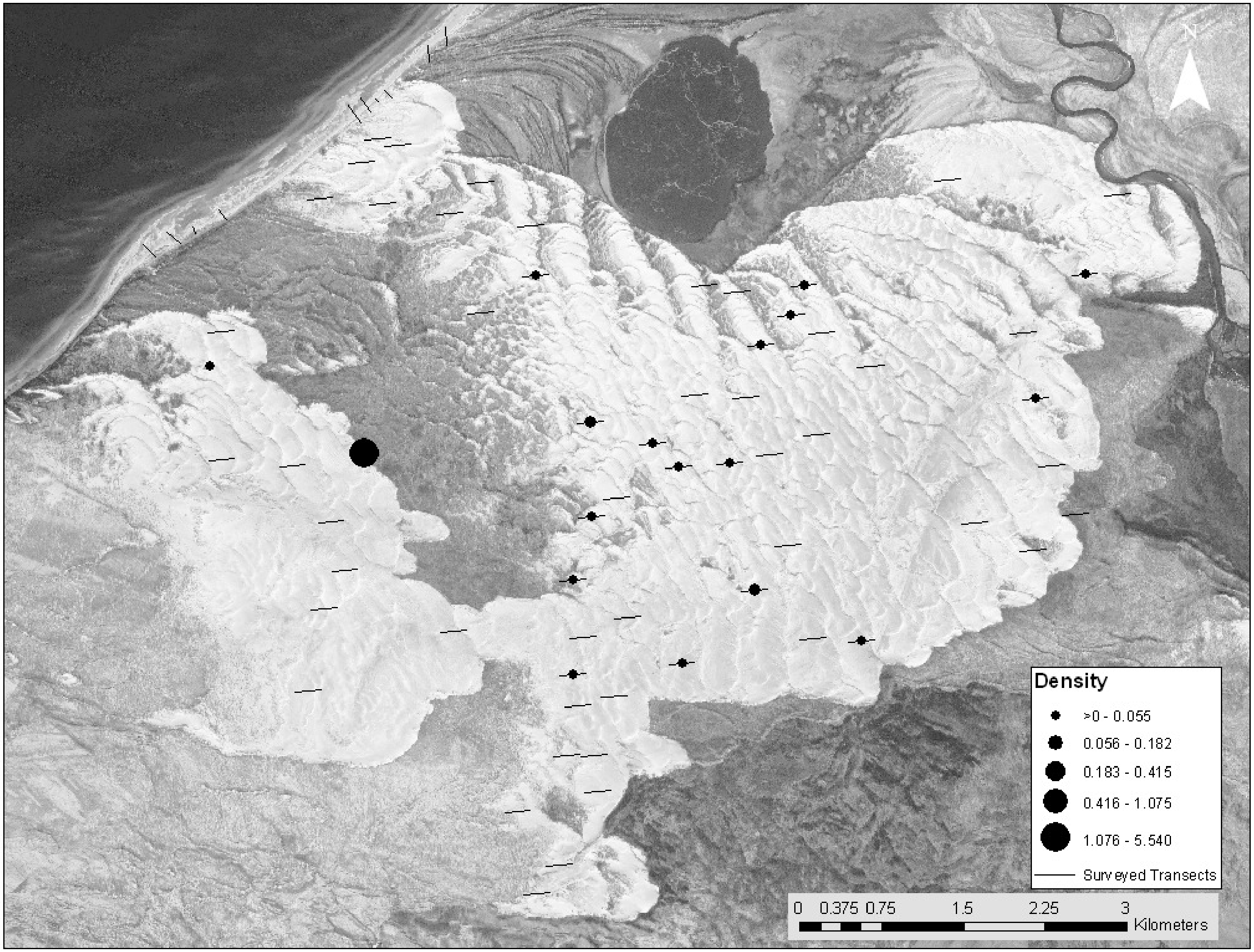


Figure 25: Distribution of *Salix turnorii* in the MacFarlane River dune field. Symbol size reflects species density (individuals m^{-2}) on each transect.

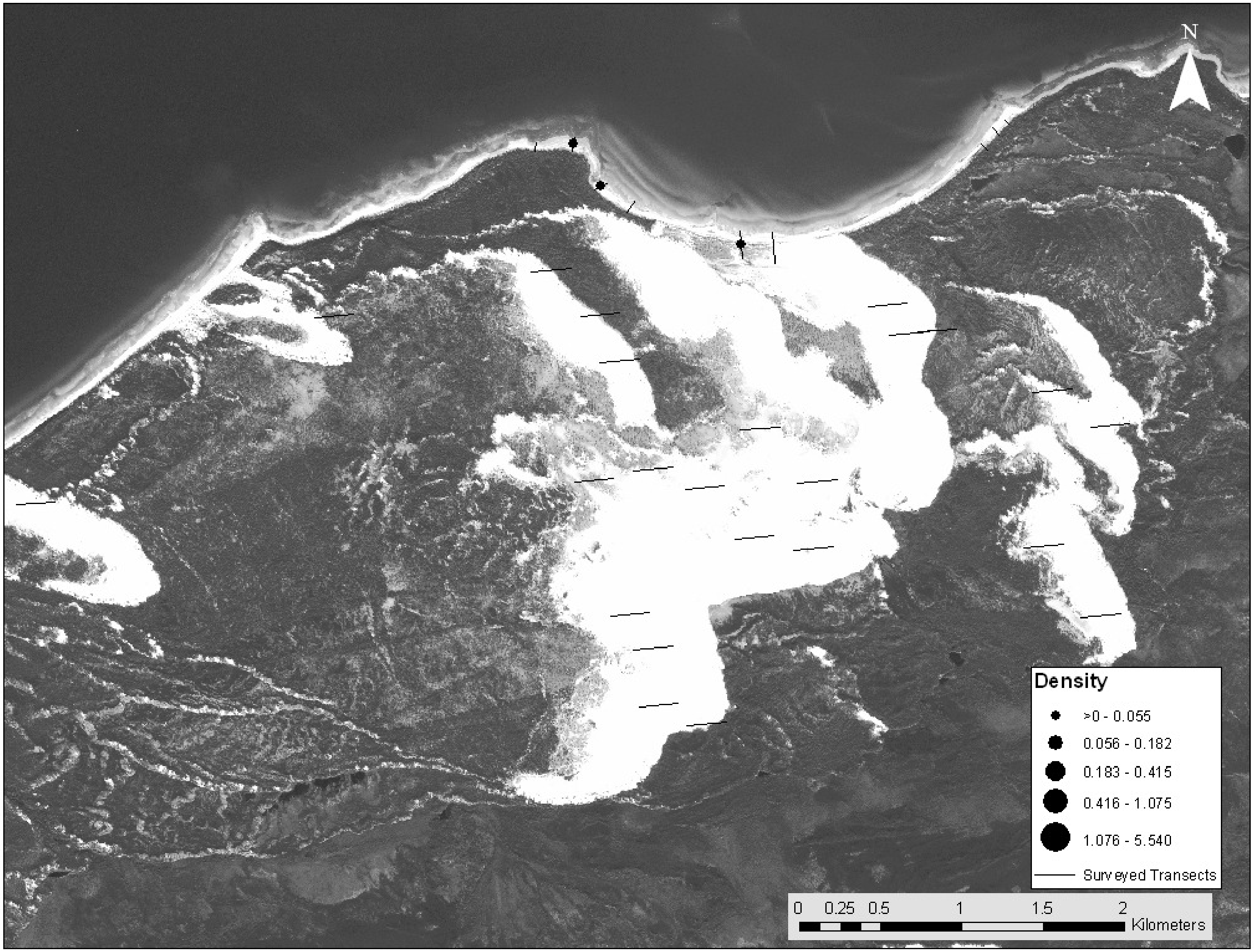


Figure 26: Distribution of Salix turnorii in the Archibald Lake dune field. Symbol size reflects species density (individuals m^{-2}) on each transect.

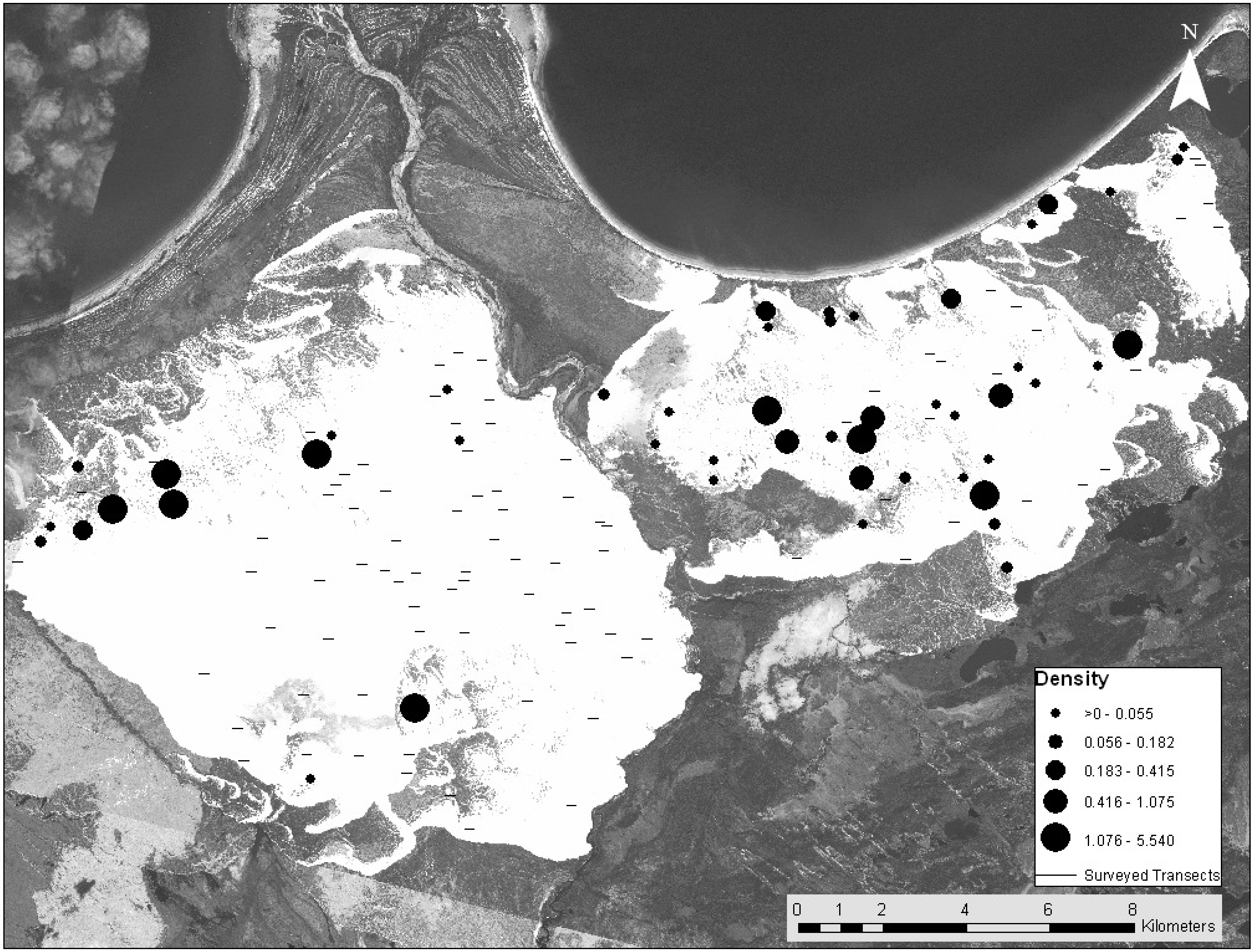


Figure 27: Distribution of *Salix tyrrellii* in the William River, Thompson Bay, and Cantara Lake dune fields. Symbol size reflects species density (individuals m^{-2}) on each transect.

