Habitat characterization of Saskatchewan's Dakota skipper, *Hesperia dacotae* population

A Thesis Submitted to the
College of Graduate and Postdoctoral Studies
In Partial Fulfillment of the Requirements
For the Degree of Master's of Environment and Sustainability
in the School of Environment and Sustainability
University of Saskatchewan
Saskatoon, Saskatchewan
Canada

By
Kelsey Marie Seidle

Permission to use

In presenting this thesis in partial fulfillment of the requirements for a Postgraduate degree from the University of Saskatchewan, I agree that the Libraries of this University may make it freely available for inspection. I further agree that permission for copying of this thesis in any manner, in whole or in part, for scholarly purposes may be granted by the professor or professors who supervised my thesis work or, in their absence, by the Head of the Department or the Dean of the College in which my thesis work was completed. It is understood that any copying, publication, or use of this thesis or parts thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and the University of Saskatchewan in any scholarly use which may be made of any material in my thesis.

Disclaimer

Reference in this thesis to any specific commercial products, process, or service by trade name, trademark, manufacturer, or otherwise, does not constitute or imply its endorsement, recommendation, or favoring by the University of Saskatchewan. The views and opinions of the author expressed herein do not state or reflect those of the University of Saskatchewan, and shall not be used for advertising or product endorsement purposes.

Requests for permission to copy or to make other uses of materials in this thesis on whole or part should be addressed to:

Head of the School of Environment and Sustainability
Room 323 Kirk Hall, 117 Science Place
University of Saskatchewan
Saskatoon, Saskatchewan S7N 5C8
Canada

Or

Dean
College of Graduate and Postdoctoral Studies
116 Thorvaldson Building, 110 Science Place
University of Saskatchewan
Saskatoon, Saskatchewan S7N 5C9
Canada

Abstract

The Dakota skipper, *Hesperia dacotae* (Skinner, 1911) (Hesperiidae), is an at-risk butterfly species that inhabits the mesic mixed-grass prairie. The Dakota skipper is listed *endangered* under the federal *Species at Risk Act*. Loss of native prairie is the main factor driving declines in Dakota skipper habitat and species abundance is assumed to be declining. Currently, there is a knowledge gap pertaining to habitat associations and availability of Saskatchewan populations. This information is critical to construct a recovery plan to secure Dakota skipper populations. The first objective was to better understand the environmental associations of Dakota skipper habitat through landscape, vegetation, soil, climate, microclimate, and Hesperiidae butterfly species occupancy. Data collection was conducted in 2015 and 2016; of the 46 sites surveyed; nine were Dakota skipper positive (*i.e.*, present) sites and 37 were negative (*i.e*., non-detect) sites. Results indicated that plant community composition was not a significant predictor of Dakota skipper presence, but three plant species were significantly associated with the species; *Pediomelum argophyllum* (Pursh) J.W.Grimes (Fabaceae), *Zizia aptera* (A.Gray) Fernald (Apiaceae), and *Schizachyrium scoparium* (Michx.) Nash (Poaceae). No soil or climate variables were significant predictors of Dakota skipper presence; however the species was significantly associated with steep slopes. Warmer maximum and average ground-level temperatures were also associated with Dakota skipper presence.

The second objective was to determine Dakota skipper habitat suitability and distribution through a landscape-level habitat distribution model based on climate normal, soil, and landscape variables. Data were obtained from publically available Dakota skipper observation locations and *in situ* data collection within Saskatchewan. A total of 66 unique survey sites were obtained; 28 of these sites were Dakota skipper positive sites whereas the remaining 38 were negative sites. A habitat distribution map ranks the suitability of Dakota skipper habitat throughout southeastern Saskatchewan. Results indicated that although the Dakota skipper inhabits the mesic mixed-grass prairie region, only 11% of this region contains exceptional habitat (habitat probabilities 0.71-1) for this species. These areas contain a significantly lower mean diurnal temperature range and a higher ammonium soil content. I conclude that although the Dakota skipper inhabits the native mesic mixed-grass prairie region, environmental constraints including climate, soil, and landscape variables restrict this species to a more limited area of available habitat then initially thought. A landscape-level habitat suitability and distribution map complemented by habitat

associations allows for more accurately targeted surveys, informs managers developing conservation and management plans, and allows for an overall better understanding of the Dakota skipper's current situation in southeastern Saskatchewan. Findings indicate that additional Dakota skipper populations are likely in Saskatchewan and future targeted surveys will allow for a full evaluation of this species' distribution and conservation status.

Acknowledgements

I would like to extend a thank you to everyone who has helped me throughout this thesis. To my supervisors Dr. Eric Lamb and Dr. Jean-Michel DeVink, thank you for the guidance along the way, for always being there when I had questions, pushing me in the right direction when needed, challenging me, and allowing me to learn. I would also like to thank my advisory committee, Dr. Angela Bedard-Haughn and Dr. Xulin Guo and my external examiner Dr. Art Davis. Additionally, thanks to Dr. Richard Westwood who I continuously consulted for butterfly identification and confirmation. Thank you for your patience and for sharing your knowledge and passion of skipper butterflies with me.

Thank you to all of the individuals in the soil science and plant science departments at the University of Saskatchewan who assisted with fieldwork and laboratory work, including my summer field assistants Cierra Wallington, Kalli Noble, and Bronwen Plumer, who weathered the sun, rain, wind, and ticks with me. Thank you to all of the plant science lab group members for the support, discussions, and critiques of my work. Thank you to Robin Brown who spent many hours taking me through the paces of soils laboratory analysis procedures, Jeremy Kiss who developed soil and landscape models, and Udayanga Attanayake for your knowledge and support on habitat suitability and distribution modeling. Thank you to my parents, who would look at every tiny orange butterfly picture and express interest in my research; and my sister, Meghan Seidle, who has edited and proofed every paper throughout my studies.

I would like to acknowledge all of the participants who provided funding in order for me to carry out this research including the Natural Sciences and Engineering Research Council of Canada (NSERC), Nature Conservancy of Canada (NCC), Environment Canada, and Stantec Consulting Ltd. Without these organizations this research would not have been possible.

I wish to extend a huge thanks to the friendly residents and landowners within southeastern Saskatchewan for allowing me to venture out and explore this beautiful river valley; the history and knowledge of the land that you have openly shared with me was always welcomed and greatly appreciated. I cannot think of a happier place than being among the flowering forbs and the fluttering butterflies of the Souris River Valley. The Souris River Valley will always hold a special place in my heart.

Dedication

To my father, Brett Seidle, who taught me to respect and care for nature from a very young age. Thank you for everything you have taught me over the years, from simply teaching me the name of a common plant on the roadside, to taking me for hikes in the forest to find deer antlers, to telling me the history of the land, and demonstrating the importance of conservation. Thank you for sharing your passion for nature, conservation, and the outdoors.

Table of contents

Permission to use i
Disclaimer i
Abstract ii
Acknowledgements iv
Dedication v
Table of contents vi
List of tables x
List of figures xii
List of abbreviations xv
1 Introduction 1
1.1 General introduction 1
1.2 Research objectives 2
1.3 Thesis organization 2
2 Literature review 3
2.1 Status 3
2.2 Biology 3
2.2.1 Adult skipper appearance 3
2.2.2 Life cycle 4
2.2.3 Distribution 5
2.2.4 Population 7
2.3 Habitat suitability 8
2.3.1 Landscape 8
2.3.2 Vegetation 9
2.3.3 Soil 10
2.3.4 Climate and microclimate 12
2.4 Dakota skipper threats, habitat threats, and best management practices 13
2.4.1 Agriculture and industry 13
2.4.2 Haying and mowing 14
2.4.3 Natural processes 16
2.4.4 Grazing 16

2.4.5 Fire ... 17
2.4.6 Insecticide use ... 19
2.4.7 Invasive and exotic species ... 19
2.4.8 Fragmentation ... 20
2.4.9 Genetics ... 21
2.4.10 Idling and succession ... 22
2.4.11 Climate change ... 23
2.5 Dakota skipper recovery ... 24
2.5.1 Habitat protection ... 25
2.5.2 Habitat restoration ... 25
2.5.3 Conservation easements ... 25
2.6 References ... 27
3 Environmental associations of the Dakota skipper, *Hesperia dacotae* (Skinner, 1911) in southeastern Saskatchewan, Canada ... 34
3.1 Abstract ... 34
3.2 Introduction ... 35
3.3 Materials and methods ... 36
3.3.1 Study region ... 36
3.3.2 Study site selection ... 36
3.3.3 Landscape and land cover surveys ... 38
3.3.4 Vegetation survey ... 38
3.3.5 Soil survey ... 39
3.3.6 Hesperiidae butterfly surveys ... 40
3.3.7 Microclimate survey ... 41
3.3.8 Climate ... 41
3.3.9 Statistical analysis ... 42
3.4 Results ... 42
3.4.1 Vegetation ... 43
3.4.2 Soil and landscape ... 44
3.4.3 Climate ... 45
3.4.4 Microclimate ... 46

3.5 Discussion 47
3.6 References 51
4 Dakota skipper, *Hesperia dacotae* (Skinner, 1911) habitat suitability and distribution in southeastern Saskatchewan, Canada 55
4.1 Abstract 55
4.2 Introduction 56
4.3 Materials and methods 57
4.3.1 Study region 57
4.3.2 Satellite imagery and pre-processing 57
4.3.3 Model calibration 58
4.3.4 Digital soil mapping 58
4.3.5 Geographic information system 61
4.3.6 Species suitability and distribution model development 62
4.4 Results 62
4.4.1 Habitat suitability and distribution 62
4.5 Discussion 66
4.6 References 71
5 General conclusions 77
5.1 Conclusion 77
5.1 References 83
6 Appendix 86
Appendix A: Plant species list 86
Appendix B: Plant species cover data 91
Appendix C: Indicator species analysis results 103
Appendix D: Soil laboratory methods and procedures 106
Appendix E: Soil laboratory results 108
Appendix F: Landscape data 110
Appendix G: Hesperiidae butterfly observations 112
Appendix H: Microclimate data 116
Appendix I: Site photos 146
Appendix J: Digital soil mapping variables 155

Appendix K: References 157

List of tables

Table 3.1: Generalized linear model results of landscape and soil variables on Dakota skipper occupancy 45

Table 3.2: Generalized linear mixed model results of microclimate variables on Dakota skipper occupancy 46

Table 3.3: Linear regression model results of microclimate and climate normal maximum and minimum monthly temperatures 47

Table 4.1: Prediction accuracy for predicting soil classes per model. Accuracy of the prediction is based on the test data set (30% of data) 60

Table 4.2: Model used and prediction accuracy of the best performing model on continuous soil properties based on the test data set (30% of data) 61

Table 4.3: Available area of each habitat probability class resulting from the Dakota skipper habitat suitability and distribution model 65

Table 4.4: Biomod2 generalized linear model habitat suitability results 65

Table A.1: Vascular plant species encountered in study sites. Latin name, common name and family are obtained from Saskatchewan Conservation Data Centre (2017); a seven letter epithet is used to refer to the species during the survey period and in Table B 86

Table B.1: All plant species within the six vegetation quadrats averaged at the site level for study sites 1 to 16. Values are percent foliar cover. Percent foliar cover is greater than 100% due to canopy layers 91

Table B.2: All plant species within the six vegetation quadrats averaged at the site level for study sites 17 to 31. Values are percent foliar cover. Percent foliar cover is greater than 100% due to canopy layers 95

Table B.3: All plant species within the six vegetation quadrats averaged at the site level for study sites 32 to 46. Values are percent foliar cover. Percent foliar cover is greater than 100% due to canopy layers 99

Table C.1: Indicator species analysis results of plant species present in study sites. Species are ranked by their indicator value and frequency indicates the number of sites (total sites = 46) in which a plant species is present 103

Table D.1: Soil laboratory analysis methods and procedures used on soil samples taken from 0-15 cm depth 106

Table E.1: Soil laboratory analysis results for each study site. All soil samples were taken from 0-15 cm intervals 108
Table F.1: Landscape data for each study site. Introduced species are species that are non-native to Saskatchewan prairies according to the Conservation Data Centre (2017) ranking of SNA. Native species are plant species that naturally occur in the Saskatchewan native prairies 110
Table G.1: Hesperiidae community observed in study sites during the 2015 and 2016 field seasons 112
Table H.1: Average maximum daily temperature (°C) for study sites 1 to 17, with the exception of site 4, 5, and 8 (not redeemed). Temperature monitor data reflects daily measurements for the time interval of 1 May 2016 to 19 September 2016 116
Table H.2: Average maximum daily temperature (°C) for study sites 18 to 31. Temperature monitor data reflects daily measurements for the time interval of 1 May 2016 to 19 September 2016 121
Table H.3: Average minimum daily temperature (°C) for study sites 1 to 17, with the exception of site 4, 5, and 8 (not redeemed). Temperature monitor data reflects daily measurements for the time interval of 1 May 2016 to 19 September 2016 126
Table H.4: Average minimum daily temperature (°C) for study sites 18 to 31. Temperature monitor data reflects daily measurements for the time interval of 1 May 2016 to 19 September 2016 131
Table H.5: Average daily temperature (°C) for study sites 1 to 17, with the exception of site 4, 5, and 8 (not redeemed). Temperature monitor data reflects daily measurements for the time interval of 1 May 2016 to 19 September 2016 136
Table H.6: Average daily temperature (°C) for study sites 18 to 31. Temperature monitor data reflects daily measurements for the time interval of 1 May 2016 to 19 September 2016 141
Table J.1: Digital soil mapping predictor variable definitions and citations 155

List of figures

Figure 2.1: A female Dakota skipper sits on narrow-leaved purple coneflower (*Echinacea angustifolia*) in its native habitat (Photo by K. Seidle) 4

Figure 2.2: Known global distribution of the Dakota skipper (grey) is contained within the American states of South Dakota, North Dakota, and Minnesota, as well as the Canadian provinces of Manitoba and Saskatchewan (redrawn from Environment Canada, 2007) 7

Figure 3.1: The study area located in southeastern Saskatchewan within the Souris River Valley (right). An insert of the Souris River shows the 3.2 km study area buffer around the Souris River channel (left). A total of 46 sites were surveyed in this area during the 2015 and 2016 field seasons 37

Figure 3.2: Example of a typical survey site with the Hesperiidae survey area (100 m by 250 m) including the vegetation quadrats (Q) and soil samples (S) running down the center. All sites target a slope; starting at the toe slope (Q1; S1), mid slope (S2), and upper slope (Q6; S3) when possible (not to scale) 39

Figure 3.3: NMDS ordinations of plant community composition (A), soil and landscape variables (B), and climate normal variables (C). Red dots indicate negative Dakota skipper occupancy and green dots indicate positive Dakota skipper occupancy. Bar graphs of significant variables degree slope (D), maximum temperature (E), and average temperature (F) with error bars representing standard error 43

Figure 4.1: Dakota skipper habitat suitability and distribution map for southeastern Saskatchewan, with dark red indicating the most suitable habitat, light red indicating least suitable habitat and white indicating no potential habitat 64

Figure G.1: Analysis of the composition of the skipper community associated with the Dakota skipper at each site through non-metric multidimensional scaling (NMDS). An ordination was performed using the first Hesperiidae or positive survey for each site. The Dakota skipper positive site (green dots) ellipse is superimposed over the Dakota skipper negative site (red dots) ellipse indicating that a subset of Hesperiidae species will be present with the Dakota skipper 115

Figure I.1: A female Dakota skipper observed on *Echinacea angustifolia*, displays her dorsal wings (Photo by K. Seidle) 146

Figure I.2: A female Dakota skipper observed on *Monarda fistulosa,* a potential nectaring plant of the Dakota skipper (Photo by K. Seidle) 146
Figure I.3: A female Dakota skipper observed on *Echinacea angustifolia,* a potential nectaring plant of the Dakota skipper (Photo by K. Seidle) 147
Figure I.4: Dakota skipper (Figure I.1) observed at the base of a south facing native prairie slope, in an actively grazed pasture, dominated by *Pediomelum argophyllum* (Photo by K. Seidle) .. 147
Figure I.5: A female and male Dakota skipper caught mating mid-flight display their ventral wings (Photo by K. Seidle) 148
Figure I.6: Three Dakota skipper butterflies found in the Coalfield Community Pasture observed just down from a functioning oil pumpjack on a steep northwest facing slope. This pasture remains native prairie due to rocky soil that is not suitable for agriculture (Photo by K. Seidle) 148
Figure I.7: A Dakota skipper positive site (same site as Figure I.6) contains a large amount of *Pediomelum argophyllum,* a significant forb to Dakota skipper presence (Photo by K. Seidle) 149
Figure I.8: A male Dakota skipper is found just beyond a large gravel pit on a west facing slope. The site is dominated by *Pediomelum argophyllum,* a significant forb to Dakota skipper presence (Photo by K. Seidle) 149
Figure I.9: A Dakota skipper site (same site as Figure I.8) is experiencing *Bromus inermis* invasion and succession further down slope (Photo by K. Seidle) 150
Figure I.10: A negative Dakota skipper site experiencing succession of *Elaeagnus commutate,* a common occurrence now that wildfires have been suppressed within the mesic mixed-grass prairie (Photo by K. Seidle) 150
Figure I.11: A negative Dakota skipper site is severely overgrazed, contains little vegetation cover, and has exposed soils. The Souris River Valley contains sandy, gravelly, and stony soils, which have been exposed on this site (Photo by K. Seidle) 151
Figure I.12: A negative Dakota skipper site containing steep slopes demonstrating how pristine native prairies occur throughout the Souris River Valley as they are too steep to be cultivated (Photo by K. Seidle) 151

Figure I.13: A Dakota skipper positive site contains steep slopes and a dominant population of *Schizachyrium scoparium,* a significant plant species to Dakota skipper presence (Photo by K. Seidle) 152
Figure I.14: A Dakota skipper negative site contains a large population of *Echinacea angustifolia* and *Monarda fistulosa,* potential nectaring plants for the Dakota skipper butterfly (Photo by K. Seidle) 152
Figure I.15: A negative Dakota skipper site contains a large population of *Lilium philadelphicum* and *Campanula rotundifolia,* potential nectaring plants for the Dakota skipper butterfly (Photo by K. Seidle) 153
Figure I.16: An abandoned painted turtle (S3) shell found within the Souris River valley. The mesic mixed-grass prairie is host to a large variety of at-risk species (Photo by K. Seidle) 153
Figure I.17: The mesic mixed-grass prairie is host to the SARA listed northern leopard frog, which is locally abundant in the native prairies of the Souris River Valley; listed as an S3 special concern in Saskatchewan (Photo by K. Seidle) 154

List of abbreviations

C	Carbon
Ca	Calcium
cm	Centimeter
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CV	Coefficient of variance
Df	Degrees of freedom
EC	Electrical conductivity
ESRI	Environmental Systems Research Institute
F	Frequency
g	Gram
GIS	Geographical Information Systems
GLM	Generalized linear model
HCl	Hydrochloric acid
IOA	Index of area of occupancy
IUCN	International Union of Conservation of Nature
IV	Instrumental variables
K	Potassium
KCl	Potassium chloride
kg	Kilogram
km	Kilometer
m	Meter
mm	Millimeters
Mg	Magnesium
mg	Milligram
MRRTF	Multi-resolution ridge top flatness
MRVBF	Multi-resolution index of valley bottom flatness
N	Nitrogen
Na	Sodium
NCC	Nature Conservancy of Canada
NH_4^+	Ammonium

NMDS	Nonmetric multidimensional scaling
NO_3^-	Nitrate
NRCAN	Natural Resources Canada
NSERC	Natural Sciences and Engineering Research Council of Canada
RMSE	Root mean squared error
SARA	Species at Risk Act
SE	Standard error
P	Phosphorus
P	P-value
pH	Potential hydrogen's
USFWS	United States Fish and Wildlife Service
Z	Z-value

1 Introduction

1.1 General introduction

Anthropogenic activities have increased pressure on native prairie species progressively throughout time (Samson and Knopf 1994; Hall *et al*. 2011), altering natural ecosystems and their associated fauna and flora (Environment Canada 2007). Consequently, North America's mesic mixed-grass native prairie ecoregion is merely a fraction of its original extent and continues to decline (Samson and Knopf 1994; Environment Canada 2007). Over the last decade the mesic mixed-grass prairie has become an endangered ecosystem, experiencing drastic declines in both quality and expanse (Samson and Knopf 1994). This ecoregion contains a diversity of native fauna and flora, several of which are prairie obligates that are also at risk (Environment Canada 2007). The Dakota skipper, *Hesperia dacotae* (Skinner, 1911) (Hesperiidae), is among these prairie obligate species (Dana 1991).

The Dakota skipper is listed as endangered by the *Committee on the Status of Endangered Wildlife in Canada* (COSEWIC) (COSEWIC 2014) and the federal *Species at Risk Act* (SARA) (Environment Canada 2017). The Dakota skipper is limited to mesic mixed-grass and tall-grass prairie regions within southern Canada and the northern United States. Due to declines in these native grassland ecoregions it is assumed that the already vulnerable Dakota skipper is also on the decline in both abundance and distribution (Environment Canada 2007). Currently, there is a lack of knowledge on Dakota skipper habitat suitability and availability (Environment Canada 2007; USFWS 2015). Obtaining knowledge on Canadian Dakota skipper populations is critical in order to obtain a continental understanding of this species. Recovery strategies and management recommendations can be guided by the identification of key knowledge relating to Dakota skipper habitat and habitat availability (Environment Canada 2007).

Butterflies are among the most studied invertebrates in the world, playing a crucial role in insect conservation biology (Ehrlich 2003). Ehrlich (2003) suggests that butterflies are a key indicator of the biodiversity of an ecosystem, and can act as an indicator of the health of the mesic mixed-grass prairie ecoregion (Royer and Marrone 1992). Ultimately, the Dakota skipper may act as an umbrella species for protection of associated native habitats, endangered ecosystems, charismatic organisms, plant, and wildlife species that are also at risk (Ehrlich 2003). Therefore, efforts to protect the Dakota skipper work to aid these native prairie ecosystems as a whole (Environment Canada 2007).

1.2 Research objectives

Two objectives are addressed within this thesis. The first objective is to identify the environmental associations of the Dakota skipper within southeastern Saskatchewan. The second objective is to assess the habitat suitability and distribution of the Dakota skipper throughout southeastern Saskatchewan.

1.3 Thesis organization

The research within this thesis is organized as follows: chapter 1 is a general introduction to the thesis. Through a literature review, chapter 2 will introduce the Dakota skipper, providing all background information needed to understand the research conducted within the thesis. Chapter 3 presents the research conducted through *in situ* field studies carried out during the 2015 and 2016 field seasons. This chapter identifies specific environmental associations indicative of Dakota skipper presence in the mesic mixed-grass prairies of southeastern Saskatchewan. Chapter 4 uses species distribution modeling of Dakota skipper habitat in order to predict the species' potential distribution in southeastern Saskatchewan. Chapter 5 is a general conclusion that summarizes and concludes chapter 3 and 4, and provides suggestions for future research and conservation priorities for the Dakota skipper. Appendices contain additional information including data collected *in situ*, data results used within chapters 3 and 4, and a photo appendix.

2 Literature review

2.1 Status

The Dakota skipper, *Hesperia dacotae* (Skinner, 1911) (Hesperiidae), is a prairie obligate Lepidoptera species listed by the *Species at Risk Act* (SARA) as *endangered* in the Canadian provinces of Saskatchewan and Manitoba (Environment Canada 2017). The Dakota skipper has been listed as an S1 or critically imperiled in Saskatchewan and a S2 or imperiled to vulnerable in Manitoba (Saskatchewan Conservation Data Centre 2017; COSEWIC 2014). The Dakota skipper has been listed as threatened under the United States *Endangered Species Act* in 2014. The species is listed as Extirpated in Illinois and Iowa, and Threatened in Minnesota, North Dakota, and South Dakota (USFWS 1973). Globally, the Dakota skipper has been listed as a G2 or Imperiled and is listed as Vulnerable under the World Conservation Union (COSEWIC 2014; World Conservation Monitoring Centre 1996).

2 .2 Biology

2.2.1 Adult skipper appearance

The Dakota skipper is a member of the insect Order Lepidoptera (butterflies and moths) and Family Hesperiidae (skipper) (COSEWIC 2014). The Dakota skipper is a small butterfly measuring between 2.1 to 3.2 cm in total wingspan. Both female and male Dakota skippers are brown to orange in colour with brown and white markings on the surface of the wings (Royer and Marrone 1992) and a light brown fringe bordering the outside of the wings (Figure 2.1) (Cochrane and Delphey 2002; Environment Canada 2007; COSEWIC 2014). The male dorsal wings contain a brown stripe imbedded with a grey strip that appears 3-D when observed closely (Royer and Marrone 1992; personal observation 2015; 2016). The female dorsal and ventral wing contains a combination of white spots. Diagnostic features include a hooked antenna, small body, and a skipping flight pattern when in flight (Royer and Marrone 1992).

Figure 2.1: A female Dakota skipper sits on narrow-leaved purple coneflower (*Echinacea angustifolia*) in its native habitat (Photo by K. Seidle).

2.2.2 Life cycle

The Dakota skipper has a brief life cycle consisting of one generation per year (McCabe 1981; Dana 1991; Royer and Marrone 1992). Throughout this time it will go through four life stages: egg, larva, pupa, and adult (COSEWIC 2014). In Canada, adult butterflies live between two to four weeks, with adults emerging around mid to late June with a prime flight season that lasts from early to mid July (Dana 1991). Flight seasons vary with geography and climate, emerging earliest in western regions of its distribution (Swengel and Swengel 1999a; Cochrane and Delphey 2002). The Dakota skipper butterfly is limited to a dispersal distance of approximately 1 km during the entirety of its adult life, though Dana (1991) suggests that the species has an even more limited flight range of 300 m. Therefore, nectaring and mating must occur within this maximum 1 km dispersal range (Cochrane and Delphey 2002).

Mating will last throughout the duration of the Dakota skipper flight season (McCabe 1981; Dana 1991). Female butterflies lay between 20 to 30 eggs daily for the first two days after emergence. This number declines with time until few eggs are laid each day towards the end of the female adult life. Each female will lay approximately 180 to 250 eggs over the course of the flight season. Eggs are laid on the underside of vegetation including erect grass blades (Dana 1991) and broad leaves (McCabe 1981) within 1 to 4 cm of the soil surface (Dana 1991). These eggs hatch within 7 to 20 days, varying based on temperature (McCabe 1981).

Larvae emerge and find shelter at the base of bunchgrass species or below ground level within the litter layer or upper soil layer. Larvae create shelters out of plant tissue attached through the use of silk; these shelters grow progressively as the larvae increase in size (McCabe 1981; Dana 1991). Larvae emerge from their shelters at night to feed on grasses while still remaining close to their shelters (McCabe 1981; Dana 1991; Royer and Marrone 1992; Cochrane and Delphey 2002). This cycle continues throughout the first to third instars, which will last from eight to 18 days. Larvae complete the fourth instar overwintering in these shelters or taking residence below ground for 16 to 35 days (Dana 1991). Larvae then diapause in the fourth instar during the winter (McCabe 1981; Dana 1991). The following spring, larvae will resume feeding on bunchgrass species and complete their last two instars of development (Dana 1991). When the temperature has reached 10°C, the larvae can develop into adults (McCabe 1981). The larvae shift from their overwintering shelters in the soil to horizontal shelters above the soil surface, built from available native grasses on site. The fifth and sixth instars are completed in the following spring lasting between 29 to 40 days. The Dakota skipper enters a pupal stage lasting between 13 to 19 days before it emerges into a butterfly. The Dakota skipper spends the majority of its life as a larva (Dana 1991) and the larvae go through a total of six instars in Canada before becoming butterflies (Cochrane and Delphey 2002).

2.2.3 Distribution

The Dakota skipper inhabits portions of the mesic mixed-grass and tall-grass prairie regions within North America (Environment Canada 2007; COSEWIC 2014). At its largest extent the Dakota skipper occupied southern Manitoba, North Dakota, eastern South Dakota, western Minnesota, Iowa, northern Illinois, and southeastern Saskatchewan (McCabe 1981; Dana 1991; Royer and Marrone 1992; Cochrane and

Delphey 2002). Current Dakota skipper populations occur in the southern portion of Canadian provinces Manitoba and Saskatchewan and south into the United States of North Dakota, South Dakota, and Minnesota (Figure 2.4). Currently, there are three populations identified within Canada. Two populations are located in Manitoba, one in the northern Interlake region and the second near the town of Griswold (COSEWIC 2014). Recently, a Dakota skipper population has been identified within the Souris River Valley of southeastern Saskatchewan (Hooper 2003). These existing Dakota skipper populations are found mainly on private lands containing remnant native prairie (Environment Canada 2007).

Distribution of the Dakota skipper is a makeup of a variety of factors. It has been suggested that the Dakota skipper will inhabit areas based on plant community, these areas will contain nectaring and larval host plants (McCabe 1981). Furthermore, it has been suggested that larval development within the upper soil layer is a key determinate for the distribution of the Dakota skipper (McCabe 1981; Dana 1991; Royer *et al*. 2008). Dana (1991) suggests that landscape and microclimate play key roles in Dakota skipper distribution, factors also supported by Kerby *et al*. (2012) who suggests climate will determine a species distribution. The USFWS (2015) state that the Dakota skipper will move for one of three reasons: a lack of nectar flowers, a local disturbance to the habitat, or in search of a mate. All factors combined have the potential to influence the distribution of Dakota skipper populations.

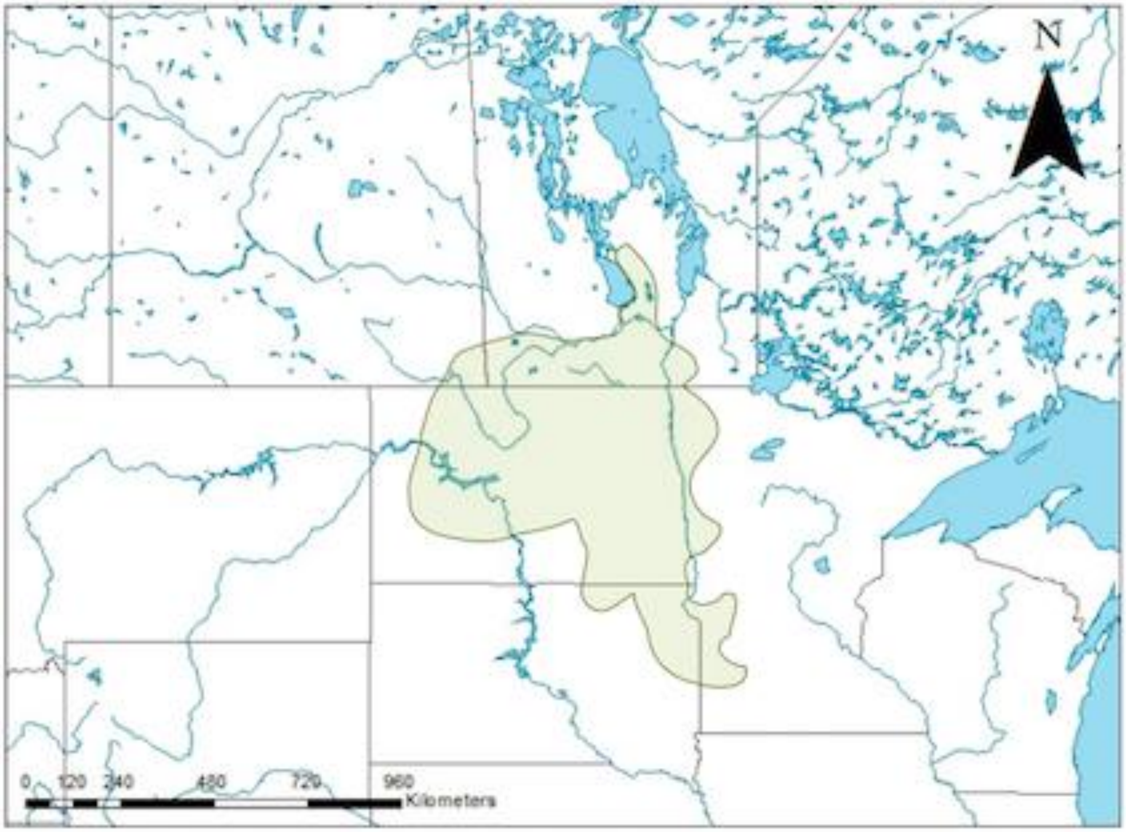

Figure 2.2: Known global distribution of the Dakota skipper (grey) is contained within the American states of South Dakota, North Dakota, and Minnesota, as well as the Canadian provinces of Manitoba and Saskatchewan (redrawn from Environment Canada 2007).

2.2.4 Population

Dana (1991) suggests that individual Dakota skipper populations may experience large but normal fluctuations from year to year. Westwood (2010) also observed that a Dakota skipper population will fluctuate at each individual site from year to year. Surveys estimate that Manitoba contains a Dakota skipper population of more than 10,000 individuals while Saskatchewan is estimated to contain a population of less than a 1,000 individuals (COSEWIC 2014). However, Dana (1991) suggests that only a half to a third of adult Dakota skippers will fly at the same time, affecting the accuracy of population estimates. Timing of surveys will also have an effect on population estimates (Webster 2007; Westwood 2010). Given these uncertainties, Dakota skipper population estimates should be taken with skepticism.

2.3 Habitat suitability

Suitable habitat is a geographic area containing physical and biological features necessary for a species to survive, reproduce, and persist. This area must contain all features necessary to carry out life processes including feeding, shelter, space, and reproduction. This geographic area must support and promote all portions of the species life-cycle (USFWS 2015; Environment Canada 2017). Suitable Dakota skipper habitat may be currently occupied sites or unoccupied sites that have the potential to contain a population now or in the future. Suitable habitat includes geographic areas that contain the environmental variables necessary for the Dakota skipper to successfully carry out its life cycle (USFWS 2015). Dakota skipper habitat suitability is based on various different abiotic and biotic components including land use, vegetation, soil, climate, and microclimate. This set of environmental characteristics will define Dakota skipper habitat.

2.3.1 Landscape

The Dakota skipper inhabits high quality remnant mesic mixed-grass and tall-grass native prairie within Canada and the United States (Royer and Marrone 1992). However, it is suggested that the Dakota skipper will inhabit only a fraction of this mesic mixed-grass prairie (Metzler *et al*. 2004) and therefore habitat is more limited than initially thought. In general, the Dakota skipper inhabits dry prairies in its western extent and wet prairies in its eastern extent (Environment Canada 2007). This trend continues into Canada. Within Saskatchewan, the Dakota skipper is typically observed in upland dry to mesic mixed-grass native prairies, whereas in Manitoba it is found in low wet to mesic tall-grass and mesic mixed-grass native prairies (COSEWIC 2003; Environment Canada 2007). Typical land uses within these regions include agriculture such as haying and monoculture crops, pastureland that is grazed by cattle, and native prairie which is left idle or managed through fire (Environment Canada 2007).

Dakota skipper populations are likely to inhabit a specific set of landscape conditions within these regions. Within Saskatchewan's mesic mixed-grass native prairie, the Dakota skipper is found to inhabit steep south facing prairie slopes (Webster 2007). Dana (1991) found that the Dakota skipper adult is more likely to move along these steep ridges rather than through valley bottoms. These steep slopes are found to support abundant sources of native flora used for nectaring and native bunchgrass species used for larval food and shelter (Dana 1991). These south facing slopes have been suggested to contain a warmer microclimate, which aid in Dakota skipper larvae development (Webster 2007; Weiss and Weiss 1998).

2.3.2 Vegetation

Habitat suitability and distribution of the Dakota skipper is predicted to be closely associated with the distribution of specific vegetative communities (McCabe 1981). Dakota skipper habitat must be dominated by a variety of native grasses and forbs, available within sufficient quantities and located within proximity to the species' populations (Cochrane and Delphey 2002; USFWS 2015). The USFWS (2015) found that Dakota skipper habitat consists of woody and shrubby vegetation occupying less than 5% of the vegetative community on dry sites and less than 25% of the vegetative community on moist sites. Invasive species were found to make up less than 5% of the vegetative community on both wet and dry sites (USFWS 2015). Cochrane and Delphey (2002) state that native prairie habitats containing a wider variety of plant species will be of greater value to the Dakota skipper.

Dakota skipper habitat must contain native prairie bunchgrasses in order for larvae to develop, feed, and find shelter. Larvae are dependent on a variety of native prairie grasses including *Schizachyrium scoparium* (Michx.) Nash, *Andropogon gerardi* Vitman, *Bouteloua curtipendula* (Michx.) Torr. In Marcy, *Sporobolus heterolepis* (A. Gray) A. Gray, and *Hesperostipa spartea* (Trin.) Barkworth (Dana 1991). Dana (1991) and Royer and Marrone (1992) found that *Schizachyrium scoparium* in particular is highly preferred by Dakota skipper larvae for feeding and constructing shelters. Larvae are dependent on these bunchgrass species as they are fine stemmed, close to the ground, develop more slowly, and are shorter in length, which enables feeding and shelter building. Tame grass species contain undesirable traits such as being too high off the ground, too hairy, too smooth, or mature too quickly which inhibits the use of these grasses to Dakota skipper larvae (Cochrane and Delphey 2002). Larval success will greatly depend on the presence and development of these native bunchgrass species within their habitat (USFWS 2015). Bunchgrasses have also been identified as ovipositing sites for Dakota skipper butterflies. Eggs are typically found on these same bunchgrass species used by the larvae (Dana 1991). Additionally, Dakota skipper butterflies have been observed to mate in shorter native grasses with little dead material in drier portions of the prairie (COSEWIC 2003).

As a herbivore, the Dakota skipper feeds on nectar of native flora in order to receive water and food (Dana 1991). Thus, native flora will in part determine the species habitat (McCabe 1981). McCabe (1981) found that local Dakota skipper populations will shift with their nectar sources. The Dakota skipper requires a variety of native flora species in order to carry out nectaring requirements (Dana 1991; Environment Canada 2007). Dana (1991) suggests that a wider variety of nectaring sources are ideal as flora will vary in their contribution and value. Ultimately, the Dakota skipper flight period must be synchronized with the bloom of these native flowers, and habitat must contain an abundant supply of these nectar sources throughout the flight season (Environment Canada 2007). Adult Dakota skippers have been found to feed on nectar from various native prairie flora including *Rudbeckia hirta* L., *Campanula rotundifolia* Boiss., *Echinacea angustifolia* DC., *Apocynum cannabinum* L., and *Lilium philadelphicum* Thunb. (COSEWIC 2003; Environment Canada 2007). Additionally, Dakota skippers have been observed to utilize flora as perching platforms during mating (Dana 1991).