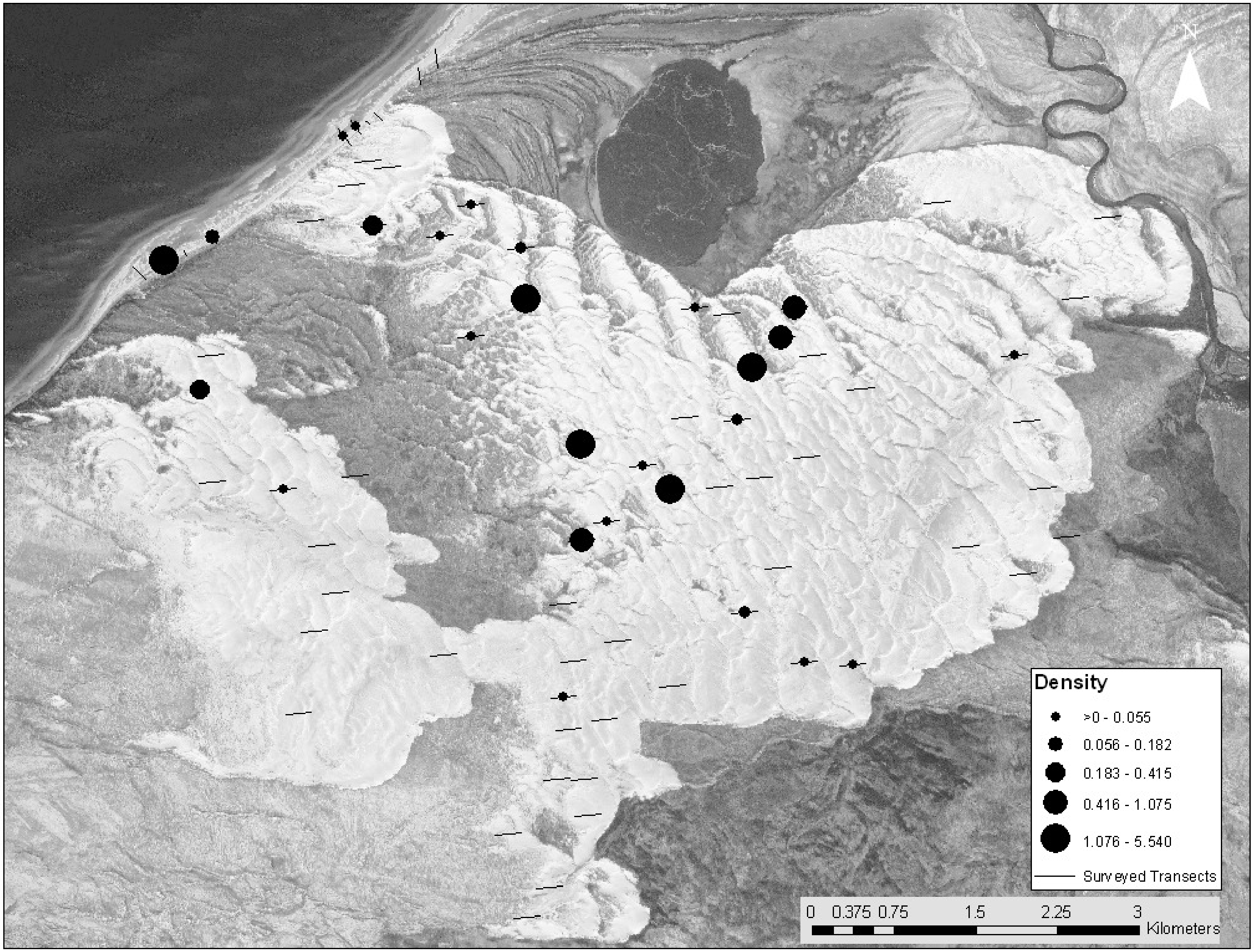


Figure 28: Distribution of *Salix tyrrellii* in the MacFarlane River dune field. Symbol size reflects species density (individuals m^{-2}) on each transect.

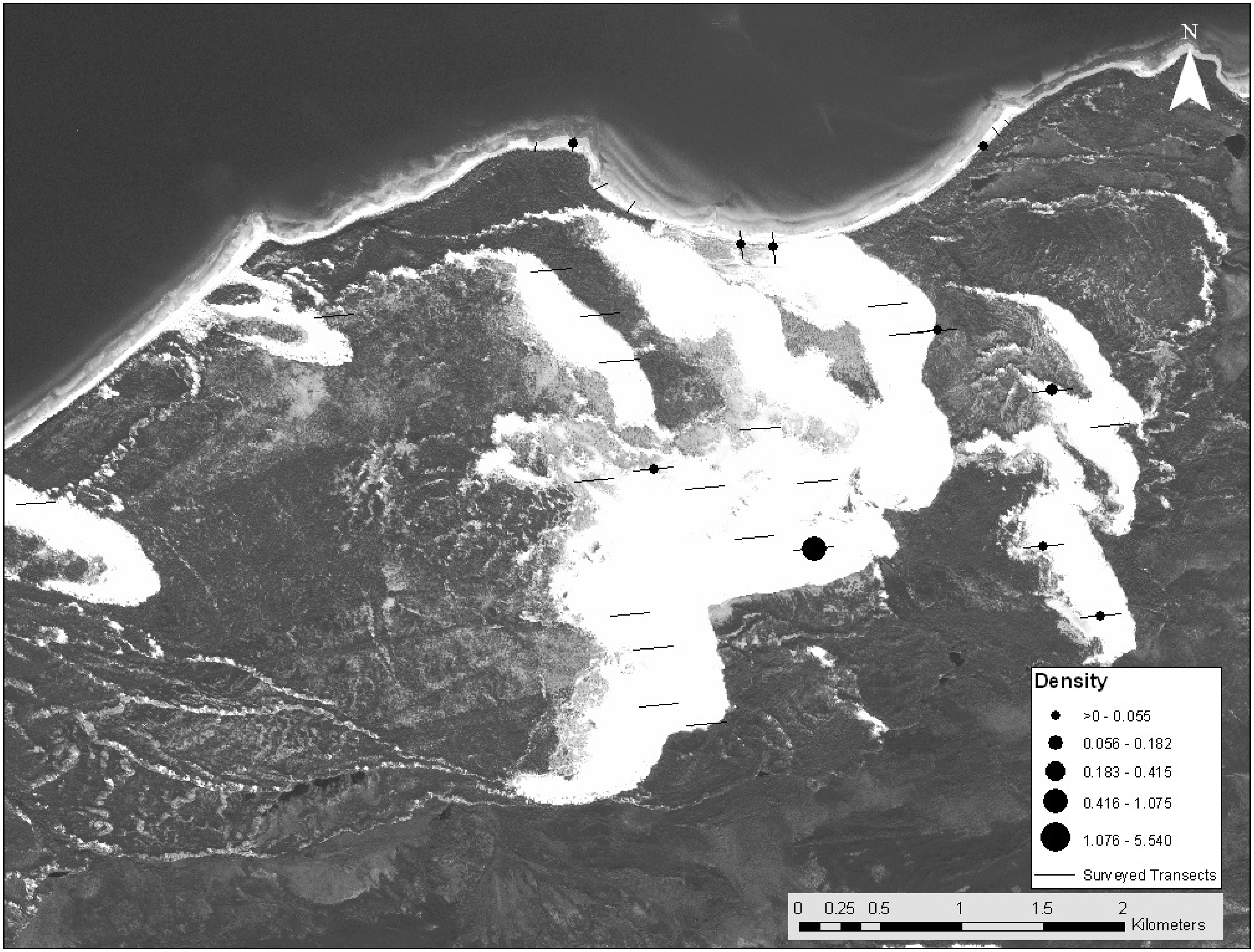


Figure 29: Distribution of *Salix tyrrellii* in the Archibald Lake dune field. Symbol size reflects species density (individuals m^{-2}) on each transect.

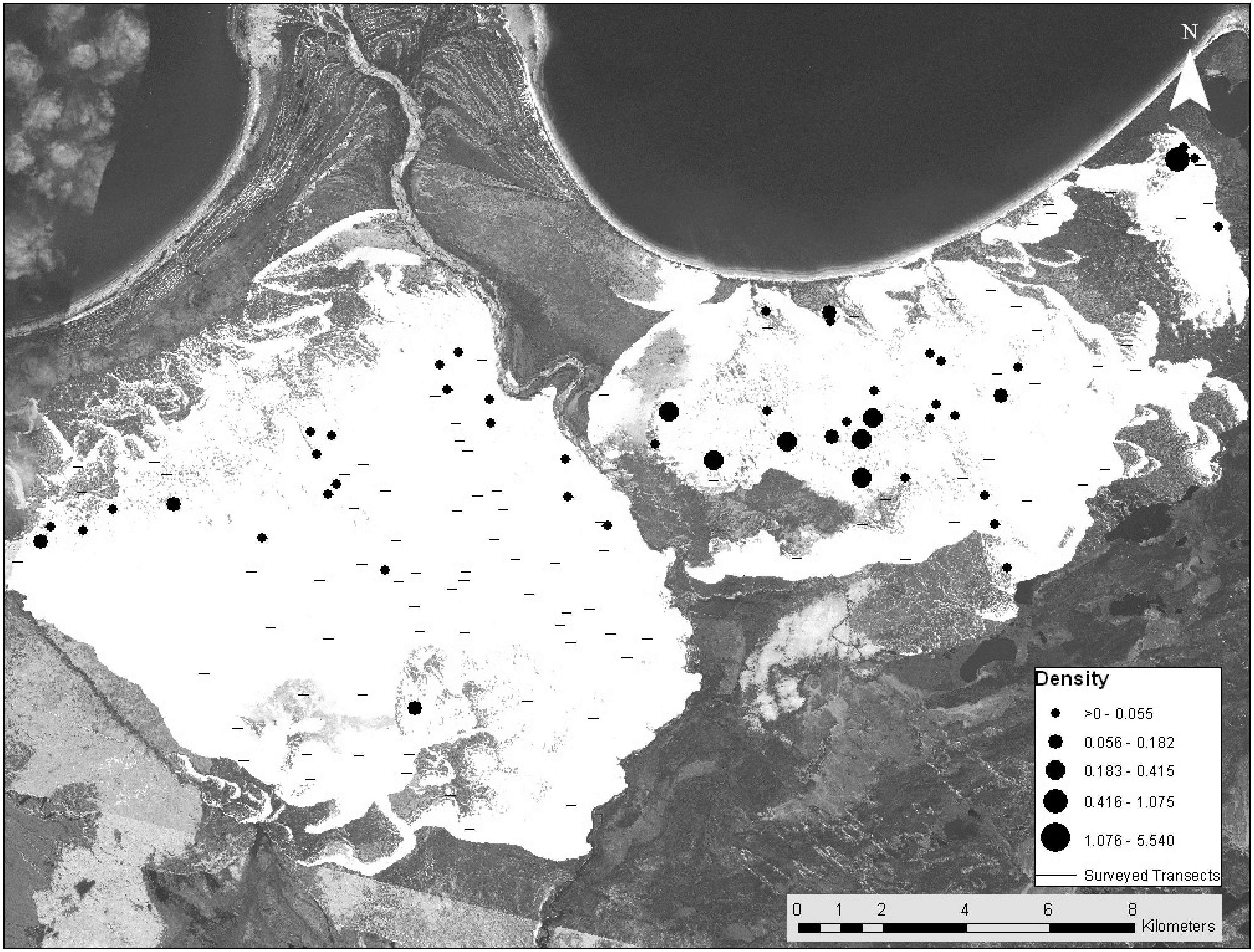


Figure 30: Distribution of *Stellaria arenicola* in the William River, Thompson Bay, and Cantara Lake dune fields. Symbol size reflects species density (individuals m^{-2}) on each transect.