2.3.3 Soil

Larval development and survival is likely to be influenced by the upper soil layer where Dakota skipper larvae spend the majority of their life cycle (McCabe 1981; Dana 1991). Royer *et al*. (2008) suggest that Dakota skipper habitat may be determined by soil conditions including soil moisture, compaction, and bulk density. Cochrane and Delphey (2002) also state that soil moisture, compaction, soil pH, surface temperature, and humidity may be factors relating to Dakota skipper larvae development. Ultimately, any changes or alterations to the soil may leave the soil uninhabitable for Dakota skipper larvae (USFWS 2015).

Royer *et al*. (2008) found there are two types of soil characteristics that Dakota skipper larvae will inhabit. The first type contains low relief, a sandy soil texture that remains saturated between the depths of 40 to 60 cm, and a soil bulk density exceeding 1.0 g/cm^3. These areas are associated with margins of glacial lakes and are susceptible to flooding (McCabe 1981; Royer *et al*. 2008). This type of Dakota skipper habitat is more commonly found in Manitoba opposed to Saskatchewan. The second soil characterization includes high relief, rolling terrain, with a sandy loam or loamy sand soil texture, and a larger variability in soil moisture and soil temperature, with a bulk density below 1.0 g/cm^3. These areas are typically associated with gravelly glacial landscapes (Royer *et al*. 2008), and are common of Saskatchewan Dakota skipper habitats opposed to Manitoba.

Dakota skipper populations are typically associated with a parent material of margins near shore glacial lakes or gravelly glacial moraine deposits and their associated soils. Dakota skipper populations inhabit glacially related surface geology (McCabe 1981) or poorly sorted glacial moraine deposits (Royer *et al*. 2008). Dakota skipper populations have been found to occupy dry to mesic alkaline soils (McCabe 1981; Royer and Marrone 1992), and are commonly associated with calcareous mesic prairie soils (McCabe 1981).

Dakota skipper larvae carry out the majority of their life cycle in the litter layer or upper soil layer (McCabe 1981; Dana 1991). Royer *et al.* (2008) suggests that precipitation, evapotranspiration, and soil moisture may be defining features of Dakota skipper habitat. These factors are affected by litter depth, soil texture, and soil bulk density (Royer *et al*. 2008; Dearborn and Westwood 2014). Dearborn and Westwood (2014) suggest that a thick litter layer at the soil surface may help to increase larval survival and development. Additional litter at the soil surface allows for greater soil moisture by lowering temperature at the soil surface (Ehrenreich and Aikman 1963). Additionally, humidity at the soil surface is decreased by water loss within the soil. Dakota skipper populations are associated with soils containing a sandy loam to loamy sand texture. Sandy soils allow water to pass through while clay soils tend to impede water movement. A sandy soil texture may lead to dryer soil surfaces, as water will pass through at a faster rate. Compacted soils on slopes result in a higher bulk density and have the potential to change the vertical water distribution. This restricts the movement of water and results in the formation of a dry surface soil layer which reduces the humidity at the soil layer, of an already dry soil texture later in the summer when larvae are developing (Royer *et al*. 2008). Therefore, the Dakota skipper typically inhabits areas that contain soils with higher water tables and permeability resulting in increased humidity at the surface of the soil (USFWS 2015).

Soil pH has also been suggested to impact Dakota skipper populations (McCabe 1981). McCabe (1981) predicts that Dakota skipper larvae may be affected by pH, with larvae inhabiting soil with a pH of 7.2 to 7.8, but no significant patterns or results were found. However, McCabe (1981) states that soil pH is an important factor in Dakota skipper larval survival and tolerance range may be less than 0.2 pH. Overall, there has been limited literature or work conducted on Dakota skipper soil preferences including micronutrients, macronutrients, pH, and electrical conductivity (EC).

2.3.4 Climate and microclimate

Dakota skipper distribution may depend in part on climatic variables. Temperature in particular is one of the most important driving forces that contributes to a species distribution (Grinnell 1917). Turner *et al*. (1987) found that butterfly survival is based on sunshine and temperature within the microclimate of their habitat. The Dakota skipper is an ectothermic species that requires heat to develop and reach maturity (Westwood and Blair 2010). Davies *et al*. (2006) found that ectothermic species located at their northern extent in range are commonly constrained by temperature. Royer *et al*. (2008) suggests that Dakota skipper populations are more limited by non-biotic habitat characteristics such as temperature and humidity experienced during the larval stage of development. Therefore, areas inhabited by Dakota skipper larvae must contain a microclimate that allows for proper development (Turner *et al*. 1987; Royer *et al*. 2008). Dakota skipper larval maturity and emergence is based on thermal units or degree day calculations (Dearborn and Westwood 2014). Dearborn and Westwood (2014) use thermal units to predict the emergence of the Dakota skipper. Research conducted on the Dakota skipper within Manitoba, determined the mean number of degree days for emergence to be between 566.4 in the southwest region and 591.6 in the southeast region of Manitoba, varying based on geography (Dearborn and Westwood 2014).

2.4 Dakota skipper threats, habitat threats, and best management practices

The Dakota skipper inhabits the native mesic mixed-grass prairie region, which has experienced significant losses over the last couple decades (Samson and Knopf 1994; Environment Canada 2007; COSEWIC 2014). This region is considered an endangered ecoregion in itself (Samson and Knopf 1994; Environment Canada 2007). The native prairie in this ecoregion has been greatly reduced with only 19% and 0.1% remaining in Saskatchewan and Manitoba, respectively (Samson and Knopf 1994). This habitat loss is mainly attributed to anthropocentric factors such as industrial and agricultural practices including monoculture, haying, grazing, burning, and insecticide use. Additionally, these practices have resulted in the introduction of invasive species, habitat fragmentation, succession, and reduced diversity. All of these practices present significant threats to the Dakota skipper and its habitat when management methods are not implemented correctly (Environment Canada 2007).

Developing land management practices in order to inform and educate landowners of strategies that accommodate Dakota skipper populations is critical to the conservation of this species (Webster 2007). Best land management practices target to maximize habitat and populations of the Dakota skipper (Britten and Glasford 2002). The USFWS (2016a), state that the timing, intensity, duration, and extent of land management activities will have a significant effect on Dakota skipper populations. Currently, the majority of known Dakota skipper populations occur on privately owned lands that are managed under different regimes. Many of the land management practices currently being implemented in these areas can be managed in a way that accommodate both landowners and Dakota skipper populations (Environment Canada 2007). Swengel and Swengel (2001) emphasize that management practices should be put in place to accommodate prairie specialist species such as the Dakota skipper.

2.4.1 Agriculture and industry

Conversion of native prairie to agricultural and industrial uses has been the main contributor to the loss of the native mesic mixed-grass prairie (Samson and Knopf 1994). Agriculture is typically practiced through monoculture row crops, eliminating the biodiversity of the native prairie through the tilling of the soil and removal of native vegetation. The USFWS (2015) state that tilling of the land will alter habitat to the point that it will no longer support a Dakota skipper population. Furthermore, industrial development such as roads, railways, and pipelines as well as gas, oil, gravel, and mining developments contribute to the elimination and fragmentation of the native prairie (Cochrane and Delphey 2002; Environment Canada 2007; Hall *et al*. 2011; COSEWIC 2014; USFWS 2015). Additionally, urban expansion (Cochrane and Delphey 2002) and recreational activities (Hall *et al*. 2011) have also contributed to the loss and disturbance of native prairie habitats. These developments result in elimination and alterations to both the soil and native vegetation (Swengel and Swengel 1999a; Cochrane and Delphey 2002), destroy Dakota skipper habitat, remain irreversible, and will no longer support a Dakota skipper population (Environment Canada 2007; USFWS 2015). Therefore, conversion of remaining native prairie to agriculture or industrial uses should be avoided in order to maintain and increase Dakota skipper habitat.

2.4.2 Haying and mowing

Haying and mowing have implication to the Dakota skipper indirectly through the alteration of vegetation that is utilized by the species throughout its life cycle and makes up this species habitat. When implemented in early summer during the Dakota skipper flight season, haying and mowing eliminate essential vegetation for nectaring and mating butterflies (McCabe 1981; Dana 1991). Swengel (1996) found that haying in late summer will reduce grass species needed by Dakota skipper larvae, haying in early spring will reduce forb species needed by butterflies, and mid-season haying maintains a diversity of the two (Solecki and Toney 1986). Haying and mowing maintain a consistent vegetation cover and a higher diversity of vegetative species richness than other forms of prairie management (Swengel 1996, Solecki and Toney 1986). This method aids in reducing succession of woody species within the native prairie (USFWS 2016b), and results in fewer invasive species due to little disturbance of the soil (Swengel 1996).

Dakota skipper larvae inhabit the upper soil layer for the majority of their life cycle, which can be altered when haying and mowing practices are implemented. Haying and mowing will lead to compaction of the upper soil layer leading to an increase in the soil bulk density, changing the soil hydrology, reducing ground water movement, and decreasing porosity of the soil in which Dakota skipper larvae occupy (Royer *et al*. 2008). Consequently, this results in change to the microclimate of Dakota skipper habitat which will affect the rate of larval development (McCabe 1981; Dana 1991). Impacts to the soil will vary based on each individual site and ultimately dictate if a Dakota skipper population can persist within an area. Furthermore, haying and mowing may result in direct impacts to the Dakota skipper populations such as killing butterflies or squishing larvae (McCabe 1981).

However, haying and mowing have been determined the best land management practice to accommodate Dakota skipper populations when implemented correctly (McCabe 1981; Swengel and Swengel 1999a). Swengel and Swengel (2001) found that insect declines were much less and shorter immediately after haying (Bulan and Barrett 1971; Morris 1975) and proved to be of greater benefit to specialist butterflies than other prairie management methods (Swengel 1996). McCabe (1981) monitored a successful Dakota skipper population under a late mowing regime for over 50 years. Haying and mowing management strategies should be conducted in late September after the Dakota skipper flight season (McCabe 1981; Swengel and Swengel 1999a). A late mowing regime will reduce the destruction of Dakota skipper eggs and larvae while allowing for Dakota skipper butterflies to take full advantage of nectar sources (Environment Canada 2007). Late mowing regimes reduce accumulation of litter, maintain plant communities through high plant diversity, decrease invasive species, and prevent succession (Solecki and Toney 1986; COSEWIC 2003). Best management practices suggest patchy mowing is beneficial to prairie specialist butterflies (Swengel and Swengel 2001). Webster (2007) found that late mowing regimes with a two year mowing cycle result in little to no impact on Dakota skipper populations (McCabe 1981; Swengel and Swengel 1999a). The USFWS (2016b) suggest to maintain a minimum of 20 cm of stubble in order to provide overwintering habitat for Dakota skipper larvae (Environment Canada 2007). Ultimately, a late haying or mowing regime should be encouraged and implemented in order to accommodate Dakota skipper populations when possible.

2.4.3 Natural processes

Prior to European settlement, native prairie regions were managed through natural disturbances including prairie fires (Sauer 1950; Vogl 1974), climate (Transeau 1935; Borchert 1950) and roaming herds of bison (Larson 1940; England and DeVos 1969; McCabe 1981; Hall *et al.* 2011) or a combination of the three (Anderson 1982; Howe 1994). However these natural processes occurred in a pristine native grassland and cannot be mimicked in current day fragmented native prairies (Swengel 2001). Current literature suggests that land management practices should be carried out after the Dakota skipper flight season while impacts on larvae should be considered throughout all times of the year (Britten and Glasford 2002; USFWS 2016a). Swengel (1996) emphasizes the importance of diverse management practices among sites. Ultimately, land management practices should stray away from large uniform treatments and be replaced by small scattered land management treatments (Swengel 1996). Both management diversity and consistency are key in maintaining these prairie habitats for prairie specialist species (Swengel and Swengel 1997). However, best management practices may vary by region and landscape, suggesting that no one management practice is best for the Dakota skipper (Swengel 2001).

2.4.4 Grazing

Prairie habitats were historically maintained by grazing herds of bison; over time these natural processes have been artificially recreated and intensified through cattle grazing. Grazing pressure and timing have been found to have harmful effects on Dakota skipper habitat through the alteration of the plant community (McCabe 1981; Cochrane and Delphey 2002; Royer *et al.* 2008). Grazing has a direct impact through the reduction of nectaring plants, larval host plants, and introduction of invasive or exotic plant species (McCabe 1981; Dana 1997). However, grazing will also reduce the succession of woody species and reduce the litter layer which helps to maintain the native plant community (Dana 1991).

Cattle may alter the upper soil layer that is occupied by Dakota skipper larvae. Cattle tend to concentrate in small areas resulting in patchy soil compaction (McCabe 1981; Cochrane and Delphey 2002; Royer *et al.* 2008). Soil compaction results in changes to soil hydrology, reduces groundwater movement, increases soil bulk density, and decreases soil porosity (Royer *et al*. 2008). This results in changes to the moisture and humidity at the soil surface which changes the microclimate of Dakota skipper habitat (Royer *et al*. 2008; Swengel 2001). Furthermore, McCabe (1981) found that cattle can physically destroy Dakota skipper larvae and eggs by stepping on them (McCabe 1981; Dana 1997; Cochrane and Delphey 2002).

If grazing practices are implemented in Dakota skipper habitat, best management methods suggest small intervals of grazing in early spring will accommodate to this species (Dana 1991). However, Dakota skipper sites vary and each site must be managed based on the knowledge of these sites (USFWS 2016b). Environment Canada (2007) states that wet mesic prairies should not be grazed at all, while dry mesic prairies can handle light grazing in early spring before nectaring plants mature. Dry mesic prairies should only be grazed in the spring before the bloom of native plants and maintain a one-year rest period rotation. McCabe (1981) observed that Dakota skipper butterflies are consistently absent from heavily grazed sites while Dana (1991) suggests that small intervals of grazing may not harm populations.

2.4.5 Fire

Prairie fires were an important component of maintaining prairie grassland ecosystems (Vogl 1974); however, current fire management regimes differ to historic management regimes in timing, intensity, and frequency (Swengel 1998). Fire management has been found to alter the native prairie plant community. Prairies that lack fire decrease in plant diversity and species richness over time (Vogl 1974). Fire reduces vegetation which aids in holding snow during the winter months, acts as an insulating factor for Dakota skipper larvae (Ehrenreich and Aikman 1963), and eliminates vegetation utilized by the larvae for food and shelter (Dana 1991). Fire immediately changes the plant community by burning nectar sources and larval host plants utilized by the Dakota skipper (McCabe 1981; Solecki and Toney 1986; Swengel 1996) however, followed by an increase in plant species the following year (Swengel 1996). Bates (2007) found that recently burned sites contain a higher diversity of plant species richness, which is valuable to Dakota skipper populations. Fire can control invasive plant species (Dana

1991) but can also create conditions for pioneer communities (Swengel 1996; Vogl 1974; Solecki and Toney 1986). Fire removes woody species which delays succession and maintains the native prairie plant community (Vogl 1974; Anderson 1982).

Fires affect the upper soil layer in which Dakota skipper larvae occupy for the majority of their life. Fire reduces the litter layer, which results in changes to the microclimate (Anderson 1982; Dana 1991). A loss of this litter layer reduces insulation in the winter months which may be detrimental to Dakota skipper larvae (Dana 1991). Likewise, loss of this litter layer increases exposure of the sun in summer months increasing larval development. Furthermore, fire exposes the soil resulting in a dry top soil layer increasing evapotranspiration rates, reducing humidity and moisture at the soil surface and resulting in desiccation of Dakota skipper larvae (Anderson 1982; Dana 1991). Fire causes direct insect mortality to Dakota skipper butterflies (Swengel 1996; Swengel and Swengel 2001) and may kill large portions of the larvae and egg population (McCabe 1981). Burns conducted in early summer destroy Dakota skipper eggs and result in adult deaths, while burns conducted during any other season have the potential to destroy larvae (McCabe 1981).

If fire practices are to be implemented in Dakota skipper habitat, best management methods suggest that they occur in a patchy framework in early spring. Fires should occur at this time in order to reduce disturbance to developing vegetation; vegetation grows rapidly in early spring (Swengel 1996), and larval feeding rates are low as they remain in the soil (Dana 1991) which can act as an insulator to the fire (Anderson 1982). Habitats with high fuel loads should avoid spring burns as they will produce heats that cause larval mortality (Dana 1991). The USFWS (2016b) state that if a site contains a large amount of fuel, haying or mowing before the burn can reduce the intensity of the fire. Fires should be carried out in a mosaic with only small sections of habitat burnt each year, with repeat burns occurring every three to four years (Dana 1991; Environment Canada 2007). Burn sites should be divided into as many units as possible and these units should contain an even amount of Dakota skipper habitat (Dana 1991; USFWS 2016b). The minimum amount of burn units should be three, with only one unit being burnt each year (Swengel and Swengel 2001). If this three year burn cycle is not possible, the site should be subsidized through light grazing or haying practices (Swengel 1996; USFWS

2016b). Ultimately, Swengel and Swengel (1997) found that sites with a fire management regime support fewer and lower densities of specialist butterflies which take longer to rebound post fire (Swengel 2001).

2.4.6 Insecticide use

Insecticide use is a common agricultural and industry practice that may be implemented in areas near Dakota skipper habitat (Royer and Marrone 1992; Hall *et al*. 2011). Insecticides are used on the perimeter of the native prairie in agricultural lands to control invasive species. These applications have the potential to drift from their original target species and indirectly affect Dakota skipper populations and habitat (Royer and Marrone 1992; Hall *et al*. 2011). A more severe threat includes a common practice used by members of the oil and gas industry who apply these sprays around industrial developments located directly in native prairie habitats (personal observation 2015). These insecticide applications present the potential to change vegetative communities (Hall *et al*. 2011) or cause direct insect mortality (Royer and Marrone 1992; Hall *et al*. 2011).

If insecticide application is required in or around Dakota skipper habitat, best management methods suggest to use caution when spraying in these areas. Ensure that sprays hit the intended target with reduced drift by applying in lower wind speeds and appropriate wind directions. It is suggested that controlling weeds and invasive species with insecticides should be avoided in Dakota skipper habitat. When needed, spot control methods should be implemented so as to reduce the negative effects on Dakota skipper populations (Environment Canada 2007).

2.4.7 Invasive and exotic species

Invasive flora causes changes to the native prairie vegetation community affecting Dakota skipper nectaring and larval host plants (Cochrane and Delphey 2002; Environment Canada 2007). When an exotic or invasive plant enters a site it crowds out native plant species, resulting in either replacing or greatly reducing the native plant community and species richness (Cochrane and Delphey 2002). An invasive or exotic species will reduce the necessary native plants needed by Dakota skipper larvae and butterflies for feeding and nectaring respectively. Environment Canada (2007) suggests limiting disturbances to the native prairie in order to reduce invasive and exotic species. If management of native prairies for invasive or exotic species is necessary, it is suggested that spot control herbicide methods be used to reduce impacts to the Dakota skipper population (Environment Canada 2007).

Invasive and exotic fauna also have the potential to affect Dakota skipper populations. Hirzel and Le Lay (2008) suggest the possibility of competitive exclusion when several butterfly species occupy a single site. Co-occurring butterflies may nectar on the same flora, resulting in one species outcompeting the other. However, McCabe (1981) suggests that co-occurring butterflies do not nectar on the same plants and Dana (1991) and Royer and Marrone (1992) suggest that predation and competition are not likely influences on the Dakota skipper populations. Therefore, no management methods have been suggested for invasive or exotic fauna.

2.4.8 Fragmentation

Fragmented landscapes limit Dakota skipper populations to remnant isolated patches of native prairie habitat (McCabe 1981). These fragmented landscapes make it difficult for the Dakota skipper to colonize new areas due to their short life span and poor dispersal capabilities (McCabe 1981; Dana 1991; Cochrane and Delphey 2002). Verboom *et al*. (1991) state that as fragmented patches of land get further away from one another the possibility of species extinction will increase and recolonization will decrease. Furthermore, fragmentation will result in increased edge effects, reducing high quality native prairie habitat (Crone and Schultz 2003)

Dakota skipper population success increases with increased habitat patch size and quality (Verboom *et al*. 1991). Crone and Schultz (2003) found that smaller patches of habitat increase the chances of a butterfly wandering to unsuitable habitat and is a large contributor to the loss of butterfly populations (Pohl *et al*. 2014). Similarly, Thomas *et al*., (1992) found that butterflies are more successful in large, non-isolated patches of habitat. Swengel and Swengel (1999b) state that larger patches of native prairie contain denser populations of skipper butterflies (Thomas *et al*. 1992; Thomas and Jones 1993). Swengel and Swengel (1997) found that the Dakota skipper did not occupy habitat less than 0.20 km^2 (19.8 ha), while smaller Dakota skipper populations were present on midsized habitats ranging between 0.30 to 1.30 km^2 (29.9 to 129.9 ha) and larger habitats containing over 1.40 km^2 (140 ha) hosted the largest populations (Swengel and Swengel 1997). In general, the chances of maintaining a species increases with larger areas of available habitat (USFWS 2015).

Best land management practices suggest that Dakota skipper habitat should be managed to reduce fragmentation and strive to maintain habitat connectivity (Environment Canada 2007). Britten and Glasford (2002) suggest that habitat fragmentation can be reduced through habitat corridors, which allows for the development of networks to enhance gene flow and allow species to spread. Ries *et al.* (2001) suggest that managing roadside habitats can be beneficial for butterfly species and act as habitat corridors between suitable native habitats. Swengel and Swengel (2001) found that specialized butterflies are less sensitive to land management treatments conducted in larger patches of habitat. However, the USFWS (2015) state that it is still beneficial to protect small fragmented pieces of suitable habitat due to the fact that the Dakota skipper does occupy these smaller sites. However, smaller habitat patches will need to contain higher quality of habitat compared to larger patches of habitat (Crone and Schultz 2003).

2.4.9 Genetics

Dakota skipper populations were once all connected, with Canadian populations being only slightly distinct from United States populations (Britten and Glasford 2002; Cochrane and Delphey 2002). Genetic variation in a species is important as it allows for a species to survive in a variety of environmental conditions. Species with high genetic variability have the potential to deal with a variety of stressors including diseases, parasites, competition, food sources, predators, and climate in unique and different ways (USFWS 2015). Current Dakota skipper populations are genetically isolated from one another resulting in an overall small genetic variability. Isolation of populations has resulted in genetically distinct and inbred populations that are susceptible to inbreeding depression and overall poor population performance, making them susceptible to local extinctions (Britten and Glasford 2002). Genetic variability accompanied by high rates of immigration can stabilize a population and prevent extinction of this species (Brown and Kodric-Brown 1977).

Best management methods suggest that protecting small Dakota skipper populations, as well as populations at the periphery of the species range is vital, as these are the individuals that have the potential to contain the largest genetic diversity (USFWS 2015). Furthermore, it is important to preserve Dakota skipper populations across the range of its distribution to maintain this genetic variability (Britten and Glasford 2002; USFWS 2015). It is important that these populations maintain connectivity through a non-fragmented landscape so immigration of individuals may be possible in order to increase genetic variation within this species (Brown and Kodric-Brown 1977). This is why it becomes necessary and essential to maintain the Saskatchewan Dakota skipper population which inhabits the northwestern periphery of the species' geographic range (Environment Canada 2007; COSEWIC 2014).

2.4.10 Idling and succession

In the absence of disturbance or management regimes, idling of land has the potential to eliminate Dakota skipper habitat through succession of the native prairie to shrub lands (Environment Canada 2007). Unmanaged prairies experience encroachment of woody tree and shrub species (McCabe 1981; Royer and Marrone 1992), an accumulation of litter and introduction of invasive species (Environment Canada 2007; Royer and Marrone 1992; Swengel and Swengel 2001). Woody species reduce light penetration to the soil surface, which alters the microclimate, moisture gradient, and plant community. Alteration of the plant community means that necessary nectaring flora and larval host plants may not be available to Dakota skipper larvae and butterflies (USFWS 2015). The USFWS (2015) found that when woody species move into an area and become dominant, Dakota skipper populations start to decline due to a lack of larval food and nectaring sources. Swengel and Swengel (1999a) found Dakota skipper populations were much lower on idle land and suggest that prairie disturbances are necessary to maintain habitat for this species. Best management methods suggest that these disturbances should mimic prehistoric processes (Vogl 1974; Anderson 1982) and are best implemented through haying or mowing.

2.4.11 Climate change

Climate change continues to result in rising temperatures, variations in precipitation, and more severe climate events, affecting the Dakota skipper and its habitat (Hall 2009). Hall *et al*. (2011) suggests that many insect species located in the north are vulnerable and less adaptable to climate change as northern portions of the world are experiencing increased and dramatic changes in comparison to southern regions. Dakota skipper populations and habitat are vulnerable to localized catastrophes spurred on by climate change including floods, fires, and droughts (Environment Canada 2007). Dakota skipper populations are particularly susceptible to habitat disturbances caused by these climate events as populations are spatially and genetically isolated from one another resulting in local extinctions (Britten and Glasford 2002). Therefore, natural events due to climate change result in the potential to extirpate a whole population of this species in a single event (Environment Canada 2007).

Climate change may affect densities, characteristics, and traits of interactions of species and their environment (Kerby *et al*. 2012). Hirzel and Le Lay (2008) state that climate change will influence and change an organism's habitat. New habitat may become available while old habitat may deteriorate (Davies *et al*. 2006). The Dakota skipper will be affected by the timing and flowering of native flora and there is potential for a shift in overall plant community, affecting mating and nectaring (Environment Canada 2007). Furthermore, climate change can affect an organism's life cycle. Dakota skipper emergence is dependent on thermal development (Dearborn and Westwood 2014), and ectothermic species will emerge at a time when nectar sources are readily available to them which will be changing based on the climate (Westwood and Blair 2010). This means that the species interacting with the Dakota skipper will vary depending on the time of year that the butterflies emerge. This presents the opportunity for different competitors and predators for the Dakota skipper (Kerby *et al*. 2012).

Dakota skipper populations must adapt to their environment or move with suitable habitat over space and time (Pease *et al*. 1989). Over many generations an organism will evolve and adapt to its environment in response to climate change (Miner *et al*. 2005). However, with one generation a year (Dana 1991) the Dakota skipper may not evolve fast enough to accommodate climate change, as climate is changing at a rate that exceeds this species' evolutionary rates (Pease *et al*. 1989). Adapting to climate change may not be possible for the Dakota skipper (Visser 2008). Therefore, this species will have to move with its habitat in time and space. Evidence suggests that species at their northern range in extent are beginning to use a larger range of habitats (Thomas *et al*. 2001; Roy and Thomas 2003). Therefore, even though suitable habitat has been mapped and classified for the Dakota skipper, there is potential that other habitat outside of its current distribution may also be suitable and important for this specie's conservation within a changing climate (USFWS 2015).

Climate change is forcing species distributions to change, resulting in species moving further north (Hall *et al*. 2011). Ehrlich (2003) states that butterflies are some of the first organisms to move with climate change and Pease *et al*. (1989) suggests that the larger the genetic variability in a population the more likely it will be able to track an environment over space and time. However, Dakota skipper populations lacks this genetic variability that would allow for them to move with their suitable habitat (Britten and Glasford 2002). Furthermore, the ability for the Dakota skipper to move with suitable habitat (Hall 2009) is limited as there is a lack of suitable habitat corridors for the Dakota skipper to travel (Britten and Glasford 2002). Therefore, it is important to manage current Dakota skipper populations to optimize habitat connectivity and genetic variability so the species may move with its habitat or adapt to new habitat in a changing climate.

2.5 Dakota skipper recovery

Environment Canada (2007) has determined that recovery of the Dakota skipper is biologically and technically possible. The recovery of the Dakota skipper will be dependent on the amount and condition of native grassland habitat that remains within the mesic mixed-grass and tall-grass prairie region of this species distribution. Action to promote recovery of the Dakota skipper is highly dependent on conservation agencies, government agencies, non-government organizations, and private landowners. These efforts must be aimed at protecting, maintaining, and restoring high quality native prairie in which the Dakota skipper inhabits (USFWS 2016a). Protection of private lands containing suitable habitat will be a key factor in this specie's recovery as this is where the majority of Dakota skipper populations remain (Environment Canada 2007).

2.5.1 Habitat protection

Dakota skipper habitat may be continually changing with climate change and anthropogenic influences (Kerby *et al*. 2012), making it essential to continue to study the Dakota skipper and classifying its habitat (USFWS 2015). Ultimately, habitat protection will be the key to maintaining and recovering Dakota skipper populations (Environment Canada 2007). It has been suggested that habitat patches currently containing Dakota skipper populations should be protected as well as protection of potential habitat to allow for species reintroduction or changes in species range and habitat due to changes in climate (USFWS 2015).

2.5.2 Habitat restoration

To date habitat restoration for prairie specialist butterflies has proven to be unsuccessful (Shepherd and Debinski 2005). The USFWS (2016b) suggest that all remnant native prairie habitats should be maintained and destruction or conversion of remaining native prairie should be avoided. Successful restoration of Dakota skipper habitat would need to be near a piece of remnant native prairie that contains a population or a habitat corridor to other occupied sites (Shepherd and Debinski 2005; USFWS 2016b). However, all native prairie restoration for Dakota skipper populations should be considered experimental. These efforts should try to mimic native prairies by containing the necessary vegetative species utilized by the Dakota skipper for nectar and larval development (USFWS 2016b).

2.5.3 Conservation easements

The USFWS (2015) found that protection of Dakota skipper habitat is best achieved through voluntary conservation easements meant to maintain and protect land of high value to the species. This is a legal agreement made voluntary by the private landowner and a cooperative approach from a conservation organization. These agreements are used to protect the conservation value of the land. This is the most cost effective way in protecting Dakota skipper habitat on private land. These arrangements should work with the landowner to develop land management practices that are beneficial to the Dakota skipper population and the private landowner. These conservation easements help to maintain Dakota skipper habitat as well as make landowners aware of this species, facilitate interest in conservation, and educate the public (USFWS 2015).

2.7 References

Anderson, R.C. 1982. An evolutionary model summarizing the roles of fire, climate, and grazing animals in the origin and maintenance of grasslands: an end paper. *In* Estes, J.R., Tyrl, R.J., and Brunken, J.N. Grasses and grasslands: systematics and ecology. Univeristy of Oklahoma Press, Norman., Oklahoma, US. Pp. 298–308.

Bates, L. 2007. The influence of prescribed burning and grazing on the Dakota skipper, *Hesperia dacotae*, habitat in south-eastern Manitoba [online]. Available from http://ion.uwinnipeg.ca/~moodie/Theses/Bates2007.pdf [accessed 10 September 2016].

Borchert, J.R. 1950. The climate of the central North American grassland. Annals of the Association of American Geographers, **40**: 1–39.

Britten, H.B. and Glasford, J.W. 2002. Genetic population structure of the Dakota skipper (Lepidoptera: *Hesperia dacotae*): A North American native prairie obligate. Conservation Genetics, **3**: 363–374.

Brown, J.H. and Kodric-Brown, A. 1977. Turnover rates in insular biogeography: effect of immigration on extinction. Ecology, **58**: 445–449. https://doi.org/10.2307/1935620.

Bulan, C.A. and Barrett G.W. 1971. The effects of two acute stresses on the arthropod component of an experimental grassland ecosystem. Ecology, **52**: 597–605.

Cochrane, J.F. and Delphey, P. 2002. Status assessment and conservation guidelines Dakota skipper *Hesperia dacotae* (Skinner) (Lepidoptera: Hesperiidae) Iowa, Minnesota, North Dakota, South Dakota, Manitoba, and Saskatchewan [online]. Available from http://ecos.fws.gov/ServCat/DownloadFile/4020?Reference=4171 [accessed 4 September 2016].

Committee on the Status of Endangered Wildlife in Canada. 2003. COSEWIC assessment and status report on the Dakota skipper *Hesperia dacotae* in Canada [online]. Available from http://publications.gc.ca/collections/Collection/CW69-14-358-2004E.pdf [accessed 10 September 2016].

Committee on the Status of Endangered Wildlife in Canada. 2014. COSEWIC Assessment and status report Dakota skipper *Hesperia dacotae* in Canada [online]. Available from https://www.registrelep-sararegistry.gc.ca/virtual_sara/files/cosewic/sr_Dakota%20Skipper_2014_e.pdf [accessed 4 September 2016].

Crone, E.E. and Schultz C.B. 2003. Movement behavior and minimum patch size for butterfly population persistence. *In* Boggs, C.L., Watt, W.B., and Ehrlich, P.R. Butterflies: ecology and evolution taking flight. University of Chicago Press, Chicago, Illinois. Pp. 561–576.

Dana, R.P. 1991. Conservation management of the prairie skippers *Hesperia dacotae* and *Hesperia ottoe*: basic biology and threat of mortality during prescribed burning in spring [online]. Available from https://conservancy.umn.edu/bitstream/handle/11299/139544/SB594.pdf?sequence=1 [accessed 4 September 2016].

Dana, R. 1997. Characterization of three Dakota skipper sites in Minnesota [online]. Available from http://files.dnr.state.mn.us/eco/nongame/projects/consgrant_reports/1997/1997_dana.pdf [accessed 17 September 2016].

Davies, Z.G., Wilson, R.J., Coles, S., and Thomas, C.D. 2006. Changing habitat associations of a thermally constrained species, the silver-spotted skipper butterfly, in response to climate warming. Journal of Animal Ecology, **75**: 247–256. https://doi.org/10.1111/j.1365-2656.2006.01044.x.

Dearborn, K. and Westwood, R. 2014. Predicting adult emergence of Dakota skipper and Poweshiek skipperling (Lepidoptera: Hesperiidae) in Canada. Journal of Insect Conservation, **18**: 875–884. https:doi.org/10.1007/s10841-014-9695-8.

Ehrenreich, J.H. and Aikman, J.M. 1963. An ecological study of the effect of certain management practices on native prairie in Iowa. Ecological Monographs, **33**: 113–130.

Ehrlich, P.R. 2003. Introduction: butterflies, test systems, and biodiversity. *In* Boggs, C.L., Watt, W.B., and Ehrlich, P.R. Butterflies: ecology and evolution taking flight. University of Chicago Press, Chicago, Illinois. Pp. 1-6.

England, R.E. and DeVos, A. 1969. Influence of animals on pristine conditions on the Canadian grasslands. Journal of Range Management, **22**: 87–94. https://doi.org/10.2307/3896187.

Environment Canada. 2007. Recovery strategy for the Dakota skipper (*Hesperia dacotae*) in Canada [online]. Available from https://www.registrelep-sararegistry.gc.ca/virtual_sara/files/plans/rs_dakota_skipper_final_1007_e.pdf [accessed 3 September 2016].

Environment Canada. 2017. Species at Risk Act [online]. Available from http://laws-lois.justice.gc.ca/eng/acts/s-15.3/ [accessed 10 September 2016].

Grinnell, J. 1917. Field tests of theories concerning distributional control. The American Naturalist, **51**: 115–128.

Hall, P.W. 2009. Sentinels on the wing: the status and conservation of butterflies in Canada. Ottawa, Ontario.

Hall, P.W., Catling, P.M., and Lafontaine, J.D. 2011. Insects at risk in the prairie region. *In* Floate, K.D. Arthropods of Canadian grasslands: inhabitants of a changing landscape. Volume 2. Biological Survey of Canada, Ottawa, Canada. Pp. 323–349.

Hirzel, A.H. and Le Lay, G. 2008. Habitat suitability modelling and niche theory. Journal of Applied Ecology, **45**: 1372–1381. https://doi.org/10.1111/j.1365-2664.2008.01524.x.

Howe, H.F. 1994. Managing species diversity in tallgrass prairie: assumptions and implications. Conservation Biology, **8**: 691–704.

Kerby, J.T., Wilmers, C.C., and Post, E. 2012. Climate change, phenology and the nature of consumer–resource interactions: advancing the match/mismatch hypothesis. *In* Ohgushi, T., Schmitz, O.J., and Holt, R.D. Trait-mediated indirect interactions: ecological and evolutionary perspectives. Cambridge University Press, Cambridge, England. Pp. 508-525.

Larson, F. 1940. The role of the bison in maintaining the short grass plains. Ecology, **21**: 113–121. https://doi.org/10.2307/1930479.

McCabe, T.L. 1981. The Dakota skipper, *Hesperia dacotae* (Skinner): range and biology, with special reference to North Dakota. Journal of the Lepidopterists' Society, **35**: 179–193.

Metzler, E.H., Shuey, J.A., Ferge, L.A., Henderson, R.A., and Goldstein, P.Z. 2004. Adapting a floral biogeography model to prairie-dependent Lepidoptera. Proceedings North American Prairie Conference, **1**: 122–132.

Miner, B.G., Sultan, S.E., Morgan, S.G., Padilla, D.K., and Relyea, R.A. 2005. Ecological consequences of phenotypic plasticity. Trends in Ecology and Evolution, **20**: 685–692. https://doi.org/10.10.1016/j.tree.2005.08.002.

Morris, M.G. 1975. Preliminary observations on the effects of burning on the Hemiptera (Heteroptera and Auchenorhyncha) of limestone grassland. Biological Conservation, **7**: 311–319. https://doi.org/10.1016/0006-3207(75)90046-4.

Pease, C.M., Lande, R., and Bull, J.J. 1989. A model of population growth, dispersal and evolution in a changing environment. Ecology, **70**: 1657–1664. https://doi.org/10.2307/1938100.

Pohl, G.R., Schmidt, B.C., Lafontaine, J.D., Landry, J.F., Anweiler, G.G., and Bird, C.D. 2014. Moths and butterflies of the prairies ecozone in Canada. *In* Giberson, D.J. and Carcamo, H.A. Arthropods of Canadian grasslands: biodiversity and systemastics Part 2. Volume 4. Biological Survey of Canada, Ottawa, Canada. Pp. 169–238.

Ries, L., Debinski, D.M., and Wieland, M.L. 2001. Conservation value of roadside prairie restoration to butterfly communities. Conservation Biology, **15**: 401–411. https://doi.org/10.1046/j.1523-1739.2001.015002401.x.

Roy, D.B. and Thomas, J.A. 2003. Seasonal variation in the niche, habitat availability and population fluctuations of a bivoltine thermophilous insect near its range margin. Oecologia, **134**: 439–444. https://doi.org/10.1007/s00442-002-1121-3.

Royer, R.A. and Marrone, G.M. 1992. Conservation status of the Dakota skipper (*Hesperia dacotae*) in North and South Dakota. Denver, Colorado [unpublished].

Royer, R.A., McKenney, R.A., and Newton, W.E. 2008. A characterization of non-biotic environmental features of prairies hosting the Dakota skipper (*Hesperia dacotae*, Hesperiidae) across its remaining U.S. range. Journal of the Lepidoperists' Society, **62**: 1–17.

Samson, F. and Knopf, F. 1994. Prairie conservation in North America. Bioscience, **44**: 418–421. https://doi.org/10.2307/1312365.

Saskatchewan Conservation Data Centre. 2017. Saskatchewan invertebrate tracked taxa list [online]. Available from http://www.biodiversity.sk.ca/SppList/invert.pdf [accessed 10 September 2016].

Sauer, C.O. 1950. Grassland climax, fire, and man. Journal of Range Management, **3**:

16–21. Available from https://www.jstor.org/stable/3894702 [accessed 3 September 2016].

Shepherd, S. and Debinski, D.M. 2005. Evaluation of isolated and integrated prairie reconstructions as habitat for prairie butterflies. Biological Conservation, **126**: 51–61. https://doi.org/10.1016/j.biocon.2005.04.021.

Solecki, M.K. and Toney, T. 1986. Characteristics and management of Missouri's public prairies. *In* Clambey, G.K. and Pemble, R.H. The prairie: past, present and future: proceedings of the ninth North American prairie conference. Tri-college Environmental Studies, Fargo, North Dakota. Pp. 168–170.

Swengel, A.B. 1996. Effects of fire and hay management on abundance of prairie butterflies. Biological Conservation, **76**: 73–85. https://doi.org/10.1016/0006-3207(95)00085-2.

Swengel, A.B. 1998. Effects of management on butterfly abundance in tallgrass prairie and pine barrens. Biological Conservation, **83**: 77–89. https://doi.org/10.1016/S0006-3207(96)00129-2.

Swengel, A.B. 2001. A literature review of insect responses to fire, compared to other conservation managements of open habitat. Biodiversity and Conservation, **10**: 1141–1169. https://doi.org/10.1023/A:1016683807033.

Swengel, A.B. and Swengel, S.R. 1997. Co-occurrence of prairie and barrens butterflies: applications to ecosystem conservation. Journal of Insect Conservation, **1**: 131–144. https://doi.org/10.1023/A:1018495428991.

Swengel, A.B. and Swengel, S.R. 1999a. Observations of prairie skippers (*Oarisma poweshiek, Hesperia dacotae, H. ottoe, H. Leonardus pawnee*, and *Atrytone arogos iowa*) (Lepidoptera: Hesperiidae) in Iowa, Minnesota, and North Dakota during 1988-1997. The Great Lakes Entomologist, **32**: 267–292.

Swengel, A.B. and Swengel, S.R. 2001. Effects of prairie and barrens management on butterfly faunal composition. Biodiversity and Conservation, **10**: 1757–1785. https://doi.org/10.1023/A:1012051510584.

Swengel, S.R. and Swengel. A.B. 1999b. Correlations in abundance of grassland songbirds and prairie butterfies. Biological Conservation, **90**: 1–11. https://doi.org/10.1016/S0006-3207(99)00015-4.

Thomas, C.D., Bodsworth, E.J., Wilson, R.J., Simmons, A.D., Davies, Z.G., Musche, M., and Conradt, L. 2001. Ecological and evolutionary processes at expanding range margins. Nature, **411**: 577–581. https://doi.org/10.1038/35079066.

Thomas, C.D. and Jones, T.M. 1993. Partial recovery of a skipper butterfly (*Hesperia comma*) from population refuges: lessons for conservation in a fragmented landscape. Journal of Animal Ecology, **62**: 472–481. https://doi.org/10.2307/5196.

Thomas, C.D., Thomas, J.A., and Warren, M.S. 1992. Distributions of occupied and vacant butterfly habitats in fragmented landscapes. Oecologia, **92**: 563–567. https://doi.org/10.1007/BF00317850.

Transeau, E.N. 1935. The prairie peninsula. Ecology, **16**: 423–437. https://doi.org/10.2307/1930078.

Turner, J.R.G., Gatehouse, C.M., and Corey, C.A. 1987. Does solar energy control organic diversity? Butterflies, moths and the British climate. Oikos, **48**: 195–205. https://doi.org/10.2307/3565855.

United States Fish and Wildlife Service. 1973. Endangered Species Act of 1973. As amended through the 108th congress [online]. Available from http://www.nmfs.noaa.gov/pr/pdfs/laws/esa.pdf [accessed 21 September 2017].

United States Fish and Wildlife Service. 2015. Endangered and threatened wildlife and plants; designation of critical habitat for the Dakota skipper and Powshiek skipperling; final rule [online]. Available from https://www.gpo.gov/fdsys/pkg/FR-2015-10-01/pdf/FR-2015-10-01-FrontMatter.pdf [accessed 17 September 2016].

United States Fish and Wildlife Service. 2016a. Guidance for interagency cooperation under section 7(a)(2) of the endangered species act for the Dakota skipper, Dakota skipper critical habitat, and Poweshiek skipperling critical habitat. Region 3 and 6 [online]. Available from http://www.fws.gov/midwest/endangered/section7/s7process/s7guid_cons.html#dask [accessed 17 September 2016].

United States Fish and Wildlife Service. 2016b. Dakota skipper conservation guidelines [online]. Available from https://www.fws.gov/midwest/endangered/insects/dask/pdf/DakotaSkipperConservationGuidelines2016Update.pdf [accessed 21 May 2016].

Verboom, J., Schotman, A., Opdam, P., and Metz, J.A.J. 1991. European nuthatch metapopulations in a fragmented agricultural landscape. Oikos, **61**: 149–156. https://doi.org/10.2307/3545332.

Visser, M.E. 2008. Keeping up with a warming world; assessing the rate of adaptation to climate change. Proceedings of the Royal Society of Biological Sciences, **275**: 649–659. https://doi.org/10.1098/rspb.2007.0997.

Vogl, R.J. 1974. Effects of fire on grassland. *In* Kozlowski, T.T. and Ahlgren, C.E. Fire and ecosystems. Academic Press, New York, USA. Pp. 139–194.

Webster, R. 2007. Dakota skipper, *Hesperia dacotae* (Skinner), survey in southeast Saskatchewan and southwest Manitoba during 2007. Charters Settlement, NB. Report available by request from Canadian Wildlife Service www.goc411.ca/en/58323/Medea-Curteanu [accessed 12 June 2015].

Weiss, S.B. and Weiss A.D. 1998. Landscape-level phenology of a threatened butterfly: A GIS-based modeling approach. Ecosystems, **1**: 299–309. https://doi.org/10.1007/s100219900023.

Westwood, R. 2010. Survey for Dakota skipper, *Hesperia dacotae*, in central, south eastern and south western Manitoba and south eastern Saskatchewan in 2010. Winnipeg, Manitoba. Report available by request from Canadian Wildlife Service www.goc411.ca/en/58323/Medea-Curteanu [accessed 12 June 2015].

Westwood, A.R. and Blair, D. 2010. Effect of regional climate warming on the phenology of butterflies in boreal forests in Manitoba, Canada. Environmental Entomology, **39**: 1122–1133. https://doi.org/10.1603/EN09143.

World Conservation Monitoring Centre. 1996. *Hesperia dacotae*: the IUCN red list of threatened species 1996 [online]. Available from http://www.iucnredlist.org/details/9968/0 [accessed 17 September 2017].

3 Environmental associations of Dakota skipper, *Hesperia dacotae* (Skinner, 1911) in southeastern Saskatchewan, Canada[1]

3.1 Abstract

The Dakota skipper, *Hesperia dacotae* (Skinner, 1911) (Lepidoptera: Hesperiidae), is an at-risk butterfly that inhabits the mesic mixed-grass prairie. Loss of native prairie is the main factor driving declines in Dakota skipper abundance. Currently, there is little knowledge on the environmental and habitat requirements of Saskatchewan populations. Our objective was to determine environmental associations of Dakota skipper in Saskatchewan through landscape, vegetation, soil, climate, microclimate, and Hesperiidae butterfly occupancy. Data collection was conducted in 2015 and 2016; a total of 46 sites were surveyed; nine of these were Dakota skipper positive (*i.e.*, present) sites and 37 were negative (*i.e.*, non-detected) sites. Results indicate that plant composition is not a significant predictor of Dakota skipper presence, but three plant species are significantly associated with the species; *Pediomelum argophyllum* (Pursh) J.W.Grimes (Fabaceae), *Zizia aptera* (A.Gray) Fernald (Apiaceae), and *Schizachyrium scoparium* (Michx.) Nash (Poaceae). No soil or climate variables were significant predictors of Dakota skipper presence; however it is significantly associated with steep slopes. Warmer maximum and average ground-level temperatures are also associated with Dakota skipper presence. Findings indicate that additional Dakota skipper populations are likely in Saskatchewan and future targeted surveys will allow for a full evaluation of the distribution of this species and conservation status.

[1] Seidle, K.M., Lamb, E.G., Bedard-Haughn, A., and DeVink, J. In Press. Environmental associations of the Dakota skipper, *Hesperia dacotae* (Skinner, 1911) in southeastern Saskatchewan. The Canadian Entomologist, Accepted March 2018.

3.2 Introduction

The Dakota skipper, *Hesperia dacotae* (Skinner, 1911) (Lepidoptera: Hesperiidae), is an at-risk prairie-obligate Lepidoptera species that inhabitants native mesic mixed-grass prairie (COSEWIC 2014). Klassen *et al*. (1989) and Layberry *et al*. (1998) describe the male Dakota skipper as a yellowish-orange butterfly containing a black brand on its forewing with occasional dull spots on its hindwing. The female Dakota skipper is greyish brown with reduced pale spots on both the forewing and the hindwing (Klassen *et al*. 1989; Layberry *et al*. 1998). The species spends the majority of its life as a larva, occupying soil level in the winter months and just above the soil surface in the summer months, where it feeds and constructs shelters from native prairie host plants. The adult Dakota skipper is dependent on diverse prairie vegetation for nectar resources and mating perches (Dana 1991). These life stage characteristics limit the Dakota skipper to high quality native prairie (Webster 2007; Westwood 2010; COSEWIC 2014) within the moist-mixed and mixed-grass ecoregion (Acton *et al*. 1998). The Dakota skipper is declining in both distribution and abundance (Layberry *et al*. 1998; COSEWIC 2014), presumably due to declines in suitable habitat. Currently, a lack of knowledge exists about the environmental associations of the Dakota skipper in southeastern Saskatchewan. The Saskatchewan Dakota skipper population was confirmed in 2001 and limited survey data are available (Hooper 2003). Saskatchewan presents a unique opportunity for Dakota skipper conservation as it contains the largest portion of remaining mesic mixed-grass prairie within the species distribution (Bailey *et al*. 2010), where the Dakota skipper population inhabits the extreme northwestern extent of its known distribution (COSEWIC 2014), and additional unidentified habitat and populations may exist.

The objective of this research is to characterize the environmental associations of the Dakota skipper in southeastern Saskatchewan. The USFWS (2015) and COSEWIC (2014) state that critical habitat is an area that contains features essential to the survival of a species. Features of this critical habitat can include the environmental associations of a species; therefore, environmental associations of the Dakota skipper are features of the environment needed for the species to persist and inhabit an area. Defining the environmental associations of the Dakota skipper in southeastern Saskatchewan may help identify suitable habitat and identification of new populations, contributing to the overall understanding and conservation of this species.

3.3 Material and methods

3.3.1 Study region

The study region was selected from the known distribution of existing Dakota skipper populations in the Souris River Valley of southeastern Saskatchewan's mesic mixed-grass ecoregion (Environment Canada 2007; COSEWIC 2014). This ecoregion is located in a semiarid climate, with a climate normal mean annual precipitation of 433 mm (Environment Canada 2017). Elevations range between 520 - 580 m within the Souris River Valley. The valley is dominated by dark brown soils developed in glacial till parent material. Agriculture makes up 80% of the land use of the mixed-grass ecoregion, while the remainder consists of natural vegetation cover, wetlands, and industrial activity such as oil, gravel, gas, and coal (Acton *et al.* 1998).

3.3.2 Study site selection

Survey sites were located within a 3.2 km buffer of the Souris River channel (Figure 3.1). Through examination of Google Earth (https://earth.google.com/web) aerial imagery from 2016, land cover was initially characterized for potential survey sites identified within this buffer. Potential survey sites were quarter sections (65 ha) that contained approximately 20% or greater of native, tame, or hay land covers, as other land cover types (*e.g.,* annual cropland) were not expected to support the Dakota skipper (Westwood 2010). A random number generator was used to select a subset of survey sites from the list of potential sites. Landowners were identified and contacted in order to obtain permission for land access. If land access was denied, the next site on the list was selected.

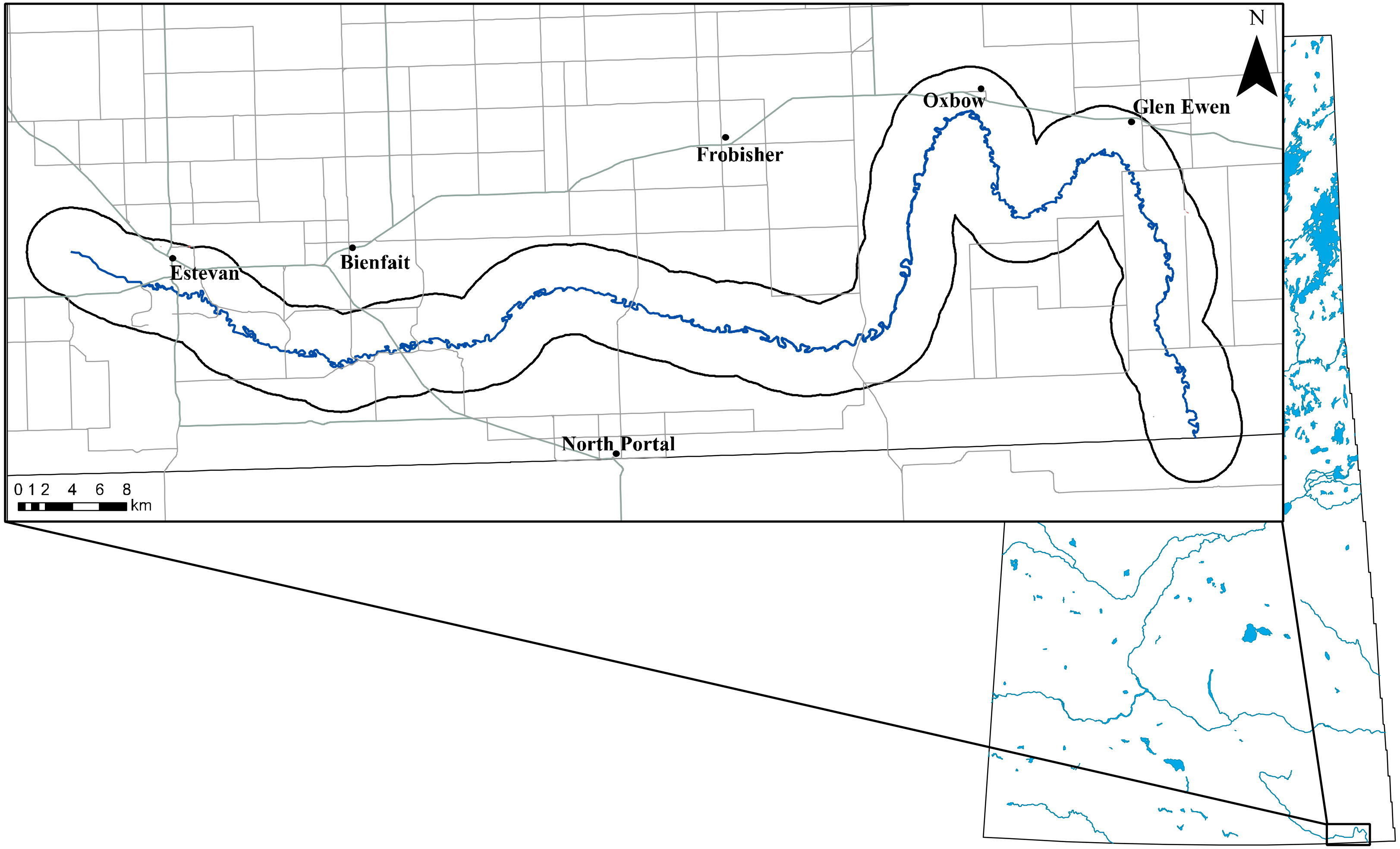

Figure 3.1: The study area located in southeastern Saskatchewan within the Souris River Valley (right). An insert of the Souris River shows the 3.2 km study area buffer around the Souris River channel (left). A total of 46 sites were surveyed in this area during the 2015 and 2016 field seasons.

3.3.3 Landscape and land cover survey

Once on site, land use and land cover were validated for accuracy and study-appropriateness by visual assessment and included in surveys if they contained appropriate land cover of native grassland, tame, or hay (Westwood 2010). Land cover was classified as native when the majority of vegetative species were native mesic mixed-grass prairie species; invaded native when the majority of the species were introduced or tame species, with no evidence of tilling or soil disturbance; tame when the majority of the species were introduced or tame species and the soil contained evidence of disturbance or tilling (Saskatchewan Conservation Data Centre 2017). Land cover was classified as hay on tame land cover that is cut annually or semi-annually. Elevation was obtained from the Natural Resources Canada (NRCAN) spatial climate model (McKenney *et al*. 2011). Slope was determined using a compass clinometer, taken at the start of each transect and measured to the height of the steepest slope within the survey transect. Heat load values were calculated for the center of each site based on McCune and Keon (2002). Landscape variables used in the analysis include elevation, degree of slope, heat load, percent introduced and native plant species, and total species richness.

3.3.4 Vegetation survey

Survey sites were selected based on the representative plant community observed within the targeted survey quarter section during field observations. Once a site was selected, a 250 m transect was staked out where 1 m^2 plant survey quadrats were placed at 50 m intervals on the transect, for a total of six 1 m^2 quadrats (Figure 3.2) (Rigney 2013). Within each survey quadrat all plants were identified to species and foliar percent cover visually estimated (Saskatchewan Conservation Data Centre 2017). Plant species that could not be identified in the field were collected for later verification. Plant data were averaged to the site level and total species richness was determined for each survey site. Plant species list is provided in Appendix A, and plant species cover is provided in Appendix B.

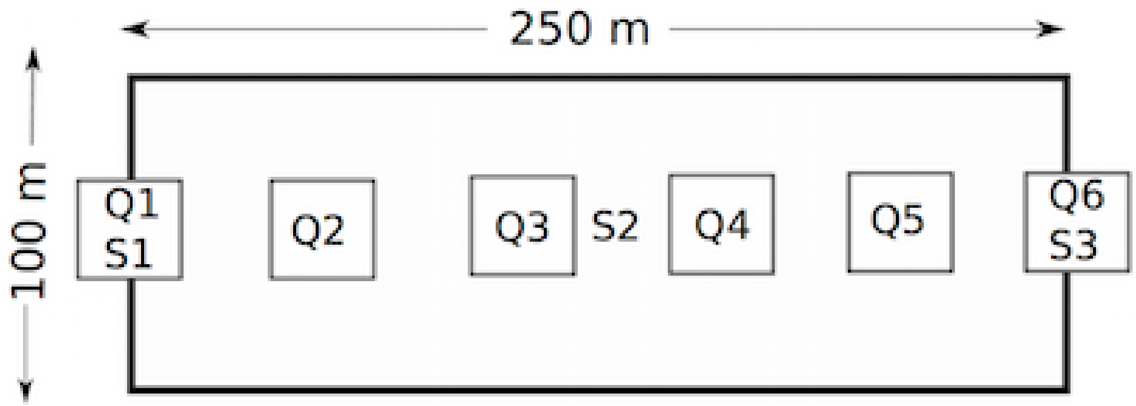

Figure 3.2: Example of a typical survey site with the Hesperiidae survey area (100 by 250 m) including the vegetation quadrats (Q) and soil samples (S) running down the center. All sites target a slope; starting at the toe slope (Q1; S1), mid slope (S2), and upper slope (Q6; S3) when possible (not to scale).

3.3.5 Soil survey

Soil surveys were conducted along the vegetation transect (Figure 3.2) with a total of three soil profiles classified and sampled at each survey site. Soil sample locations were selected based on landform changes, targeting an upper slope, mid slope, and toe slope to fully capture the site-level variation. Soil profiles were classified on site through soil augering and soil pits; an auger sample was taken from each profile at an interval of 0-15 cm. Soils were described and classified according to the Canadian System of Soil Classification (Soil Classification Working Group 1998). Ground litter measurements were taken with a measuring tape at each soil sample site and bulk density samples were taken using a bulk density hand punch for the interval of 0-15 cm.

In 2015, soils were air-dried and ground to pass through a 2-mm sieve, then analyzed for potential hydrogen's (pH), electrical conductivity (EC), sodium (Na), calcium (Ca), magnesium (Mg), potassium (K), phosphorous (P), organic carbon (C), and inorganic C. Initial statistical analysis of 2015 soils determined these variables to be unlikely environmental associations of the Dakota skipper. Soil samples for 2015 and 2016 survey sites were analyzed for gravimetric water content of field-moist and air-dried soils, particle analysis, nitrogen (N), and total C. All soil variables were averaged at the site level; variables used in the analysis include bulk density, gravimetric field-moist and air-dried soil moisture, percent sand, silt, and clay content, organic C, ammonium (NH_4^+) and ammonia (NO_3^-), A horizon depth, and litter depth. All soil methods, analysis, and citations are provided in Appendix D and Appendix K.

3.3.6 Hesperiidae butterfly surveys

Hesperiidae butterfly surveys were conducted among the vegetation and soil transect at each site (Figure 3.2). Surveys were conducted between 29 June 2015 to 29 July 2015 and 3 July 2016 to 20 July 2016. Survey methods followed those of Westwood (2010). Briefly, an area of 100 by 250 m was staked out the night or morning before the survey; care was taken not to disturb the survey area. Surveys were conducted between the hours of 9:00 and 18:00 when temperatures had reached or exceeded 20°C in sunny or cloudy weather with a wind speed less than 20 km per hour; the optimal conditions for adult Hesperiidae to be in flight. Two observers walking side by side observed an area of approximately 5 m ahead and 5 m to each side. Butterfly nets were used to capture adult specimens, which were released immediately after identification and photographic records taken. Surveys were carried out for a total of 30 minutes for each survey site. Survey time was limited to search time and excluded time spent pursuing and identifying a specimen. In 2015, two surveys were carried out at each site a minimum of one week apart; in 2016 to maximize survey coverage, only one survey was carried out at a site if a Dakota skipper observation was made on the first survey. Identification of a single Dakota skipper butterfly confirmed the presence of this species at that location, and thus the site was scored as a positive site. When no Dakota skipper butterflies were observed following the survey protocol, the species is assumed to be absent and the site is considered negative. Surveys targeted the Dakota skipper; however, similar species of Hesperiidae, including Peck's skipper, *Polites peckius* (Kirby, 1837), Long dash skipper, *Polites mystic* (Edwards, 1863), European skipper, *Thymelicus lineola* (Ochsenheimer, 1808), and Tawny-edged skipper, *Polites themistocles* (Latreille, 1824) were also captured and recorded. All sites are analyzed based on species detected presence. Hesperiidae butterfly observations are provided in Appendix G. Hesperiidae butterfly observation locations are not presented due to the presence of the endangered species on private lands.

3.3.7 Microclimate survey

Microclimate monitoring was conducted during the 2016 growing season at the 2015 sites to determine if there were ground-level temperature differences between Dakota skipper positive and negative sites. One to three Logtag temperature recorders were placed on the soil surface of each 2015 site on 30 April 2016 and 1 May 2016 and recovered on 19 September 2016 and 20 September 2016. During this period, data loggers recorded air temperature (°C) at half hour intervals. All negative Dakota skipper sites had one temperature logger that was placed in the middle of the vegetation transect. Positive Dakota skipper sites had two to three temperature loggers placed at even intervals along the transect to ensure successful collection of microclimate data in the limited positive sites, in the event that a data logger malfunctioned or could not be recovered; as there were few within-site differences temperatures were later averaged to the site level. Variables analyzed include maximum daily temperature (°C), minimum daily temperature, and average daily temperature. All temperature logger data are provided in Appendix H.

3.3.8 Climate

Climate normal data were obtained from the NRCAN spatial model of growing season variables for Canada as described in McKenney *et al*. (2011); 10 km gridded data were obtained for the study region for the climate normal period of 1981 to 2010. A value was assigned to each site to determine if there were climate normal differences between Dakota skipper positive and negative sites. Variables include annual mean temperature (°C); mean diurnal range; isothermality; temperature seasonality; maximum temperature during the warm period; minimum temperature during the cold period; temperature range; average temperature during the wettest, driest, warmest, and coldest quarter; annual precipitation (mm); precipitation during the wettest and driest period; seasonal precipitation; precipitation during the wettest, driest, warmest, and coldest quarter; Julian days since the start and end of the growing season; total amount of growing season days; average precipitation; annual minimum and maximum temperature; monthly minimum and maximum temperatures; and monthly precipitation.

3.3.9 Statistical analysis

All variables were transformed to a 0-centered standard normal deviate, averaged, and analyzed at the site level. Differences in vegetative communities between Dakota skipper positive and negative sites were explored using nonmetric multidimensional scaling (NMDS) through R library vegan (R Core Team 2015; Oksanen *et al*. 2016); a permanova was used to test for significant differences in community composition. Associations of individual plant species with Dakota skipper presence were assessed through an indicator species analysis through R library labdsv (R Core Team 2015; Roberts 2016). Climate normal, soil, and landscape variables for Dakota skipper positive and negative sites were explored using NMDS through R library vegan (R Core Team 2015; Oksanen *et al*. 2016); a permanova was used to test for significant differences in Dakota skipper positive and negative sites. A generalized linear model with a binomial distribution was fit for using function glm on each soil and landscape variable to determine whether individual soil and landscape variables significantly predicted Dakota skipper presence. Site level heterogeneity in soil and landscape variables were examined through an analysis of coefficients of variation (CV). CVs were calculated using the R library goeveg (R Core Team 2015; Goral and Schellenberg 2017). Comparison of microclimate variables between Dakota skipper positive and negative sites were explored using generalized linear mixed models fit using function glmer (R Core Team 2015; Bates *et al*. 2015). Models had a binomial distribution and site was a random factor. CVs were calculated using the R library goeveg (R Core Team 2015; Goral and Schellenberg 2017). Microclimate and climate normal variables were analyzed through a linear regression model.

3.4 Results

During the 2015 and 2016 field seasons, a total of 46 sites (31 in 2015 and 15 in 2016) were surveyed for Hesperiid butterflies; nine of these sites were positive Dakota skipper sites while the remaining 37 were negative sites. Vegetation and soil data was obtained for all 46 sites. Ground-level microclimate data were retrieved from 28 sites (five positive Dakota skipper sites and 23 negative sites). Climate normal data were obtained for all 46 sites from McKenny *et al*. (2011). Representative site photos taken during the study period are provided in Appendix I.

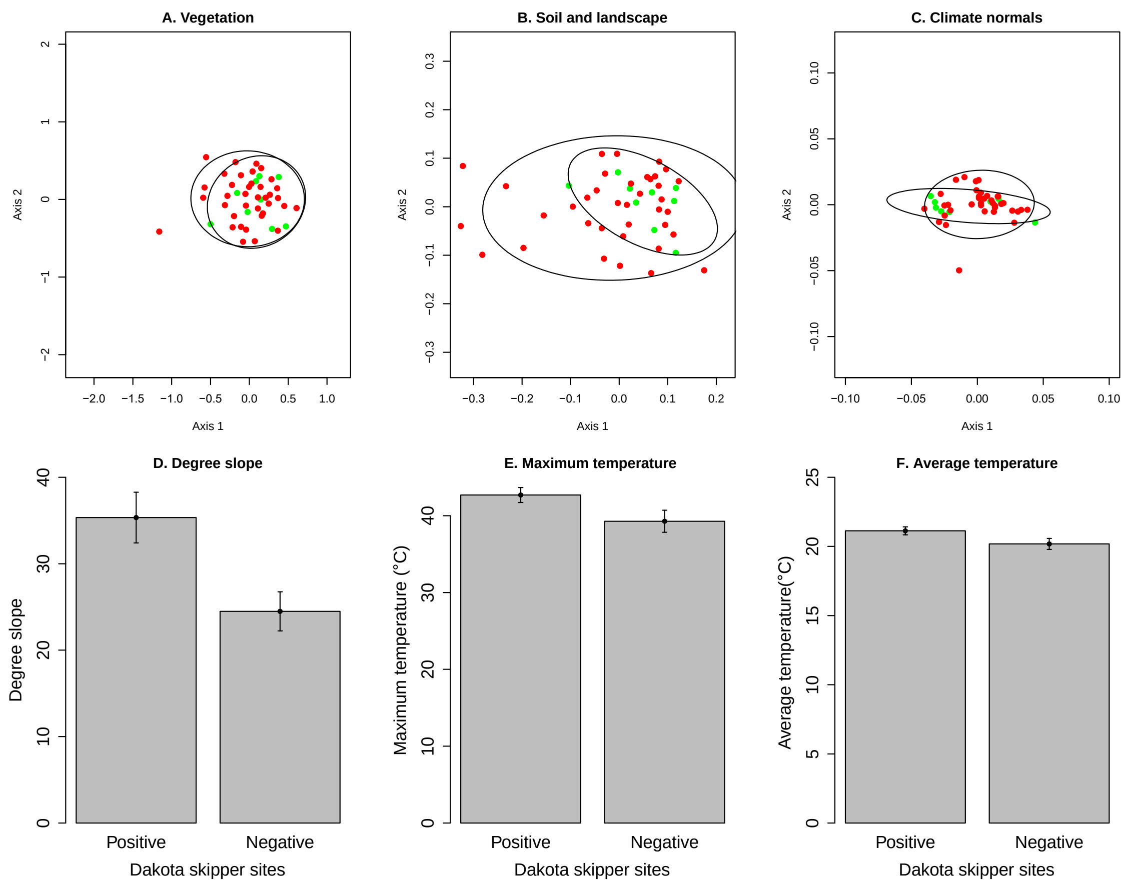

Figure 3.3: NMDS ordinations of plant community composition (A), soil and landscape variables (B), and climate normal variables (C). Red dots indicate negative Dakota skipper occupancy and green dots indicate positive Dakota skipper occupancy. Bar graphs of significant variables degree slope (D), maximum temperature (E), and average temperature (F) with error bars representing standard error.

3.4.1 Vegetation

There were no significant differences in plant composition between Dakota skipper positive and negative sites (F=0.6447; df=45; P=0.943) (Figure 3.3A). The two-dimensional NMDS has a final stress of 0.248. The first axis represents a gradient from plant communities dominated by *Rumex crispus* Cham. & Schltdl. (Polygonaceae), *Poa palustris* L. (Poaceae), *Trifolium hybridum* L. (Fabaceae), and *Hordeum jubatum* L.

(Poaceae) on the negative end to *Lilium philadelphicum* Thunb. (Liliaceae), *Juniperus horizontalis* Moench (Cupressaceae), and *Lygodesmia juncea* (Pursh) Hook. (Asteraceae) on the positive end. The second axis represents a gradient from plant communities dominated by *Poa palustris*, *Rumex* (Polygonaceae) specie, and *Erigeron caespitosus* Nutt. (Asteraceae) on the negative end to *Symphyotrichum ericoides* (L.) G.L.Nesom (Asteraceae), *Asclepias ovalifolia* Decne. (Asclepiadaceae), *Sonchus arvense* L. (Asteraceae), and *Cerastium nutans* Raf. (Caryophyllaceae) on the positive end. All observed plant species are listed in Appendix A and raw plant species site data are provided in Appendix B.

Indicator species analysis results identified three plant species that were significant indicators of Dakota skipper presence. *Pediomelum argophyllum* (Pursh) J.W.Grimes (Fabaceae) (IV=0.637; P=0.050) and *Schizachyrium scoparium* (Michx.) Nash (Poaceae) (IV=0.561; P=0.016) are common across all sites but more abundant in the Dakota skipper positive sites. *Zizia aptera* (A.Gray) Fernald (Apiaceae) (IV=0.207; P=0.038) is uncommon throughout the study area but more likely to be present in positive Dakota skipper sites. Full indicator species analysis results are provided in Appendix C. There were no significant indicator species for Dakota skipper negative sites.

3.4.2 Soil and landscape

There were no significant overall differences in soil and landscape variables between Dakota skipper positive and negative sites (F=1.253; df=45; P=0.223) (Figure 3.3B). The two-dimensional NMDS has a final stress of 0.175. The first axis represents a gradient from sites dominated by bulk density, percent sand content, and percent introduced species on the negative end to percent silt content, degree slope, organic C, and percent clay content on the positive end. The second axis represents a gradient from sites dominated by bulk density and percent native prairie species on the negative end to percent introduced species, litter depth, field-moist, and air-moist soil water content on the positive end. Full soils data are provided in Appendix E, and site landscape data are provided in Appendix F. Degree slope (P=0.045) was the only landscape variable significantly associated with Dakota skipper presence (Table 3.1); positive sites had a higher average slope of 35.33° while negative sites averaged 24.49° (Figure 3.3D).

Table 3.1: Generalized linear model results of landscape and soil variables on Dakota skipper occupancy.

Variables	Coefficient	Z	P	CV
Degree slope	**3.781**	**2.004**	**0.045**	**-**
Elevation	10.19	0.844	0.399	-
Introduced	0.387	0.225	0.822	0.377
Native	-0.460	-0.208	0.835	0.252
Species richness	-2.201	-0.70	0.484	-
Litter depth	0.135	0.085	0.933	0.548
NH_4^+	3.766	1.625	0.104	0.268
NO_3^-	1.058	0.557	0.578	0.695
Organic carbon	-1.055	-0.339	0.734	0.250
Air-dried water content	3.252	1.580	0.114	0.341
Field-moist water content	0.171	0.102	0.919	0.515
Bulk density	-4.895	-0.893	0.372	0.107
A horizon	-0.669	-0.372	0.710	0.455
Sand	-4.773	-1.443	0.149	0.231
Silt	2.039	1.013	0.311	0.372
Clay	4.344	1.559	0.119	0.247
Heat load	-1.020	-0.094	0.925	-

(Z = z-value; P = p-value; CV = Coefficient of variation).

3.4.3 Climate

There were no significant differences in overall climate conditions between Dakota skipper positive and negative sites (F=0.838; df=45; P=0.398) (Figure 3.3C). The two-dimensional NMDS has a final stress of 0.0287. The first axis represents a gradient from sites dominated by annual minimum temperature, October and April minimum temperatures on the negative end to November and March maximum temperatures and average precipitation on the positive end. The second axis represents a gradient from sites dominated by December, November, and January precipitation on the negative end to October, April, and annual minimum temperatures, and elevation on the positive end.

3.4.4 Microclimate

Maximum daily temperature and average daily temperature were significantly higher at Dakota skipper positive sites (Table 3.2). Dakota skipper positive sites had an average maximum daily temperature of 42.68°C while negative sites had an average maximum daily temperature of 39.28°C (Figure 3.3E). Similarly, Dakota skipper positive sites had an average daily temperature of 21.13°C, while negative sites had an average daily temperature of 20.18°C (Figure 3.3F). Minimum temperature was not significantly higher with Dakota skipper presence. While the climate normals are estimated at much coarser scale (10 km), there was a significant positive relationship between both maximum and minimum monthly temperature microclimate and the climate normals (Table 3.3).

Table 3.2: Generalized linear mixed model results of microclimate variables on Dakota skipper occupancy.

Variables	Coefficient	Z	P	CV
Maximum daily temperature	**0.284**	**7.734**	**<0.001**	**0.265**
Minimum daily temperature	0.187	-0.412	0.680	0.542
Average daily temperature	**0.310**	**5.026**	**<0.001**	**0.223**

(Z = z-value; P = p-value; CV = Coefficient of variation)

Table 3.3: Linear regression model results of microclimate and climate normal maximum and minimum monthly temperatures.

Variable	Coefficient	Z	P
Monthly maximum temperature	**0.0515**	**3.323**	**0.001**
Monthly minimum temperature	**0.0271**	**25.696**	**<0.001**

(Z = z-value; P = p-value).

3.5 Discussion

During the study period the Dakota skipper was observed at nine randomly selected sites throughout the Souris River Valley, adding to the previously known Saskatchewan populations (Hooper 2003; Webster 2007; Westwood 2010). These results indicate that Dakota skipper populations are more prevalent within the Souris River Valley than initially thought. Dana (1991) states that the Dakota skipper requires a variety of native flora, which will vary in their contribution as nectaring sources. Results indicate that variation in native plant community composition does not appear to control Dakota skipper distribution; however, three native plant species were significantly associated with Dakota skipper presence including the forbs *Pediomelum argophyllum* and *Zizia aptera* and native grass *Schizachyrium scoparium.* Soil and landscape variables, with the exception of slope, were generally not good predictors of Dakota skipper detected occupancy. Slope was the only landscape variable with a significant relationship to detected occupancy of Dakota skippers, with populations tending to occur on steeper native prairie slopes. Additionally, the Dakota skipper tends to inhabit locations that contain a warmer average and maximum daily microclimate within this region.

Dakota skipper presence is possible across a fairly wide range of vegetative community compositions, especially when plant species *Pediomelum argophyllum, Zizia aptera*, and *Schizachyrium scoparium* are present. Dakota skipper occupancy is significantly associated with native forb species *Pediomelum argophyllum* and *Zizia* *aptera*. Ultimately, the Dakota skipper is a herbivore and requires native forbs for nectaring (Dana 1991). Furthermore, Dakota skipper butterflies have been observed using native flora as perching platforms; Dana (1991) indicates that the Dakota skipper will perch on the tallest vegetation within a habitat while seeking a potential mate. During the study period, *Pediomelum argophyllum* was prevalent on both positive and negative sites and was often the tallest forb within the site, making it an ideal perching platform for the Dakota skipper during the mating season. Although not found to be significant in previous studies (McCabe 1981; Dana 1991; Dana 1997; Webster 2007; Westwood 2010), these native forb species are important indicators of Dakota skipper populations of southeastern Saskatchewan as they are likely of value to the butterflies for both nectaring and mating activities.

The Dakota skipper is also significantly associated with the native grass species, *Schizachyrium scoparium*. Layberry *et al*. (1998) and Webster (2007) note that *Schizachyrium scoparium* is a host to Dakota skipper larvae. Additionally, Dana (1991) found that *Schizachyrium scoparium* is a favored native bunchgrass species used by Dakota skipper larvae for food and shelter. Native prairie bunchgrass species are necessary for Dakota skipper larvae survival as they are fine stemmed, close to the ground, and develop slower, while tame grass species mature quickly, are high off the ground and tend to be overly hairy or smooth. These characteristics of tame grass species inhibit the use of these grasses to Dakota skipper larvae while characteristics of native bunchgrass species enable larvae to develop shelters and feed later into the season (Dana 1991; Cochrane and Delphey 2002). Native prairie bunchgrass species are also used by the adult life form of the Dakota skipper (Webster 2007); Westwood (2010) observed female Dakota skipper ovipositing on *Schizachyrium scoparium,* and eggs can be found on these same bunchgrass species (Dana 1991). The USFWS (2015) states that Dakota skipper success will greatly depend on the presence and development of these bunchgrass species as both larvae and adult life forms of this species use them.