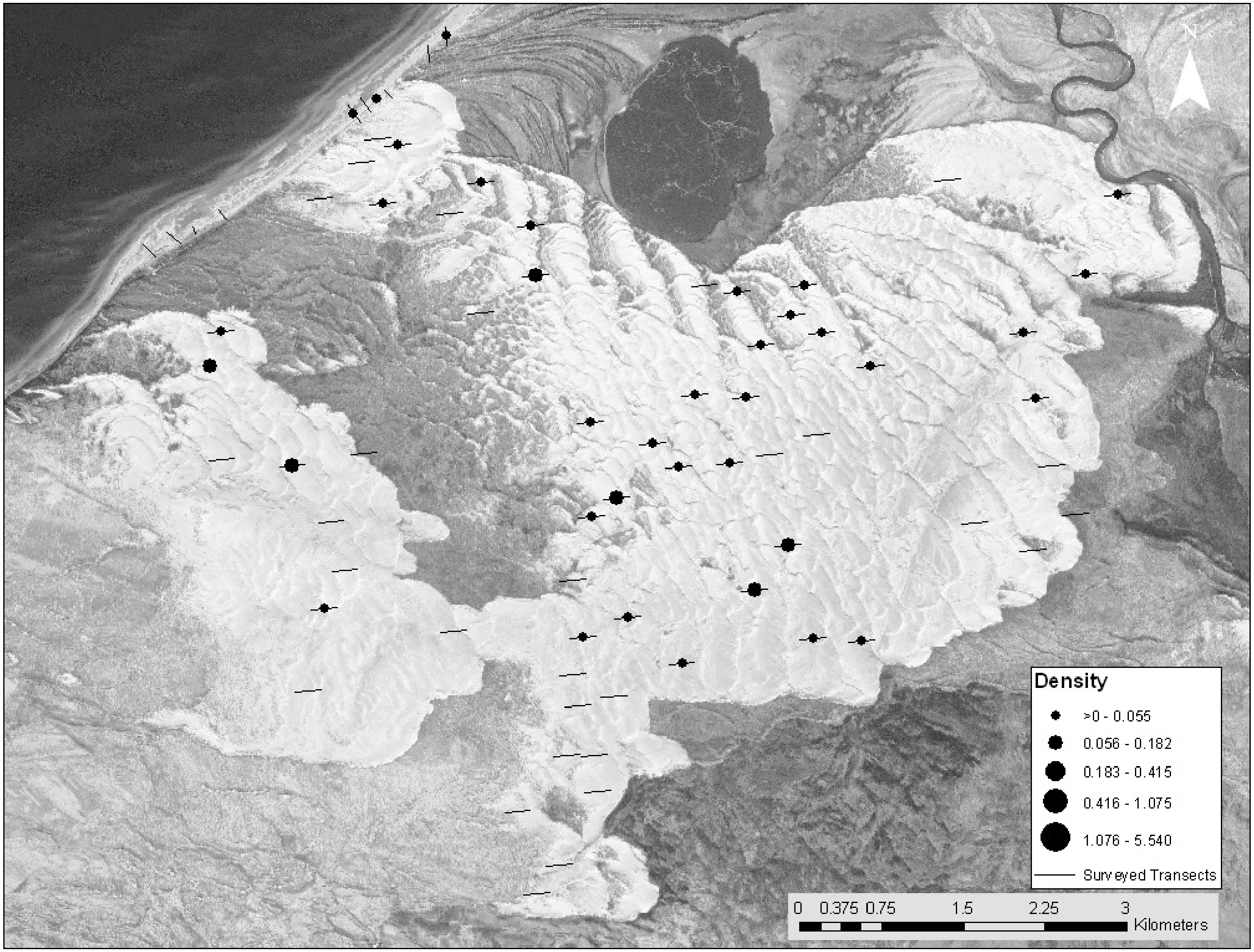


Figure 31: Distribution of *Stellaria arenicola* in the MacFarlane River dune field. Symbol size reflects species density (individuals m^{-2}) on each transect.

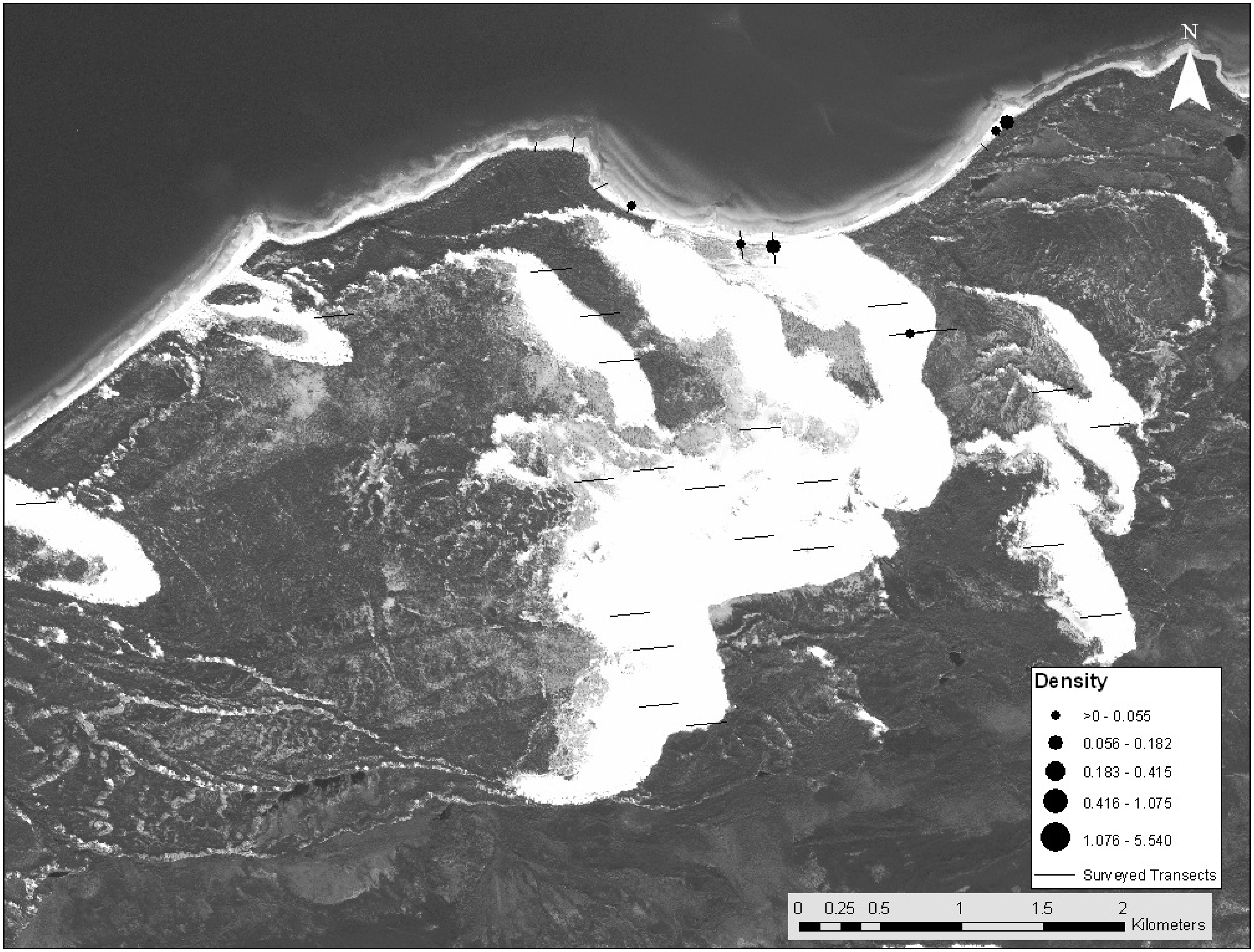


Figure 32: Distribution of *Stellaria arenicola* in the Archibald Lake dune field. Symbol size reflects species density (individuals m^{-2}) on each transect.

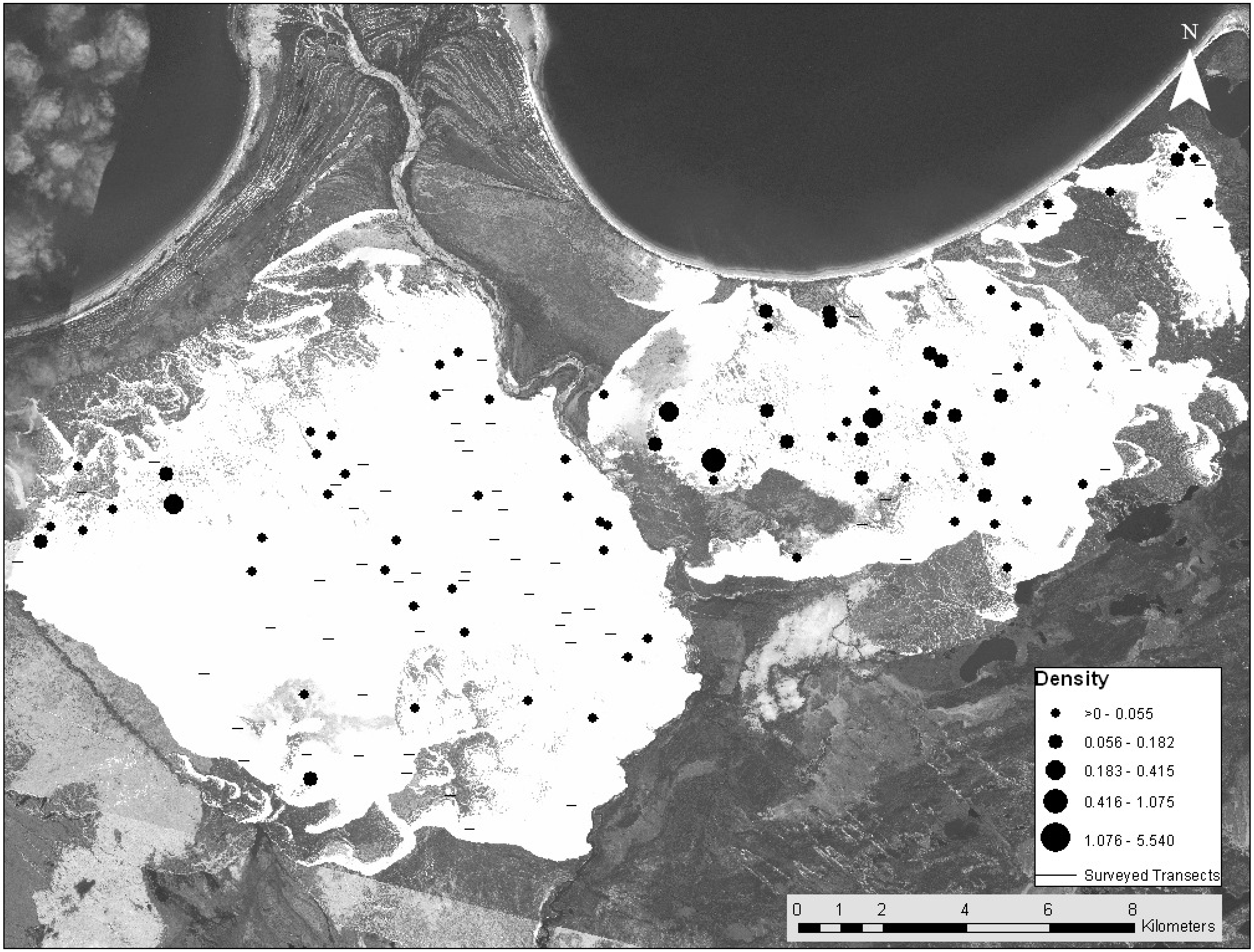


Figure 33: Distribution of *Tanacetum huronense* in the William River, Thompson Bay, and Cantara Lake dune fields. Symbol size reflects species density (individuals m^{-2}) on each transect.