Soil and landscape variables were found to overlap between positive and negative Dakota skipper sites, suggesting they are generally not good predictors of Dakota skipper presence within the Souris River Valley, Saskatchewan. However, significant differences in percent slope between positive and negative sites suggest that Dakota skippers may prefer sites on significantly steeper south (sites 18; Dakota skipper observations 3; proportion 0.17), east (sites 8; Dakota skipper observations 2; proportion 0.25), and west (sites 12; Dakota skipper observations 4; proportion 0.35) facing slopes opposed to north (sites 2; Dakota skipper observations 0; proportion 0) facing slopes. This is consistent with Webster's (2007) Dakota skipper population observations within this region, all of which were on steep south facing slopes. The Dakota skipper is an ectothermic species that requires heat for development and Saskatchewan Dakota skipper populations are at the extreme northern extent of their distribution (COSEWIC 2014); these south and west facing slopes contain a warmer microclimate that may be needed for Dakota skipper larval development (Weiss and Weiss 1998).

Climate normal variables were found to overlap in positive and negative Dakota skipper sites indicating that climate normals are generally not good predictors of Dakota skipper presence within the Souris River Valley. Past research indicates that Dakota skipper distribution may be influenced by climate factors including temperature, humidity (McCabe 1981; Royer *et al*. 2008; Dearborn and Westwood 2014), and precipitation-evaporation ratios which affect larval development (McCabe 1981; Royer *et al*. 2008). However, Turner *et al*. (1987) found that these climate patterns are observed at the microclimate of the habitat of a butterfly.

Ground-level maximum and daily average temperatures were higher at Dakota skipper positive sites in southeastern Saskatchewan compared to Dakota skipper negative sites. This is likely due to the Dakota skipper being an ectothermic species that requires heat to develop and reach maturity (Dearborn and Westwood 2014). Southern Saskatchewan is at the northwestern edge of the Dakota skipper’s range; these results suggest that the Dakota skipper may be limited to warmer than average sites in this region. Minimum growing season daily temperatures were not a significant indicator of Dakota skipper habitat, however it is possible that higher minimum winter temperatures would also be significantly associated with Dakota skipper presence. Ehrenreich and Aikman (1963) state that increased litter and snow cover provides insulation to Dakota skipper larvae that spend the winter months in the upper soil layers, protecting them from extreme cold temperatures. The extreme cold temperatures and limited snow cover common in this region may limit overwinter larval survival in southeastern Saskatchewan.

Climate normals and the microclimate maximum and minimum monthly temperatures are significantly related to one another, indicating there is a relationship between climate normals and microclimate. This indicates that climate normals are a good proxy for microclimate conditions, suggesting that climate normals can be used as predictors of Dakota skipper habitat. This is important, as mapped climate normal values are available for large-scale modeling of potential Dakota skipper habitat.

In conclusion, the Dakota skipper populations of southeastern Saskatchewan appear to be limited to native prairie containing significant vegetative species, steep landscape slopes and a warm microclimate. These results indicate that Dakota skipper populations are possible on a variety of sites within southeastern Saskatchewan given the presence of appropriate vegetation on the correct landscape positions that contain a warmer microclimate. Additional Dakota skipper populations are likely present in southern Saskatchewan; further research focused on modeling and mapping potential habitat in this region is underway. Targeted survey efforts focused in this potential habitat is important to fully evaluate the conservation status of the Dakota skipper. As we begin to understand this specie's habitat assocations, we can begin to develop best management techniques (Layberry *et al*. 1989; Webster 2007; Environment Canada, 2007; COSEWIC 2014).

3.6 References

Acton, D.F., Padbury, G.A., and Stushnoff, C.T. 1998. The ecoregions of Saskatchewan. Canada Plain's Research Centre, University of Regina, Regina, Saskatchewan, Canada.

Bailey, A., McCartney, D., and Schellenberg, M. 2010. Management of Canadian prairie rangeland. Agriculture and Agri-Food Canada, Government of Canada, Swift Current, Saskatchewan, Canada.

Bates, D., Mächler, M., Bolker, B., and Walker, S. 2015. Fitting linear mixed-effects models using lme4. Journal of Statistical Software, **67**:1-48. https://doi.org/10.18637/jss.v067.i01.

Cochrane, J.F. and Delphey, P. 2002. Status assessment and conservation guidelines Dakota skipper *Hesperia dacotae* (Skinner) (Lepidoptera: Hesperiidae) Iowa, Minnesota, North Dakota, South Dakota, Manitoba, and Saskatchewan [online]. Available from http://ecos.fws.gov/ServCat/DownloadFile/4020?Reference=4171 [accessed 4 September 2016].

Committee on the Status of Endangered Wildlife in Canada. 2014. COSWIC Assessment and status report Dakota skipper *Hesperia dacotae* in Canada [online]. Available from https://www.registrelep-sararegistry.gc.ca/virtual_sara/files/cosewic/sr_Dakota%20Skipper_2014_e.pdf [accessed 4 September 2016].

Dana, R.P. 1991. Conservation management of the prairie skippers *Hesperia dacotae* and *Hesperia ottoe*: basic biology and threat of mortality during prescribed burning in spring [online]. Available from https://conservancy.umn.edu/bitstream/handle/11299/139544/SB594.pdf?sequence=1 [accessed 4 September 2016].

Dana, R. 1997. Characterization of three Dakota skipper sites in Minnesota [online]. Available from http://files.dnr.state.mn.us/eco/nongame/projects/consgrant_reports/1997/1997_dana.pdf [accessed 17 September 2016].

Dearborn, K. and Westwood, R. 2014. Predicting adult emergence of Dakota skipper and Poweshiek skipperling (Lepidoptera: Hesperiidae) in Canada. Journal of Insect

Conservation, **18**: 875–884. https//:doi.org/10.1007/s10841-014-9695-8.
Ehrenreich, J.H. and Aikman, J.M. 1963. An ecological study of the effect of certain management practices on native prairie in Iowa. Ecological Monographs, **33**: 113–130.
Environment Canada. 2007. Recovery strategy for the Dakota skipper (*Hesperia dacotae*) in Canada [online]. Available from https://www.registrelep-sararegistry.gc.ca/virtual_sara/files/plans/rs_dakota_skipper_final_1007_e.pdf [accessed 3 September 2016].
Environment Canada. 2017. Canadian climate normals 1971-2000 station data: Estevan A [online]. Available from http://climate.weather.gc.ca/climate_normals/results_e.html?searchType=stnName&txtStationName=Estevan&searchMethod=contains&txtCentralLatMin=0&txtCentralLatSec=0&txtCentralLongMin=0&txtCentralLongSec=0&stnID=2896&dispBack=0&month1=0&month2=12 [accessed 6 April 2017].
Goral, F. and Schellenberg, J. 2017. Function for community data and ordinations. R package version 0.3.3 [online]. Available from https://cran.r-project.org/web/packages/goeveg/index.html [accessed 19 January 2017].
Hooper, R.R. 2003. Dakota skipper (*Hesperia dacotae*) in Saskatchewan. Blue Jay, **61**: 124–125.
Klassen, P., Westwood, A.R., Preston, W.B., and McKillop, W.B. 1989. The butterflies of Manitoba. Manitoba Museum of Man and Nature, Winnipeg, Manitoba, Canada.
Layberry, R.A., Hall, P.W., and Lafontaine, J.D. 1998. The butterflies of Canada. Univeristy of Toronto Press, Toronto, Ontario, Canada.
McCabe, T.L. 1981. The Dakota skipper, *Hesperia dacotae* (Skinner): range and biology, with special reference to North Dakota. Journal of the Lepidoptersits' Society, **35**: 179–193 [online].
McCune, B. and Keon, D. 2002. Equations for potential annual direct incident radiation and heat load. Journal of Vegetation Science, **13**: 603–606. https://doi.org/10.1111/j.1654-1103.2002.tb02087.x.
McKenney, D.W., Hutchinson, M.F., Papadopol, P., Lawrence, K., Pedlar, J., Campbell, K., Milewska, E., Hopkinson, R.F., Price, D., and Owen, T. 2011. Customized

spatial climate models for North America. American Meterological Society, 1611–1622 [online]. Available from https://journals.ametsoc.org/doi/pdf/10.1175/2011BAMS3132.1 [accessed on 12 September 2016].

Oksanen, J., Blanchet, F.G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P.R., O'Hara, B., Simpson, G.L., Solymos, P., Henry, M., Stevens, H., Szoecs, E., and Wagner, H. 2016. Vegan: community ecology package. R package version 2.4-1 [online]. Available from https://cran.r-project.org/package=vegan [accessed 19 January 2017].

R Core Team. 2015. R: A language and environment for statistical computing [online]. Available from www.r-project.org/ [accessed 9 Janurary 2017].

Rigney, C.L. 2013. Habitat characterization and biology of the threatened Dakota skipper (*Hesperia dacotae*) in Manitoba [online]. Available from http://winnspace.uwinnipeg.ca/handle/10680/576 [accessed 4 September 2017].

Roberts, D.W. 2016. Labdsv: ordination and multivariate analysis for ecology. R package version 1.8-0 [online]. Available from https://cran.r-project.org/package=labdsv [accessed 19 January 2017].

Royer, R.A., McKenney, R.A., and Newton, W.E. 2008. A characterization of non-biotic environmental features of prairies hosting the Dakota skipper (*Hesperia dacotae,* Hesperiidae) across its remaining U.S. range. Journal of the Lepidoperists' Society, **62**: 1–17.

Saskatchewan Conservation Data Centre. 2017. Saskatchewan vascular plant taxa list [online]. Available from www.biodiversity.sk.ca/SppList/vasc.pdf [accessed 17 September 2017].

Soil Classification Working Group. 1998. The Canadian system of soil classification [online]. Available from http://sis.agr.gc.ca/cansis/publications/manuals/1998-cssc-ed3_manual.pdf [accessed 9 May 2018].

Turner, J.R.G., Gatehouse, C.M., and Corey, C.A. 1987. Does solar energy control organic diversity? Butterflies, moths and the British climate. Oikos, **48**: 195–205.

United States Fish and Wildlife Service. 2015. Endangered and threatened wildlife and plants; designation of critical habitat for the Dakota skipper and Powshiek skipperling; final rule [online]. Available from https://www.gpo.gov/fdsys/pkg/FR-2015-10-01/pdf/FR-2015-10-01-FrontMatter.pdf [accessed 17 September 2016].

Webster, R. 2007. Dakota skipper, *Hesperia dacotae* (Skinner), survey in southeast Saskatchewan and southwest Manitoba during 2007. Charters Settlement, NB. Report available by request from Canadian Wildlife Service www.goc411.ca/en/58323/Medea-Curteanu [accessed 12 June 2015].

Weiss, S.B. and Weiss A.D. 1998. Landscape-level phenology of a threatened butterfly: A GIS-based modeling approach. Ecosystems, **1**: 299–309. https://doi.org/10.1007/s100219900023.

Westwood, R. 2010. Survey for Dakota skipper, *Hesperia dacotae*, in central, south eastern and south western Manitoba and south eastern Saskatchewan in 2010. Winnipeg, Manitoba. Report available by request from Canadian Wildlife Service www.goc411.ca/en/58323/Medea-Curteanu [accessed 12 June 2015].

4 Dakota skipper, *Hesperia dacotae* (Skinner, 1911) habitat suitability and distribution in southeastern Saskatchewan, Canada

4.1 Abstract

The Dakota skipper, *Hesperia dacotae* (Skinner, 1911) (Hesperiidae), is an at-risk Lepidoptera species that, in Canada, is limited to high-quality native mesic mixed-grass prairie regions of Saskatchewan and Manitoba. Due to declines in the native mesic mixed-grass prairie, the Dakota skipper population is also assumed to be declining. Currently, there is little knowledge about Dakota skipper habitat suitability and distribution within Saskatchewan. The objective of this research was to determine these habitat attributes through a landscape-level habitat model based on climate normal, soil, and landscape variables. Data was obtained from publically available formal adult Dakota skipper survey observation locations and data collected within Saskatchewan. A total of 66 unique survey sites were obtained; 28 of these sites were Dakota skipper positive (*i.e.*, present) sites while the remaining 38 were negative (*i.e.*, non-detect) sites. A habitat distribution map ranks the suitability of Dakota skipper habitat throughout southern Saskatchewan based on mapped variables. Results indicate that the Dakota skipper can be found broadly in the mesic mixed-grass prairie region, however only 125.94 km^2 of the 550 km^2 area contains high quality habitat (habitat probabilities 0.71-1). This high quality habitat has a significantly lower mean diurnal temperature range and a higher soil ammonium content. I conclude that although the Dakota skipper inhabits the native mesic mixed-grass prairie region, environmental constraints likely restrict this species to a more limited natural distribution than initially thought. This landscape-level habitat suitability and distribution map assists in the development of conservation and management plans and allows for the development of best management practices that accommodate Dakota skipper populations in southeastern Saskatchewan.

4.2 Introduction

The Dakota skipper, *Hesperia dacotae* (Skinner, 1911) (Hesperiidae), is an at-risk prairie specialist Lepidoptera species limited to the native mesic mixed-grass prairie (COSEWIC 2014). The Dakota skipper butterfly is a inconspicuous species with greyish-brown females containing vague spots on the hindwing and yellowish-orange males containing a brand on the forewing and occasional spots on the hindwing (Klassen *et al*. 1989; Layberry *et al*. 1998). The adult butterfly is dependent on a diverse vegetative cover including flowering forbs, while larvae inhabit an undisturbed soil layer and depend on prairie grass species to feed from and which to construct shelters (Dana 1991). A lack of suitable habitat is considered the main threat to Dakota skipper populations (COSEWIC 2014; Environment Canada 2007).

The mesic mixed-grass prairie ecoregion has experienced large declines in natural land covers over the last decade; these areas are considered to be endangered in themselves (Bailey *et al*. 2010). Only 19% of Saskatchewan's mesic mixed-grass native prairie is estimated to remain, with continued declines (Samson and Knopf 1994). Of this region, Dana (1991) suggests that less than 2% of original Dakota skipper habitat remains. Indicators of high quality habitat within the Saskatchewan Dakota skipper range include the presence of the plant species *Pediomelum argophyllum* (Pursh) J.W.Grimes (Fabaceae), *Zizia aptera* (A.Gray) Fernald (Apiaceae), and *Schizachyrium scoparium* (Michx.) Nash (Poaceae), steep landscape slopes, and warmer maximum and average daily ground-level temperatures (Chapter 3). Given these environmental associations, the extent of high quality Dakota skipper habitat within the mixed grass ecoregion is unclear. Here landscape-level habitat modeling is used to estimate this extent.

Habitat suitability and distribution modeling is well suited for rare and endangered species such as the Dakota skipper. Generally, specialized species with small geographic ranges are modeled more accurately than generalist species (Hernandez *et al*. 2006). The interactions of the Dakota skipper with its environment throughout all life stages will determine its distribution (Hernandez *et al*. 2006; Elith and Graham 2009; Guisan and Zimmermann 2000). Important environmental variables available in regional GIS databases will enable extrapolation to predict areas of unsurveyed habitat that have the potential to be inhabited by this species (Brotons *et al*. 2004).

The objective of this research is to develop a Dakota skipper habitat suitability and distribution model for southeastern Saskatchewan. This model will allow for the identification of suitable habitat for this species. This is key knowledge needed to construct a species recovery and management plan (Environment Canada 2007; Heikkinen *et al*. 2007). Making management decisions on up to date and current information allows for accurate planning for this specie's conservation (USFWS 2016).

4.3 Materials and methods

4.3.1 Study region

The study region was selected based on historically recorded adult Dakota skipper observations in southeastern Saskatchewan (Hooper 2003; Webster 2007; Westwood 2010; Stantec Consulting Limited 2012 (unpublished); Chapter 3). All confirmed Saskatchewan Dakota skipper observations are located within the Souris River Valley region of southeastern Saskatchewan. This area ranges from Estevan, Saskatchewan, east to Oxbow, Saskatchewan, and south to the United States border. The landscape-level habitat distribution mapping study area extrapolates to the north, east, and west of these confirmed historical Dakota skipper observations (Chapter 3).

4.3.2 Satellite imagery and pre-processing

Remote sensing was used to identify native, hay, and tame land covers within southeastern Saskatchewan (Bradley *et al*. 2012; Chapter 3). Analysis was carried out through PCI Geomatica. Two Sentinel-2 images with a 10 m resolution were acquired from the United States Geological Survey for the date of May 17, 2016. Images used for land cover classification were selected to have the same date to eliminate seasonal variations. These dates were selected, as they are the dates closest to the majority of the field surveys, *in-situ* data collection, and adult Dakota skipper observations (Chapter 3). Additionally, May is a month where cultivated fields generally have exposed soils, exhibiting distinguishable reflective characteristics from native, tame, and hay land covers. Images were atmospherically corrected into ground reflectance values and mosaicked together. An unsupervised classification with 16 classes was performed. Similar land covers were aggregated and an accuracy assessment was performed. The land cover layer was assessed based on the producer's accuracy (74.83%) which is the probability that a certain land cover on the ground is classified correctly, the user's accuracy (85.45%) which is the probability that the class on the map will be present on the ground and the Kappa statistic (0.81) which accommodates the effects of chance agreement (Foody 2002).

4.3.3 Model calibration

All publically available formal adult Dakota skipper surveys resulting in presence or non-detect and incidental observations within Saskatchewan from any year were used to calibrate the habitat suitability and distribution model (Binzenhöfer *et al*. 2005). Formal adult Dakota skipper surveys include Lepidoptera surveys conducted by qualified personal with the primary intent of assessing adult Dakota skipper presence. In the event that a site was surveyed multiple times, only one confirmed Dakota skipper observation was required to document the site as a positive site, as one observation is enough to assume the corresponding habitat supported a population (Binzenhöfer *et al*. 2005). Sites where a formal survey was performed and no confirmed observations were made were considered as Dakota skipper negative sites. Elimination of bias from clustered locations was addressed by combining multiple observations that occurred separated by distances of less than 250 m into a single observation, which is the scale at which the majority of the data was collected during the 2015 and 2016 field seasons (Hernandez *et al*. 2006; Chapter 3). All publically available formal survey and confirmed adult Dakota skipper observation records within the province of Saskatchewan used to calibrate the model included observations by Hooper (2003) (n=1), Webster (2002 (n=5); 2007 (n=12)), Westwood (2010) (n=6), Stantec Consulting Limited (2012 (unpublished data)) (n=17), and Chapter 3 (2015 (n=31); 2016 (n=15)). After elimination of repeat surveys, a total of 66 sites were included in the model, with 28 of these being positive Dakota skipper sites and 38 being negative sites.

4.3.4 Digital soil mapping

Significant environmental associations of Saskatchewan's Dakota skipper population include steep landscape slopes, warmer maximum and average daily ground-level microclimate temperatures, and the presence of *Pediomelum argophyllum, Zizia aptera*, and *Schizachyrium scoparium* (Chapter 3). These significant environmental associations guided the variables to be mapped as potential inputs for the habitat suitability and distribution model.

Through digital soil mapping, soil and landscape variables were mapped at a 50 m resolution, based on *in situ* data collection (Chapter 3), the Prairie Soil Carbon Balance dataset (McConkey *et al*. 2000), Detailed Soil Survey (Agriculture and Agri-food Canada 2010), and a 50 m digital elevation model. Eight predictive model types were tested for the mapping, namely classification and regression trees, bagged classification and regression trees, random forest, artificial neural network, support vector machine, logistic model tree, multiple linear regression, and cubist regression using the caret package (Kuhn 2008) and R statistical software (R Core Team 2015). All models were trained and tested using the soils data collected during the 2015 and 2016 field seasons (Chapter 3). An additional nine points; seven located within the study area and two located just outside of the study area, obtained from the Prairie Soil Carbon Balance dataset were also used in the mapping (McConkey *et al*. 2000). These nine additional points helped to increase model accuracy by including a wider range of soil variability within the modeled variables. A total of 147 data points (three soil profiles per site; 46 sites; nine additional points from Prairie Soil Carbon Balance) were used in the digital soil mapping process, where 70% of the data was used as a training set of sample points and 30% of the data was used as a testing set of sample points. The training dataset was used to generate the models and the testing dataset was used to assess the accuracy of the models. The target soil variables mapped included soil class, bulk density, organic carbon (C), percent sand, percent silt, percent clay, A horizon depth, ammonium (NH_4^+), and nitrate (NO_3^-). The target soil variables were predictively mapped based on a variety of predictor variables. Many of the predictor variables were derived from a 50 m digital elevation model; these included aspect, slope, general curvature, plan curvature, profile curvature, tangential curvature, slope height, normalized height, standardized height, convergence index, slope length and steepness factor, catchment area, specific catchment area, specific dispersal area, wetness index, valley depth, terrain ruggedness index, mid slope position, multi-resolution ridge top flatness (MRRTF), and multi-resolution index of valley bottom flatness (MRVBF). These variables were calculated using SAGA (Conrad *et al.* 2015). All 50 m digital elevation model variables are defined and citations provided in Appendix J and Appendix K. Additional predictor variables were derived from the Detailed Soil Survey, including soil order, soil zone, soil texture, percent sand, percent silt, and percent clay (Agriculture and Agri-food Canada 2010).

Predictor variables were mapped for the entire study region. The models used the training sample points to determine common characteristics between the predictor variables and the target soil variables. The model then predicted the target soil variable values for each sample point and compared these values to the observed field survey values to determine model accuracy. Soil class was the only categorical variable mapped, where the bagged CART model had the highest accuracy with 65% accuracy and a kappa score of 0.386 and was used to map soil classes for the entire study region (Table 4.1).

Table 4.1: Prediction accuracy for predicting soil classes per model. Accuracy of the prediction is based on the test data set (30% of data).

Model	Testing set (30% of data)	
	Accuracy	Kappa
Random forest	58	0.270
CART	53	0.222
Bagged CART	**65**	**0.386**
Artificial neural network	46	0.000
Support vector machine with radial basis function	48	0.068
Logistic model tree	60	0.329

Other metrics were used to assess the prediction accuracy for mapped continuous soil variables (Table 4.2). The r^2 value represents the level of agreement between the predicted values and the observed field survey values to measure model precision. Concordance assesses the model precision and accuracy. Root mean squared error (RMSE) measures the average error of the predictions. All soil variables with the exception of A horizon depth and NO_3^- were used as predictor variables in the development of the landscape-level Dakota skipper habitat suitability and distribution model as they had unacceptable r^2 values ($r^2 < 0.07$) (Table 4.2).

Table 4.2: Model used and prediction accuracy of the best performing model on continuous soil properties based on the test data set (30% of data).

Soil property	Model	r^2	Concordance	RMSE	RMSE unit	Bias
Bulk density	Cubist	0.229	0.421	0.18	g/cm^3	-0.015
% sand	Cubist	0.280	0.331	13.08	%	-1.911
% clay	Cubist	0.177	0.370	7.33	%	0.774
% silt	Cubist	0.136	0.259	9.97	%	0.559
Organic carbon	Random forest	0.096	0.282	10.02	mg/g	-0.301
NH_4^+	Random forest	0.073	0.226	2.72	ug/g	0.674
A horizon depth	Random forest	0.043	0.094	9.98	cm	2.146
NO_3^-	bagged regression tree	0.022	-0.200	19.60	ug/g	0.295

(RMSE = root mean squared error)

4.3.5 Geographic information system

Landscape-level geographic information data were used to develop the Dakota skipper habitat suitability and distribution model based on climate normal, soil, and landscape variables. All data were displayed, manipulated, and analyzed in Arcmap 10.5 (ESRI 2011). Climate normal raster layers were obtained from Natural Resources Canada (NRCAN), provided at a 10 km resolution and included the following variables; mean diurnal temperature range, maximum temperature of warm period, minimum temperature of cold period, annual precipitation, precipitation of wet period, and precipitation of dry period (McKenney *et al*. 2011). Soil and landscape variables were created as described above through digital mapping at a 50 m resolution, and included the following variables: soil class, bulk density, organic C, percent sand, percent silt, percent clay, NH_4^+, aspect, slope, and elevation. All Dakota skipper survey sites were displayed as points and overlaid on the predictor variable raster layers, where unique values for each point were extracted from these raster layers to be used in model calibration.

4.3.6 Species suitability and distribution model development

A generalized linear model (GLM) using presence-absence data with a binary function was used to determine significant environmental variables for Dakota skipper habitat. GLM's have been extensively used and tested with presence-absence species data and are an accurate modeling method in habitat suitability and distribution modeling (Brotons *et al*. 2004). Data were synthesized in R through biomod2 (R Core Team 2015; Thuiller *et al*. 2016) and a GLM. One thousand models were evaluated and the model of best fit was selected based on the highest tss, kappa, and roc scores. A unique formula, determined from the model of best fit was entered into the raster calculator in Arcmap 10.5 (ESRI 2011) to produce a Dakota skipper habitat probability raster layer with 10 classes, where 1 indicates the most suitable habitat and 0 indicates the least suitable habitat (Figure 4.1). The resulting Dakota skipper habitat probability raster layer was resampled to 10 m and clipped to the native, tame, and hay land cover polygon layer at this same scale to obtain the final raster image of available Dakota skipper habitat in southeastern Saskatchewan.

4.4 Results

4.4.1 Habitat suitability and distribution

A landscape-level habitat suitability and distribution model for the Dakota skipper was developed for southeastern Saskatchewan (Figure 4.1). The study area contains a total of 550 km^2 of native prairie, tame, and hay land cover. Of this area, 125.94 km^2 was identified as high quality Dakota skipper habitat (habitat probabilities 0.71-1.0) whereas 164.78 km^2 was ranked in the top 50% of habitat quality (habitat probabilities 0.51-1.0) and 345.32 km^2 ranked in the bottom 50% of habitat quality (habitat probabilities 0.0-0.5). The available area of each habitat probability class is presented in Table 4.3.

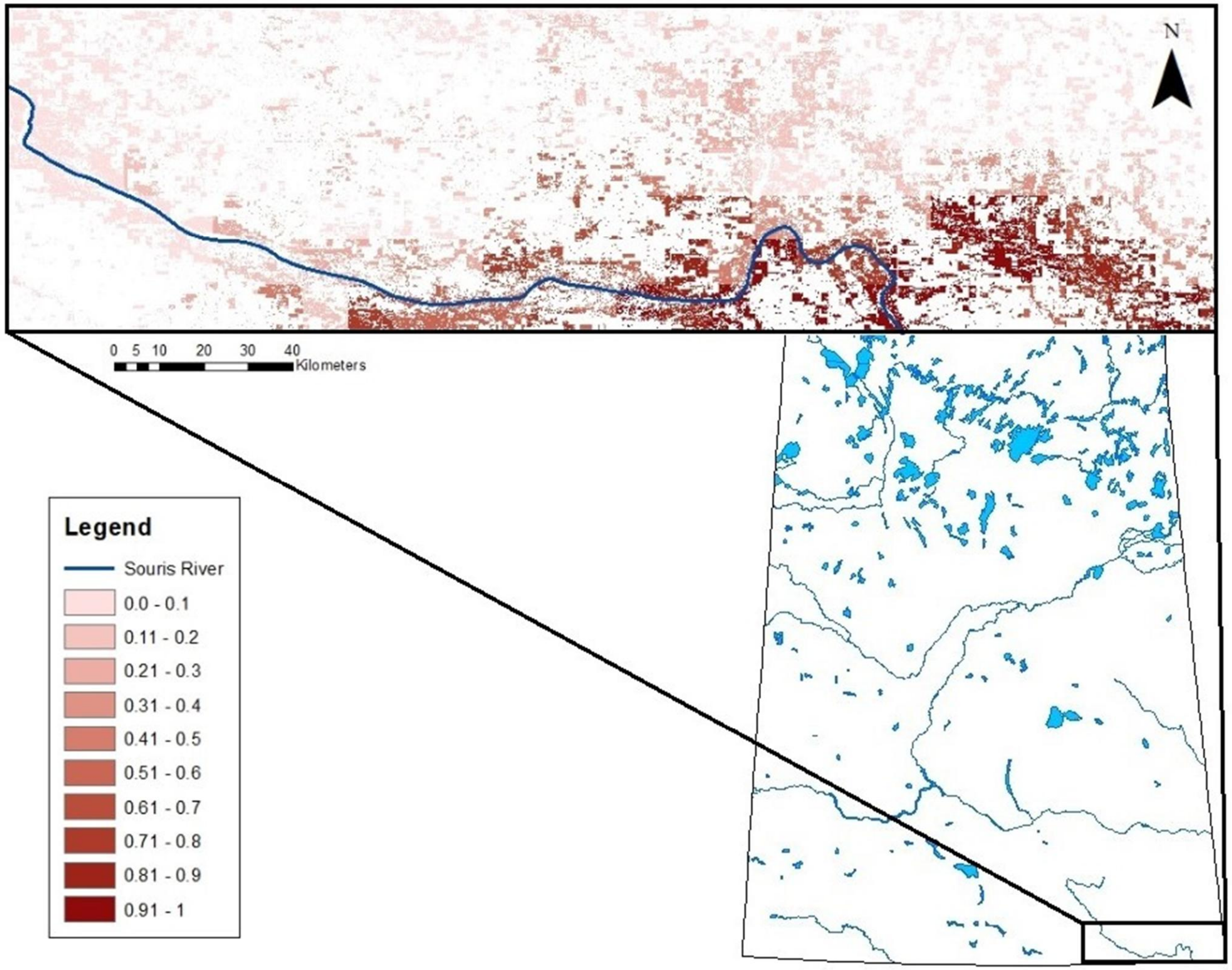

Figure 4.1: Dakota skipper habitat suitability and distribution map for southeastern Saskatchewan, with dark red indicating the most suitable habitat, light red indicating least suitable habitat and white indicating no potential habitat.

Table 4.3: Available area of each habitat probability class resulting from the Dakota skipper habitat suitability and distribution model.

Probability	Total area (km^2)
0.0 – 0.1	177.06
0.11 – 0.2	86.94
0.21 – 0.3	34.58
0.31 – 0.4	28.74
0.41 – 0.5	18.00
0.51 – 0.6	25.66
0.61 – 0.7	13.18
0.71 - 0.8	39.26
0.81 – 0.9	30.02
0.91 –1.0	56.66

Two variables were significant predictors of Dakota skipper habitat suitability and distribution in the model. NH_4^+ was higher in positive Dakota skipper sites than negative sites (Positive = 8.62 ug g^{-1}; SE ±0.158; Negative = 8.03 ug g^{-1}; SE ± 0.194; P = 0.038), and positive Dakota skipper sites had a lower mean diurnal temperature range than negative sites (Positive = 124.75; SE ± 0.216; Negative = 125.39; SE ± 0.171; P = 0.012) (Table 4.4).

Table 4.4: Biomod2 generalized linear model habitat suitability model results.

Variable	Coefficient	Z	P
Intercept	-213.656	-0.272	0.786
Mean diurnal temperature range	**1.386**	**2.527**	**0.012**
Soil	1.534	-0.010	0.991
Heatload	29.477	1.877	0.061
NH_4^+	**-0.850**	**-2.075**	**0.038**
Annual precipitation	0.076	1.451	0.147

(Z = z-value; P = p-value).

4.5 Discussion

The landscape-level habitat suitability and distribution model reported here indicates that the Dakota skipper is more limited in its distribution than originally thought due to environmental constraints. Specific requirements for soil, landscape, and climate normal conditions suggest that only a limited portion of the native mesic mixed-grass prairie region containing high quality habitat is likely to support Dakota skipper populations in southeastern Saskatchewan. The landscape-level habitat suitability and distribution model presented here identifies these areas in southeastern Saskatchewan containing high quality habitat for this species. Dakota skipper habitat is further refined based on habitat associations including areas containing steep landscape slopes and warmer daily maximum and average ground-level microclimate temperatures with the presence of plant species *Pediomelum argophyllum, Zizia aptera,* and *Schizachyrium scoparium* (Webster 2007; Westwood 2010; Chapter 3). These regions are important areas of conservation as these are the locations where new Dakota skipper populations are likely to be identified and potential reintroductions may be viable.

Dakota skipper population size and presence increases with increased habitat patch size and quality (Verboom *et al*. 1991; Thomas *et al*. 1992). Smaller habitat patches increase the chances of a butterfly wandering into unsuitable habitat, and can be a large contributor to the loss of butterfly populations (Crone and Schultz 2003; Pohl *et al*. 2014). Larger patches of native prairie contain denser populations of skipper butterflies (Swengel and Swengel 1999). Dakota skipper populations tend not to occur in habitat patches less than 0.20 km^2 (19.8 ha), whereas smaller populations were present on midsized habitat patches ranging between 0.30 to 1.30 km^2 (29.9 to 129.9 ha) and the largest populations were present on habitat patches of 1.40 km^2 (140 ha) or greater (Swengel and Swengel 1997). In general, the chances of maintaining a species increases with larger areas of available habitat. Therefore, areas under 0.20 km^2 (19.8 ha) are unlikely to support a viable Dakota skipper population, further limiting habitat of this species in the mesic mixed-grass prairie region of southeastern Saskatchewan.

Mean diurnal temperature range was a significant predictor of Dakota skipper habitat suitability in the landscape-level habitat suitability and distribution model. Dakota skipper habitat is significantly associated with temperature and climate variables as this species is an ectotherm that depends on heat to develop and mature over a large portion of its life-cycle (Westwood and Blair 2010; Dearborn and Westwood 2014). The habitat model indicates that lower mean diurnal temperature ranges are more likely to support Dakota skipper populations and increase habitat quality, indicating that less variation and extremes in temperatures make an ideal habitat for this species. Extreme high temperatures have the potential to dry out the upper soil layers and Dakota skipper larvae that inhabit this zone (Royer *et al*. 2008), while extreme low temperatures have the potential to freeze overwintering larvae (Ehrenreich and Aikman 1963). Warmer maximum and average daily ground-level microclimate temperatures are also significantly associated with Dakota skipper presence (Chapter 3). Furthermore, it was determined that climate measurements can act as a proxy for the ground-level microclimate. Therefore, it may be that extreme low temperatures are the limiting factor for Dakota skipper survival and habitat suitability. Ultimately, lower average diurnal ranges will be a determinate in Dakota skipper habitat suitability and species occupancy in southeastern Saskatchewan.

Dakota skipper emergence is dependent on thermal development (Dearborn and Westwood 2014), including lower mean diurnal temperature ranges and warmer maximum and average ground-level microclimate temperatures which will be changing with climate change (Westwood and Blair 2010; Chapter 3). Dakota skipper populations must adapt to their environment or move with suitable habitat over space and time (Pease *et al*. 1989). However, with one generation a year (Dana 1991), the Dakota skipper may not evolve fast enough to accommodate climate change, as climate is changing at a rate that exceeds evolutionary rates (Pease *et al*. 1989; Hirzel and Le Lay 2008). Adapting to climate change may not be possible for the Dakota skipper and this species will have to move with its habitat in time and space (Hirzel and Le Lay 2008; Visser 2008).

Northern portions of the world are experiencing increased climate changes (Hall *et al*. 2011), and Saskatchewan's Dakota skipper population is located at this northwestern extent where population are less adaptable to these changes. Changes in climate will shift habitat, forcing species distributions to change, tending to result in species movement further north (Hall 2009). Evidence suggests that species at their northern range in extent are beginning to use a larger range of habitats (Thomas *et al*.

2001; Roy and Thomas 2003; Hall 2009). New habitat may become available while old habitat may deteriorate (Davies *et al*. 2006). While these habitats may be climatically suitable for the Dakota skipper they may not contain the appropriate vegetation utilized by this species. Additionally, the ability for the Dakota skipper to move with suitable habitat (Hall 2009) is limited, as there is a lack of suitable habitat corridors for the Dakota skipper to travel (Britten and Glasford 2002). It is increasingly important to define Dakota skipper habitat in Saskatchewan as these populations present the greatest opportunity for distribution growth in the future. Therefore, although habitat has been mapped and classified for the Dakota skipper, there is potential that other habitat outside of its current distribution may also be important for this species conservation within a changing climate (USFWS 2016).

Higher NH_4^+soil content was also a significant predictor of Dakota skipper habitat suitability. Higher levels of NH_4^+ are correlated with greater soil moisture levels (Zhang and Wienhold 2002). Dakota skipper larvae spend the majority of their life-cycle in the upper soil layers (Dana 1991). Royer *et al*. (2008) suggests that Dakota skipper larvae will require soil with higher moisture content to avoid desiccation during the warmest months of the year. Additionally, increased soil NH_4^+ will increase plant growth. The Dakota skipper butterfly requires a variety of prairie forbs to nectar, while larvae depend on prairie bunch grass species for feeding and building shelters. The Dakota skipper depends on a healthy plant community to carry out all portions of its life-cycle (Dana 1991). Three plant species *Pediomelum argophyllum, Zizia aptera,* and *Schizachyrium scoparium* are significantly associated with Dakota skipper presence (Chapter 3). Increased NH_4^+ in the soil may provide a diverse plant community for the Dakota skipper to utilize throughout all portions of it's life-cycle. Ultimately, a higher content of NH_4^+ in the soil is a key determinate in Dakota skipper habitat suitability and quality in southeastern Saskatchewan.

Dakota skipper environmental associations identified in Chapter 3, complemented by significant variables to the habitat suitability and distribution model, are indicative of habitat requirements of this species in southeastern Saskatchewan. These significant habitat variables allow for the development of best management practices for this species. With the exception of one population, all known existing Dakota skipper populations in

Canada are found on private land (Westwood 2010; Chapter 3), making it crucial to develop best management practices and to inform private landowners. Dakota skipper habitat management must be implemented carefully to avoid impacts to both Dakota skipper larvae and butterflies (USFWS 2016).

Best management methods of current pristine habitat suggests that disturbances to these areas should mimic prehistoric processes (Vogl 1974; Anderson 1982) and are best implemented through a combination of haying, mowing, grazing, or fire (McCabe 1981; Anderson 1982; Dana 1991; Swengel 1996, 2001; Layberry *et al*. 1998; Swengel and Swengel 1999; Webster 2007). Haying, mowing, grazing, or fire management strategies should be conducted in early spring before the flight season or late September after the flight season to reduce impacts to Dakota skipper butterflies, while impacts on larvae should be considered at all times of the year (McCabe 1981; Swengel and Swengel 1999). Best management practices suggest patchy treatments are beneficial to prairie specialist butterflies (Swengel and Swengel 2001). Ultimately, land management practices should be sensitive to scale to ensure that a mosaic of habitat patches are maintained for the Dakota skipper at any site in any given year (Swengel 2001). Both management diversity and consistency are key in maintaining habitat for prairie specialists (Swengel and Swengel 1997). Restoration of arable land to native prairie habitat usable by the Dakota skipper has to date been unsuccessful (Shepherd and Debinski 2005). Therefore, all attempts to restore Dakota skipper habitat should be considered experimental. Restoration of Dakota skipper habitat will need to occur near native prairie with known Dakota skipper occupancy (Shepherd and Debinski 2005; USFWS 2016). These attempts to restore Dakota skipper habitat should occur in high quality habitat regions as indicated by the landscape-level habitat suitability model presented here and will need to contain Dakota skipper habitat associations as defined in Chapter 3.

Identification of Dakota skipper environmental associations (Chapter 3) along with habitat suitability and distribution in southeastern Saskatchewan is key information needed to construct a Dakota skipper conservation strategy. This information aids in conservation and management planning for the Dakota skipper by allowing for the identification of unknown populations, suitable sites for reintroduction, providing estimates of available habitat, and guiding future survey efforts for regions within southeastern Saskatchewan that have yet to be assessed (Heikkinen *et al*. 2007; Environment Canada 2007). A habitat suitability and distribution model can help guide the selection and management of protected lands currently or potentially occupied by this species, and assist the planning and implementation of conservation strategies by informing managers on the current and future states of Dakota skipper conservation (Hernandez *et al*. 2006; Heikkinen *et al*. 2007).

4.6 References

Agriculture and Agri-food Canada. 2010. Detailed soil survey [online]. Available from https://open.canada.ca/data/dataset/7ed13bbe-fbac-417c-a942-ea2b3add1748 [accessed 10 December 2018].

Anderson, R.C. 1982. An evolutionary model summarizing the roles of fire, climate, and grazing animals in the origin and maintenance of grasslands: an end paper. *In* Estes, J.R., Tyrl, R.J., and Brunken, J.N. Grasses and grasslands: systematics and ecology. Univeristy of Oklahoma Press, Norman., Oklahoma, US. Pp. 298–308.

Bailey, A., McCartney, D., and Schellenberg, M. 2010. Management of Canadian prairie rangeland. Agriculture and Agri-Food Canada, Government of Canada, Swift Current, Saskatchewan, Canada.

Binzenhöfer, B., Schröder, B., Strauss, B., Biedermann, R., and Settele, J. 2005. Habitat models and habitat connectivity analysis for butterflies and burnet moths - the example of *Zygaena carniolica* and *Coenonympha arcania*. Biological Conservation, **126**: 247–259. https://doi.org/10.1016/j.biocon.2005.05.009.

Bradley, B.A., Olsson, A.D., Wang, O., Dickson, B.G., Pelech, L., Sesnie, S.E., and Zachmann, L.J. 2012. Species detection vs. habitat suitability: are we biasing habitat suitability models with remotely sensed data? Ecological Modelling, **244**: 57–64. https://doi.org/10.1016/j.ecolmodel.2012.06.019.

Britten, H.B. and Glasford, J.W. 2002. Genetic population structure of the Dakota skipper (Lepidoptera: *Hesperia dacotae*): A North American native prairie obligate. Conservation Genetics, **3**: 363–374. https://doi.org/10.1023/A:10205767.

Brotons, L., Thuiller, W., Araújo, M.B., and A.H. Hirzel. 2004. Presence absence versus presence-only modelling methods for predicting bird habitat suitability. Ecography, **27**: 437–448. https://doi.org/0906-7590.2004.03764.x.

Committee on the Status of Endangered Wildlife in Canada. 2014. COSWIC assessment and status report Dakota skipper *Hesperia dacotae* in Canada [online]. Available from https://www.registrelep-sararegistry.gc.ca/virtual_sara/files/cosewic/sr_Dakota%20Skipper_2014_e.pdf [accessed 4 September 2016].

Conrad, O., Bechtel, B., Bock, M., Dietrich, H., Fischer, E., Gerlitz, L., Wehberg, J., Wichmann, V., and Bohner, J. 2015. System for automated geoscientific analyses (SAGA) v. 2.1.4. Geoscientific Model Development, **8**: 1991-2007. https://doi.org/10.5194/gmd-8-1991-2015.

Crone, E.E. and Schultz C.B. 2003. Movement behavior and minimum patch size for butterfly population persistence. *In* Boggs, C.L., Watt, W.B., and Ehrlich, P.R. Butterflies: ecology and evolution taking flight. University of Chicago Press, Chicago, Illinois. Pp. 561–576.

Dana, R.P. 1991. Conservation management of the prairie skippers *Hesperia dacotae* and *Hesperia ottoe*: basic biology and threat of mortality during prescribed burning in spring [online]. Available from https://conservancy.umn.edu/bitstream/handle/11299/139544/SB594.pdf?sequence=1 [accessed 4 September 2016].

Davies, Z.G., Wilson, R.J., Coles, S., and Thomas, C.D. 2006. Changing habitat associations of a thermally constrained species, the silver-spotted skipper butterfly, in response to climate warming. Journal of Animal Ecology, **75**: 247–256. https://doi.org/10.1111/j.1365-2656.2006.01044.x.

Dearborn, K. and Westwood, R. 2014. Predicting adult emergence of Dakota skipper and Poweshiek skipperling (Lepidoptera: Hesperiidae) in Canada. Journal of Insect Conservation, **18**: 875–884. https:doi.org/10.1007/s10841-014-9695-8.

Ehrenreich, J.H. and Aikman, J.M. 1963. An ecological study of the effect of certain management practices on native prairie in Iowa. Ecological Monographs, **33**: 113–130.

Elith, J. and Graham, C.H. 2009. Do they? How do they? Why do they differ? On finding reasons for differing performances of species distribution models. Ecography, **32**: 66–77. https://doi.org/10.1111/j.1600-0587.2008.05505.x.

Environment Canada. 2007. Recovery strategy for the Dakota skipper (*Hesperia dacotae*) in Canada [online]. Available from https://www.registrelep-sararegistry.gc.ca/virtual_sara/files/plans/rs_dakota_skipper_final_1007_e.pdf [accessed 3 September 2016].

ESRI. 2011. ArcGIS Desktop: Release 10.

Foody, G.M. 2002. Status of land cover classification accuracy assessment. Remote

Sensing of Environment, **80**: 185-201. https://doi.org/10.1016/S0034-4257(01)00295-4.

Guisan, A. and Zimmermann, N.E. 2000. Predictive habitat distribution models in ecology. Ecological Modelling, **135**: 147–186. https://doi.org/10.1016/S0304-3800(00)00354-9.

Hall, P.W. 2009. Sentinels on the wing: the status and conservation of butterflies in Canada. Ottawa, Ontario.

Hall, P.W., Catling, P.M., and Lafontaine, J.D. 2011. Insects at risk in the prairie region. *In* Floate., K.D. Arthropods of Canadian grasslands: inhabitants of a changing landscape. Volume 2. Biological Survey of Canada, Ottawa, Canada. Pp. 323–349.

Heikkinen, R.K., Luoto, M., Kuussaari, M., and Toivonen, T. 2007. Modelling the spatial distribution of a threatened butterfly: Impacts of scale and statistical technique. Landscaping and Urban Planning, **79**: 347–357. https://doi.org/10.1016/j.landurbplan.2006.04.002.

Hernandez, P.A., Graham, C.H., Master, L.L., and Albert, D.L. 2006. The effect of sample size and species characteristics on performance of different species distribution modeling methods. Ecography, **29**: 773–785. https://doi.org/10.1111/j.0906-7590.2006.04700.x.

Hirzel, A.H. and G. Le Lay. 2008. Habitat suitability modelling and niche theory. Journal of Applied Ecology, **45**: 1372–1381. https://doi.org/10.1111/j.1365-2664.2008.01524.x

Hooper, R.R. 2003. Dakota skipper (*Hesperia dacotae*) in Saskatchewan. Blue Jay, **61**: 124–125.

Klassen, P., Westwood, A. R., Preston, W.B., and McKillop, W.B. 1989. The butterflies of Manitoba. Manitoba Museum of Man and Nature, Winnipeg, Manitoba, Canada.

Kuhn, M. 2008. Building predictive models in R using the caret package. Journal of Statitical Software, **28**: 1–26. https://doi.org/10.18637/jss.v028.i05.

Layberry, R. A., Hall, P.W., and Lafontaine, J.D. 1998. The butterflies of Canada. Univeristy of Toronto Press, Toronto, Ontario, Canada.

McCabe, T.L. 1981. The Dakota skipper, *Hesperia dacotae* (Skinner): range and biology, with special reference to North Dakota. Journal of the Lepidoptersits' Society, **35**:

179–193.

McConkey, B., Cerkowniak, D., Fan, J., Bentham, M., and Desjardins, R. 2000. Carbon sequestration in prairie soils and their potential for climate change mitigation. Saskatoon, Saskatchewan, Canada [unpublished].

McKenney, D.W., Hutchinson, M.F., Papadopol, P., Lawrence, K., Pedlar, J., Campbell, K., Milewska, E., Hopkinson, R.F., Price, D., and Owen, T. 2011. Customized spatial climate models for North America. American Meterological Society, 1611–1622.

Pease, C.M., Lande, R., and Bull, J.J. 1989. A model of population growth, dispersal and evolution in a changing environment. Ecology, **70**: 1657–1664. https://doi.org/10.2307/1938100.

Pohl, G.R., Schmidt, B.C., Lafontaine, J.D., Landry, J.F., Anweiler, G.G., and Bird, C.D. 2014. Moths and butterflies of the prairies ecozone in Canada. *In* Giberson, D.J. and Carcamo, H.A. Arthropods of Canadian grasslands: biodiversity and systemastics part 2. Volume 4. Biological Survey of Canada, Ottawa, Canada. Pp. 169–238.

R Core Team. 2015. R: A language and environment for statistical computing [online]. Available from http://www.r-project.org/ [accessed 8 Janurary 2016].

Roy, D.B. and Thomas, J.A. 2003. Seasonal variation in the niche, habitat availability and population fluctuations of a bivoltine thermophilous insect near its range margin. Oecologia, **134**: 439–444. https://doi.org/10.1007/s00442-002-1121-3.

Royer, R.A., McKenney, R.A., and Newton, W.E. 2008. A characterization of non-biotic environmental features of prairies hosting the Dakota skipper (*Hesperia dacotae*, Hesperiidae) across its remaining U.S. range. Journal of the Lepidoperists' Society, **62**: 1–17.

Samson, F. and Knopf, F. 1994. Prairie conservation in North America. Bioscience, **44**: 418–421. https://doi.org/10.2307/1312365.

Shepherd, S. and Debinski, D.M. 2005. Evaluation of isolated and integrated prairie reconstructions as habitat for prairie butterflies. Biological Conservation, **126**: 51–61. https://doi.org/10.1016/j.biocon.2005.04.021.

Swengel, A.B. 1996. Effects of fire and hay management on abundance of prairie butterflies. Biological Conservation, **76**: 73–85. https://doi.org/10.1016/0006-

3207(95)00085-2.

Swengel, A.B. 2001. A literature review of insect responses to fire, compared to other conservation managements of open habitat. Biodiversity and Conservation, **10**: 1141–1169. https://doi.org/10.1023/A:1016683807033.

Swengel, A.B. and Swengel, S.R. 1997. Co-occurrence of prairie and barrens butterflies: applications to ecosystem conservation. Journal of Insect Conservation, **1**: 131–144. https://doi.org/10.1023/A:1018495428991.

Swengel, A.B. and Swengel, S.R. 1999. Observations of prairie skippers (*Oarisma poweshiek, Hesperia dacotae, H. ottoe, H. Leonardus pawnee*, and *Atrytone arogos iowa*) (Lepidoptera: Hesperiidae) in Iowa, Minnesota, and North Dakota during 1988-1997. The Great Lakes Entomologist, **32**: 267–292.

Swengel, A.B. and Swengel, S.R. 2001. Effects of prairie and barrens management on butterfly faunal composition. Biodiversity and Conservation, **10**: 1757–1785. https://doi.org/10.1023/A:1012051510584.

Thomas, C.D., Bodsworth, E.J., Wilson, R.J., Simmons, A.D., Davies, Z.G., Musche, M., and Conradt, L. 2001. Ecological and evolutionary processes at expanding range margins. Nature, **411**: 577–581. https://doi.org/10.1038/35079066.

Thomas, C.D., Thomas, J.A., and Warren, M.S. 1992. Distributions of occupied and vacant butterfly habitats in fragmented landscapes. Oecologia, **92**: 563–567. https://doi.org/10.1007/BF00317850.

Thuiller, W., Georges, D., Engler, R., and Breiner, F. 2016. Biomod2: ensemble platform for species distribution modeling [online]. Available from https://cran.r-project.org/web/packages/biomod2/biomod2.pdf [accessed 10 December 2016].

United States Fish and Wildlife Service. 2016. Guidance for interagency cooperation under section 7(a)(2) of the endangered species act for the Dakota skipper, Dakota skipper critical habitat, and Poweshiek skipperling critical habitat. Region 3 and 6 [online]. Available from http://www.fws.gov/midwest/endangered/section7/s7process/s7guid_cons.html#dask [accessed 17 September 2016].

Verboom, J., Schotman, A., Opdam, P., and Metz, J.A.J. 1991. European nuthatch metapopulations in a fragmented agricultural landscape. Oikos, **61**: 149–156.

https://doi.org/10.2307/3545332.

Visser, M.E. 2008. Keeping up with a warming world; assessing the rate of adaptation to climate change. Proceedings of the Royal Society of Biological Sciences, **275**: 649–659. https://doi.org/10.1098/rspb.2007.0997.

Vogl, R.J. 1974. Effects of fire on grassland. *In* Kozlowski, T.T. and Ahlgren, C.E. Fire and ecosystems. Academic Press, New York, USA. Pp. 139–194.

Webster, R. 2007. Dakota skipper, *Hesperia dacotae* (Skinner), survey in southeast Saskatchewan and southwest Manitoba during 2007. Charters Settlement, NB. Report available by request from Canadian Wildlife Service www.goc411.ca/en/58323/Medea-Curteanu [accessed 12 June 2015].

Westwood, R. 2010. Survey for Dakota skipper, *Hesperia dacotae*, in central, south eastern and south western Manitoba and south eastern Saskatchewan in 2010. Winnipeg, Manitoba. Report available by request from Canadian Wildlife Service www.goc411.ca/en/58323/Medea-Curteanu [accessed 12 June 2015].

Westwood, R.A. and Blair, D. 2010. Effect of regional climate warming on the phenology of butterflies in boreal forests in Manitoba, Canada. Environmental Entomology, **39**: 1122–1133. https://doi.org/10.1603/EN09143.

Zhang, R. and Wienhold, B.J. 2002. The effects of soil moisture on mineral nitrogen, soil electrical conductivity, and pH. Nutrient Cycling in Agroecosystems **63**: 251–254. https://doi.org/10.1023/A:1021115227884.

5 General conclusions

5.1 Conclusion

The studies presented in this thesis provide an overview of the environmental associations that define the distribution of Saskatchewan's Dakota skipper, *Hesperia dacotae* (Skinner, 1911) (Hesperiidae), population. I identified nine new Dakota skipper sites in southeastern Saskatchewan's Souris River Valley region. These populations add to the previous identified Saskatchewan Dakota skipper population regions (Hooper 2003; Webster 2007; Westwood 2010). The identification of nine new sites from a randomly selected sample of 46 sites indicates that Dakota skipper populations are likely more prevalent throughout this region than originally thought. The plant community, soil, and climate variables associated with Dakota skipper presence in Chapter 3 define the site-level environmental characteristics of habitat occupied by these populations in southeastern Saskatchewan. This information was applied at a landscape-level scale in Chapter 4 to predict Dakota skipper habitat suitability and distribution within this region. Both the site-level information from Chapter 3 and the landscape-level predictions from Chapter 4 define potential Saskatchewan Dakota skipper habitat, placing conservation organizations in a better position to protect this federally-listed endangered species. The research presented in this thesis fills key knowledge gaps of Saskatchewan's Dakota skipper population environmental associations and habitat suitability and distribution needed to construct a conservation management plan for this species (Environment Canada 2007).

Environmental associations of Saskatchewan's Dakota skipper population were identified in Chapter 3. Briefly, the overall environmental characteristics of Dakota skipper habitat were generally overlapping between positive and negative sites. Whereas overall plant community composition did not significantly differ between Dakota skipper positive and negative sites, three plant species were found to be significantly associated with presence of this species. These plant species include the forbs, *Pediomelum argophyllum* (Pursh) J.W.Grimes (Fabaceae), *Zizia aptera* (A.Gray) Fernald (Apiaceae), and native bunchgrass, *Schizachyrium scoparium* (Michx.) Nash (Poaceae). Soil and landscape variables were not found to be significantly different between Dakota skipper positive and negative sites with the exception of a significant positive association between steeper slopes and the presence of this species. Climate normal indicators were not significantly different between Dakota skipper positive and negative sites, however warmer maximum and average daily ground-level microclimates were significantly associated with Dakota skipper presence. Additionally, ground-level microclimates are a proxy for climate normals, indicating that climate data could be used to identify Dakota skipper habitat. This is important, as microclimate data is typically not available at a landscape-level scale, but climate data could be modeled at smaller scales to aid in the identification of potential Dakota skipper sites in southeastern Saskatchewan.

The distribution of suitable Dakota skipper habitat was identified in Chapter 4 through a landscape-level habitat distribution model. The habitat model identified two variables that increase Dakota skipper habitat quality including increased ammonium (NH_4^+) and lower mean diurnal temperature ranges. Through the landscape-level habitat model we conclude that although the Dakota skipper inhabits the mixed-grass ecoregion, it cannot be assumed the entire ecoregion contains suitable habitat. There are environmental factors and habitat requirements driving the distribution of this species, making Dakota skipper habitat more limited than initially thought. The Dakota skipper habitat distribution model identified areas in southeastern Saskatchewan likely to contain Dakota skipper populations based on habitat suitability. Future survey and conservation efforts should target high quality Dakota skipper habitat areas as identified in the distribution model presented in Chapter 4.

The limited environmental differences between Dakota skipper positive and negative sites indicate that intensive site-level sampling for Dakota skipper habitat in southeastern Saskatchewan may not be needed. These results suggest that more general native prairie conservation strategy would be helpful to Saskatchewan Dakota skipper populations. However, the Dakota skipper distribution map and habitat affinities identified in this thesis provide conservation organizations with clear criteria to rank individual parcels of land based on potential value to this species. High potential value lands for the Dakota skipper as identified in Chapter 4, will guide conservation organizations on areas to target for habitat conservation and preservation. These high quality lands could then be protected for this species through purchasing or land stewardship agreements.

The weak habitat associations of this species, but large number of new sites identified in the study period, suggest larger populations in Saskatchewan than considered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in past status updates of this species (COSEWIC 2003, 2014). During the study period, nine new Dakota skipper sites are added to the previously known Dakota skipper populations in southeastern Saskatchewan. Whereas the Dakota skipper is currently listed as an endangered species in Canada (COSEWIC 2014), increased population information allows for more informed assessments of the species conservation. COSEWIC has designated the Dakota skipper based on the B2ab (i,ii,iii,iv,v) criteria. The B2 criterion refers to species that have a small index of area of occupancy (IOA), or the sum of areas from 2 km by 2 km squares around each occurrence. The a sub-criterion refers to species that are severely fragmented or found at a limited number of locations (locations are defined by threats). The b sub-criterion refers to declines in the number of populations, extent of occurrence, or habitat quality. Based on the results of this study, there would likely be no change in how the criteria above apply to the Dakota skipper. The nine new Dakota skipper positive sites in this study contribute 36 km^2 (4 km^2 each) to the IOA, which is not enough to push this value above the 500 km^2 threshold used for ranking the species as endangered (IUCN 2001; COSEWIC 2015; Government of Canada 2017).

Defining Dakota skipper environmental associations and habitat suitability allows for the development of best management practices to manage and maintain habitat for this species. Current Dakota skipper habitat should be managed to maintain the environmental associations identified in Chapter 3, including significant plant species on steep slopes containing warmer climate conditions. However, it may be that this species appears to inhabit steep landscape slopes as these are the only remaining pristine native prairie in this region, as they are too steep to till. Therefore, there is potential for the Dakota skipper to use flatter native prairie regions within this area given the right microclimate. Given the historic loss of grassland habitat on arable land in this region (Bailey *et al*. 2010), it is likely that present Dakota skipper populations are much smaller than historic population sizes.

Habitat containing known Dakota skipper populations should be managed and maintained as per current management regimes, as presence of this species suggests that ongoing management methods are effective in maintaining a population. Several positive Dakota skipper sites were located in actively grazed pastures, whereas the remainder of the positive sites were located on steep landscape slopes that were not being managed. Best management methods should strive to maintain the environmental association identified in Chapter 3; including steep landscape slopes with significant plant species. Whereas it is evident that the Dakota skipper occupies these steep slopes, flatter landscapes should also be managed for this species as it is likely that populations historically occupied these landforms, and have the potential to occupy these areas in the future. While these steep landscape slopes can remain idle and experience little succession, flatter regions within this area will need to be managed in order to reduce succession. A light to medium grazing management regime should be implemented on flatter landforms in order to maintain Dakota skipper habitat. These grazing regimes were observed to effectively maintain habitat quality throughout the study period and in previous studies (Dana 1991; Environment Canada 2007). When managing Dakota skipper habitat, it is important to take into account impacts on the adult butterflies during the flight season as well as impacts to larvae throughout the entire year (McCabe 1981; Swengel and Swengel 1999). It is particularly important to manage these sites to maintain bunchgrass species such as *Schizachyrium scoparium*, as multiple studies have determined these bunchgrass species to be important to larval development (Dana 1991; Royer and Marrone 1992; Layberry *et al*. 1998). Additionally, it is important to maintain a diverse flora community during the adult Dakota skipper flight season, to allow for nectaring and mating activities (McCabe 1981; Dana 1991; Cochrane and Delphey 2002; Environment Canada 2007). Therefore, intensive activities such as haying or moderate to heavy grazing should occur outside of the Dakota skipper flight season, ideally implemented in early spring prior to plant development, or in late September after the flight season (McCabe 1981; Swengel and Swengel 1999). Attempts to restore Dakota skipper habitat should be considered experimental. Restoration of Dakota skipper habitat will need to occur near native prairie with known Dakota skipper occupancy (Shepherd and Debinski 2005; USFWS 2016). These attempts to restore Dakota skipper habitat should occur in areas that provide connectivity between existing positive sites in high quality habitat regions, as indicated in Chapter 4, and will need to contain Dakota skipper habitat associations as defined in Chapter 3.

The research findings from Chapter 3 and 4 of this thesis are a valuable insight to Saskatchewan's Dakota skipper population and this species' current and future situations. These findings address several novel areas relating to Dakota skipper life history, which help to fill key habitat suitability knowledge gaps for this federally-endangered species. These findings contribute to a wider overall understanding of the Saskatchewan and global Dakota skipper population. Additionally, this information allows for the identification of high quality Dakota skipper habitat that should be targeted for future surveys, habitat protection, conservation easements, and species reintroduction in southeastern Saskatchewan. Little knowledge previously existed about the environmental associations and habitat suitability and distribution of Saskatchewan's Dakota skipper population. Filling this knowledge gap allows for a better overall understanding of this species in the development of conservation and management plan for this species (Environment Canada 2007).

Future work on Saskatchewan's Dakota skipper population should be based on findings from Chapter 3 and 4 in this thesis. Additional Dakota skipper surveys are needed throughout southern Saskatchewan and should focus on high quality habitat identified in the Chapter 4 landscape-level habitat model, complemented by site-level environmental associations identified in Chapter 3. These surveys should target the known Dakota skipper distribution within Saskatchewan's Souris River Valley as there is only spotty survey coverage throughout this region, and better survey coverage is needed to understand the Saskatchewan Dakota skipper population dynamics. This includes surveying of known Dakota skipper populations in this region over many years to assess the site population dynamic. Only when an understanding of the Dakota skipper population in this region has been developed, should surveys further target the periphery of the specie's known Saskatchewan range, as this is the area that is most likely to contain new Dakota skipper populations. Therefore, surveys should be conducted north and west of the species' known Saskatchewan distribution. Webster (2007) suggests that additional survey efforts need to target other areas of the Saskatchewan's mixed-grass prairie ecoregion including unexplored tributaries along the Souris River Valley. Similar mesic mixed-grass habitats located along other southern Saskatchewan river systems including the Qu'Appelle River, the Assiniboine River, and the South Saskatchewan River have the potential to contain Dakota skipper populations and should be explored for suitable habitat and surveyed for existing populations.

Further work is needed to understand within-site population dynamics of Dakota skipper populations. It appears that the Dakota skipper may be present in more sites than indicated in this study. This may be due in part to undetected occurrences (detection error) or to the population dynamics of this species. Many sites within Saskatchewan have been surveyed for multiple years, with Dakota skipper populations present at a location in some years but absent in others (Hooper 2003; Webster 2007; Westwood 2010; COSEWIC 2014; Chapter 3). It is unclear whether the absences represent detection errors or meta-population dynamics that see the species blinking on and off at individual sites. Therefore, more research is needed to understand the within-site population dynamics of Saskatchewan's Dakota skipper populations.

Research findings in Chapter 3 and 4 of this thesis contribute to a wider overall understanding of insect conservation biology and the mesic mixed-grass ecosystem. Butterflies are some of the most widely studied terrestrial invertebrate groups, and as such play a crucial role in insect conservation biology (Ehrlich 2003). Additionally, butterflies can act as a key indicator of the biodiversity of an ecosystem, therefore gauging the health of the mixed-grass prairie ecoregion (Royer and Marrone 1992; Ehrlich 2003). This species occupies an endangered ecosystem (*i.e.* grassland of North America) containing many other at-risk fauna and flora (Environment Canada 2007). The Dakota skipper can act as an umbrella species for the protection of associated native habitats, plant, and wildlife species that are also at-risk (Ehrlich 2003). Therefore, efforts to protect the Dakota skipper benefit these native prairie ecosystems as a whole (Environment Canada 2007). This thesis builds on our understanding of this unique native prairie ecosystem's larger native fauna and flora community of which the Dakota skipper is a component.

5.2 References

Bailey, A., McCartney, D., and Schellenberg, M. 2010. Management of Canadian prairie rangeland. Agriculture and Agri-Food Canada, Government of Canada, Swift Current, Saskatchewan, Canada.

Cochrane, J.F. and Delphey, P. 2002. Status assessment and conservation guidelines Dakota skipper *Hesperia dacotae* (Skinner) (Lepidoptera: Hesperiidae) Iowa, Minnesota, North Dakota, South Dakota, Manitoba, and Saskatchewan [online]. Available from http://ecos.fws.gov/ServCat/DownloadFile/4020?Reference=4171 [accessed 4 September 2016].

Committee on the Status of Endangered Wildlife in Canada. 2003. COSEWIC assessment and status report on the Dakota skipper *Hesperia dacotae* in Canada [online]. Available from http://publications.gc.ca/collections/Collection/CW69-14-358-2004E.pdf [accessed 10 September 2016].

Committee on the Status of Endangered Wildlife in Canada. 2014. COSWIC assessment and status report Dakota skipper *Hesperia dacotae* in Canada [online]. Available from https://www.registrelep-sararegistry.gc.ca/virtual_sara/files/cosewic/sr_Dakota%20Skipper_2014_e.pdf [accessed 4 September 2016].

Committee on the Status of Endangered Wildlife in Canada. 2015. COSEWIC assessment process, categories and guidelines [online]. Available from http://www.cosewic.gc.ca/94D0444D-369C-49ED-A586-EC00C3FEF69B/Assessment_process_and_criteria_e.pdf [accessed 15 April 2018].

Dana, R.P. 1991. Conservation management of the prairie skippers *Hesperia dacotae* and *Hesperia ottoe*: basic biology and threat of mortality during prescribed burning in spring [online]. Available from https://conservancy.umn.edu/bitstream/handle/11299/139544/SB594.pdf?sequence=1 [accessed 4 September 2016].

Ehrlich, P.R. 2003. Introduction: butterflies, test systems, and biodiversity. *In* Boggs, C.L., Watt, W.B., and Ehrlich, P.R. Butterflies: ecology and evolution taking flight. Univeristy of Chicago Press, Chicago, Illinois. Pp. 1-6.

Environment Canada. 2007. Recovery strategy for the Dakota skipper (*Hesperia dacotae*) in Canada [online]. Available from https://www.registrelep-sararegistry.gc.ca/virtual_sara/files/plans/rs_dakota_skipper_final_1007_e.pdf [accessed 3 September 2016].

Government of Canada. 2017. COSEWIC wildlife species assessment: process categories and guidelines [online]. Available from https://www.canada.ca/en/environment-climate-change/services/committee-status-endangered-wildlife/wildlife-species-assessment-process-categories-guidelines.html [accessed 15 April 2018].

Hooper, R.R. 2003. Dakota skipper (*Hesperia dacotae*) in Saskatchewan. Blue Jay, **61**: 124–125.

IUCN. 2001. IUCN red list catagories and criteria: version 3.1 [online]. Available from http://www.redlist.org/

Layberry, R. A., Hall, P.W., and Lafontaine, J.D. 1998. The butterflies of Canada. Univeristy of Toronto Press, Toronto, Ontario, Canada.

McCabe, T.L. 1981. The Dakota skipper, *Hesperia dacotae* (Skinner): range and biology, with special reference to North Dakota. Journal of the Lepidoptersits' Society, **35**: 179–193.

Royer, R.A. and Marrone, G.M. 1992. Conservation status of the Dakota skipper (*Hesperia dacotae*) in North and South Dakota. Denver, Colorado [unpublished].

Shepherd, S. and Debinski, D.M. 2005. Evaluation of isolated and integrated prairie reconstructions as habitat for prairie butterflies. Biological Conservation, **126**: 51–61. https://doi.org/10.1016/j.biocon.2005.04.021.

Swengel, A.B. and Swengel, S.R. 1999. Observations of prairie skippers (*Oarisma poweshiek, Hesperia dacotae, H. ottoe, H. Leonardus pawnee,* and *Atrytone arogos iowa*) (Lepidoptera: Hesperiidae) in Iowa, Minnesota, and North Dakota during 1988-1997. The Great Lakes Entomologist, **32**: 267–292.

United States Fish and Wildlife Service. 2016. Dakota skipper conservation guidelines [online]. Available from https://www.fws.gov/midwest/endangered/insects/dask/pdf/DakotaSkipperConservationGuidelines2016Update.pdf [accessed 21 May 2016].

Webster, R. 2007. Dakota skipper, *Hesperia dacotae* (Skinner), survey in southeast Saskatchewan and southwest Manitoba during 2007. Charters Settlement, NB.

Report available by request from Canadian Wildlife Service www.goc411.ca/en/58323/Medea-Curteanu [accessed 12 June 2015].

Westwood, R. 2010. Survey for Dakota skipper, *Hesperia dacotae*, in central, south eastern and south western Manitoba and south eastern Saskatchewan in 2010. Winnipeg, Manitoba. Report available by request from Canadian Wildlife Service www.goc411.ca/en/58323/Medea-Curteanu [accessed 12 June 2015].

6 Appendix

Appendix A: Plant species list

Table A.1: Vascular plant species encountered in study sites. Latin name, common name and family are obtained from Saskatchewan Conservation Data Centre (2017); a seven letter epithet is used to refer to the species during the survey period and in Table B.1.

Scientific name	Family	Epithet	Common name	G rank	S rank
Achillea millefolium Ledeb.	Asteraceae	Achi mil	common yarrow	S5	G5
Agropyron cristatum (L.) P.Beauv.	Poaceae	Agro cri	crested wheatgrass	G5TRN	SNA
Agrostis scabra Tuck.	Poaceae	Agro sca	hair grass	G5T5	S4
Ambrosia psilostachya DC.	Asteraceae	Ambr cor	perennial ragweed	G5	SNA
Amelanchier alnifolia (Nutt.) Nutt. Ex M.Roem	Rosaceae	Amel aln	Saskatoon	G5T5	S5
Andropogon gerardi Vitman	Poaceae	Andr ger	big bluestem	G5	S4
Anemone cylindrica A.Gray	Ranunculaceae	Anem cyl	long-fruited anemone	G5	S4
Anemone patens Hoppe	Ranunculaceae	Anem pat	prairie crocus	G5T5	S5
Antennaria parvifolia Nutt.	Asteraceae	Ante par	small-leaved everlasting	G5	S4
Artemisia absinthium L.	Asteraceae	Arte abs	absinthe	GNR	SNA
Artemisia cana Pursh	Asteraceae	Arte can	hoary sagebrush	G5T5	S5
Artemisia frigida Willd.	Asteraceae	Arte fri	pasture sage	G5	S5
Artemisia ludoviciana Besser.	Asteraceae	Arte lud	prairie sage	G5T5	S5
Asclepias ovalifolia Decne.	Asclepiadaceae	Ascl ova	oval-leaved milkweed	G5	S5
Asclepias speciosa Torr.	Asclepiadaceae	Ascl spe	common milkweed	G5	S4
Astragalus agrestis Douglas ex G. Don	Fabaceae	Astr agr	field milk-vetch	G5	S4
Astragalus bisulcatus A.Gray	Fabaceae	Astr bis	two-grooved milk-vetch	G5T5	S4
Astragalus crassicarpus Nutt.	Fabaceae	Astr cra	ground plum	G5T5	S4
Astragalus specie	Fabaceae	Astr sp	milk-vetch specie		
Avenula hookeri (Scribn.) Holub	Poaceae	Aven hoo	Hooker’s oat grass	G5	S5
Bouteloua curtipendula (Michx.) Torr. In Marcy	Poaceae	Bout cur	side-oat grama	G5T5	S3

(Continued on next page)

Table A.1: Continued

Scientific name	Family	Epithet	Common name	G rank	S rank
Bouteloua gracilis (Kunth) Lag. Ex Griffiths	Poaceae	Bout gra	blue grama	G5	S5
Brassica rapa L.	Brassicaceae	Bras rap	field mustard	GNRTNR	SNA
Bromus inermis Steven	Poaceae	Brom ine	smooth brome	G5	SNA
Campanula rotundifolia Boiss.	Campanulaceae	Camp rot	harebell	G5	S5
Carex species	Cyperaceae	Care spp.	sedge species		
Cerastium nutans Raf.	Caryophyllaceae	Cera nut	long-stalked chickweed	G5T5	S4
Cirsium arvense (L.) Scop.	Asteraceae	Cirs arv	Canada thistle	GNR	SNA
Cirsium undulatum Spreng.	Asteraceae	Cirs und	wavy-leaved thistle	G5T5	S4
Comandra umbellata (L.) Nutt.	Santalaceae	Coma umb	bastard toadflax	G5T5	S5
Cornus sericea L.	Cornaceae	Corn ser	red-osier dogwood	G5T5	S4
Dalea purpurea Vent.	Fabaceae	Dale pur	hairy prairie-clover	G5T5	S4
Echinacea angustifolia DC.	Asteraceae	Echi ang	narrow-leaved purple coneflower	G4T4	S3
Elaeagnus commutata Bernh. Ex Rydb.	Elaeagnaceae	Elae com	silverberry	G5	S4
Elymus lanceolatus (Scribn. & J.G.Sm.) Gould	Poaceae	Elym lan	northern wheatgrass	G5T5	S5
Elymus repens (L.) Gould	Poaceae	Elym rep	creeping wild rye	GNR	SNA
Elymus trachycaulus (Link) Hoover	Poaceae	Elym tra	slender wheatgrass	G5T5	S5
Erigeron acris C.B.Clarke	Asteraceae	Erig acr	bitter fleabane	G5T5	S4
Erigeron caespitosus Nutt.	Asteraceae	Erig cae	tufted fleabane	G5	S4
Erigeron glabellus Nutt.	Asteraceae	Erig gla	streamside fleabane	G5T5	S5
Erigeron philadelphicus Willd.	Asteraceae	Erig phi	Philadelphia fleabane	G5T5	S4
Escobaria vivipara (Nutt.) Buxb.	Cactaceae	Esco viv	pincushion cactus	G5T5	S4
Equisetum arvense L.	Equisetaceae	Equi arv	common horsetail	G5	S5
Euphorbia esula Kotschy ex Boiss.	Euphorbiaceae	Euph esu	leafy spurge	GNRTNR	SNA
Fragaria virginiana Mill.	Rosaceae	Frag vir	smooth wild strawberry	G5T5	S5
Gaillardia aristata Pursh	Asteraceae	Gail ari	great-flowered gaillardia	G5	S4
Galium boreale Lapeyr. Ex DC.	Rubiaceae	Gali bor	northern bedstraw	G5	S5
Gaura coccinea Nutt.	Onagraceae	Gaur coc	scarlet gaura	G5	S4

(Continued on next page)

Table A.1: Continued

Scientific name	Family	Epithet	Common name	G rank	S rank
Geum triflorum Torr.	Rosaceae	Geum tri	three-flowered avens	G5T5	S5
Glycyrrhiza lepidota Nutt.	Fabaceae	Glyc lep	wild licorice	G5	S4
Grindelia squarrosa (Pursh) Dunal	Asteraceae	Grin squ	gumweed	G5	S5
Gutierrezia sarothrae Kuntze	Asteraceae	Guti sar	broomweed	G5	S4
Helianthus annuus L.	Asteraceae	Heli ann	common annual sunflower	G5	S4
Hesperostipa comata (Trin. & Rupr.) Barkworth	Poaceae	Hesp com	needle-and-thread grass	G5T5	S5
Heterotheca villosa (Pursh) Shinners	Asteraceae	Hete vil	hairy false golden-aster	G5T5	S5
Heuchera richardsonii R.Br.	Saxifragaceae	Heuc ric	alumroot	G5	S4
Hordeum jubatum DC.	Poaceae	Hord jub	fox-tail barley	G5T5	S5
Juncus balticus Willd.	Juncaceae	Junc bal	88altic rush	G5	S4
Juniperus horizontalis Moench	Cupressaceae	Juni hor	creeping juniper	G5	S5
Koeleria macrantha (Ledeb.) Schult.	Poaceae	Koel mac	June grass	G5	S5
Liatris ligulistylis (A.Nelson) Rydb.	Asteraceae	Liat lig	meadow blazing-star	G5	S4
Liatris punctata Hook.	Asteraceae	Liat pun	dotted blazing star	G5T5	S5
Lilium philadelphicum Thunb.	Liliaceae	Lili phi	western red lily	G5T4T5	S4
Linum lewisii Pursh	Linaceae	Linu lew	flax	G5T5	S4
Linum rigidum Sarato ex Parl.	Linaceae	Linu rig	large-flower yellow flax	G5T5	S5
Lithospermum canescens (Michx.) Lehm.	Boraginaceae	Lith can	hoary puccoon	G5	S4
Lycopodium specie	Lycopodiaceae	Lyco sp	club-moss specie		
Lygodesmia juncea D.Don ex Hooker.	Asteraceae	Lygo jun	skeleton-weed	G5	S5
Lysimachia maritima (L.) Galasso, Banfi & Soldano	Primulaceae	Lysi mar	sea-milkwort	G5	S4
Medicago lupulina L.	Fabaceae	Medi lup	black medic	GNR	SNA
Medicago sativa Urb.	Fabaceae	Medi sat	alfalfa	GNRTNR	SNA
Melilotus albus Desr.	Fabaceae	Meli alb	white sweet-clover	G5	SNA
Melilotus officinalis (L.) Lam.	Fabaceae	Meli off	yellow sweet-clover	GNR	SNA
Monarda fistulosa Hook.	Lamiaceae	Mona fis	wild bergamont	G5T5	S4

(Continued on next page)

Table A.1: Continued

Scientific name	Family	Epithet	Common name	G rank	S rank
Mulgedium pulchellum G.Don	Asteraceae	Mulg pul	common blue lettuce	G5T5	S4
Nassella viridula (Trin.) Barkworth	Poaceae	Nass vir	green needlegrass	G5	S5
Oenothera biennis Walter	Onagraceae	Oeno bie	yellow evening primrose	G5	S4
Orthocarpus luteus Nutt.	Scrophulariaceae	Orth lut	Owl's-clover	G5	S4
Oxytropis lambertii Pursh	Fabaceae	Oxyt lam	stemless point-vetch	G5TNR	S3
Oxytropis specie	Fabaceae	Oxyt sp	locoweed specie		
Pascopyrum smithii Barkworth & D.R.Dewey	Poaceae	Pasc smi	western wheatgrass	G5	S5
Pediomelum argophyllum (Pursh) J.W.Grimes	Fabaceae	Pedi arg	silvery scurf pea	G5	S5
Penstemon gracilis Nutt.	Scrophulariaceae	Pens gra	lilac beardtongue	G5T4T5	S4
Poa palustris L.	Poaceae	Poa pal	fowl blue grass	G5	S4
Poa pratensis Pollich	Poaceae	Poa pra	Kentucky blue grass	G5	SNA
Polygala alba Nutt.	Polygalaceae	Poly alb	white milkwort	G5	S3
Polygala senega L.	Polygalaceae	Poly sen	seneca snakeroot	G4G5	S4
Potentilla specie	Rosaceae	Pote sp	cinquefoil specie		
Potentilla norvegica Schur	Rosaceae	Pote nor	rough cinquefoil	G5	S4
Prunus virginiana Du Roi	Rosaceae	Prun vir	chokecherry	G5T5	S5
Ratibida columnifera (Nutt.) Wooton & Standl.	Asteraceae	Rati col	prairie cone-flower	G5	S4
Rosa arkansana Porter	Rosaceae	Rosa ark	low prairie rose	G5	S5
Rumex crispus Cham. & Schltdl.	Polygonaceae	Rume cri	curled dock	GNR	SNA
Rumex specie	Polygonaceae	Rume sp	dock specie		
Schizachyrium scoparium (Michx.) Nash	Poaceae	Schi sco	little bluestem	G5T5	S4
Solidago missouriensis Nutt.	Asteraceae	Soli mis	low goldenrod	G5T5	S5
Solidago mollis Bartl.	Asteraceae	Soli mol	velvet goldenrod	G5T5	S4
Solidago rigida L.	Asteraceae	Soil rig	stiff goldenrod	G5T5	S4
Sonchus arvensis L.	Asteraceae	Sonc arv	field sow-thistle	GNRTNR	SNA
Sphaeralcea coccinea (Nutt.) Rydb.	Malvaceae	Spha coc	scarlet mallow	G5T5	S5

(Continued on next page)

Table A.1: Continued

Scientific name	Family	Epithet	Common name	G rank	S rank
Spiraea alba Du Roi	Rosaceae	Spir alb	narrow-leaved meadow-sweet	G5T5	S4
Symphoricarpos occidentalis Hook	Caprifoliaceae	Symp occ	western snowberry	G5	S5
Symphyotrichum ericoides (L.) G.L.Nesom	Asteraceae	Symp eri	tufted white prairie aster	G5T5	S5
Symphyotrichum falcatum (Lindl.) G.L.Nesom	Asteraceae	Symp fal	white prairie aster	G5T4T5	S4
Taraxacum officinale F.H.Wigg	Asteraceae	Tara off	common dandelion	G5T5	SNA
Thalictrum venulosum Trel.	Ranunculaceae	Thal ven	veiny meadow-rue	G5	S4
Thermopsis rhombifolia (Nutt. Ex Pursh) Richardson	Fabaceae	Ther rho	golden-bean	G5	S5
Tragopogon dubius Scop.	Asteraceae	Trag dub	yellow goat’s-beard	GNR	SNA
Trifolium hybridum E.H.L.Krause	Fabaceae	Trif hyb	alsike clover	GNR	SNA
Vicia americana Muhl. Ex Willd.	Fabaceae	Vici ame	American purple vetch	G5T5	S5
Zizia aptera (A.Gray) Fernald	Apiaceae	Zizi apt	heart-leaved Alexander’s	G5	S4

Appendix B: Plant species cover data

Table B.1: All plant species within the six vegetation quadrats averaged at the site level for study sites 1 to 16. Values are percent foliar cover. Percent foliar cover is greater than 100% due to canopy layers.