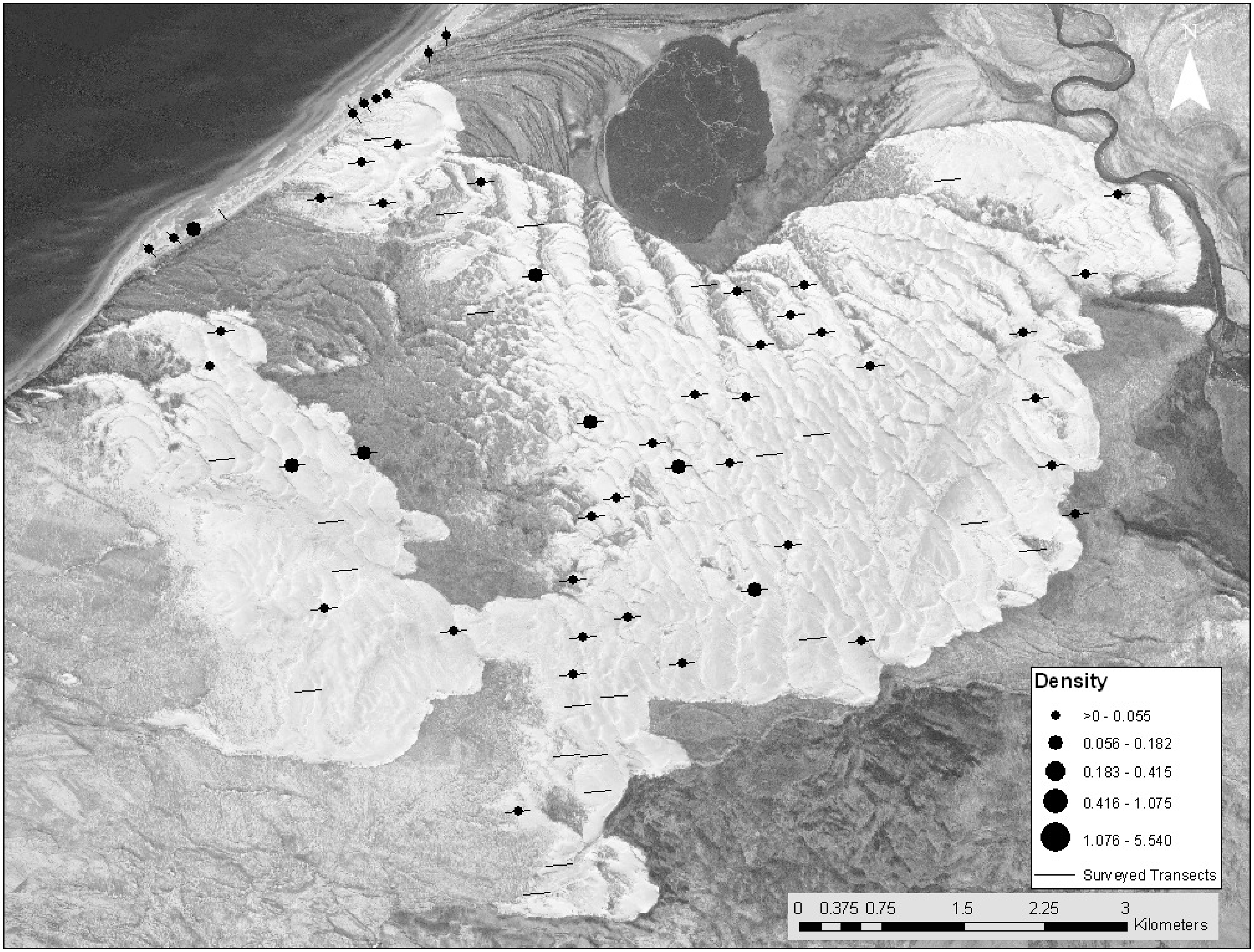


Figure 34: Distribution of *Tanacetum huronense* in the MacFarlane River dune field. Symbol size reflects species density (individuals m^{-2}) on each transect.

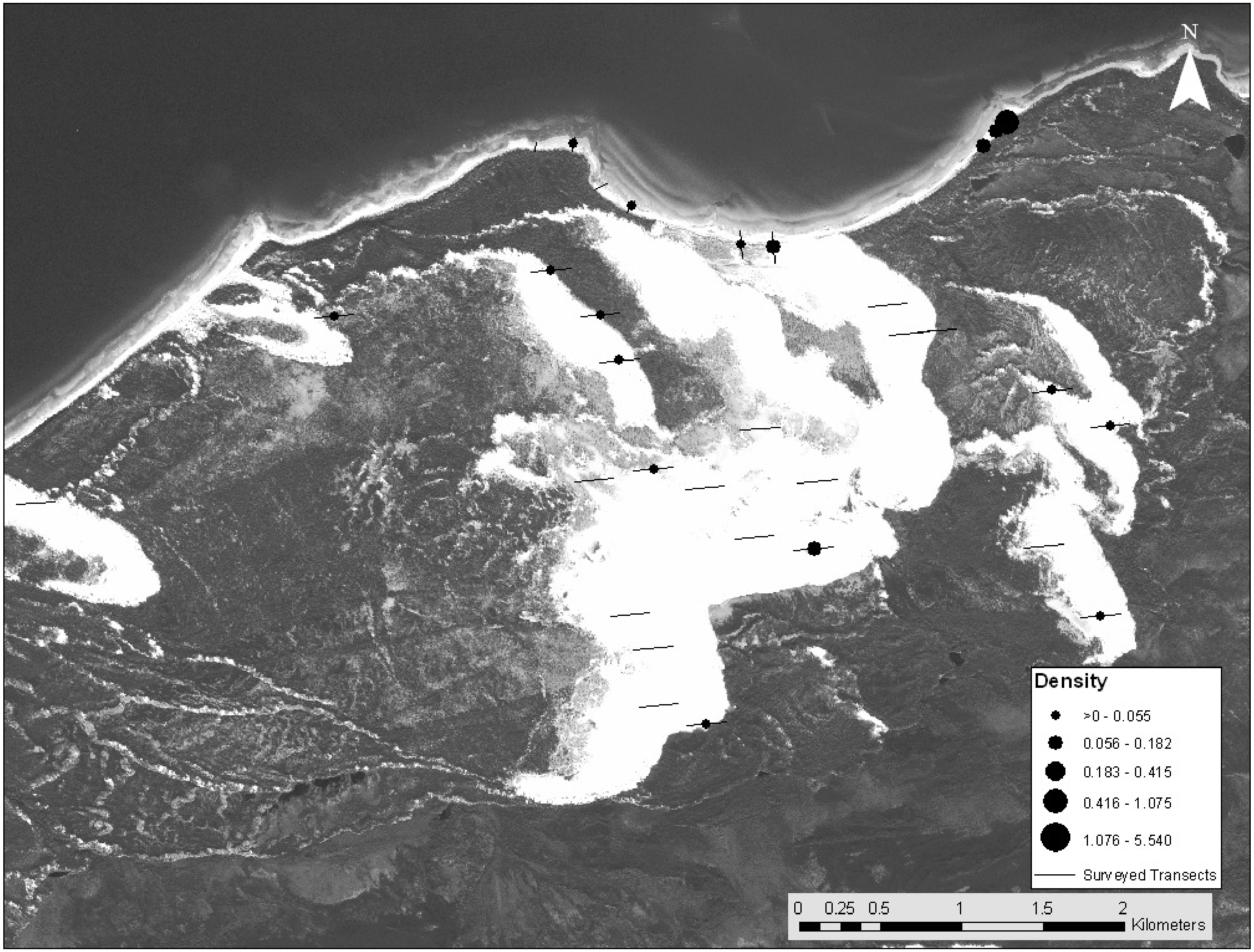


Figure 35: Distribution of *Tanacetum huronense* in the Archibald Lake dune field. Symbol size reflects species density (individuals m^{-2}) on each transect.

Endemic Populations on Lake Athabasca Beaches

A key recommendation of Lamb (2010) was the survey of the beaches of Lake Athabasca for endemic populations. To that end 19 beach transects ranging in length from 46m to 209m were surveyed for a total of 2.369km of transect. Habitats recorded on these transects included FFSB (the forest fringe), BASW (backswamps), DYSA (dynamic slopes), PEBE (pebble beaches), and SABE (sandy beaches) (Table 6). Due to the limited number of transects surveyed no statistically robust analysis of occurrence rates or habitat affinities could be done. Occurrence rates and mean densities from the beach transects are presented in Table 14.

Seven of the endemic species had high frequency and abundance on the beaches (Table 14). The exceptions were *Achillea millefolium* and *Armeria maritima* with no observations and *Salix turnorii* with only 9 individuals observed on 3 of the 19 transects. These data highlight the importance of the beaches of Lake Athabasca as a habitat for the endemic flora.

Table 14: Number of endemic individuals observed on beach transcts, the % ot transects where the species were observed, and average abundance (individuals m^{-2}) across all beach transects and only within transects occupied by that species.

Species	# Individuals and % of Transects Occupied	Avg. Abundance m^{-2}	Avg. Abundance m^{-2} in Occupied Transects
Achillea millefolium	0 (0)	0	n/a
Armeria maritima	0 (0)	0	n/a
Deschampsia mackenzieana	1582 (42.11)	0.259	0.616
Salix brachycarpa	221 (21.05)	0.010	0.048
Salix silicicola	1095 (63.16)	0.037	0.059
Salix turnorii	9 (15.79)	<0.001	0.003
Salix tyrrellii	20146 (63.16)	0.745	1.179
Stellaria arenicola	107 (42.11)	0.013	0.031
Tanacetum huronense	443 (84.21)	0.075	0.089

Community Level Patterns

Habitats differed in their average species richness and endemic species composition. Figure 36 displays the frequency of habitat segments with zero through nine endemic species observed, and Figure 37 summarizes the average species richness in each of the habitat types. Most habitat segments (31.9%) were empty or contained only one species (31.0). Smaller numbers of segments contained more complex endemic communities with multiple species. Species richness was lowest in the gravel pavements and wood habitats, higher in the lichen, and high and low slope dune habitats, and highest in the wet and saline interdune slacks. The best model was better than a null model (χ^2_2 = 50.040, p<0.0001) and included three groups of habitats (combined GRPV and WOOD, with a mean richness per transect segment of 0.89 ±1.27sd; combined HSDN, LSDN, and LICH with a mean richness of 1.60 ±1.67sd, and combined SIDS and WIDS with a mean richness of 3.02 ±2.11sd)

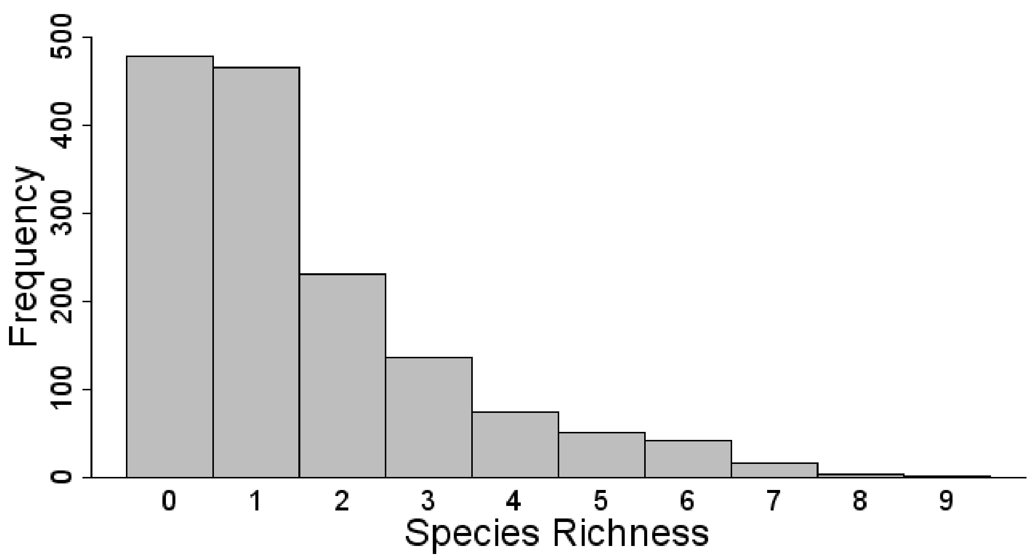


Figure 36: Frequency of habitat segments observed with endemic species richness ranging from zero through nine species co-occurring.

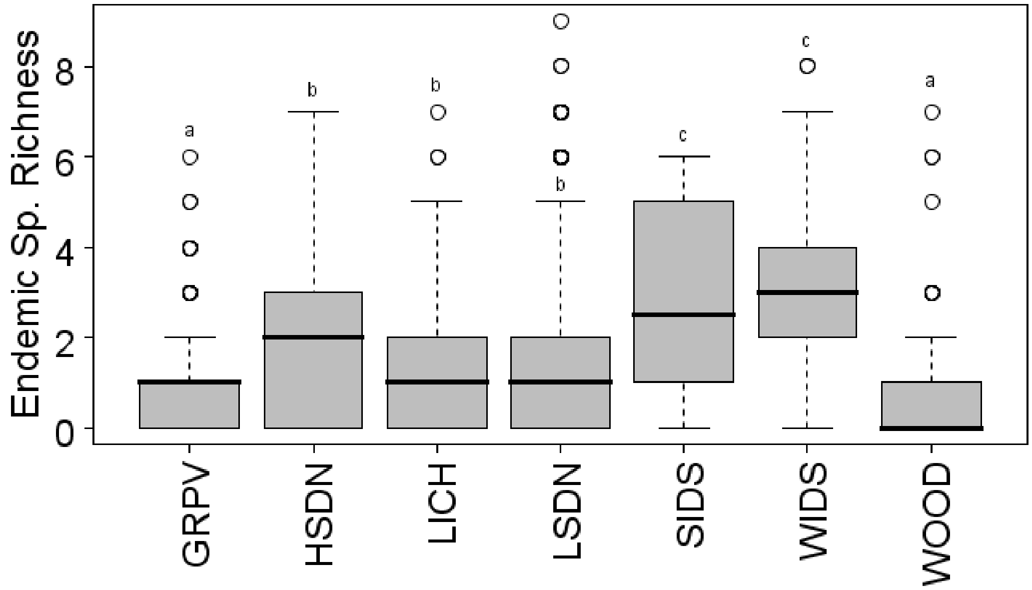
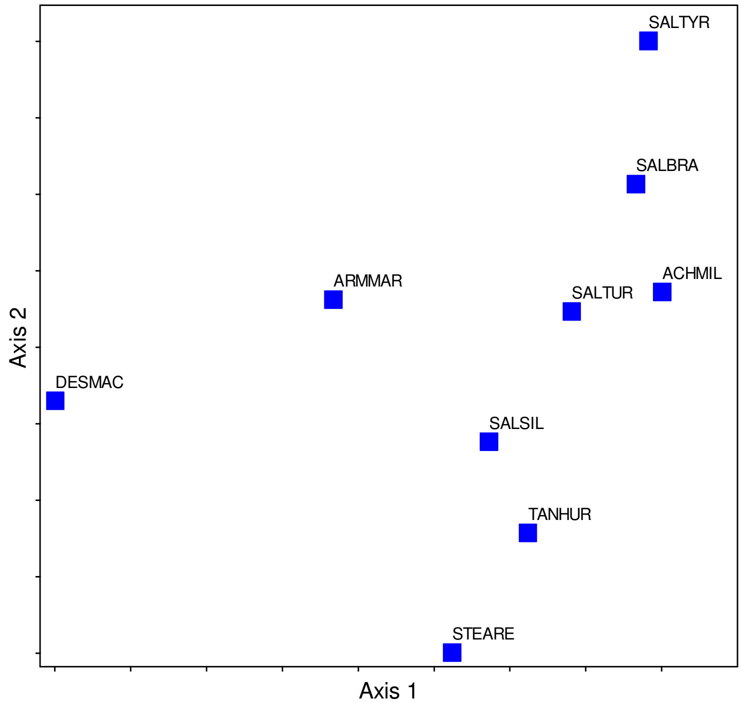