Species	1*	2	3	4	5	6*	7	8	9	10*	11	12	13	14	15	16
Achi mil	0.33	2.50			0.33		2.33	3.33		1.17			0.33	0.83	1.83	
Agro cri																
Agro sca																
Ambr cor			5.83										2.50		0.33	
Amel aln				1.17												
Andr ger																
Anem cyl							0.67				0.33					0.67
Anem pat		3.17	2.00	0.83	8.33	0.67	0.83	4.50	4.00	3.33	1.50	0.83		1.33		3.17
Ante par	3.00								3.33	2.33				3.33	2.00	
Arte abs									1.17					8.33		
Arte can																
Arte fri	0.83	5.83	0.33	3.67	2.83		1.50	1.67	1.83	5.00	2.33	1.67	0.33	4.17	1.17	0.17
Arte lud		3.00	3.33	4.17	3.33	1.67	2.00	9.17	2.50	0.83	4.17	2.50	1.33			
Ascl ova																
Ascl spe									0.83		0.33	0.83			1.33	
Astr agr	10.00			0.33	3.67				0.33					4.17	3.67	2.50
Astr bis	0.83	3.50														
Astr cra																
Astr sp		4.00	0.83													0.33
Aven hoo		18.33									1.67					
Bout cur																
Bout gra		0.83									0.83					
Bras rap									0.33							
Brom ine	11.67	11.67	5.33			3.33	6.67			5.83		4.17	28.33			20.00
Camp rot		0.67			0.33		0.33									
Care spp																

(Continued on next page)

Table B.1: Continued

Species	1*	2	3	4	5	6*	7	8	9	10*	11	12	13	14	15	16
Cera nut						0.33										
Cirs arv	0.83					0.33										
Cirs und							1.17			2.00	3.17	0.33				0.33
Coma umb		8.67		2.83	2.83		2.83	2.50	2.33		2.00	0.33		0.33	2.00	2.33
Corn ser				11.67		4.17										
Dale pur		1.33		0.83	2.50	0.83	1.67		5.67		1.50	0.33		1.17	0.17	4.50
Echi ang	0.50	2.00		2.33	3.17	3.33	0.33	0.83	2.50	0.67	1.17	0.50		1.50	0.33	
Elae com			7.83		0.83	1.67	7.50	5.83								0.33
Elym lan																
Elym rep						4.17	0.83									
Elym tra		3.33	17.50	12.50	9.17		1.17		3.33			11.67		21.33	19.67	14.17
Erig acr											2.00					
Erig cae		0.33														
Erig gla															5.67	
Erig phi																
Esco viv														0.83		
Equi arv																
Euph esu																
Frag vir										0.33						
Gail ari		1.17			0.33										1.67	
Gali bor	0.50		1.67	0.83	1.67	2.83	4.00	5.00		0.83	1.33	3.33			0.83	5.00
Gaur coc	0.33		1.33	3.17	4.17	1.00		0.33	0.33		0.33	1.00	0.83	2.00	1.50	
Geum tri					1.17		0.67									
Glyc lep			1.67	0.83		5.83	1.67				0.83		9.17			
Grin squ									0.33					0.33		
Guti sar																
Heli ann				1.67		1.67	3.83		12.17	1.33	4.67	4.17				5.50
Hesp com	16.67	9.17	5.00	22.50	19.17	1.67	22.50	18.33	23.33	13.33	15.00	15.00		30.83	4.17	7.50
Hete vil									1.33							

(Continued on next page)

Table B.1: Continued

Species	1*	2	3	4	5	6*	7	8	9	10*	11	12	13	14	15	16
Heuc ric								0.83								
Hord jub																
Juni hor									2.50						0.83	10.33
Koel mac		23.33	8.33	7.50	8.33		5.83		13.33	2.50		1.67			5.83	
Liat lig												0.33				
Liat pun				0.33	1.67		1.17	2.50	0.33	0.33				0.83		
Lili phi																0.33
Linu lew				0.33	1.17		0.67		0.83	0.50		1.17			0.17	0.83
Linu rig															0.33	
Lith can			0.83													
Lyco sp		4.17								0.83					0.83	
Lygo jun																
Lysi mar						0.33									1.67	0.33
Medi lup		0.33														
Medi sat	0.33			1.33		11.67	26.17		5.00					0.83		0.33
Meli alb																
Meli off																
Mona fis			0.83													
Mulg pul	0.33	5.00	2.00	0.33	1.17				0.83		2.00	1.33	1.17			
Nass vir	0.17			5.00	0.83							2.50				
Oeno bie						0.33			1.67							
Orth lut																
Oxyt lam											0.33				1.67	
Oxyt sp					0.83										0.83	
Pasc smi										25.00	11.67		1.67		6.67	1.67
Pedi arg	0.50	0.33	1.67	1.17	0.33	2.50	4.33	2.83	0.83	3.33	3.33	1.17	5.00	0.83	1.17	0.50
Pens gra		3.67														
Poa pal															4.17	
Poa pra	70.83	13.33	60.00	30.83	25.00	50.00	25.00	45.00	15.00	42.50	48.33	40.00	59.17	23.33	51.67	34.17

(Continued on next page)

Table B.1: Continued

Species	1*	2	3	4	5	6*	7	8	9	10*	11	12	13	14	15	16
Poly alb															0.50	0.67
Poly sen									5.00							
Pote sp	0.33															
Pote nor								0.83	0.33	1.17	0.33	0.83		3.50	0.83	
Prun vir								0.33				1.67				
Rati col			0.83		0.83	0.33	0.33		2.67	5.00	1.33			3.83	5.50	0.17
Rosa ark		1.67	2.50	0.67	5.83	0.83		0.83			2.17	1.50	3.33	2.50		0.67
Rume cri																
Rume sp																
Schi sco					5.00	20.83	3.33		15.83	5.00	5.00	4.17			2.50	17.50
Soli mis						0.83										
Soli mol					0.33	0.83	0.33	0.83				1.67				
Soil rig	0.50															1.67
Sonc arv																
Spha coc																
Spir alb												0.83		0.83		
Symp occ	0.83	1.33	4.17	5.00	5.00	4.17	5.00	4.17		2.50	11.17	25.00	15.00	0.33	0.83	
Symp eri													0.83			
Symp fal	0.83															
Tara off	1.83	1.50		0.33			0.33								0.67	
Thal ven												1.67				
Ther rho								14.67		0.33		1.33		0.33		
Trag dub						0.33		0.83								
Trif hyb																
Vici ame		0.83						3.67		3.33	1.67	0.67		1.17	2.50	0.33
Zizi apt																
Ground	4.83		2.50	0.83	4.17	0.83			3.33					15.83	0.83	
Rock		1.67					3.33				0.83			1.67		
Feces										1.67				3.33		

* indicates positive (present) Dakota skipper site

Table B.2: All plant species within the six vegetation quadrats averaged at the site level for study sites 17 to 31. Values are percent foliar cover. Percent foliar cover is greater than 100% due to canopy layers.

Species	17*	18	19	20	21	22	23	24	25	26	27	28*	29	30	31
Achi mil	1.33			4.17	1.33	1.67		1.83	0.83	0.33			2.67	0.83	2.17
Agro cri					8.33				6.67				3.00		
Agro sca								6.33		1.33					
Ambr cor				1.67									0.83		
Amel aln									0.83						
Andr ger															
Anem cyl					0.50										
Anem pat	0.50	1.00				4.00	5.00	1.17	0.83			1.67		0.83	
Ante par			0.83			1.67		1.33					6.33		
Arte abs	0.33		0.83												
Arte can					0.83	0.83							3.83		
Arte fri	3.00	1.17	5.17	3.00	2.83	2.33	2.50	0.83	0.83	1.33		0.50	7.00	0.83	1.67
Arte lud	2.33	5.83		2.83		1.33		3.67	5.33	3.83			6.67	7.00	1.67
Ascl ova										0.50				0.83	
Ascl spe															
Astr agr		1.67	0.33	1.17	3.00	6.00			0.33	1.67		2.83			
Astr bis															
Astr cra	0.33		1.17												
Astr sp						1.33	3.00							0.83	
Aven hoo								1.67		1.67					
Bout cur															
Bout gra			1.67									2.00			
Bras rap															
Brom ine	30.00		5.00	12.50	3.33		1.67						16.67	32.50	15.83
Camp rot	0.67		0.33				1.33			1.83				1.33	
Care spp										1.67					3.33
Cera nut															
Cirs arv										2.50	0.83				0.33

(Continued on next page)

Table B.2: Continued

Species	17*	18	19	20	21	22	23	24	25	26	27	28*	29	30	31
Cirs und		0.67	0.67				5.00	0.83	2.17	0.83				2.50	1.67
Coma umb	5.00	1.33	3.33	0.83	2.83	0.33	1.17	2.50	0.50			0.83		0.50	
Corn ser															
Dale pur		1.17	0.83	0.83	3.00		0.50	0.50	1.33	0.50		4.67			0.33
Echi ang		4.33		0.33	3.00	0.83	3.83					1.83		2.00	
Elae com			0.83	4.17			6.17		2.17	2.17				5.50	
Elym lan															
Elym rep								5.00							
Elym tra	7.50	2.17							5.83		53.33	14.67		5.00	
Erig acr															
Erig cae															
Erig gla															
Erig phi												0.50			
Esco viv			0.83												
Equi arv															
Euph esu															
Frag vir														0.83	
Gail ari								0.83							
Gali bor	1.67							0.50	0.67	1.17		1.33		3.33	
Gaur coc	2.00	2.50	3.50	5.33	1.33	1.67	3.67	1.67	1.67	0.83	0.83	1.83	0.33	3.00	2.17
Geum tri															
Glyc lep	1.67			4.67					1.33	4.17			3.00	1.33	
Grin squ				1.67				1.17					0.33		1.67
Guti sar												0.50			
Heli ann	3.00	5.00		1.33			1.33		3.00	0.83		2.17		2.17	
Hesp com	4.17	12.50	10.83	1.67	12.50	16.67	24.17	1.33	17.50	1.67		23.17		1.67	
Hete vil	5.00										0.33		13.33		1.33
Heuc ric															
Hord jub									0.83	5.00	19.33				6.67

(Continued on next page)

Table B.2: Continued

Species	17*	18	19	20	21	22	23	24	25	26	27	28*	29	30	31
Juni hor												6.67			
Koel mac	1.67	2.50	6.67		9.17	5.00		1.67				10.00	1.67		
Liat lig	0.33	0.50					1.33							0.83	
Liat pun												0.33			
Lili phi															
Linu lew							2.33					1.17			
Linu rig					0.33	0.33						0.83			
Lith can															
Lyco sp													5.00		
Lygo jun															
Lysi mar															
Medi lup			0.33	4.67	1.33								0.50		3.33
Medi sat					1.17							0.50			0.83
Meli alb											5.00	0.33	0.33	0.50	
Meli off									0.33		0.83				0.83
Mona fis							9.50		2.50					3.33	
Mulg pul	0.33	1.33					0.33		1.33	0.67	3.83			1.83	2.50
Nass vir					18.33		15.00	1.33		1.67	5.00	1.67			
Oeno bie												0.83			0.33
Orth lut												0.83			
Oxyt lam	0.33		0.33												
Oxyt sp								2.50							
Pasc smi			18.33	5.00	16.67		10.00	5.00	6.33	10.83	7.50	4.17			20.00
Pedi arg	3.50	0.83	1.67	0.83	1.00	2.67	1.17	3.83	0.83			1.17	0.83	2.50	
Pens gra															
Poa pal											8.33				
Poa pra	58.33	70.83	20.83	56.67	30.83	61.67	28.33	58.33	57.50	65.00	5.00	18.33	39.17	34.17	50.83
Poly alb	0.33				3.83	3.00						0.33			
Poly sen															

(Continued on next page)

Table B.2: Continued

Species	17*	18	19	20	21	22	23	24	25	26	27	28*	29	30	31
Pote sp															
Pote nor				0.83	0.83				0.33		0.33		0.33	1.83	0.83
Prun vir															
Rati col		0.83	5.83	2.50	2.17	4.00	0.33	4.17				2.17	0.83	3.33	1.33
Rosa ark	0.50	0.83	6.33	5.17	0.33	1.83		3.00	0.83	0.33		1.67	1.33		5.00
Rume cri											0.83				
Rume sp									1.17						
Schi sco		3.33										9.17		1.67	
Soli mis				4.67			1.67								
Soli mol	0.33	5.83	2.50	1.17	0.33	3.83	0.83	7.50					6.50	2.50	
Soil rig													0.33	5.00	
Sonc arv															
Spha coc						0.83	0.83								
Spir alb															
Symp occ	0.83	3.33	13.33	3.33	1.33	1.67	7.83	3.67	7.50	8.67		2.50		8.00	
Symp eri														0.83	
Symp fal															
Tara off			2.00	1.17	0.67	0.50		1.67	0.33		0.83				1.17
Thal ven	0.83													0.83	
Ther rho				0.83		6.67		2.50		2.50			0.83	0.83	
Trag dub		0.33			0.50			0.33	0.50						
Trif hyb											0.83				0.83
Vici ame	0.33	0.33	1.17						0.33						
Zizi apt															
Ground			9.17		0.83	0.83					19.17	15.33	9.17		10.00
Rock			1.17					5.50	3.33	0.83	4.17	1.67	3.33		
Feces			1.67	0.83				2.50		0.83					

* indicates positive (present) Dakota skipper site

Table B.3: All plant species within the six vegetation quadrats averaged at the site level for study sites 32 to 46. Values are percent foliar cover. Percent foliar cover is greater than 100% due to canopy layers.

Species	32	33	34*	35	36	37	38*	39	40	41	42	43*	44	45	46*
Achi mil	2.83			1.67		1.17	0.83	2.17	3.00		1.83			1.00	1.33
Agro cri										15.00					
Agro sca															
Ambr cor															
Amel aln															
Andr ger										8.33					2.50
Anem cyl	1.50		0.33	0.33	1.83	0.33	1.83	0.83		1.17			1.67	2.17	0.83
Anem pat		0.33	2.00			1.67				0.83			0.83		
Ante par	1.17				0.83		1.33								0.83
Arte abs									1.33						
Arte can															
Arte fri	0.83	2.33	1.33	2.17	1.83	1.67	2.17			2.83	3.33	2.50	5.83		1.67
Arte lud	4.67	0.50	0.33	3.83	2.67	0.83	4.83	3.33	6.17	5.00	5.50		3.33	2.17	12.17
Ascl ova															
Ascl spe		1.33		1.67			0.83			0.67	2.17				0.33
Astr agr															
Astr bis															
Astr cra					0.83										
Astr sp															
Aven hoo				5.83	10.83	12.00		7.50		4.17	12.50	10.00		1.67	
Bout cur														2.50	
Bout gra												6.67			
Bras rap															
Brom ine	9.17	5.83	10.00	16.67					23.33	3.33		15.00	11.67		
Camp rot								0.83		0.67	0.83			0.83	
Care spp															
Cera nut				1.67											
Cirs arv					0.50					0.67	0.33		0.83		

(Continued on next page)

Table B.3: Continued

Species	32	33	34*	35	36	37	38*	39	40	41	42	43*	44	45	46*
Cirs und	1.17			1.67	0.67	2.00	1.17	1.83	2.50	1.33	4.17		0.50	1.00	4.00
Coma umb	0.83	1.67	1.33			1.67		0.83				3.33		1.33	0.50
Corn ser															
Dale pur		0.50	1.17	0.50	0.33	1.83	0.83	1.00		0.50	1.00	2.00		1.33	0.83
Echi ang	0.83	0.83	0.50			2.33		0.83	0.50	0.50	3.00	3.83		2.83	
Elae com		4.17	5.00				3.83			1.67			9.67	5.50	5.00
Elym lan				22.50		5.00	5.83	1.67	1.67		9.17	5.83	2.50	4.17	5.00
Elym rep															
Elym tra		1.67	3.33						5.00	3.33	4.17				2.50
Erig acr															
Erig cae															
Erig gla													0.83		
Erig phi															
Esco viv															
Equi arv															
Euph esu								1.33							
Frag vir															
Gail ari	0.83				1.67	0.83									
Gali bor	3.33			1.50	2.50	3.67		0.83		3.33	1.50		2.50	1.33	0.83
Gaur coc		0.67				0.50	2.17			0.83	0.33	3.33	2.17		1.17
Geum tri				1.00		1.00									
Glyc lep	3.33	1.33	1.67	0.83	0.50		3.33				3.83		4.17	5.83	0.83
Grin squ															
Guti sar															
Heli ann	2.83	4.17	1.33	6.33	4.33	3.00	2.50	4.17	2.17	4.17	0.83		1.33	0.50	4.33
Hesp com	16.67	30.00	13.33		5.00	25.00	11.67	15.00		7.50		22.50	10.00	5.83	7.50
Hete vil		1.33			1.33		0.83	1.33		1.67			0.83		0.50
Heuc ric	0.33														
Hord jub															

(Continued on next page)

Table B.3: Continued

Species	32	33	34*	35	36	37	38*	39	40	41	42	43*	44	45	46*
Juni hor										2.50					
Koel mac										3.33		2.50		1.67	
Liat lig									0.50	1.50					
Liat pun	1.33		0.83									0.50	1.67		
Lili phi															
Linu lew		2.00	0.50			0.83				1.67		0.50		1.00	
Linu rig															
Lith can															
Lyco sp															
Lygo jun		0.33				0.33	0.50					1.33			
Lysi mar		0.33													
Medi lup	1.67								11.33						
Medi sat									2.50	7.50	0.83	4.17			
Meli alb					1.00				0.83						
Meli off						0.33				0.67		5.00		0.67	
Mona fis		2.67											3.83	2.50	3.33
Mulg pul		0.33		0.83	1.50	1.00		0.50		0.33	0.83	5.83		1.83	
Nass vir	5.00	5.83	7.00		17.50	3.33	13.33								5.00
Oeno bie		2.00								1.33					
Orth lut															
Oxyt lam				1.17	1.17	2.50						0.83			
Oxyt sp			0.83												
Pasc smi															1.67
Pedi arg	2.67	0.33	2.33	3.33	2.83	2.33	7.50	0.83	3.33	5.33	6.33	4.17		0.50	3.83
Pens gra	0.50														
Poa pal															
Poa pra	50.00	26.67	41.67	40.00	37.50	20.83	30.00	46.67	41.67	29.17	40.83	10.00	40.00	42.83	45.00
Poly alb															
Poly sen															

(Continued on next page)

Table B.3: Continued

Species	32	33	34*	35	36	37	38*	39	40	41	42	43*	44	45	46*
Pote sp															
Pote nor															1.00
Prun vir															
Rati col		0.50	0.83	1.83	1.67		1.67	1.33		0.67	2.50				
Rosa ark			2.00	3.17	2.17	2.17		2.50	1.33		2.50		0.83	0.83	0.83
Rume cri															
Rume sp															
Schi sco		7.50	3.00	2.50		6.67	4.17	11.67		3.33		15.83		5.83	2.50
Soli mis		0.50				0.50	2.50						0.83	1.33	
Soli mol									0.50						
Soil rig	0.33	0.33	0.67	2.33	1.17	2.50	1.33		3.50				1.67		0.50
Sonc arv				0.50	2.50									0.83	0.50
Spha coc															
Spir alb					0.83										
Symp occ	8.83	12.50	9.17	2.83	13.00	4.17	8.83	5.50	3.83		12.50		16.67	13.83	8.67
Symp eri															
Symp fal															
Tara off	0.50				1.67		0.33		3.17	0.50					
Thal ven														0.33	
Ther rho	0.33		5.00								0.50				
Trag dub				1.00			0.67	0.50		0.50	1.50			1.33	0.33
Trif hyb															
Vici ame	2.50	1.17	2.83			1.33		1.33	1.33	0.50	1.67	1.33	0.83	0.83	0.33
Zizi apt					0.33	0.33	0.83								1.33
Ground	10.83	11.00	9.17	13.83	15.00	16.67	16.67	12.17	8.00	9.17	12.50	15.00	10.00	17.50	14.17
Rock	1.67					5.00		5.00	1.67	2.50				4.17	
Feces	3.67		1.83				3.00	2.50	1.67	0.83	3.33		0.83		0.83

* indicates positive (present) Dakota skipper site

Appendix C: Indicator species analysis results

Table C.1: Indicator species analysis results of plant species present in study sites. Species are ranked by their indicator value and frequency indicates the number of sites (total sites = 46) in which a plant species is present.

Dakota skipper site	Species	Indicator value	P-value	Frequency
Negative	*Rosa arkansana*	0.546	0.111	33
	Solidago mollis	0.333	0.240	16
	Medicago lupulina	0.216	0.254	8
	Campanula rotundifolia	0.229	0.304	12
	Achillea millefolium	0.414	0.306	28
	Gaillardia aristata	0.189	0.311	7
	Grindelia squarrosa	0.162	0.389	6
	Taraxacum officinale	0.284	0.390	18
	Symphoricarpos occidentalis	0.501	0.423	39
	Astragalus specie	0.162	0.434	6
	Ambrosia coronopifolia	0.135	0.473	5
	Avenula hookeri	0.195	0.543	12
	Geum triflorum	0.108	0.569	4
	Agropyron cristatum	0.108	0.570	4
	Melilotus albus	0.115	0.571	6
	Hordeum jubatum	0.108	0.571	4
	Artemisia ludoviciana	0.447	0.586	36
	Elymus trachycaulus	0.306	0.594	22
	Cirsium flodmanii	0.328	0.605	25
	Spiraea alba	0.081	0.618	3
	Galium boreale	0.358	0.625	28
	Liatris ligulistylis	0.127	0.628	7
	Mulgedium pulchellum	0.343	0.636	26
	Artemisia absinthium	0.097	0.663	5
	Anemone patens	0.331	0.690	26
	Asclepias speciosa	0.142	0.698	10
	Koeleria macrantha	0.262	0.700	20
	Monarda fistulosa	0.123	0.709	8
	Potentilla norvegica	0.201	0.717	15
	Ratibida columnifera	0.354	0.720	29
	Artemisia cana	0.081	0.747	3
	Artemisia frigida	0.470	0.796	41
	Thermopsis rhombifolia	0.175	0.796	13
	Penstemon gracilis	0.054	0.828	2
	Prunus virginiana	0.054	0.831	2
	Comandra umbellata	0.350	0.836	30
	Agrostis scabra	0.054	0.842	2

(Continued on next page)

Table C.1: Continued

Dakota skipper site	Species	Indicator value	P-value	Frequency
Negative	*Erigeron glabellus*	0.054	0.842	2
	Tragopogon dubius	0.155	0.875	13
	Polygala alba	0.081	0.889	6
	Oxytropis lambertii	0.097	0.915	8
	Cirsium arvense	0.105	0.947	9
	Pascopyrum smithii	0.172	0.983	16
	Lycopodium specie	0.060	1.000	4
	Amelanchier alnifolia	0.054	1.000	2
	Asclepias ovalifolia	0.054	1.000	2
	Carex species	0.054	1.000	2
	Escobaria vivipara	0.054	1.000	2
	Heuchera richardsonii	0.054	1.000	2
	Poa palustris	0.054	1.000	2
	Sphaeralcea coccinea	0.054	1.000	2
	Symphyotrichum ericoides	0.054	1.000	2
	Trifolium hybridum	0.054	1.000	2
	Sonchus arvense	0.053	1.000	4
	Lysimachia maritima	0.051	1.000	4
	Bouteloua curtipendula	0.027	1.000	1
	Brassica rapa	0.027	1.000	1
	Erigeron acris	0.027	1.000	1
	Erigeron caespitosus	0.027	1.000	1
	Euphorbia esula	0.027	1.000	1
	Lilium philadelphicum	0.027	1.000	1
	Lithospermum canescens	0.027	1.000	1
	Polygala senega	0.027	1.000	1
	Rumex crispus	0.027	1.000	1
	Rumex specie	0.027	1.000	1
Positive	*Schizachyrium scoparium*	0.561	0.016	22
	Zizia aptera	0.207	0.038	4
	Pediomelum argophyllum	0.637	0.050	42
	Lygodesmia juncea	0.204	0.059	4
	Bouteloua gracilis	0.203	0.064	5
	Erigeron philadelphicus	0.111	0.181	1
	Orthocarpus luteus	0.111	0.190	1
	Potentilla specie	0.111	0.192	1
	Hesperostipa comata	0.535	0.196	39
	Gutierrezia sarothrae	0.111	0.208	1
	Symphyotrichum falcatum	0.111	0.219	1
	Antennaria parvifolia	0.265	0.250	13
	Nassella viridula	0.321	0.267	17

(Continued on next page)

Table C.1: Continued

Dakota skipper site	Species	Indicator value	P-value	Frequency
Positive	*Elymus lanceolatus*	0.198	0.330	10
	Bromus inermis	0.381	0.338	25
	Cornus sericea	0.066	0.343	2
	Andropogon gerardii	0.061	0.346	2
	Elymus repens	0.083	0.358	3
	Astragalus bisulcatus	0.055	0.359	2
	Fragaria virginiana	0.069	0.362	2
	Medicago sativa	0.265	0.390	24
	Liatris punctata	0.202	0.487	12
	Vicia americana	0.323	0.576	24
	Glycyrrhiza lepidota	0.295	0.627	22
	Solidago missouriensis	0.131	0.661	8
	Linum rigidum	0.086	0.668	4
	Oenothera biennis	0.105	0.707	6
	Heterotheca villosa	0.178	0.751	12
	Linum lewisii	0.203	0.754	16
	Solidago rigida	0.176	0.790	14
	Helianthus annuus	0.356	0.805	30
	Echinacea angustifolia	0.346	0.822	30
	Poa pratensis	0.507	0.867	46
	Eleagnus commutata	0.221	0.880	29
	Thalictrum venulosum	0.061	0.882	4
	Melilotus officinalis	0.094	0.893	7
	Gaura coccinea	0.391	0.911	35
	Dalea purpurea	0.362	0.926	33
	Anemone cylindrica	0.169	0.943	15
	Astragalus agrestis	0.144	0.992	15
	Juniperus horizontalis	0.070	1.000	5
	Oxtropis specie	0.050	1.000	4
	Cerastium nutans	0.050	1.000	2
	Astragalus crassicarpus	0.045	1.000	3

Appendix D: Soil laboratory methods and procedures

Table D.1: Soil laboratory analysis methods and procedures used on soil samples taken from 0-15 cm depth.

Variable	Sites	Method	Analysis	Citation
Gravimetric content of field-moist soil	2015, 2016	Oven dry method		Ellert *et al*. 2007
Gravimetric content of air-dry soils	2015, 2016	Oven dry method		Ellert *et al*. 2007
Bulk density	2015, 2016	Standard core method		Hao *et al*. 2008
Particle analysis	2015, 2016	Modified pipette procedure		Indorante *et al*. 1990
Ammonium (NH_4^+)	2015, 2016	Potassium chloride (KCl) extraction	Colorimetry using a technicon auto analyzer	Maynard *et al*. 2008
Ammonia (NO_3^-)	2015, 2016	Potassium chloride (KCl) extraction	Colorimetry using a technicon auto analyzer	Maynard *et al*. 2008
pH	2015	1:2 ratio of soil to water		Hendershot *et al*. 2008
Electrical conductivity (EC)	2015	1:2 ratio of soil to water		Miller and Curtin 2008
Sodium (Na)	2015	Mehlich 3-Extractable Elements	Flame emission on Agilent's atomic absorption spectrometer AA240	Ziadi and Sen Tran 2008
Calcium (Ca)	2015	Mehlich 3-Extractable Elements	Atomic absorption on Agilent's atomic absorption spectrometer AA240	Ziadi and Sen Tran 2008

(Continued on next page)

Table D.1: Continued

Variable	Sites	Method	Analysis	Citation
Magnesium (Mg)	2015	Mehlich 3-Extractable Elements	Atomic absorption Agilent's atomic absorption spectrometer AA240	Ziadi and Sen Tran 2008
Potassium (K)	2015	Mehlich 3-Extractable Elements	Flame emission Agilent's atomic absorption spectrometer AA240	Ziadi and Sen Tran 2008
Phosphorous (P)	2015	Modified Kelowna extractions	Colorimetry on technicon auto analyzer	Ashworth and Mrazek 1995
Organic carbon (C)	2015	Pretreated with hydrochloric acid (HCl), combustion at 1100°C	LECO C632 carbon combustion analyzer	Skjemstad and Baldock 2008
Inorganic C	2015	Difference of total carbon and organic carbon		Skjemstad and Baldock 2008
Total C	2015, 2016	Combustion at 1100°C	LECO C632 carbon combustion analyzer	Skjemstad and Baldock 2008

Appendix E: Soil laboratory results

Table E.1: Soil laboratory analysis results for each study site. All soil samples were taken from 0-15 cm intervals.

Site	Bulk density	Litter depth	Field-moist gravimetric water content	Air-dried gravimetric water content	Sand	Silt	Clay	Organic C	NH_4^+	NO_3^-
Units	(g/cm^3)	(cm)	(%)	(%)	(%)	(%)	(%)	(mg C/ g of soil)	(mg N/kg of soil)	(mg N/kg of soil)
1*	1.41	0.83	8.28	1.97	47.76	22.67	29.56	36.68	7.52	3.22
2	1.58	0.42	5.21	1.90	63.70	16.84	19.46	38.66	9.15	2.39
3	1.39	1.83	9.01	1.28	60.57	22.62	16.81	36.06	7.43	2.08
4	1.47	1.67	12.52	2.53	44.72	25.32	29.96	24.98	6.90	4.28
5	1.35	0.08	7.59	2.18	47.15	25.07	27.79	34.54	7.90	1.28
6*	1.24	1.33	9.32	2.45	45.71	22.90	31.39	31.92	9.40	2.69
7	1.37	1.17	9.14	2.18	49.31	18.94	31.75	34.64	9.26	1.58
8	1.45	0.83	6.23	1.08	76.01	9.11	14.88	26.19	4.50	0.93
9	1.36	0.67	9.07	1.01	47.10	33.92	18.97	65.19	9.30	13.05
10*	1.40	1.00	14.44	2.74	39.09	25.46	35.45	27.23	8.69	7.83
11	1.23	1.67	10.83	2.45	49.19	23.11	27.70	42.32	12.43	6.44
12	1.20	2.33	16.97	2.18	50.15	22.47	27.39	42.40	10.09	6.70
13	1.62	1.83	8.49	0.60	83.14	5.31	11.55	22.68	8.53	3.27
14	1.53	0.00	7.87	1.70	48.28	22.55	29.18	26.87	5.66	2.10
15	1.34	1.33	25.60	2.18	41.38	30.51	28.11	31.43	6.70	3.87
16	1.34	1.00	8.00	1.01	50.43	31.24	18.33	34.29	6.41	2.54
17*	1.39	1.50	8.55	1.49	67.56	11.59	20.85	28.45	6.72	4.57
18	1.35	2.33	13.95	1.83	49.50	25.72	24.78	29.69	7.18	8.38
19	1.40	0.75	9.44	1.97	57.27	19.28	23.45	35.26	6.71	3.59
20	1.55	0.75	5.40	1.01	69.12	16.53	14.35	29.72	5.92	2.88
21	1.44	2.00	8.51	1.83	35.54	39.01	25.45	41.34	6.63	1.56
22	1.38	1.33	8.77	1.55	60.40	20.24	19.36	31.53	4.88	2.17

(Continued on next page)

Table E.1: Continued

Site	Bulk density	Litter depth	Field-moist gravimetric water content	Air-dried gravimetric water content	Sand	Silt	Clay	Organic C	NH_4^+	NO_3^-
Units	(g/cm^3)	(cm)	(%)	(%)	(%)	(%)	(%)	(mg C/ g of soil)	(mg N/kg of soil)	(mg N/kg of soil)
23	1.37	1.00	11.31	2.46	38.74	33.10	28.16	32.66	6.55	0.71
24	1.43	2.00	8.31	2.81	47.87	24.63	27.51	49.18	8.03	1.91
25	1.22	1.50	10.65	2.66	44.11	21.75	34.14	37.89	6.96	0.42
26	1.61	2.67	10.10	0.81	70.94	12.01	17.05	19.87	5.29	2.84
27	1.68	0.92	7.36	1.97	40.22	25.75	34.04	24.63	5.74	1.59
28*	1.35	0.83	8.14	1.83	30.22	42.67	27.12	42.25	8.20	1.55
29	1.78	0.58	3.72	0.74	83.58	5.10	11.32	18.50	4.25	2.08
30	1.49	1.08	10.83	1.90	46.25	21.94	31.81	32.64	7.26	1.49
31	1.88	0.42	3.43	0.74	78.08	7.08	14.85	17.91	4.21	1.71
32	1.22	0.33	24.17	2.67	50.11	19.04	30.86	40.65	5.87	4.49
33	1.19	0.42	23.95	2.11	55.25	16.16	28.59	32.22	4.94	4.95
34*	1.37	1.08	21.02	1.97	55.36	17.51	27.13	28.20	6.86	3.81
35	1.26	1.33	24.55	1.76	59.00	16.78	24.22	32.77	3.14	3.63
36	1.29	1.50	30.02	2.39	45.91	25.70	28.39	29.43	4.44	5.59
37	1.57	0.58	14.72	1.63	57.64	17.06	25.30	22.60	9.46	6.42
38*	1.32	2.17	18.30	2.05	52.79	22.19	25.02	37.19	9.10	6.57
39	1.19	1.33	23.52	2.97	46.92	22.07	31.01	38.91	9.85	6.45
40	1.47	0.25	12.96	2.18	55.22	19.28	25.50	32.16	3.49	1.31
41	1.33	1.50	16.99	2.11	46.14	24.69	29.17	31.94	4.80	3.97
42	1.23	1.67	24.11	2.89	51.26	20.61	28.13	32.50	4.13	6.37
43*	1.33	0.92	11.22	3.10	55.63	16.28	28.09	24.76	4.01	2.65
44	1.32	0.50	11.15	1.97	70.30	12.11	17.59	33.17	5.69	3.31
45	1.35	0.83	20.35	3.09	51.97	26.65	21.38	33.98	5.74	6.21
46*	1.44	0.83	18.45	3.16	37.16	35.66	27.17	31.03	9.91	4.59

***** indicates positive (present) Dakota skipper site

Appendix F: Landscape data

Table F.1: Landscape data for each study site. Introduced species are species that are non-native to Saskatchewan prairies according to the Conservation Data Centre (2017) ranking of SNA. Native species are plant species that naturally occur in the Saskatchewan native prairies.

Site	Elevation	Slope	Introduced	Native	Dominant land cover	Species richness
	(m)	(Degree)	(%)	(%)		
1*	554	45	85.50	41.33	Tame	22
2	551	12	26.83	109.83	Native	29
3	552	30	71.17	65.17	Tame	22
4	518	40	32.50	90.50	Native	27
5	516	45	25.00	100.17	Native	31
6*	554	40	69.83	57.50	Tame	28
7	438	30	60.17	78.17	Native	31
8	580	8	45.83	83.00	Native	22
9	554	35	21.50	112.00	Native	32
10*	578	20	50.33	80.67	Native	26
11	548	35	51.50	79.83	Native	29
12	559	48	44.50	89.67	Native	31
13	543	6	90.00	39.00	Tame	14
14	516	12	32.50	107.17	Native	28
15	577	20	52.67	83.67	Native	35
16	568	25	54.83	81.17	Native	28
17*	517	25	88.66	47.50	Tame	28
18	554	20	71.84	58.33	Tame	24
19	545	30	29.67	97.83	Native	30
20	518	15	76.67	57.17	Tame	28
21	543	17	46.17	86.33	Native	29
22	580	5	62.17	69.33	Native	25
23	552	40	35.00	103.83	Native	26
24	549	5	66.17	68.50	Native	31
25	548	35	68.67	67.17	Native	32
26	562	2	68.33	56.83	Tame	28
27	556	30	14.17	122.17	Native	18
28*	534	35	19.17	119.00	Native	26
29	549	5	60.50	73.67	Native	34
30	519	25	69.67	71.17	Tame	34
31	555	0	75.67	61.00	Tame	25
32	554	40	62.50	77.67	Native	29
33	549	40	32.50	98.17	Native	31
34*	571	35	51.67	77.67	Native	28
35	554	7	59.84	81.67	Native	27
36	552	20	43.83	91.67	Native	30
37	561	35	23.17	112.17	Native	34

(Continued on next page)

Table F.1: Continued

Site	Elevation	Slope	Introduced	Native	Dominate land cover	Species richness
	(m)	(Degree)	(%)	(%)		
38*	565	35	32.17	103.17	Native	29
39	563	25	50.34	83.67	Native	27
40	544	42	86.67	44.17	Tame	24
41	534	37	58.67	80.17	Native	39
42	552	20	47.67	92.67	Native	28
43*	545	48	34.17	107.83	Native	23
44	517	30	53.00	82.83	Native	26
45	537	35	46.66	91.17	Native	33
46*	554	35	49.83	92.67	Native	35

***** indicates positive (present) Dakota skipper site

Appendix G: Hesperiidae butterfly observations

Table G.1: Hesperiidae community observed in study sites during the 2015 and 2016 field seasons⁺.

Site	Survey	*Hesperia dacotae* (Skinner, 1911)	*Polites mystic* (Edwards, 1863)	*Thymelicus lineola* (Ochsenheimer, 1808)	*Polites peckius* (Kirby, 1937)	*Polites themistocles* (Latreille, 1824)
1*	1	2	3	8	0	0
1	2	0	0	0	0	0
2	1	0	2	1	0	0
2	2	0	0	0	0	0
3	1	0	3	0	0	1
3	2	0	1	0	0	0
4	1	0	0	0	0	0
4	2	0	0	0	0	0
5	1	0	8	2	1	1
5	2	0	0	0	0	0
6*	1	2	3	5	0	0
6	2	0	0	0	0	0
7	1	0	7	22	0	0
7	2	0	0	0	0	0
8	1	0	0	0	0	0
8	2	0	0	0	0	0
9	1	0	0	0	0	0
9	2	0	0	0	0	0
10	1	0	0	0	4	0
10*	2	1	0	0	0	0
11	1	0	4	0	0	0
11	2	0	0	0	0	0
12	1	0	3	0	0	0
12	2	0	0	0	0	0
13	1	0	19	0	1	0
13	2	0	1	0	0	0
14	1	0	0	0	0	0
14	2	0	0	0	0	0
15	1	0	0	0	2	0
15	2	0	2	0	0	0
16	1	0	2	1	0	0
16	2	0	0	0	0	0
17*	1	1	8	0	0	0
17	2	0	1	0	0	0
18	1	0	3	0	0	0
18	2	0	0	0	0	0

(Continued on next page)

Table G.1: Continued

Site	Survey	*Hesperia dacotae* (Skinner, 1911)	*Polites mystic* (Edwards, 1863)	*Thymelicus lineola* (Ochsenheimer, 1808)	*Polites peckius* (Kirby, 1937)	*Polites themistocles* (Latreille, 1824)
19	1	0	5	3	1	0
19	2	0	0	0	0	0
20	1	0	12	0	0	1
20	2	0	1	0	0	0
21	1	0	1	0	0	0
21	2	0	2	0	0	0
22	1	0	1	0	0	0
22	2	0	0	0	0	0
23	1	0	0	0	0	0
23	2	0	0	0	0	0
24	1	0	0	0	13	2
24	2	0	0	0	1	0
25	1	0	0	0	0	0
25	2	0	0	0	0	0
26	1	0	0	0	0	0
26	2	0	4	0	0	0
27	1	0	0	0	0	0
27	2	0	0	0	0	0
28*	1	1	6	1	0	0
28	2	0	1	0	0	0
29	1	0	0	0	0	0
29	2	0	0	0	0	0
30	1	0	0	0	0	0
30	2	0	0	0	0	0
31	1	0	0	0	0	0
31	2	0	0	0	0	0
32	1	0	3	0	1	0
32	2	0	0	0	0	0
33	1	0	0	0	0	0
33	2	0	0	0	0	0
34*	1	1	3	0	0	0
34	2	-	-	-	-	-
35	1	0	5	0	0	0
35	2	0	0	0	0	0
36	1	0	5	0	3	0
36	2	0	2	0	1	0
37	1	0	1	0	0	0
37	2	0	0	0	0	0
38*	1	1	5	0	4	0
38	2	-	-	-	-	-

(Continued on next page)

Table G.1: Continued

Site	Survey	*Hesperia dacotae* (Skinner, 1911)	*Polites mystic* (Edwards, 1863)	*Thymelicus lineola* (Ochsenheimer, 1808)	*Polites peckius* (Kirby, 1937)	*Polites themistocles* (Latreille, 1824)
39	1	0	2	0	1	0
39	2	0	2	0	1	0
40	1	0	0	1	1	0
40	2	0	0	0	1	0
41	1	0	2	0	0	1
41	2	0	0	0	0	0
42	1	0	24	0	3	3
42	2	0	0	0	0	0
43*	1	1	1	0	0	0
43	2	-	-	-	-	-
44	1	0	5	0	1	0
44	2	0	2	1	0	0
45	1	0	1	0	0	0
45	2	0	0	0	0	0
46*	1	3	0	0	0	0
46	2	-	-	-	-	-

***** indicates positive (present) Dakota skipper site

+ Hesperiidae butterfly observation location information not presented due to populations occurring on private lands.

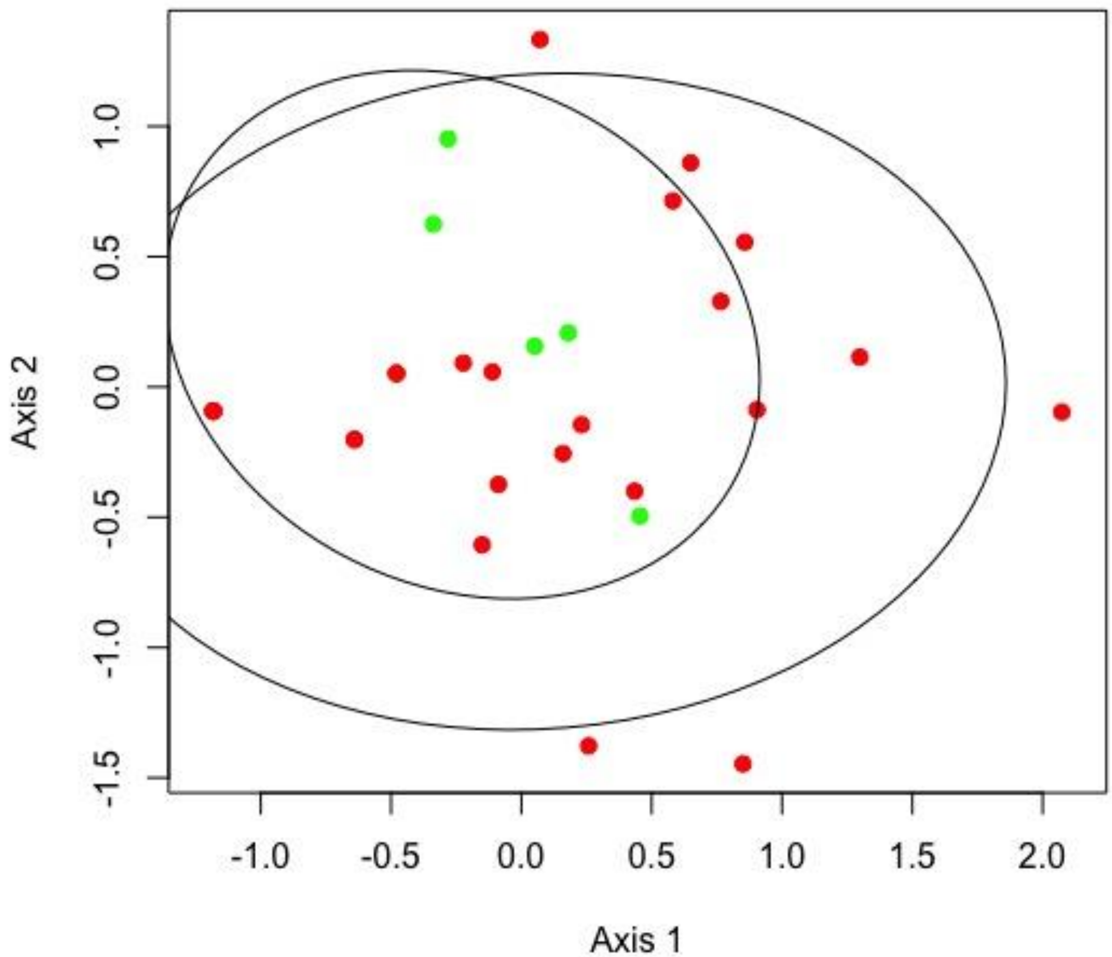

Figure G.1: Analysis of the composition of the skipper community associated with the Dakota skipper at each site through non-metric multidimensional scaling (NMDS). An ordination was performed using the first Hesperiidae or positive survey for each site. The Dakota skipper positive site (green dots) ellipse is superimposed over the Dakota skipper negative site (red dots) ellipse indicating that a subset of Hesperiidae species will be present with the Dakota skipper.

Appendix H: Microclimate data

Table H.1: Average maximum daily temperature (°C) for study sites 1 to 17, with the exception of site 4, 5, and 8 (not redeemed). Temperature monitor data reflects daily measurements for the time interval of 1 May 2016 to 19 September 2016.

Day	1*	2	3	6*	7	9	10*	11	12	13	14	15	16	17*
1	49.11	33.78	35.11	38.25	46.94	47.28	45.03	47.50	45.28	46.50	36.33	33.50	34.61	40.06
2	50.17	44.83	42.72	44.47	55.67	45.83	46.97	48.00	47.39	51.11	41.33	43.22	37.44	48.80
3	52.00	41.00	43.78	42.75	55.33	51.94	50.69	49.61	49.28	55.11	43.00	45.89	41.44	48.13
4	51.50	45.22	42.06	41.25	57.61	50.11	48.50	49.72	49.72	51.56	42.72	43.00	40.00	47.39
5	50.72	47.39	45.11	45.97	56.33	50.11	50.39	50.33	51.83	50.56	47.50	48.06	45.28	50.74
6	54.11	50.67	48.17	50.36	58.72	54.33	53.61	52.00	54.44	56.56	50.28	51.61	49.06	53.94
7	42.94	37.06	37.67	34.94	49.67	42.61	42.19	42.67	43.56	46.50	43.11	37.22	33.89	43.22
8	50.00	44.67	42.28	42.61	55.33	46.72	48.06	45.17	46.89	49.78	46.50	44.17	41.50	47.93
9	44.00	40.11	41.22	41.67	46.67	46.72	45.53	44.50	45.83	50.56	40.39	43.67	40.83	46.22
10	46.94	39.17	40.11	39.86	48.11	51.06	47.31	46.78	45.39	58.39	44.78	43.17	38.83	48.46
11	15.72	13.11	12.22	13.47	13.56	14.00	14.33	15.94	14.39	15.28	14.50	13.33	14.33	14.63
12	13.83	14.61	12.67	13.17	14.83	12.39	17.22	18.06	16.28	15.22	15.00	18.61	14.44	15.33
13	12.61	11.00	10.72	11.69	11.39	10.72	13.61	12.56	11.06	9.61	11.61	12.56	10.39	13.89
14	36.89	27.44	30.22	29.33	44.61	32.39	30.17	33.17	36.11	35.56	32.72	27.00	27.61	35.43
15	38.83	38.67	29.50	32.92	45.44	27.83	36.78	37.67	35.22	33.50	36.50	29.78	30.67	37.41
16	45.33	37.50	37.22	39.72	48.17	40.61	42.44	42.61	40.56	43.33	40.22	38.28	38.44	45.15
17	51.00	43.61	42.39	45.00	51.94	50.56	43.39	45.22	45.94	55.11	47.56	40.50	45.11	48.89
18	47.00	44.50	45.33	46.97	54.56	47.56	46.22	48.50	49.06	53.33	48.11	46.22	46.78	52.96
19	44.89	45.61	42.28	44.36	49.61	45.39	45.61	42.83	45.72	46.44	44.72	43.67	44.44	48.98
20	47.67	43.72	44.89	45.94	53.33	54.56	50.19	48.67	46.72	55.89	50.67	48.28	48.89	52.30
21	46.78	40.39	41.94	42.58	52.11	50.44	46.72	45.72	47.17	56.94	46.61	42.50	42.83	49.17
22	44.67	41.11	38.78	39.28	50.56	45.78	44.94	43.72	44.67	53.11	44.78	39.06	40.44	48.54
23	50.78	50.61	49.00	47.72	55.44	49.33	52.42	45.89	51.83	53.72	56.06	45.50	45.56	56.57
24	48.72	46.61	43.00	43.67	49.61	41.72	45.81	42.44	36.06	42.22	49.44	39.50	40.44	49.13
25	43.67	42.83	43.33	44.44	45.50	38.94	48.17	36.17	40.78	45.28	50.28	36.89	38.33	50.83
26	21.56	19.11	17.67	18.86	18.33	17.50	16.28	20.17	16.78	19.72	24.83	15.44	16.28	21.28

(Continued on next page)

Table H.1: Continued

Day	1*	2	3	6*	7	9	10*	11	12	13	14	15	16	17*
27	21.06	20.61	20.33	19.53	22.00	16.39	17.53	18.50	15.67	18.83	28.28	15.00	16.17	23.70
28	44.94	30.83	30.94	32.36	38.78	31.72	33.81	26.89	22.00	25.11	36.56	33.00	33.44	29.59
29	27.56	27.06	22.17	26.11	26.33	26.22	30.53	26.11	23.61	29.83	45.44	28.67	30.00	32.04
30	50.61	40.06	43.67	42.03	50.00	42.22	48.08	42.72	47.33	47.72	48.56	41.06	42.67	50.59
31	34.39	32.56	27.39	34.64	32.22	25.94	36.06	31.28	24.89	34.67	30.17	29.44	29.94	32.48
32	14.39	14.17	13.33	13.94	14.89	12.94	14.33	14.83	13.22	13.00	15.11	13.17	13.17	15.06
33	48.17	36.39	40.56	40.22	52.61	40.67	47.64	40.78	44.28	44.67	46.83	38.44	41.78	44.11
34	45.83	37.61	37.50	42.64	51.78	39.67	46.72	41.67	38.06	49.50	45.22	42.44	43.06	49.26
35	47.83	38.11	41.22	39.81	49.83	32.56	45.25	40.00	42.39	39.00	45.94	34.50	36.50	49.28
36	50.78	39.94	43.78	43.86	56.78	41.89	50.08	46.78	51.56	50.22	48.28	42.72	44.06	49.33
37	50.56	41.78	42.83	44.42	55.44	40.33	49.08	45.94	49.22	48.67	47.33	39.61	41.94	48.98
38	44.44	38.67	42.33	44.50	51.39	45.39	52.06	43.94	47.72	47.72	46.61	44.11	43.50	42.83
39	45.61	41.56	47.22	44.08	57.39	51.06	52.33	45.44	46.17	53.00	50.78	49.61	52.11	49.74
40	46.50	40.83	39.17	44.44	53.94	47.11	52.72	45.67	46.72	52.22	47.22	46.28	49.56	50.44
41	49.83	44.78	43.83	48.44	59.11	52.33	55.47	47.67	48.11	57.72	50.50	50.89	52.94	53.41
42	53.61	44.22	46.33	43.39	55.44	44.94	52.94	44.22	47.17	54.44	48.28	45.17	45.78	50.91
43	42.39	32.17	34.61	34.67	42.83	42.83	39.72	36.17	36.83	37.83	48.78	31.61	39.06	41.37
44	37.00	34.33	33.06	34.00	42.39	40.83	47.83	36.94	37.28	38.33	46.72	41.00	40.78	39.83
45	50.17	44.83	42.11	47.28	57.94	48.94	54.14	43.28	48.39	54.06	55.50	50.22	52.28	50.48
46	44.89	33.11	28.61	33.61	50.83	35.72	42.75	33.44	34.11	37.89	42.17	39.28	39.39	35.50
47	52.44	44.78	44.83	42.61	57.61	43.28	52.11	44.44	48.33	52.44	56.06	43.11	44.39	50.70
48	38.22	34.06	31.39	38.44	41.50	40.06	44.61	31.17	33.00	38.22	45.78	44.17	42.50	39.87
49	52.94	44.83	44.50	41.42	50.22	43.17	52.58	43.00	47.39	51.67	55.72	43.78	46.28	49.98
50	48.83	40.78	39.39	44.78	53.61	49.78	49.97	44.89	45.17	49.33	55.44	46.94	49.17	47.69
51	48.72	36.94	36.17	37.61	42.72	36.72	46.39	35.50	39.06	47.17	48.11	36.33	36.67	42.87
52	51.89	43.22	34.89	42.06	49.22	43.28	51.25	43.28	38.61	54.78	57.89	42.28	42.67	48.19
53	49.11	40.00	35.72	43.11	52.72	42.56	50.28	42.00	38.89	54.89	60.83	45.11	44.56	45.63
54	46.06	35.39	29.11	37.08	51.39	38.56	48.47	35.61	31.17	40.33	52.56	35.00	43.50	40.02
55	47.39	39.17	36.67	44.83	53.00	47.56	52.00	41.22	36.72	51.28	55.50	43.11	50.72	46.91

(Continued on next page)

Table H.1: Continued

Day	1*	2	3	6*	7	9	10*	11	12	13	14	15	16	17*
56	51.44	39.94	38.06	43.25	52.11	48.89	51.47	42.72	37.06	48.94	57.06	41.83	47.22	45.48
57	46.94	33.44	31.72	34.75	37.33	26.22	43.61	30.44	31.94	40.89	44.67	33.83	30.11	38.61
58	32.22	29.83	23.61	25.56	28.44	30.28	37.83	23.89	23.67	28.50	31.06	29.39	29.78	32.70
59	34.78	29.78	25.78	31.17	34.39	33.94	40.08	29.22	28.72	35.61	37.33	39.89	35.22	34.54
60	48.94	42.94	40.67	42.81	51.94	44.50	53.78	41.28	35.39	49.28	57.78	47.28	48.67	44.72
61	54.44	45.50	40.72	44.28	55.33	43.17	55.33	45.44	36.89	53.22	59.72	45.67	47.56	46.76
62	50.61	38.78	36.50	41.17	51.28	45.78	53.39	41.00	33.44	50.56	52.83	42.00	49.33	44.94
63	45.39	35.61	32.44	37.58	45.50	42.72	46.03	36.61	32.83	42.33	49.50	41.44	42.83	41.28
64	40.17	34.33	29.22	35.69	44.67	39.39	45.44	37.11	32.33	46.06	45.22	42.44	41.11	37.30
65	31.94	30.44	24.17	29.47	33.72	34.28	37.94	31.22	28.61	38.28	45.06	40.50	38.44	32.80
66	51.78	44.89	35.17	40.03	50.67	43.39	51.14	40.78	34.22	48.22	50.94	40.94	44.06	44.19
67	46.11	39.17	36.50	35.50	39.67	42.50	49.83	37.39	32.44	51.22	52.72	43.22	41.33	42.63
68	50.39	45.06	39.50	44.19	54.06	45.22	50.58	43.94	34.39	55.44	58.00	48.39	50.33	45.85
69	33.61	29.50	27.50	26.64	39.94	27.78	34.39	24.17	22.06	30.50	41.22	32.89	27.67	27.93
70	47.22	39.44	34.78	40.61	50.11	43.22	48.69	39.94	34.33	53.22	54.61	45.72	47.17	41.81
71	44.44	37.28	30.67	39.14	46.39	40.39	47.47	34.33	30.11	43.06	51.39	45.39	46.11	39.80
72	48.39	40.61	36.06	39.64	47.33	37.44	43.36	38.56	32.28	44.44	48.94	42.06	41.72	43.70
73	47.83	38.17	31.00	33.83	42.00	36.83	44.03	33.94	30.83	46.06	47.56	41.00	40.72	41.78
74	38.33	29.17	28.72	27.36	30.22	33.94	35.83	27.83	27.50	36.28	40.72	33.56	32.67	33.44
75	35.17	25.83	22.67	28.44	29.28	30.22	37.92	30.11	25.72	34.06	35.83	32.78	28.67	25.87
76	43.50	33.28	30.94	31.50	41.83	32.17	48.08	36.00	29.28	45.78	46.22	43.78	40.61	37.33
77	46.39	42.00	39.39	33.58	50.00	36.61	47.03	32.72	28.50	50.56	54.72	45.50	43.44	42.89
78	35.33	31.94	27.50	28.86	33.56	37.67	45.50	33.17	26.89	39.61	49.22	45.61	44.39	32.65
79	48.17	39.22	36.83	37.42	44.94	35.61	47.33	42.28	33.11	48.06	54.61	40.44	41.72	45.09
80	46.06	42.61	38.33	39.33	47.78	41.33	50.78	40.78	35.17	46.94	52.39	45.39	46.28	45.28
81	53.83	44.56	40.06	40.14	53.50	44.61	52.39	44.39	37.00	56.22	60.33	48.44	46.94	48.81
82	54.11	46.39	41.72	41.50	51.83	42.44	52.39	44.22	39.22	52.94	58.72	48.67	48.28	49.13
83	53.83	47.17	42.44	40.17	50.56	41.89	50.50	42.67	40.17	52.44	57.17	46.39	42.61	49.54
84	50.89	43.17	38.67	38.89	48.67	43.72	47.72	42.17	34.61	48.39	55.61	46.00	41.39	46.65

(Continued on next page)

Table H.1: Continued

Day	1*	2	3	6*	7	9	10*	11	12	13	14	15	16	17*
85	48.94	38.17	30.89	35.47	41.00	39.44	48.58	32.61	34.94	45.33	48.89	42.56	35.17	40.41
86	51.44	44.39	38.22	36.03	43.89	42.11	49.89	38.50	36.83	47.11	52.28	43.56	38.67	46.46
87	52.17	46.94	42.44	40.92	49.06	46.89	52.61	42.89	37.94	56.22	59.61	50.61	47.11	50.52
88	47.83	45.83	37.61	36.03	42.22	33.67	40.03	36.44	30.17	44.22	54.89	40.39	35.72	45.13
89	48.83	47.33	38.61	39.17	45.89	31.33	37.06	33.17	32.44	41.22	54.39	40.56	33.61	49.26
90	50.89	48.50	41.22	40.17	49.50	42.89	51.11	39.44	36.83	45.06	59.06	46.39	41.89	50.07
91	47.00	45.78	40.94	39.22	44.22	42.22	50.78	37.61	35.67	41.11	60.44	49.00	39.06	48.20
92	53.33	51.89	42.06	46.39	53.22	44.83	53.39	44.22	38.56	45.61	60.22	48.06	45.06	50.87
93	51.06	46.22	38.50	43.83	48.28	42.61	49.33	37.44	35.06	42.33	53.50	45.89	39.61	45.56
94	47.06	43.00	31.61	39.28	45.39	43.50	52.94	33.44	32.50	39.17	55.94	45.22	38.33	41.46
95	50.44	46.33	37.17	47.31	47.17	44.50	55.94	40.00	39.67	43.17	59.61	48.06	39.22	47.33
96	46.56	46.78	36.61	46.69	46.11	43.89	53.33	41.33	41.22	43.06	55.72	48.39	41.61	45.81
97	46.61	43.72	33.11	45.17	44.56	40.89	52.06	38.61	35.06	40.83	53.50	38.39	34.50	43.20
98	45.78	47.50	36.44	48.17	49.44	44.72	56.72	39.89	37.06	44.72	61.78	48.78	39.89	48.28
99	49.50	46.00	37.94	47.03	49.67	49.94	54.17	42.72	38.61	45.06	56.28	45.06	40.56	48.78
100	39.94	35.17	28.17	45.39	42.00	39.56	49.44	35.56	33.56	37.83	47.11	42.33	38.17	36.61
101	46.83	39.17	34.83	50.86	46.33	41.56	55.17	42.06	38.44	41.78	55.94	45.11	35.28	45.35
102	45.78	36.94	30.78	45.89	42.78	44.17	51.83	41.00	32.44	39.22	51.44	37.22	35.56	39.65
103	41.06	35.06	32.33	39.83	39.56	44.50	50.69	36.67	31.39	37.11	54.39	40.44	35.33	38.87
104	44.94	39.56	33.67	49.94	40.56	36.94	46.56	36.28	34.17	37.06	53.61	36.94	29.06	40.96
105	43.17	39.17	30.56	46.42	37.89	42.39	51.44	36.22	34.61	42.89	47.78	40.44	32.22	38.63
106	44.61	40.94	32.39	44.94	41.00	41.89	53.81	39.89	34.67	38.56	56.17	42.44	34.17	39.94
107	53.22	45.94	37.94	50.86	46.94	45.22	54.78	44.22	38.44	45.00	61.94	48.44	36.11	46.00
108	53.72	47.33	40.67	52.36	50.11	46.94	55.31	45.22	39.50	45.61	63.67	45.89	34.61	46.89
109	54.50	48.67	39.67	51.67	44.11	47.72	57.17	41.94	41.44	45.22	62.17	47.56	35.33	47.69
110	57.89	51.72	42.39	55.31	52.89	49.22	58.47	46.06	43.17	57.61	66.33	50.11	35.17	51.09
111	39.50	35.78	27.72	35.92	32.89	33.17	45.97	29.72	31.28	38.50	46.56	33.33	26.33	36.00
112	38.22	36.83	27.33	36.58	34.22	26.11	40.39	29.83	26.56	32.00	42.78	30.56	26.56	33.48
113	45.11	42.61	29.50	41.19	40.83	35.67	55.08	33.00	32.50	45.28	54.00	36.22	28.44	37.96

(Continued on next page)

Table H.1: Continued

Day	1*	2	3	6*	7	9	10*	11	12	13	14	15	16	17*
114	51.22	47.89	36.50	49.75	45.67	40.06	57.78	39.22	38.39	49.00	55.33	43.83	33.83	44.54
115	53.83	51.44	41.17	55.44	52.33	47.28	60.61	44.67	41.00	49.50	58.33	49.33	36.17	48.59
116	35.39	38.89	28.44	30.81	31.56	35.39	44.83	27.61	31.61	38.94	42.72	38.00	29.33	34.44
117	31.11	30.67	25.39	24.42	25.78	26.06	37.22	26.89	25.28	29.89	40.11	27.67	20.39	32.78
118	48.78	45.28	32.11	45.94	45.17	40.06	54.44	37.00	35.50	44.94	54.61	41.33	30.39	42.41
119	46.78	40.00	34.78	41.53	41.28	38.61	50.94	34.83	32.33	42.22	49.11	39.44	30.83	44.80
120	47.89	38.78	28.78	49.28	46.17	42.00	52.22	34.56	33.44	45.22	52.67	42.06	28.44	37.48
121	51.17	40.39	35.06	48.53	46.83	39.33	51.36	40.44	34.56	44.22	55.11	44.56	30.22	41.89
122	51.00	43.50	30.72	47.19	45.89	39.50	53.53	36.67	34.50	45.33	56.50	38.78	27.11	41.00
123	47.17	41.56	32.72	44.53	44.67	40.28	52.31	38.72	38.11	43.17	51.56	39.89	30.67	41.13
124	40.17	31.00	23.72	32.36	36.28	39.67	44.78	32.89	32.67	36.67	39.67	35.28	29.44	33.31
125	43.11	40.00	33.94	41.22	43.00	37.83	47.33	35.94	37.22	38.78	48.17	40.78	33.78	40.67
126	37.78	33.72	31.06	38.42	35.06	38.33	41.47	32.44	35.61	36.56	40.11	41.89	33.50	35.70
127	29.33	31.22	22.89	26.47	30.44	26.44	32.06	24.28	22.44	27.83	38.33	28.28	23.89	27.83
128	32.11	32.56	25.83	28.31	27.61	24.44	36.97	24.50	22.56	26.17	32.50	26.39	21.33	29.61
129	21.72	21.11	17.00	20.64	20.22	16.28	20.22	20.72	17.44	20.67	23.00	19.11	17.94	19.19
130	34.28	31.17	22.50	31.75	33.22	28.39	44.39	24.22	26.28	31.00	42.11	28.89	23.56	28.83
131	19.67	18.33	16.22	19.17	19.33	19.44	25.94	18.83	18.06	20.39	20.83	20.56	19.56	18.44
132	23.78	22.17	18.28	22.75	23.50	22.89	30.53	20.89	20.33	25.06	29.83	25.78	21.83	23.96
133	29.89	28.78	21.83	28.33	32.17	25.78	44.08	24.17	24.61	27.94	39.83	26.83	20.28	28.13
134	32.33	27.39	20.89	29.39	31.11	23.94	37.22	24.78	24.17	26.89	40.00	29.44	23.06	28.87
135	38.94	31.33	24.61	33.89	33.56	25.56	42.31	30.94	28.78	31.39	39.33	31.28	23.22	29.80
136	27.50	24.06	17.72	23.08	27.89	17.39	27.81	21.17	19.00	20.72	33.61	20.28	15.56	23.37
137	36.17	27.06	18.72	33.33	33.17	22.78	41.36	24.56	25.06	27.22	40.06	22.39	15.72	26.74
138	35.56	29.00	22.72	34.58	35.83	27.67	43.08	28.06	28.61	31.67	38.94	28.11	21.44	29.02
139	40.33	30.56	23.78	36.06	37.11	27.22	41.64	31.67	28.22	34.33	37.33	30.61	23.39	29.37
140	29.83	26.94	19.28	30.86	28.94	28.94	40.50	24.28	25.00	29.83	30.33	26.44	20.28	23.87
141	23.22	23.11	24.50	34.31	39.67	30.94	46.61	31.50	32.50	33.06	24.17	32.00	24.89	24.31
142	22.44	21.50	21.39	21.19	22.00	22.39	25.03	21.94	22.00	21.78	21.89	21.44	24.56	21.83

* indicates positive (present) Dakota skipper site

Table H.2: Average maximum daily temperature (°C) for study sites 18 to 31. Temperature monitor data reflects daily measurements for the time interval of 1 May 2016 to 19 September 2016.

Day	18	19	20	21	22	23	24	25	26	27	28*	29	30	31
1	39.89	38.33	31.56	38.89	27.83	49.72	40.44	43.89	35.39	49.56	46.97	37.83	54.06	40.17
2	45.06	43.78	41.06	42.28	34.33	50.50	49.61	51.22	40.94	51.44	51.14	45.22	53.33	47.44
3	44.89	42.39	39.28	42.39	34.11	54.22	48.50	52.22	43.89	55.28	52.08	47.61	58.28	47.44
4	46.17	41.33	37.67	45.56	35.28	54.83	48.78	53.28	46.39	57.83	54.08	48.39	60.17	49.17
5	49.00	45.89	45.83	42.67	37.72	52.78	51.39	52.11	38.83	58.22	54.06	47.72	56.22	53.06
6	52.94	49.22	49.00	47.89	40.11	56.61	53.03	55.22	45.56	60.94	56.42	51.06	59.67	56.17
7	38.00	36.44	32.28	36.00	30.39	45.67	40.42	47.72	30.22	49.94	47.53	44.39	48.22	42.78
8	47.56	42.00	44.06	42.33	35.50	50.33	48.39	50.17	37.00	56.39	51.81	47.72	52.72	50.56
9	46.06	42.06	40.94	39.44	32.67	48.72	45.11	46.00	34.67	52.06	49.64	41.94	49.78	45.33
10	46.06	42.22	42.33	39.50	34.17	52.33	42.50	48.22	33.33	43.67	45.86	44.11	41.28	44.89
11	13.33	14.89	13.78	14.44	11.61	15.44	14.33	14.61	13.33	14.22	16.47	14.17	13.72	14.94
12	16.61	15.89	15.11	14.89	10.50	17.06	16.50	21.56	12.83	16.44	16.25	15.22	13.67	16.83
13	9.89	12.67	11.00	11.39	6.94	14.33	12.08	15.56	7.22	17.56	13.58	10.44	11.72	17.22
14	33.00	26.72	25.44	24.50	22.39	37.83	34.39	43.89	18.22	40.78	38.53	34.67	39.67	34.83
15	33.61	35.78	28.56	31.61	21.72	37.83	34.31	41.17	31.33	41.44	43.06	35.89	35.50	39.28
16	45.17	36.39	34.44	34.28	33.39	45.06	43.64	48.94	32.44	48.17	46.69	41.11	46.17	46.22
17	46.94	44.83	39.78	41.11	37.72	51.39	47.22	49.89	40.39	52.44	50.42	47.44	56.56	44.89
18	52.28	48.11	44.61	40.11	36.17	52.50	50.03	51.00	40.00	53.83	51.17	45.44	56.11	48.67
19	46.72	45.39	43.83	35.78	33.67	47.39	46.67	44.89	37.94	50.56	48.94	43.11	49.78	48.11
20	51.72	46.67	47.78	43.61	41.11	53.39	50.89	52.33	39.67	56.28	53.06	49.17	52.83	52.94
21	50.50	45.67	45.00	42.89	38.72	52.22	46.72	47.61	37.72	54.44	49.17	45.22	48.89	48.67
22	50.00	44.17	45.94	41.06	35.28	48.83	44.39	44.67	36.94	51.17	47.69	43.06	41.78	44.67
23	53.44	48.22	50.11	39.00	43.00	52.72	51.50	52.22	38.94	60.56	54.78	52.44	53.39	56.61
24	42.72	48.72	47.22	34.22	32.50	49.39	44.58	42.00	38.72	47.78	49.53	45.11	40.44	46.94
25	41.06	48.89	42.56	33.94	29.50	45.17	47.69	40.22	35.22	49.89	51.03	42.00	43.33	47.28
26	17.72	21.06	21.72	16.17	13.94	17.06	16.31	17.11	14.61	18.39	17.97	18.50	16.67	18.11
27	16.39	24.78	23.33	17.22	14.33	15.83	15.75	16.56	15.28	15.39	16.92	19.22	17.83	16.06
28	28.22	27.89	31.00	23.94	21.17	28.28	25.50	29.72	20.67	25.78	36.14	26.44	27.61	28.89

(Continued on next page)

Table H.2: Continued

Day	18	19	20	21	22	23	24	25	26	27	28*	29	30	31
29	25.50	31.06	32.17	24.00	19.61	26.56	29.19	30.11	21.11	22.56	25.06	29.00	20.78	25.39
30	48.50	43.61	43.28	36.22	37.89	48.72	47.56	47.44	36.22	47.50	50.50	50.17	42.33	45.56
31	28.17	28.44	33.39	25.67	23.72	29.72	32.53	37.83	30.78	26.50	30.47	32.56	28.11	31.72
32	13.39	13.78	14.94	13.11	12.89	14.72	15.28	15.00	13.06	14.00	15.31	14.44	14.44	13.50
33	45.00	37.33	37.17	35.28	33.50	46.11	46.81	47.39	32.78	45.17	47.08	46.67	43.67	36.72
34	50.78	43.17	43.28	37.00	37.56	48.56	47.03	43.50	39.83	40.50	47.44	42.83	40.33	37.89
35	47.17	35.89	39.78	37.06	36.50	46.44	42.89	47.78	36.78	45.50	47.86	45.78	48.89	39.78
36	50.78	39.06	39.44	40.11	44.61	53.89	50.58	51.28	42.33	48.94	50.28	51.17	53.11	40.50
37	49.06	39.78	40.94	39.33	45.50	52.33	48.69	49.72	41.72	46.28	50.69	50.50	56.78	44.11
38	46.94	32.67	40.33	39.28	45.06	51.22	51.00	48.67	42.00	48.33	51.36	44.72	49.00	47.06
39	53.44	45.50	49.83	40.56	46.17	52.11	50.86	48.39	44.56	48.17	51.03	47.61	45.61	51.00
40	52.44	42.28	45.11	37.28	43.61	52.61	49.28	45.56	40.00	51.00	50.42	47.83	46.89	52.67
41	58.06	47.11	50.39	41.83	48.67	55.44	53.14	51.11	45.67	53.94	55.69	51.61	50.11	58.67
42	52.28	42.72	43.89	39.72	42.72	55.06	50.06	51.94	38.89	51.61	53.92	53.72	51.44	57.06
43	42.11	38.44	38.50	31.89	28.94	37.11	39.03	35.39	29.89	38.39	43.36	39.00	29.56	34.72
44	38.94	32.50	39.44	27.33	28.78	43.44	43.86	45.83	26.72	42.78	52.28	45.39	31.06	42.50
45	58.22	45.39	50.11	38.06	43.50	55.67	52.92	50.06	44.11	50.11	56.50	50.50	44.89	50.06
46	45.39	35.11	39.94	30.56	29.33	39.00	40.78	36.22	28.17	36.00	41.75	44.33	32.94	37.00
47	54.61	40.89	46.83	38.06	29.56	51.39	47.61	50.67	43.94	45.39	54.31	52.33	46.67	47.44
48	42.50	34.94	45.00	27.72	23.78	32.44	38.31	37.44	30.72	31.72	41.89	35.33	29.39	39.61
49	55.89	40.94	45.83	34.11	30.89	54.50	47.78	49.22	41.11	47.00	56.33	48.06	46.56	47.28
50	56.44	42.06	48.06	37.61	32.72	50.50	48.25	45.33	40.89	46.22	54.47	46.56	42.89	46.33
51	47.22	37.00	40.00	31.17	23.72	52.06	40.31	45.72	30.94	40.78	51.08	43.22	43.39	38.89
52	54.61	38.39	43.17	32.22	31.00	54.22	45.67	49.22	40.00	45.17	54.75	47.28	50.00	49.17
53	55.67	44.00	47.22	39.33	35.28	52.89	46.14	49.28	44.61	43.67	54.06	49.11	43.00	48.83
54	44.78	33.50	43.83	33.28	22.44	46.44	43.00	50.94	31.22	39.17	48.94	44.33	34.50	34.11
55	58.11	38.61	48.39	33.94	38.78	52.89	48.53	53.89	41.11	44.89	55.47	45.44	40.33	38.50
56	58.72	40.50	48.83	37.67	39.72	51.50	46.53	52.11	42.17	45.72	56.92	48.06	41.44	39.83
57	45.83	35.11	40.33	27.00	27.94	45.78	35.47	41.89	32.61	34.61	44.39	38.78	37.00	24.17