Figure 37: Endemic richness (number of species with at least one individual present in a habitat segment) in each major habitat type. The letters above the whiskers indicate groups of habitats that differ significantly in their mean species richness. The thick horizontal line is the median, and the lower and upper bounds of the box represent the 25th and 75th percentiles respectively.

Species co-occurrence patterns were analyzed using a non-metric multidimensional scaling ordination. All habitat segments with at least one endemic occurrence were included in the ordination, with endemic presence or absence. An optimal 3 axis solution was identified with a final stress of 12.346 and final instability of <0.00001. The ordination axes explained 45.0, 24.1, and 21.9 percent of the variation in the distance matrix respectively for a total $r^2 = 0.909$ (Figure 38). The ordinations indicate that *Deschampsia mackenzieana* and to a lesser extent *Armeria maritima* had very different patterns of occurrence from the remainder of the species in this study. Figure 39 shows that *Deschampsia* was frequently encountered in habitat segments where other endemic species were absent, while the other eight endemic species typically were found co-occurring with one or more of the other endemics.



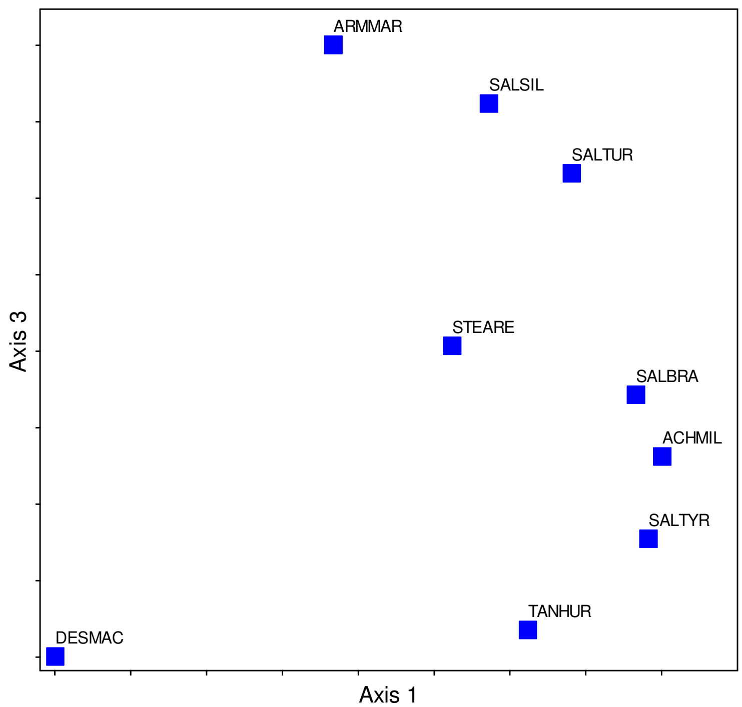


Figure 38: NMS ordination results of species occurrence data (axes scaled from minimum to maximum axis scores). Axis 1 accounted for 45.0% of the variance in the distance matrix while axes 2 and 3 accounted for 24.1% and 21.9% respectively.

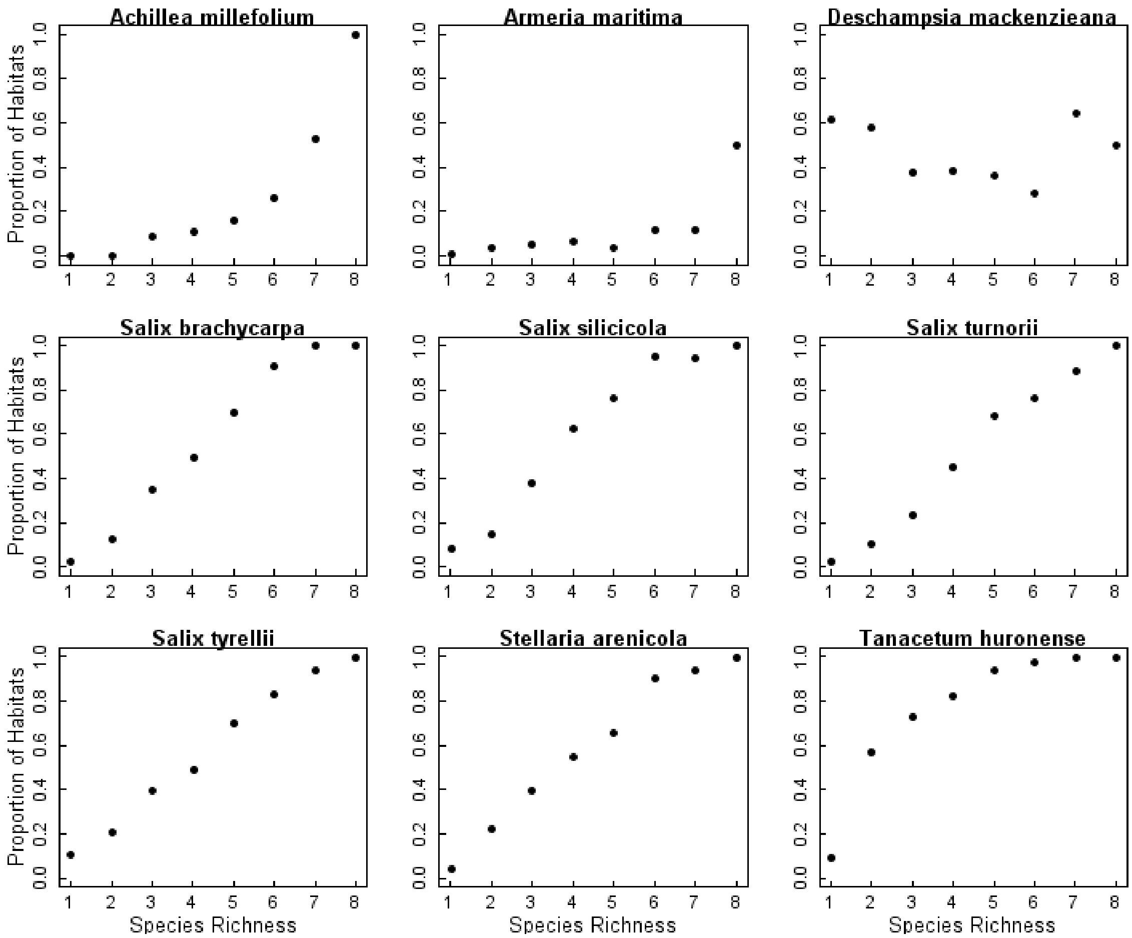


Figure 39: Relationship between endemic species richness and the proportion of habitat segments at each level of endemic species richness occupied by a particular species. *Deschampsia mackenzieana* and *Armeria maritima* have very different patterns of co-occurrence from the other species in this survey.

Incidental Observations of Human impact in the Athabasca Sand Dunes

Very few indicators of human impact were observed during this survey. Two old ATV tracks were observed in 2009 on gravel pavements in the William river dunes, and one set of tracks on a gravel pavement in 2010 (Table 15). All of these tracks were relatively straight appeared to be from individuals travelling directly to a destination on a trip rather than from joyriding. Both sets of tracks observed in 2009 may have been made by the same individual on the same trip. No impacts from camping or other activities were observed.

Table 15: ATV tracks observed during surveys. The UTMs are zone 12. At least one additional track was identified in 2009 in the William river dunes in the vicinity of transects 205 and 206, but the exact location was not recorded.

Year	UTM Northing	UTM Easting	Notes
2009	6546319	0596671	Two sets of tracks running generally north to south. Tracks ~0.8m between wheels.
2009	6545438	0601339	Tracks ~0.8m between wheels.
2010	6548897	254776	2 sets of quad tracks running north-south across gravel pavement.

Incidental Observations of invasive species in the Athabasca Sand Dunes

While this survey was focused on the endemic species at risk in the Athabasca Sand Dunes, survey team members in both years were also asked to watch for potential weedy and invasive species in the study area. In particular, in 2009 botanists Dr. George Argus and Anna Leighton spent time examining all species in both the dune field and shoreline communities of Lake Athabasca. No potentially invasive species were identified in these searches or as incidental observations by transect survey teams in either year.

Evaluation of transect survey error

Four transects (123, 133, 195, 217) were surveyed twice in 2009 and four transects (97, 166, 400, and 2010009) in 2010 to permit estimates of survey error rates. These transects are recorded in the datafiles as 123.1 and 123.2 etc. Only the transect labeled ".1" of each repeat pair was included in the previous analyses in this report. Differences in habitat classification, species occurrence rates, and counts were assessed based on the repeat surveys.

Variation in habitat and habitat modifier classification occurred between survey teams (Figure 40; Figure 41). Habitat type classification was generally consistent. The variation in the positions of transitions between major habitat types (for example the transition between gravel pavements and dune habitats on transect 217) were generally small and can be attributed to both GPS error and the difficulty in precisely locating a transition point on a smooth gradient between two habitat types. Some differences in habitat classification are apparent. In transect 133 differences in classification between LSDN and WIDS habitats occurred, while on transect 195 differences between LSDN and HSDN occurred. Similarly on transect 97 there were differences in classification between the WOOD, WIDS, and LICH habitats. Substantial variation in habitat modifier classification occurred between field teams. Aspect was frequently misreported, suggesting that allowing surveyors to make estimates based on the knowledge that transects are oriented East-West is insufficient and that compasses should be used.

Some variation in habitat classification should be expected, as the imposition of a habitat classification on continuously varying features forces surveyors to make judgment calls in intermediate cases. This variation observed does, however, point to a need to ensure consistency in classification between field teams. Based on this observation, the 2010 survey team surveyed a "refresher" transect as a group partway through the field expedition to ensure that consistency was maintained. Future surveys should continue to incorporate resurveys to monitor variation.

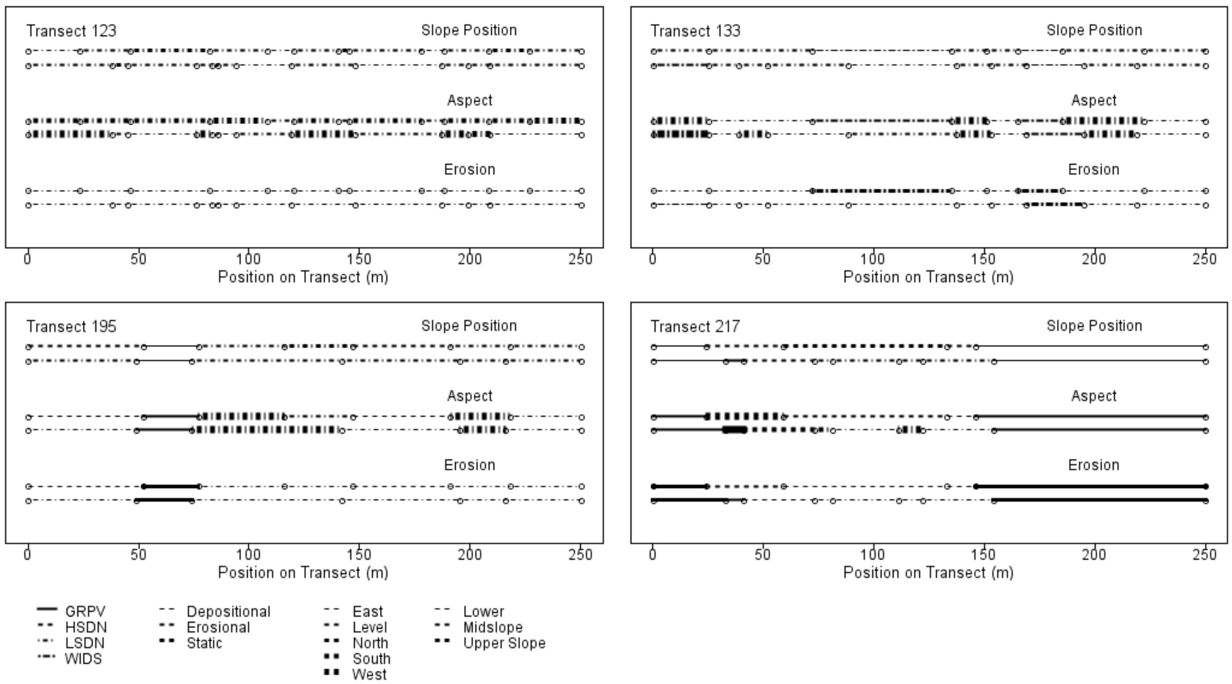


Figure 40: Variation in habitat classification between surveys in 2009. Each pair of lines contrasts the classifications for habitat (line symbols) and habitat modifiers (line thickness) between the two surveys of each transect. The lower line of each pair represents the .1 transect (used in the main analyses), and the .2 transect (only used for analyses of error variation).

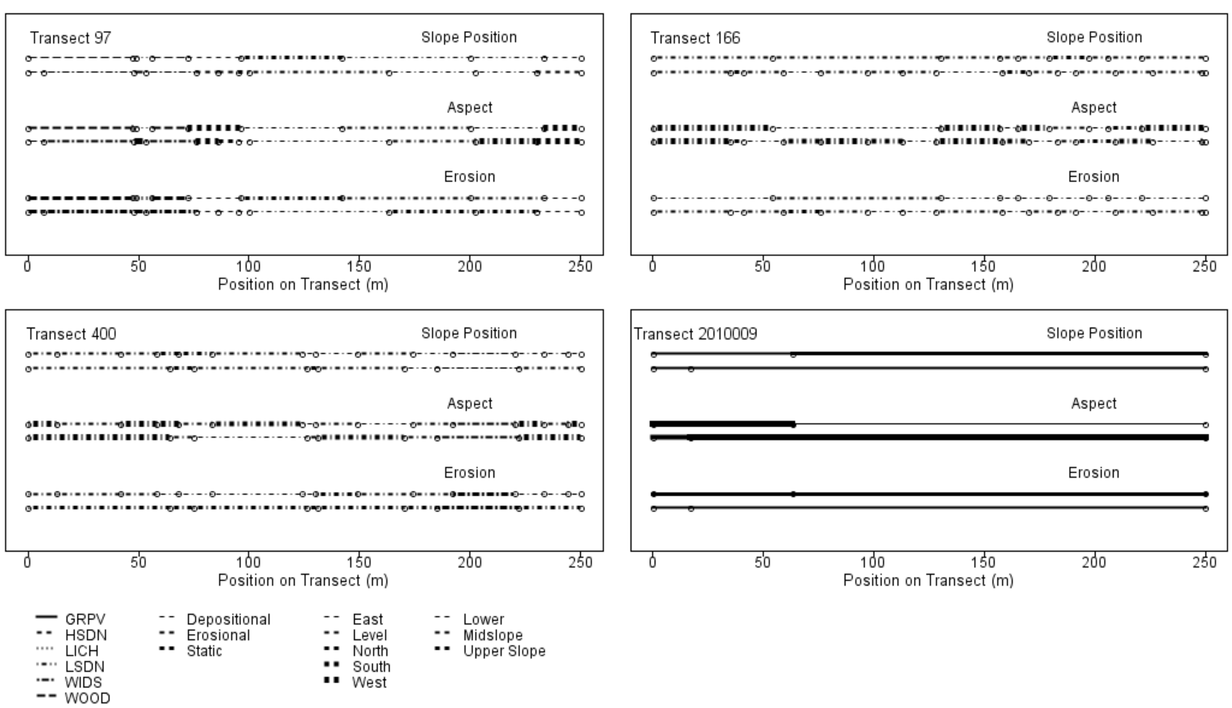


Figure 41. Variation in habitat classification between surveys in 2010. Each pair of lines contrasts the classifications for habitat (line symbols) and habitat modifiers (line thickness) between the two surveys of each transect. The lower line of each pair represents the .1 transect (used in the main analyses), and the .2 transect (only used for analyses of error variation).

Species detection rates and counts were generally consistent between surveys (Table 16-Table 23). Differences in species detection between surveys occurred in only two cases in 2009 and three cases in 2010. One *Salix tyrrellii* was detected in the first survey of transect 217 but not in the second, while three *Tanacetum huronense* individuals were detected in the second survey of transect 217 but not in the first (Table 21). On transect 97 two and transect 400 three *Salix turnorii* were detected on one survey but not the other (Table 16; Table 22). In both these cases large numbers of *Salix tyrrellii* were recorded on both transects. On transect 166 a single *Stellaria arenicola* was detected on one survey but not the other (Table 19). These minor differences between transects in the species occurrences identified indicates that we can have a high degree of confidence in species detection rates in this survey. Deviations in species counts between surveys occurred in most cases. In only 10 of those cases was the deviation more than 10 individuals between surveys, but many of these discrepancies were more than 100 individuals. These large discrepancies likely result from the greater error inherent rapidly counting large numbers of individuals. The discrepancies cannot be attributed to differences between the square meter estimation and direct count methods since all of the records in transect 123 and 195 were directly counted, while a combination of hand counting and areal estimation were used in transects 133 and 217. Greater variation in counts should be expected when more individuals are present as it is more likely that an individual may be missed or double counted. With the potential exception of transect 133 where nearly all counts were lower in the second survey, there is no evidence for systematic bias (over or underestimation) in counts between survey teams or between survey years.

Table 16: Total counts of each species observed during two surveys of transect 97 and the difference between those counts.

Species	97.1	97.2	Difference
Achillea millefolium	0	0	0
Armeria maritima	0	0	0
Deschampsia mackenzieana	0	0	0
Salix brachycarpa	702	503	199
Salix silicicola	0	0	0
Salix turnorii	2	0	2
Salix tyrrellii	97	291	-194
Stellaria arenicola	14	5	9
Tanacetum huronense	7	11	-4

Table 17: Total counts of each species observed during two surveys of transect 123 and the difference between those counts.

Species	123.1	123.2	Difference
Achillea millefolium	0	0	0
Armeria maritima	0	0	0
Deschampsia mackenzieana	314	754	-440
Salix brachycarpa	0	0	0
Salix silicicola	0	0	0
Salix turnorii	0	0	0
Salix tyrrellii	0	0	0
Stellaria arenicola	0	0	0
Tanacetum huronense	24	24	0

Table 18: Total counts of each species observed during two surveys of transect 133 and the difference between those counts.

Species	133.1	133.2	Difference
Achillea millefolium	0	0	0
Armeria maritima	0	0	0
Deschampsia mackenzieana	184	288	-104
Salix brachycarpa	1	1	0
Salix silicicola	57	63	-6
Salix turnorii	0	0	0
Salix tyrrellii	0	0	0
Stellaria arenicola	14	23	-9
Tanacetum huronense	86	143	-57

Table 19: Total counts of each species observed during two surveys of transect 166 and the difference between those counts.

Species	166.1	166.2	Difference
Achillea millefolium	0	0	0
Armeria maritima	0	0	0
Deschampsia mackenzieana	84	90	-6
Salix brachycarpa	420	521	-101
Salix silicicola	0	0	0
Salix turnorii	0	0	0
Salix tyrrellii	435	344	91
Stellaria arenicola	1	0	1
Tanacetum huronense	20	17	3

Table 20: Total counts of each species observed during two surveys of transect 195 and the difference between those counts.

Species	195.1	195.2	Difference
Achillea millefolium	0	0	0
Armeria maritima	0	0	0
Deschampsia mackenzieana	2	3	-1
Salix brachycarpa	0	0	0
Salix silicicola	33	29	4
Salix turnorii	0	0	0
Salix tyrrellii	0	0	0
Stellaria arenicola	23	23	0
Tanacetum huronense	16	15	1

Table 21: Total counts of each species observed during two surveys of transect 217 and the difference between those counts.

Species	217.1	217.2	Difference
Achillea millefolium	0	0	0
Armeria maritima	2	1	1
Deschampsia mackenzieana	11	14	-3
Salix brachycarpa	0	0	0
Salix silicicola	724	283	441
Salix turnorii	22	53	-31
Salix tyrrellii	1	0	1
Stellaria arenicola	0	0	0
Tanacetum huronense	0	3	-3

Table 22: Total counts of each species observed during two surveys of transect 400 and the difference between those counts.

Species	400.1	400.2	Difference
Achillea millefolium	0	0	0
Armeria maritima	0	0	0
Deschampsia mackenzieana	0	0	0
Salix brachycarpa	22	26	-4
Salix silicicola	0	0	0
Salix turnorii	3	0	3
Salix tyrrellii	6999	7499	-500
Stellaria arenicola	0	0	0
Tanacetum huronense	30	33	-3

Table 23: Total counts of each species observed during two surveys of transect 2010009 and the difference between those counts.

Species	2010009.1	2010009.2	Difference
Achillea millefolium	0	0	0
Armeria maritima	0	0	0
Deschampsia mackenzieana	4	5	-1
Salix brachycarpa	0	0	0
Salix silicicola	0	0	0
Salix turnorii	0	0	0
Salix tyrrellii	0	0	0
Stellaria arenicola	0	0	0
Tanacetum huronense	0	0	0

Summary and conclusions

This occupancy survey represents the first comprehensive assessment of the populations of endemic species at risk in the Athabasca Sand Dunes. Large populations of nine of the ten target endemic taxa were observed during this survey. This section summarizes the key messages from the data presented in this report relevant to each species and provides recommendations for future work to ensure the integrity of the Athabasca endemic populations.

Achillea millefolium var. *megacephala*

Achillea millefolium was present in very low abundance in the dune fields with only 592 individuals (0.29% of the total endemic observations) recorded in survey transects (Table 11). *Achillea* was patchily distributed in the Cantara Lake, Thompson Bay, and William River dune fields. It was absent from the Archibald Lake and MacFarlane River fields. *Achillea* was most frequent in wet interdune slacks with progressively lower incidence woodlands, in lichen-crowberry heaths, low slope dunes, and high slope dunes (Table 13). *Achillea* was absent from gravel pavements and saline slacks. While *Achillea* can be found on the Lake Athabasca beaches (Lamb pers. observation), incidence there is clearly low as no individuals were observed in any of the beach transects (Table 14). When present *Achillea* was most abundant in wet interdune slack habitats, but in all cases the *Achillea* abundances were low with median densities of less than 0.1 individuals m^{-2} (Figure 4).

Wet interdune slacks are clearly the critical habitat for *Achillea millefolium* as both incidence and abundance was highest in that habitat. Other important habitats for *Achillea* include lichen crowberry heaths, and woodlands near dune edges. Dune slacks likely provide preferred conditions for seed germination and seedling establishment. The low frequency of *Achillea* in low-slope dune habitats relative to other species that are also common in the dune slack habitats suggests that *Achillea* has a limited ability to tolerate burial by moving sand. *Achillea* had a high frequency of occurrence in woodland habitats suggest that this habitat may be more important to this species than earlier thought. Give the low density in woodlands, however, it is unclear whether the woodland populations are a net propagule source or sink.

*Achillea millefolium'*s very small population size and limited distribution is cause for significant concern. A short-term population bottleneck in the dune slack habitats could have devastating consequences for this taxa. For example, if changes in rainfall patterns or hydrology temporarily limited the ability of established *Achillea* individuals to persist in dune slacks there are few propagule sources on the landscape for the population to re-establish from.

Armeria maritima ssp. *interior*

Armeria maritima was the least abundant species observed during the occupancy survey with only 272 individuals identified (Table 11). *Armeria* was most frequent in gravel pavement and wet and saline slack habitats with most other observations occurring in low slope dunes (Table 13). Median abundances when present were less than 0.1 individuals m^{-2}, and there were no significant differences in abundance between habitats, though there was a trend for higher density when present in gravel pavement, low-slope dune, and woodland habitats (Figure 5). *Armeria maritima* was concentrated in the northeastern sector of the William River dune field, patchily distributed in the Thompson Bay and MacFarlane River fields, and was absent from the Archibald lake field. The *Armeria* populations observed showed frequent evidence of recent flowering and successful seed set. Germination rates from a small seed collection were nearly 100% following cold stratification.

Gravel pavements are clearly the critical habitat for *Armeria maritima*. This species appears to be a specialist on stable sand substrates. The cushion-like sub-shrub growth form of this species is likely poorly adapted for burial and excavation by moving sand, hence the high populations in gravel pavement habitats where stony surface reduces sand movement. Many of the plants in wet dune slacks were in locations with sparse vegetation, suggesting a limited ability to persist under substantial overhead cover (Lamb, pers. observation). As well, many of the *Armeria* populations found on low-slope dunes occurred adjacent to gravel pavements on places where sand appeared to be accumulating (Lamb, pers. observation). This suggests that many of the populations occurring on low-slope dunes originated on gravel pavements and are soon to be buried by an advancing dune.

Armeria maritima's low population sizes, growth form, and preferred habitat make this species potentially highly vulnerable. Most *Armeria* individuals likely germinated and established on sandy substrates stabilized by gravel pavements. This germination habitat is likely very vulnerable to acid precipitation (Canadian Council of Ministers of the Environment 2004, Aherne 2008, Whitfield et al. 2010). Preliminary investigations at the University of Saskatchewan suggest that root growth rates of *Armeria* would be substantially impaired following germination on an acidified substrate (i.e. in the aftermath of a precipitation event carrying substantial acid deposition) (Figure 42). Failure to rapidly extend a deep tap root in a well drained sand habitat would likely lead to substantial seedling mortality. The pollination ecology of *Armeria* may also carry vulnerabilities. North American *Armeria maritima* varieties are generally capable of self pollination (Baker 1966), but the showy pink flowers suggest insect pollination may be important for gene flow between sub-populations (Fægri and van der Pijl 1971). Little is known about the potential pollinators of this species, though European *Armeria maritima* subspecies on coastal dunes are pollinated by bumblebees (*Bombus* spp.) (Eisikowitch and Woodell 1975). A disruption of the pollination system of this species could rapidly lead to reduced genetic diversity in this species. *Armeria* has relatively large seeds suggesting that the potential for the development of a long-lived seed bank may not be large (Thompson et al. 1993). Finally the low growth form of this species from a single rootstock likely makes it highly vulnerable to disturbance by all-terrain vehicles. A wheel passing over an individual would likely damage or break the rootstock, likely killing that plant. A great deal more needs to be learned about the autecology of this species before a comprehensive assessment of the status of endemic *Armeria maritima* populations can be made.

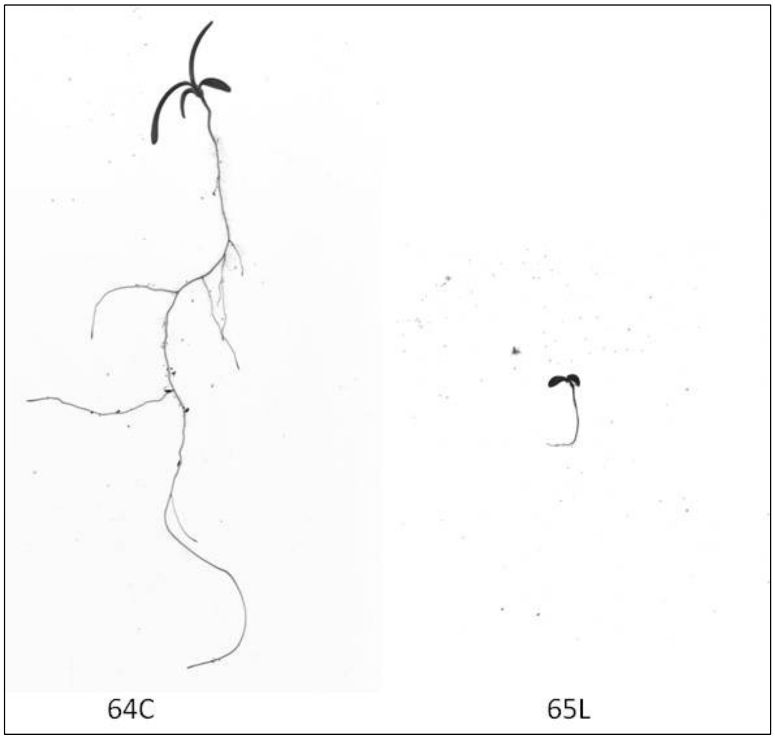


Figure 42: Impact of acid exposure on 9 day old *Armeria maritima* seedlings. Seedlings were grown in a greenhouse on sand collected from the Athabasca Sand Dunes. Plants labeled C were treated with distilled water while plants labeled L were exposed to a pH 1.7 mixture of Sulfuric and Nitric acids. The acid treatment was much more severe than expected deposition in the sand dunes region (Aherne 2008), however the treatment demonstrates the likely consequence of acid deposition exceeding critical loads to seedlings germinating in poorly buffered sandy substrates.

Deschampsia mackenzieana

Deschampsia mackenzieana one of the most widely distributed and frequently encountered endemic species in this study (Table 13). Deschampsia was present in all habitat types, though at much reduced abundance in the "non-dune" habitats (lichen crowberry heaths and woodlands). *Deschampsia* abundances were highest in high and low-slope dune habitats and wet interdune slacks. Flowering individuals and seedlings of *Deschampsia mackenzieana* were frequently encountered.

Deschampsia's occurrence patterns are different from the other endemic species in the Athabasca Sand Dunes. While most endemics tend to co-occur with other endemics (Figure 38; Figure 39), *Deschampsia* is frequently found alone, particularly in low-slope dune habitats. This co-occurrence pattern likely arises from differences in preferred germination habitat from the other endemic species. Extensive populations of *Deschampsia* seedlings were observed in areas of open sand. These seedling populations were typically characterized by high abundances in a limited area (10 to 100 m^2) and a sharp boundary to neighbouring areas with no seedlings. No differences in surface conditions between locations with seedlings and adjacent locations without seedlings were generally obvious. Given that *Deschampsia* is thought to germinate at most 0.5cm below the sand surface (Raup and Argus 1982), it is likely that subtle differences in moisture regimes are important in determining the germination and establishment patterns of *Deschampsia*.

The wide distribution of *Deschampsia* within the dune environment suggests that the Athabasca sand dunes as a whole should be considered critical habitat for this species. No obvious threats to *Deschampsia mackenzieana* populations were noted during this survey. The robust populations suggest that continued efforts to minimize human impacts on the sand dune environment should ensure the continued healthy population size of this species. The species is extremely common in unstable surface environments, suggesting that it is likely to be minimally affected by surface disturbance by ATVs. The open sand germination environment is potentially vulnerable to a range of threats including climate change and acid deposition, however. Climate change driven changes in rainfall regimes could reduce germination and establishment success. Long-term trends toward dune stabilization could threaten *Deschampsia* given its lower abundances in stabilized habitats such as woodlands and lichen heaths. The most likely short-term threat is acid deposition in the Athabasca region (Canadian Council of Ministers of the Environment 2004, Aherne 2008, Whitfield et al. 2010), as the species commonly germinates on open sand likely following precipitation events. Preliminary investigations at the University of Saskatchewan suggest that root growth rates of *Armeria maritima* (Figure 42) and *Stellaria arenicola* (Figure 44) are substantially impaired following germination on an acidified substrate (i.e. in the aftermath of a precipitation event carrying substantial acid deposition). Assuming a similar impairment of root growth for *Deschampsia,* a failure to rapidly extend deep roots in a well drained sand habitat would likely lead to substantial seedling mortality.

Lechea intermedia var. *depauperata*

No individuals of *Lechea intermedia* were observed during this study. Dr. Rob Wright and Anna Leighton investigated locations where herbarium specimens were previously collected (Site 1: 59°07 30.4 N, 108°55 35.6 W; Site 2: 59°07 28 N 108°55 26 W) at the northeast tip of Cantara lake in 2009. The site was a soft sandy shoreline of along a marshy wetland (Figure 43). No evidence of the presence of *Lechea* was found at either of these locations. The water table was high at the time of the visit, suggesting that *Lechea* may not have successfully germinated and/or established in 2009. Given that *Lechea* is an annual it is likely that the species was present in the seedbank. Without further information potential threats to this species cannot be evaluated. Efforts to resolve this data deficiency should be a priority.

Figure 43: Site on the northeast shore of Cantara lake searched for *Lechea intermedia* in 2009

Salix brachycarpa var. *psammophila*

Salix brachycarpa was most frequent in wet and saline interdune slacks, and moderately frequent in low-slope dunes and lichen heaths. *Salix brachycarpa* was widely distributed in the Thompson Bay dune field and common around the margins of the William River, MacFarlane River, and Archibald Lake dune fields. With the exception of lower abundance in gravel pavements and woodlands there were few patterns in the abundance of *S. brachycarpa* in occupied habitats. *Salix brachycarpa* is often much shorter in stature than the other endemic *Salix* species in the Athabasca sand dunes. The lower incidence of this species in habitats dominated by moving sand such as low-slope dunes likely reflects a limited tolerance to burial and excavation relative of the other *Salix* species. The relative absence of *S. brachycarpa* from areas such as the center of the William River dune field likely reflects the higher incidence of non-preferred habitats such as gravel pavements there.

The concentration of *Salix brachycarpa* in wet dune slacks suggests that that habitat should likely be designated critical habitat for the species. No obvious threats to *Salix brachycarpa* populations were identified, however as with many of the other endemic species the concentration of the population in the dune slacks represents a potential limiting factor for this species. The consistently moist soil in interdune slacks provides favourable germination and establishment conditions that likely contribute to the high frequency of *Salix* species in that habitat (Raup and Argus 1982). A short-term population bottleneck in the dune slack habitats could substantially reduce populations of *Salix brachycarpa*. For example, if changes in rainfall patterns or hydrology temporarily limited the ability of established *S. brachycarpa* individuals to persist in dune slacks there are limited propagule sources on the landscape for the population to re-establish from.

Salix silicicola

Salix silicicola was frequently encountered in all habitats except gravel pavements and woodlands. *Salix silicicola* was widely distributed in the Thompson Bay and MacFarlane River dune fields and common around the margins of the William River and Archibald Lake dune fields. When present, *S. silicicola* was most abundant on low slope active dunes, and moderately abundant in high-slope dunes and wet interdune slack habitats The majority of *S. silicicola* individuals encountered in low-slope dunes and similar habitats occurred in large, well established clumps. In wet interdune slacks smaller individuals occurring in less well defined clumps were frequently encountered.

The wide distribution of *S. silicicola* within the dune environment suggests that the Athabasca sand dunes as a whole should be considered critical habitat for this species. The distribution of *S. silicicola* populations (Table 13; Figure 8) is consistent with a species that primarily germinates and establishes in wet interdune slacks, with mature individuals persisting as large clumps in other habitats following the burial of old slacks by moving sand. Unlike species such as *Achillea millefolium* and *Salix brachycarpa*, most reproductively mature *Salix silicicola* individuals were found outside of wet dune slack habitats. Thus, even if temporary reproductive failures occurred in dune slacks, an abundant propagule rain will be available in subsequent years. *Salix silicicola* is also abundant on Lake Athabasca beaches (Table 14). This population likely suffers from high mortality from ice push, but scattered mature individuals can be found.

No obvious threats to *Salix silicicola* populations were identified. The robust populations suggest that continued efforts to minimize human impacts on the sand dune environment should ensure the continued healthy population size of this species.

Salix turnorii

Salix turnorii was frequently encountered in all habitats except lichen-crowberry heaths and woodland. *Salix turnorii* was widely distributed in the Thompson Bay and MacFarlane River dune fields, common around the margins of the William River dune field, but present only on beaches at the margin of the Archibald Lake dune field. When present, *S. turnorii* was most abundant in wet and saline interdune slacks, moderately abundant in high and low slope dunes and lichen heaths, and in low abundance on gravel pavements and in woodlands.

The wide distribution of *S. turnorii* within the dune environment suggests that the Athabasca sand dunes as a whole should be considered critical habitat for this species. As with *S. silicicola* and *S. tyrrellii* the distribution of *S. turnorii* is consistent with a species that primarily germinates and establishes in wet interdune slacks, with mature individuals persisting as large clumps in other habitats following the burial of old slacks by moving sand. Unlike species such as *Achillea millefolium* and *Salix brachycarpa*, most reproductively mature *Salix turnorii* individuals were found outside of wet dune slack habitats. Thus, even if temporary reproductive failures occurred in dune slacks, an abundant propagule rain will be available in subsequent years. *Salix turnorii* occasionally present on Lake Athabasca beaches (Table 14). This beach population likely suffers from high mortality from ice push, but scattered mature individuals can be found.

No obvious threats to *Salix turnorii* populations were observed in these surveys. The robust populations suggest that continued efforts to minimize human impacts on the sand dune environment should ensure the continued healthy population size of this species.

Salix tyrrellii

Salix tyrrellii was most frequently encountered in lichen-crowberry heath, wet interdune slack, and woodland habitats, less commonly encountered in low and high slope dunes and saline slacks, and least frequent on gravel pavements. *Salix tyrrellii* was widely distributed in all of the dune fields. When present, *S. t tyrrellii* was most abundant in wet interdune slacks, with abundance declining in other habitats.

The wide distribution of *S. tyrrellii* within the dune environment suggests that the Athabasca sand dunes as a whole should be considered critical habitat for this species. As with *S. silicicola* and *S. turnorii* the distribution of *S. tyrrellii* is consistent with a species that primarily germinates and establishes in wet interdune slacks, with mature individuals persisting as large clumps in other habitats following the burial of old slacks by moving sand. Unlike species such as *Achillea millefolium* and *Salix brachycarpa*, most reproductively mature *Salix tyrrellii* individuals were found outside of wet dune slack habitats. Thus, even if temporary reproductive failures occurred in dune slacks, an abundant propagule rain will be available in subsequent years. *Salix tyrrellii* was very frequent on Lake Athabasca beaches (Table 14). This beach population likely suffers from high mortality from ice push, but scattered mature individuals can be found.

No obvious threats to *Salix tyrrellii* populations were observed in these surveys. The robust populations suggest that continued efforts to minimize human impacts on the sand dune environment should ensure the continued healthy population size of this species.

Stellaria arenicola

Stellaria arenicola was most frequently encountered in wet and saline interdune slacks and high slope dunes, less frequent in low slope dunes, and least frequent in lichen heaths, gravel pavements, and woodlands. *Stellaria arenicola* was widely distributed in the Thompson Bay and MacFarlane River dune fields and common around the margins of the William River and Archibald Lake dune fields. When present, *Stellaria* was most abundant in saline slacks and lichen-crowberry heaths, moderately abundant in high and low slope dunes and wet-interdune slacks, and least abundant in gravel pavements and woodlands.

The wide distribution of *S. tyrrellii* within the dune environment suggests that the Athabasca sand dunes as a whole should be considered critical habitat for this species. The high frequency of *Stellaria* in lichen-crowberry heaths merits further investigation. The heaths are not generally considered important *Stellaria* habitat, yet they supported had a median abundance of nearly 1 individual m^2, the highest observed for any species in this study. As was noted by Macdonald et al. (1987), in this survey *Stellaria arenicola* was occasionally found co-occurring in the dune fields with the closely related *Stellaria longipes*.

No obvious threats to *Stellaria arenicola* populations were observed. The species is extremely common in unstable surface environments, suggesting that it is likely to be minimally affected by surface disturbance by ATVs. The open sand germination environment is potentially vulnerable to a range of threats including climate change and acid deposition, however. Climate change driven changes in rainfall regimes could reduce germination and establishment success. The most likely short-term threat is acid deposition in the Athabasca region (Canadian Council of Ministers of the Environment 2004, Aherne 2008, Whitfield et al. 2010), as the species likely germinates on open sand likely following precipitation events. Preliminary investigations at the University of Saskatchewan suggest that root growth rates of *Stellaria arenicola* are substantially impaired following germination on an acidified substrate (i.e. in the aftermath of a precipitation event carrying substantial acid deposition) (Figure 44). A failure to rapidly extend deep roots in a well drained sand habitat would likely lead to substantial seedling mortality.

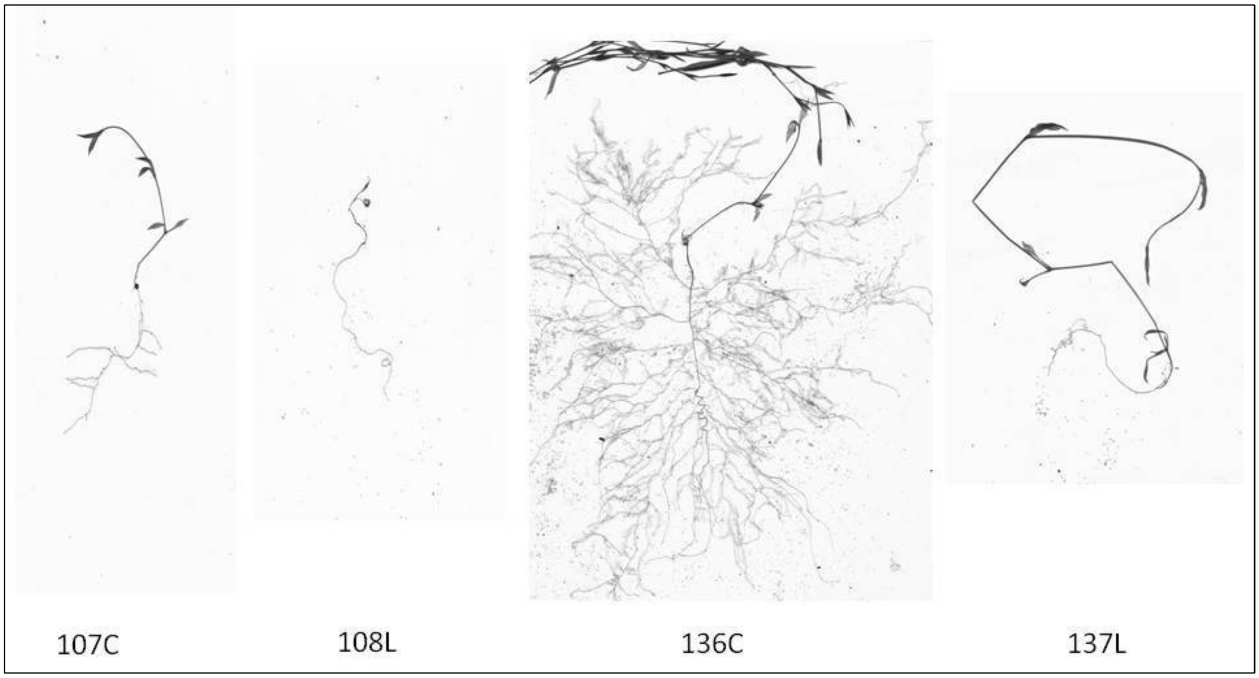


Figure 44: Impact of acid exposure on 12 day old (107 and 108) and 42 day old (136 and 137) *Stellaria arenicola* seedlings. Seedlings were grown in a greenhouse on sand collected from the Athabasca Sand Dunes. Plants labeled C were treated with distilled water while plants labeled L were exposed to a pH 1.7 mixture of Sulfuric and Nitric acids. The acid treatment was much more severe than expected deposition in the sand dunes region (Aherne 2008), however the treatment demonstrates the likely consequence of acid deposition exceeding critical loads to seedlings germinating in poorly buffered sandy substrates.

Tanacetum huronense var. *floccosum*

Tanacetum huronense was most frequently encountered in high slope and saline and wet interdune slacks. *Tanacetum* was moderately frequent in low-slope dunes and lichen heaths and less frequent in other habitats. *Tanacetum huronense* was widely distributed in all of the dune fields. When present, *Tanacetum* was most abundant when present in wet interdune slacks and high slope dunes, less abundant in lichen heaths, low-slope dunes, and woodlands, and least abundant on gravel pavements and saline slacks. *Tanacetum* was frequently observed on the upper margins of beaches along Lake Athabasca.

The wide distribution of *Tanacetum huronense* within the dune environment suggests that the Athabasca sand dunes as a whole should be considered critical habitat for this species. As with *S. silicicola* and *S. turnorii* the distribution of *T. huronense* is consistent with a species that primarily germinates and establishes in wet interdune slacks, with mature individuals persisting as large clumps in other habitats following the burial of old slacks by moving sand. Unlike species such as *Achillea millefolium* and *Salix brachycarpa*, most reproductively mature *T. huronense* individuals were found outside of wet dune slack habitats. Thus, even if temporary reproductive failures occurred in dune slacks, an abundant propagule rain will be available in subsequent years.

No obvious threats to *Tanacetum huronense* populations were observed in this survey. Flowering individuals were frequently encountered, as were seedlings and juvenile plants in wet interdune slacks.

The robust populations suggest that continued efforts to minimize human impacts on the sand dune environment should ensure the continued healthy population size of this species.

Recommendations for Future Research

The present survey covered all of the major sand dune complexes within the Athabasca Sand Dunes Provincial Park. Consistent transect coverage was achieved and this survey thus provides a comprehensive picture of the current distribution and abundance of the Athabasca endemics. Future research should be largely focused on narrower questions linked to the conservation of particular species. The following should be considered priorities for future research:

1. Acid deposition represents the most likely short to medium term threat to the Athabasca endemic species. This threat is likely most acute for species including *Armeria maritima, Deschampsia mackenzieana,* and *Stellaria arenicola* that frequently germinate and establish on open sand. Investigations are needed to evaluate the germination ecology of these species and the potential threat that acid deposition may pose to the future viability of these populations. This research is most urgent for *Armeria maritima* given the low population sizes and non-clonal habit of that species.
2. A general effort to understand how climate changes in the Athabasca region are likely to result in long-term trends toward dune stabilization and related changes in the dune environment is important for the conservation of all of the Athabasca endemic species.
3. Investigations into the seed and seedling ecology of all of the Athabasca endemic species are needed. It is likely that the seedling life stage and regeneration niche (Grubb 1977) is a primary determinant of adult population sizes, particularly for long-lived clonal species such as the willows and *Tanacetum*.
4. Investigations of the ecology and hydrology of wet dune slacks. This is important because wet dune slacks are important habitat for all of the endemics and critical habitat for *Achillea millefolium* and *Salix brachycarpa*.
5. A general landscape classification of the Athabasca Sand Dunes region with particular emphasis on delineating gravel pavements and wet dune slacks. Such a classification would provide a strong tool to identify the critical habitat for many of the Athabasca endemic species.
6. The low *Achillea millefolium* population and the concentration of that population in wet dune slacks, a small proportion of the dune landscape, is of immediate concern. Research priorities specific to *Achillea* include:
    a. Evaluating the preferred seedling germination and establishment conditions of *Achillea*
    b. Determining the sensitivity of the adult dune slack populations of *Achillea* to changing environmental conditions, particularly water table position.
    c. Determining the extent of other propagule sources such as a buried seedbank and seed rain from non-dune slack populations.
7. The low *Armeria maritima* population and the concentration of that population in gravel pavements, a habitat vulnerable to disturbance, is of immediate concern. Research priorities specific to *Armeria* include:
    a. A comprehensive study of the reproductive biology and germination ecology of *Armeria.*
    b. An assessment of the sensitivity of *Armeria* seedlings to acid deposition.
    c. Delineation of the extent of critical habitat for *Armeria* through a landscape classification to identify gravel pavement habitats.

8. The continued lack of data on *Lechea intermedia* is of immediate concern. Assessment of the status of this species is difficult without further information. Field work specifically investigating potential *Lechea* habitat should be a priority.

Conclusion

The data presented in this report represent the most comprehensive survey conducted to date on the Athabasca endemic populations. These data represent a strong foundation for a status reassessment for all of these species with the exception of *Lechea intermedia*. Status reassessment to a higher level of concern may be justified given 1) the endemic status of all of these taxa, 2) the limited population sizes and distributions within the dune complex of some taxa, particularly *Achillea millefolium, Armeria maritima*, and *Salix brachycarpa*, and 3) potential threats to the dune environment including acid deposition and climate change.

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