(Continued on next page)

Table H.2: Continued

Day	18	19	20	21	22	23	24	25	26	27	28*	29	30	31
58	29.33	28.61	33.06	24.28	24.00	36.11	35.47	35.33	24.83	33.11	35.44	28.94	24.78	23.44
59	33.39	34.50	42.89	27.50	28.50	32.50	34.25	33.78	27.94	35.61	38.64	38.33	26.67	27.39
60	55.33	40.61	52.67	38.67	39.28	53.17	46.78	54.72	41.33	40.61	51.08	48.22	42.22	33.06
61	57.94	41.33	51.89	37.50	39.78	55.28	49.31	55.33	45.67	44.06	53.86	52.33	49.83	34.56
62	57.17	40.78	48.00	35.61	39.00	53.00	48.86	51.67	44.61	44.06	54.00	47.83	45.44	32.72
63	52.44	32.39	45.17	27.28	27.83	44.33	40.58	46.50	34.83	39.56	49.47	39.28	35.56	28.50
64	52.39	34.61	43.72	34.44	28.33	50.33	42.22	46.33	43.39	39.22	46.14	45.89	34.28	31.83
65	37.50	32.39	37.72	27.44	27.17	32.00	33.17	39.78	27.06	31.50	35.22	39.83	26.56	29.83
66	51.33	34.22	48.72	34.28	36.83	53.89	44.67	52.61	39.89	47.33	53.25	52.22	45.11	36.00
67	57.83	35.83	49.44	33.61	31.28	53.67	40.94	50.06	40.50	45.50	52.42	50.94	37.22	36.39
68	58.83	37.11	57.28	36.61	37.44	52.78	46.64	53.11	45.61	45.78	53.36	55.50	43.22	36.39
69	27.39	32.67	36.39	26.83	21.67	26.33	29.53	28.28	24.67	27.67	32.11	36.39	31.61	30.61
70	50.17	38.11	53.67	36.00	32.39	47.39	44.22	50.33	41.56	41.61	51.03	48.11	40.56	39.56
71	48.33	34.72	52.39	33.11	29.17	47.22	40.89	47.94	34.39	41.06	49.67	46.33	32.39	39.33
72	50.00	37.83	49.67	35.22	28.67	41.50	35.78	48.50	38.89	35.67	46.00	50.17	35.61	39.56
73	50.78	35.33	48.67	30.11	27.22	51.11	36.86	45.33	34.89	32.83	49.17	45.61	38.00	28.50
74	33.44	27.28	38.89	23.22	21.17	39.72	31.25	42.39	23.33	30.17	39.58	39.89	30.06	24.94
75	40.44	26.78	29.89	24.39	21.78	31.56	27.64	41.61	23.39	28.67	35.67	41.06	27.78	24.22
76	47.44	30.67	48.17	30.22	29.44	40.50	37.33	46.33	33.83	33.89	40.08	49.39	35.39	27.67
77	50.28	35.33	55.06	35.39	33.39	49.00	39.58	50.56	35.00	33.72	42.92	50.89	42.56	27.94
78	38.28	32.94	48.39	31.22	28.28	42.61	36.39	40.33	34.56	32.50	49.22	40.22	28.94	28.33
79	58.11	34.00	48.17	28.50	28.28	48.39	37.61	50.22	31.83	39.00	47.33	46.61	44.17	31.17
80	52.94	39.44	54.72	34.17	32.94	49.72	41.56	51.56	39.11	37.56	52.19	48.28	39.39	31.06
81	58.22	39.56	57.61	37.67	38.56	54.39	44.28	56.83	45.33	44.22	54.53	54.22	49.06	34.00
82	59.17	41.00	59.72	39.44	40.11	53.28	44.78	54.61	44.17	44.83	52.25	52.89	44.33	34.89
83	59.83	38.28	54.94	34.89	37.17	53.67	42.22	54.28	43.11	43.33	53.00	51.39	48.89	34.06
84	53.06	38.39	56.22	34.28	36.11	47.22	37.94	52.11	39.00	39.61	52.31	50.33	40.67	31.83
85	48.50	33.06	51.33	29.06	28.50	51.28	35.33	52.72	32.72	42.44	51.75	44.06	35.39	32.56
86	53.06	33.28	49.17	30.22	33.00	52.33	37.33	53.67	36.22	43.44	51.86	46.89	44.56	33.44

(Continued on next page)

Table H.2: Continued

Day	18	19	20	21	22	23	24	25	26	27	28*	29	30	31
87	58.06	40.00	58.50	38.28	39.56	55.56	42.36	56.11	46.06	44.61	55.39	52.17	46.83	40.61
88	42.00	36.00	49.44	30.56	29.33	36.56	33.92	43.39	33.50	34.61	38.22	44.17	40.78	32.78
89	50.89	41.56	57.06	35.22	33.33	41.83	41.64	49.94	39.28	34.39	40.14	46.11	43.67	34.11
90	53.94	44.22	58.89	35.33	36.94	54.39	45.75	55.67	43.39	43.17	53.25	47.06	44.44	40.22
91	49.56	45.17	54.72	35.50	36.44	56.72	45.81	55.44	41.61	42.89	52.11	44.39	39.00	41.33
92	52.00	44.94	60.61	38.61	39.17	56.83	51.58	58.22	43.61	43.33	52.33	53.22	47.56	42.28
93	53.67	41.00	55.39	36.67	35.89	50.17	38.72	52.39	40.00	43.94	53.36	48.50	44.39	42.28
94	50.44	35.94	55.17	33.94	33.06	51.06	43.19	54.11	36.28	46.28	51.92	47.83	36.44	47.44
95	57.72	39.00	53.56	33.61	38.44	53.67	47.67	57.72	43.17	49.28	54.89	47.89	42.72	49.00
96	52.44	40.94	53.17	34.44	36.56	49.56	39.78	56.00	40.39	45.89	52.81	45.28	42.72	48.11
97	44.89	32.00	46.83	28.06	29.72	50.83	37.89	55.44	33.06	44.33	49.72	44.67	40.44	40.17
98	50.89	38.50	51.39	34.00	38.56	48.11	44.56	58.33	42.17	46.17	52.28	55.61	40.61	44.56
99	57.17	40.56	56.00	36.17	36.06	52.11	43.42	52.22	44.17	45.78	56.69	54.61	45.00	48.67
100	45.61	33.67	47.78	30.56	30.94	44.22	38.19	53.11	33.89	44.44	49.31	47.67	32.33	45.17
101	57.94	40.94	52.28	34.50	37.89	55.06	42.64	56.56	42.44	46.39	53.78	52.44	44.39	51.56
102	52.94	33.17	48.83	33.17	33.83	48.56	38.11	52.06	42.00	42.67	51.69	51.17	42.00	45.72
103	45.78	37.00	47.22	34.22	32.72	46.06	39.31	50.06	38.06	42.72	49.61	51.50	35.72	45.00
104	54.39	37.17	47.78	31.78	33.78	45.28	39.58	57.72	36.94	41.83	50.17	47.28	38.39	45.50
105	51.33	37.11	45.50	31.72	32.94	44.22	41.22	55.78	36.50	45.50	49.11	51.17	40.83	44.67
106	50.89	34.11	47.28	35.28	33.72	51.83	40.28	58.78	35.28	47.00	50.44	54.39	44.11	49.33
107	57.72	42.39	53.39	36.89	40.78	52.11	48.58	60.22	44.72	50.22	55.25	59.50	44.83	54.44
108	56.00	44.83	54.61	38.22	39.50	52.89	47.44	61.72	43.89	48.33	55.58	60.28	48.11	52.67
109	58.22	39.33	54.11	37.44	39.33	51.28	48.06	60.44	43.83	47.72	54.69	59.22	49.50	53.22
110	58.94	43.89	58.28	38.78	43.17	55.56	49.53	61.22	44.61	44.83	57.17	61.94	50.39	53.94
111	34.61	31.56	40.33	28.56	21.72	38.39	35.06	50.94	30.44	41.56	44.25	41.17	29.89	35.22
112	38.78	26.67	44.17	24.61	22.44	36.11	33.69	46.44	27.00	32.44	32.89	40.06	33.28	32.56
113	48.56	29.22	48.17	29.89	29.72	44.94	34.44	56.72	32.89	42.56	50.53	50.28	39.83	43.94
114	55.00	36.28	53.67	32.56	35.78	51.11	40.56	59.39	41.61	45.89	55.11	49.67	45.00	49.00
115	57.83	40.56	58.50	38.17	41.67	56.11	42.72	61.89	47.61	48.78	58.31	56.50	48.17	52.39

(Continued on next page)

Table H.2: Continued

Day	18	19	20	21	22	23	24	25	26	27	28*	29	30	31
116	29.72	30.78	43.50	28.78	28.56	36.50	33.17	47.44	28.00	41.94	44.33	46.39	24.56	38.33
117	25.72	27.61	36.94	21.33	21.11	27.33	24.64	37.39	21.11	25.61	32.00	36.78	23.06	27.50
118	50.44	29.39	50.39	30.06	33.39	48.00	35.44	58.00	31.72	45.39	52.75	52.72	42.89	45.89
119	41.78	31.06	48.39	29.56	31.61	41.39	33.64	56.44	31.33	44.56	51.17	49.39	33.61	43.44
120	48.00	31.22	51.00	31.11	35.61	47.83	35.78	58.67	36.67	46.67	54.92	52.83	39.61	46.61
121	52.39	36.78	52.28	33.22	34.44	45.83	37.97	57.61	37.50	44.06	46.75	53.39	42.94	47.67
122	51.61	31.33	49.33	29.67	34.39	46.22	36.53	58.22	34.22	44.61	52.83	54.39	40.67	43.78
123	48.50	35.61	49.22	32.33	32.72	45.44	38.28	55.78	35.00	43.61	49.92	51.78	35.00	43.67
124	42.56	28.28	38.50	30.61	28.89	38.39	34.94	45.06	29.44	38.72	47.19	43.11	29.83	38.56
125	49.00	34.78	46.39	34.17	33.33	44.00	38.72	53.00	34.17	37.83	48.47	44.44	34.33	44.11
126	34.06	34.39	41.83	31.44	30.00	36.11	35.39	53.67	32.06	38.39	42.11	40.22	28.83	37.00
127	27.39	27.50	39.06	24.28	20.89	24.61	26.39	35.06	20.28	31.33	31.08	41.39	23.00	27.17
128	31.50	25.83	39.50	23.89	20.83	33.67	29.36	41.50	22.28	30.11	33.81	31.17	23.33	32.28
129	19.56	20.11	23.94	17.17	16.06	18.44	19.17	22.22	15.83	17.89	19.67	23.00	17.83	17.94
130	34.78	26.00	46.89	22.61	24.44	38.72	34.17	57.28	22.44	32.83	38.97	42.94	25.39	31.39
131	17.83	17.72	24.50	18.06	17.17	18.72	20.58	27.33	16.17	21.00	23.47	25.78	16.67	20.50
132	21.50	22.17	33.61	19.06	18.11	22.83	27.53	33.78	17.28	26.06	29.75	33.61	17.72	23.78
133	34.56	23.89	39.56	21.06	22.28	36.11	28.33	53.17	20.22	33.50	35.58	36.94	21.17	29.56
134	32.28	26.17	38.00	20.94	21.44	29.78	28.81	46.89	22.83	27.44	35.86	39.00	25.67	29.39
135	40.00	28.94	41.78	23.72	27.50	35.72	31.92	53.67	28.44	27.50	32.17	41.83	27.67	33.78
136	29.67	19.11	29.61	16.83	14.83	25.61	20.67	37.78	15.89	21.72	24.83	34.83	20.44	23.11
137	38.22	20.44	37.44	18.28	22.50	36.50	27.53	50.33	22.28	29.33	38.47	41.39	28.83	30.61
138	41.00	25.06	39.50	22.56	23.28	37.89	30.11	50.94	24.44	31.61	40.78	38.83	28.89	35.00
139	40.94	24.78	40.39	26.44	29.83	38.39	30.75	50.22	26.11	27.28	33.75	43.33	31.39	30.44
140	36.17	23.28	35.78	22.22	25.06	34.06	31.14	46.33	23.78	32.11	39.72	36.78	25.22	31.67
141	45.33	23.83	36.56	26.56	34.72	42.39	32.42	56.00	28.33	33.06	42.86	42.56	30.28	39.61
142	21.11	21.67	21.61	22.67	24.22	21.22	22.92	21.11	21.22	22.17	22.47	22.00	21.67	22.83

* indicates positive (present) Dakota skipper site

Table H.3: Average minimum daily temperature (°C) for study sites 1 to 17, with the exception of site 4, 5, and 8 (not redeemed). Temperature monitor data reflects daily measurements for the time interval of 1 May 2016 to 19 September 2016.

Day	1*	2	3	6*	7	9	10*	11	12	13	14	15	16	17*
1	-5.22	-4.06	-2.67	-1.64	-1.94	-2.06	-6.22	-7.17	-4.78	-5.67	-3.22	-6.28	-5.72	-3.20
2	-5.17	-5.06	-4.50	-5.83	-4.61	-2.11	-6.06	-8.39	-5.56	-8.28	-5.94	-5.83	-6.17	-5.67
3	2.11	3.56	3.00	1.19	3.44	5.50	2.08	0.06	2.17	-0.33	2.56	2.28	1.72	1.31
4	0.50	-0.17	1.72	-2.31	2.22	2.61	1.19	-2.28	1.33	-0.83	0.56	0.94	-0.67	-0.61
5	1.11	1.94	1.94	3.69	4.72	4.22	0.89	-0.28	2.78	-0.78	1.67	0.83	0.39	1.83
6	7.83	7.72	8.06	5.64	9.44	9.00	8.06	3.06	7.61	6.39	8.67	7.72	6.11	5.39
7	2.44	2.44	0.22	2.31	3.44	4.78	1.17	-0.72	2.00	-0.06	0.67	2.61	2.39	1.22
8	-2.83	-3.56	-2.28	-6.08	-0.44	-0.39	-2.14	-5.50	-1.22	-4.17	-3.33	-1.56	-3.06	-3.85
9	4.94	-0.11	2.22	1.11	3.78	3.78	4.75	-1.78	1.72	-1.22	0.56	3.72	2.56	-0.06
10	3.33	2.78	2.67	5.19	5.94	7.61	3.08	1.83	5.06	1.89	4.17	3.89	3.44	2.80
11	3.83	3.78	4.06	4.33	4.78	5.33	2.25	1.61	4.00	1.00	3.83	2.44	2.44	3.89
12	0.83	0.94	1.94	1.06	2.50	3.50	0.00	0.89	2.50	0.28	2.06	-0.17	0.44	1.24
13	2.33	1.06	1.78	1.03	3.33	1.39	1.89	2.78	3.50	1.50	-0.11	1.06	1.56	0.61
14	-0.67	-1.11	-0.61	-1.92	-0.39	-2.11	-3.31	-2.56	-1.17	-3.22	-2.89	-3.50	-2.67	-1.72
15	0.78	-0.44	-1.00	-1.61	1.11	1.33	-1.36	-3.33	1.67	-2.28	-1.61	-0.56	-2.39	-2.13
16	-1.72	-3.67	-1.17	-4.83	-0.28	-1.94	-3.08	-5.78	-0.33	-3.33	-2.78	-2.83	-4.28	-3.59
17	-1.39	-1.22	-1.17	-3.08	0.56	0.39	-3.22	-3.28	0.50	-3.00	-2.44	-1.78	-2.61	-2.28
18	-0.72	-0.94	-0.89	-2.25	1.83	2.11	2.56	-3.44	1.06	-3.61	-1.61	0.89	-1.11	-1.39
19	7.56	5.56	5.39	5.78	7.56	8.67	5.14	2.50	6.67	4.78	5.11	6.89	4.83	3.13
20	4.56	4.61	4.56	5.83	7.39	7.00	7.22	3.67	6.72	3.50	5.50	7.06	5.78	4.04
21	5.61	8.11	8.44	8.97	9.11	9.56	5.81	6.50	8.44	6.28	9.50	6.78	6.11	8.37
22	6.44	7.11	6.44	7.28	7.61	7.61	3.03	5.39	6.89	5.33	6.22	4.17	3.89	5.89
23	11.50	11.39	11.33	9.89	12.33	12.06	9.61	8.06	10.78	8.56	12.06	10.72	8.83	11.61
24	4.61	3.89	4.83	1.36	6.06	4.61	1.78	-0.28	4.94	1.61	3.11	2.11	0.94	2.39
25	1.33	1.67	4.06	0.33	4.56	4.06	2.83	-0.89	3.11	-1.06	3.61	2.83	0.11	1.78
26	3.61	3.94	3.94	3.86	5.28	6.11	1.97	0.94	4.61	0.61	4.17	3.50	2.50	3.78
27	11.72	11.17	11.56	9.86	11.17	9.22	6.00	9.17	10.50	8.17	12.72	7.00	7.00	11.91
28	10.78	11.39	10.78	9.67	10.89	10.11	8.14	9.11	10.22	8.94	11.17	8.50	7.89	10.96

(Continued on next page)

Table H.3: Continued

Day	1*	2	3	6*	7	9	10*	11	12	13	14	15	16	17*
29	11.94	11.11	11.00	10.72	11.78	10.78	9.08	10.83	11.00	11.00	11.06	8.89	9.56	11.11
30	8.11	7.89	6.72	6.53	9.22	6.50	2.67	4.39	7.67	4.67	8.67	3.33	3.44	7.13
31	5.17	4.67	4.78	4.31	7.11	6.67	5.42	2.22	6.39	2.78	6.11	5.44	3.11	4.02
32	9.17	8.56	8.61	8.03	9.39	8.06	8.33	8.61	8.94	8.06	9.17	7.39	7.67	8.70
33	7.61	6.83	6.67	5.78	7.33	6.22	5.64	4.89	7.00	5.28	7.61	5.44	5.72	6.48
34	6.94	5.61	5.89	6.08	8.28	8.28	6.75	3.72	7.50	4.50	7.67	7.22	6.28	4.89
35	11.61	12.22	11.22	10.83	12.28	12.28	9.00	9.56	11.78	9.72	12.61	10.06	9.33	10.37
36	11.06	9.44	10.50	9.42	10.72	10.06	8.47	7.67	9.67	8.94	9.56	8.33	7.83	9.22
37	9.44	9.44	9.33	6.39	8.61	9.94	7.67	4.83	8.89	6.78	8.56	7.44	7.33	8.00
38	7.33	7.89	6.61	4.78	7.56	8.17	5.08	3.56	6.83	4.33	6.44	5.61	6.00	7.37
39	7.06	6.17	6.17	8.28	9.17	10.50	6.56	4.22	7.44	4.22	6.67	6.22	4.44	5.72
40	11.67	11.06	11.33	11.64	12.33	14.33	12.08	9.44	11.33	10.22	11.17	11.67	10.28	10.98
41	11.50	11.06	11.72	13.67	13.89	15.28	15.00	11.67	13.33	11.78	12.94	15.17	13.06	11.48
42	14.33	14.06	12.56	13.67	15.06	15.61	13.67	12.00	13.56	12.94	15.50	13.83	13.00	13.19
43	13.78	12.56	12.67	12.19	13.67	14.33	12.64	12.22	12.56	12.67	14.44	11.33	12.22	13.02
44	11.67	10.39	9.83	8.69	13.17	11.94	9.03	7.33	10.83	7.50	12.67	8.39	7.67	10.30
45	7.28	6.56	6.50	6.56	9.78	9.44	8.42	4.94	8.00	5.00	8.72	6.50	4.61	6.20
46	12.78	13.33	12.44	13.08	14.33	16.11	12.56	11.89	14.00	12.22	13.89	13.28	11.28	13.02
47	12.67	11.89	10.78	11.69	13.28	13.78	12.11	11.44	12.50	10.72	13.06	11.44	11.61	11.78
48	15.33	15.22	14.06	14.08	15.78	16.28	13.22	12.94	14.22	13.89	16.39	13.11	11.83	15.15
49	12.39	12.56	12.00	9.61	12.72	13.72	10.72	9.67	12.00	8.22	12.83	10.61	9.33	12.04
50	12.61	11.44	10.56	10.36	13.22	13.44	10.47	8.94	11.61	8.94	12.78	11.00	10.06	10.70
51	13.89	12.56	13.67	12.28	13.06	13.56	11.50	11.83	12.78	11.00	13.00	10.78	10.67	13.33
52	10.22	10.17	11.00	8.94	10.89	10.78	8.67	7.22	9.94	6.83	9.22	7.56	8.00	9.54
53	9.61	8.78	8.50	8.25	10.89	11.33	10.22	6.72	9.33	5.11	8.83	8.78	6.56	7.78
54	13.50	12.11	10.83	10.08	13.50	14.00	12.00	10.78	11.72	10.72	13.33	11.44	10.39	10.93
55	9.50	9.39	8.44	7.58	11.28	11.56	10.08	7.06	9.83	7.89	10.44	7.94	7.33	8.11
56	10.67	11.78	11.11	11.56	12.94	14.22	10.06	10.28	12.44	11.00	11.83	9.89	8.89	10.91
57	15.28	14.28	14.89	13.56	14.11	14.56	14.03	13.56	14.22	13.56	14.22	13.00	12.78	14.89

(Continued on next page)

Table H.3: Continued

Day	1*	2	3	6*	7	9	10*	11	12	13	14	15	16	17*
58	14.56	14.00	14.50	13.28	13.89	14.33	13.53	13.50	13.89	13.33	13.83	12.78	12.61	14.33
59	11.89	12.33	10.50	11.83	14.00	15.17	12.94	10.39	12.83	10.00	12.44	12.00	10.72	12.06
60	9.22	9.67	8.44	9.25	10.94	12.00	10.58	8.11	9.89	7.78	9.83	9.44	7.11	8.56
61	10.67	11.28	10.22	9.78	12.33	13.11	11.64	8.50	10.83	8.72	11.00	10.72	8.44	9.63
62	11.61	11.56	9.56	10.61	11.94	13.17	9.92	8.83	11.61	8.61	11.22	9.78	8.44	10.54
63	8.50	8.94	8.67	9.39	10.17	13.78	9.97	7.89	9.94	8.78	8.33	8.83	7.50	8.28
64	13.22	13.39	13.00	13.17	13.83	15.50	13.28	13.50	13.67	13.28	13.72	12.11	10.94	13.20
65	16.11	15.67	15.50	15.11	16.06	17.94	16.42	14.67	15.94	15.61	15.33	15.56	15.06	15.50
66	12.83	13.50	12.39	12.03	15.39	16.11	12.06	11.89	13.83	9.89	12.94	12.00	10.56	12.74
67	12.39	12.17	10.28	11.31	14.94	14.72	11.36	10.83	12.83	8.78	12.22	10.67	9.72	11.63
68	10.00	10.00	9.56	8.53	12.89	12.50	9.92	8.67	9.94	6.50	10.17	8.44	7.72	9.37
69	12.00	12.50	10.39	10.11	13.78	14.28	11.81	8.72	12.22	8.61	12.39	10.11	9.61	11.94
70	10.78	11.00	9.11	9.06	12.72	11.89	9.50	8.33	10.11	7.33	10.11	8.22	7.06	10.56
71	15.50	15.17	15.00	15.36	16.33	17.11	15.44	14.72	15.39	14.94	15.17	14.89	14.22	15.46
72	17.00	17.06	15.78	16.61	17.50	14.83	16.19	14.89	16.17	15.39	16.89	15.50	14.83	16.63
73	16.28	15.39	15.78	15.00	17.39	15.89	16.03	14.00	15.44	13.61	15.11	14.44	14.22	16.13
74	15.78	14.72	14.50	13.83	14.83	14.94	14.86	14.17	14.39	14.00	13.78	12.89	13.11	15.65
75	16.50	15.56	15.11	14.47	15.67	15.67	13.81	13.00	14.39	13.22	15.28	12.83	12.56	15.81
76	13.56	13.78	11.72	12.03	13.61	13.89	12.61	11.39	13.06	11.28	11.67	11.11	9.94	13.00
77	11.89	11.83	9.67	10.39	13.56	13.50	11.22	10.44	12.44	9.78	10.61	11.00	9.50	10.85
78	12.22	12.06	10.11	11.89	14.11	14.61	12.36	11.11	12.89	10.39	11.67	11.67	11.11	12.20
79	14.28	13.83	11.61	13.00	15.17	15.67	15.22	12.44	14.56	13.06	13.11	13.39	13.11	13.30
80	11.89	11.67	11.17	11.11	13.78	14.67	13.17	10.17	12.72	10.17	10.33	11.94	10.06	10.85
81	17.39	17.17	16.94	17.42	18.28	19.06	17.97	16.61	17.22	16.83	17.11	17.28	15.72	16.26
82	16.44	15.94	14.00	15.11	18.56	19.22	17.69	14.50	16.83	13.72	15.67	15.83	15.44	15.50
83	12.89	13.56	12.61	12.81	16.11	16.44	15.50	11.50	15.00	11.94	13.78	13.56	13.28	12.67
84	10.94	10.72	9.83	10.31	13.50	14.78	13.31	9.89	12.94	9.44	10.61	11.50	10.61	9.96
85	17.50	16.61	16.22	16.28	17.61	17.67	17.14	15.44	16.33	15.11	15.94	14.56	14.67	17.04
86	15.00	13.83	12.00	13.75	15.44	15.50	15.36	12.72	14.33	11.83	13.17	12.11	12.56	13.39

(Continued on next page)

Table H.3: Continued

Day	1*	2	3	6*	7	9	10*	11	12	13	14	15	16	17*
87	12.39	11.56	9.78	13.03	14.44	15.89	14.25	11.17	13.61	10.72	10.94	12.61	11.39	10.61
88	13.33	14.22	11.50	14.75	16.00	15.67	13.03	12.78	14.06	11.44	13.28	12.00	11.61	13.72
89	12.44	13.11	13.78	14.36	14.22	14.28	11.75	11.17	13.44	11.67	12.67	10.67	9.89	13.50
90	9.39	8.78	7.17	10.61	12.06	13.28	10.19	8.17	11.00	7.33	8.67	9.44	9.33	8.76
91	8.22	7.44	5.89	8.22	11.11	11.50	10.72	6.50	9.94	6.00	7.06	8.61	6.67	6.35
92	10.11	10.39	9.11	11.22	13.33	13.11	12.42	9.28	11.83	9.56	10.56	10.83	9.22	9.57
93	12.94	15.11	15.28	16.19	16.94	17.28	15.28	14.83	15.78	15.89	15.11	14.33	13.44	13.67
94	14.67	13.89	12.61	13.03	17.78	15.39	14.53	11.28	13.50	11.56	13.56	11.72	11.61	13.48
95	12.94	12.61	12.67	11.56	15.22	12.44	12.50	9.61	12.83	11.56	11.39	9.89	8.89	11.50
96	13.94	13.22	12.67	11.67	15.89	16.56	14.25	11.89	14.17	13.06	13.28	13.22	12.28	12.59
97	11.72	9.72	9.89	9.83	13.56	13.89	11.42	8.94	12.44	9.72	10.89	10.06	10.11	9.52
98	8.44	7.28	8.11	7.19	11.67	11.83	10.11	6.72	10.17	6.39	8.22	8.44	6.89	6.98
99	10.22	11.50	9.11	11.64	13.56	14.56	10.72	9.00	11.89	10.11	11.33	9.00	8.72	10.96
100	16.72	16.94	16.61	16.58	17.00	18.83	17.36	16.72	16.94	17.06	17.50	16.89	16.39	17.06
101	16.39	15.94	16.33	14.94	18.06	17.83	15.11	12.89	15.94	15.00	15.39	14.22	14.39	16.67
102	14.06	14.89	14.33	11.86	15.61	15.17	13.03	11.28	13.78	12.28	12.50	11.83	12.06	13.89
103	14.72	14.11	13.56	13.31	15.17	15.33	13.42	13.33	13.72	13.39	13.83	12.28	12.61	14.31
104	13.50	14.39	13.39	10.89	15.61	15.89	13.47	10.72	14.50	13.22	13.44	11.61	12.72	13.98
105	11.44	12.00	11.39	9.22	13.94	14.44	11.75	8.83	12.17	9.83	11.17	10.56	10.72	10.93
106	11.72	12.44	10.44	11.22	13.56	12.83	11.31	8.83	11.83	8.89	11.00	9.50	9.50	11.31
107	8.78	9.33	8.28	9.31	12.50	11.28	10.36	6.61	9.44	6.56	8.44	8.56	7.17	8.46
108	11.61	12.11	10.67	12.58	13.83	13.83	11.56	10.39	12.61	10.44	11.83	11.06	9.94	12.35
109	10.44	10.39	11.06	9.67	13.11	13.06	10.97	8.17	12.17	10.39	10.67	10.44	8.72	9.98
110	11.28	12.00	10.44	14.06	14.83	15.28	11.78	10.50	13.72	12.50	11.33	11.61	10.61	11.87
111	12.56	12.67	12.11	11.50	15.89	16.28	13.11	10.06	13.44	11.56	12.61	13.00	12.56	11.91
112	12.22	12.33	12.11	11.69	14.61	13.83	10.25	10.89	12.61	11.44	12.22	10.61	9.94	12.04
113	7.89	8.56	7.44	7.72	10.94	11.44	7.36	8.44	10.11	7.17	8.61	7.33	7.00	7.74
114	6.67	7.89	7.50	9.11	11.50	10.22	6.81	6.28	9.50	6.61	8.39	6.56	5.44	7.39
115	13.72	9.44	12.00	10.97	13.44	12.78	12.75	9.44	12.06	11.17	12.22	12.17	10.28	10.20

(Continued on next page)

Table H.3: Continued

Day	1*	2	3	6*	7	9	10*	11	12	13	14	15	16	17*
116	12.17	13.17	12.17	11.56	13.61	15.00	10.36	8.22	11.94	9.61	11.83	9.83	10.33	12.74
117	10.28	10.00	10.56	8.22	12.33	13.72	10.42	7.28	11.28	8.83	10.28	9.89	9.67	9.69
118	9.44	9.17	8.06	9.08	12.61	12.33	10.64	9.22	11.44	8.61	10.44	10.00	8.94	9.41
119	8.44	8.94	9.83	8.06	12.56	12.50	10.47	7.78	11.44	9.83	10.22	9.17	8.83	8.11
120	7.22	7.61	7.00	5.53	8.78	8.50	6.28	4.28	7.39	5.72	7.00	5.17	4.83	7.13
121	9.22	10.50	10.50	11.44	12.89	14.50	11.72	9.67	11.72	10.61	9.44	11.83	8.56	10.04
122	6.61	7.50	6.72	5.17	8.78	9.89	6.44	4.17	7.94	5.06	6.50	6.11	5.78	5.61
123	6.44	6.78	5.89	7.92	10.56	11.67	8.03	5.56	8.89	6.44	6.83	7.33	6.39	6.61
124	8.17	9.83	10.94	11.56	12.72	14.22	10.61	10.44	12.39	11.67	10.44	10.11	9.28	10.94
125	12.56	12.61	12.89	13.14	14.11	16.00	13.36	12.44	13.72	13.28	12.83	13.72	11.72	12.74
126	14.72	14.89	15.94	16.31	16.89	17.89	15.50	15.17	16.83	16.50	16.50	15.78	14.56	15.33
127	9.44	8.94	8.06	8.50	11.83	13.44	9.72	7.44	10.72	8.00	8.89	9.28	8.83	8.78
128	8.83	9.61	9.50	8.64	11.44	12.28	9.61	7.83	10.50	8.39	8.61	8.94	8.33	9.43
129	7.00	7.72	7.00	6.56	9.50	10.00	7.11	6.50	8.44	5.78	7.72	6.33	6.78	6.96
130	5.83	7.94	6.61	7.44	8.44	11.72	9.03	6.56	9.44	8.28	6.50	8.83	6.78	6.13
131	4.11	6.22	5.56	7.11	8.44	10.83	6.50	5.89	8.61	8.22	4.06	5.61	5.50	4.67
132	5.22	6.00	6.72	4.81	7.94	8.67	6.56	3.44	7.11	5.94	5.56	5.17	3.33	5.89
133	8.22	9.17	8.67	6.97	9.06	10.50	6.92	4.89	8.39	6.11	7.50	6.67	6.22	7.72
134	4.17	4.44	5.22	3.22	7.22	7.44	5.89	2.50	5.67	3.44	4.56	4.33	1.78	4.28
135	6.72	6.83	6.61	6.89	8.83	9.06	5.97	4.50	8.00	6.72	6.11	5.56	4.50	6.63
136	8.11	8.22	7.72	7.56	8.50	8.56	7.25	6.44	8.06	6.56	7.28	5.72	5.67	8.09
137	3.78	2.56	3.00	2.44	4.44	3.06	-0.50	1.17	3.56	0.44	3.39	-1.22	-0.72	1.52
138	3.56	1.11	2.06	1.92	4.67	5.61	4.00	0.67	4.61	1.67	1.22	2.50	1.44	1.04
139	5.50	5.50	5.44	6.97	7.78	8.72	6.50	5.61	8.06	6.50	5.22	6.06	4.78	6.15
140	3.22	3.22	2.89	3.31	6.06	9.39	4.94	2.00	5.56	2.72	3.44	5.22	4.28	3.00
141	2.06	2.33	1.94	3.08	4.72	6.94	4.03	1.33	4.94	1.44	2.00	3.50	2.22	1.87
142	16.94	16.89	16.89	17.00	16.06	16.94	13.17	17.17	17.00	16.11	17.44	16.39	11.83	17.02

* indicates positive (present) Dakota skipper site

Table H.4: Average minimum daily temperature (°C) for study sites 18 to 31. Temperature monitor data reflects daily measurements for the time interval of 1 May 2016 to 19 September 2016.

Day	18	19	20	21	22	23	24	25	26	27	28*	29	30	31
1	-5.67	-3.56	-1.17	-2.00	-1.72	-4.50	-8.61	-6.39	-6.67	-1.44	-4.69	-4.06	-2.89	-4.00
2	-9.00	-4.06	-3.78	-2.83	-3.94	-4.50	-8.17	-7.06	-7.06	-2.44	-4.67	-4.11	-6.17	-5.61
3	-0.78	2.83	3.78	5.83	4.00	3.33	0.50	1.50	2.56	4.33	3.53	3.33	1.22	1.44
4	-3.50	1.17	1.89	2.61	2.67	0.94	-1.64	-0.61	1.11	2.33	0.22	1.67	-0.28	-0.06
5	-0.56	2.33	3.50	4.22	4.67	2.67	-0.28	1.78	0.61	4.17	2.47	3.33	2.22	1.33
6	3.56	8.78	7.33	8.94	10.22	8.11	3.42	4.17	6.83	8.50	8.78	8.78	5.50	6.39
7	-2.33	3.67	2.17	8.67	1.22	4.06	-0.83	0.33	1.33	5.61	3.36	1.72	1.17	1.17
8	-6.17	-1.89	-2.33	0.89	-0.89	-0.67	-4.50	-3.50	-1.67	0.78	-1.67	-0.72	-2.00	-2.44
9	-1.78	2.22	2.06	6.56	5.39	3.00	-1.83	0.17	1.06	3.61	2.47	3.17	0.67	1.06
10	3.17	4.72	4.72	7.72	6.17	5.72	1.83	3.33	3.83	6.67	5.69	6.00	4.44	4.17
11	2.67	4.67	3.56	6.06	3.89	5.50	0.53	1.17	2.44	7.11	4.64	3.94	5.67	2.50
12	1.67	2.00	1.28	3.78	3.17	3.72	0.17	0.22	0.83	4.78	2.28	2.50	4.17	1.78
13	2.28	1.89	-0.28	3.39	2.22	4.00	1.28	2.11	2.11	4.39	1.42	3.22	3.44	1.06
14	-1.78	-1.33	-2.39	-0.50	-0.56	-2.11	-4.56	-4.94	-1.44	1.33	-2.17	-1.22	0.50	-1.89
15	-4.83	0.17	-0.50	2.00	-0.06	1.50	-4.53	-2.06	-1.17	2.94	-0.50	1.50	0.22	-0.94
16	-6.22	-1.94	-2.78	-0.78	0.11	-1.39	-6.33	-4.00	-2.17	0.78	-2.72	-0.78	-1.94	-3.17
17	-4.39	-0.50	-1.17	1.22	-1.17	0.94	-3.69	-2.44	-1.89	2.28	-0.50	0.17	-1.22	-1.22
18	-4.17	0.39	0.33	4.56	3.61	1.83	-3.83	-2.11	-1.06	2.89	0.47	0.33	-0.50	-0.78
19	4.83	5.83	4.83	8.94	8.11	5.78	4.50	6.22	7.61	8.17	8.39	7.06	4.56	6.44
20	4.61	6.44	5.67	8.67	9.22	6.50	4.19	4.78	7.22	8.61	5.08	7.22	6.28	5.44
21	8.00	9.33	8.94	10.22	8.83	8.72	5.83	7.56	6.67	10.00	7.94	9.22	9.22	7.94
22	6.28	7.00	5.39	8.06	7.17	7.83	4.58	5.72	5.06	9.17	6.83	7.56	8.22	6.00
23	7.61	12.94	11.78	12.56	11.11	11.11	7.06	8.28	8.06	12.22	12.28	11.83	10.61	9.50
24	-0.61	4.33	3.78	6.28	4.72	4.17	-1.47	0.44	2.44	5.50	3.61	5.17	4.17	1.78
25	-1.11	4.06	2.44	5.50	4.61	3.33	-2.17	-1.06	0.39	5.50	4.06	4.50	2.06	1.67
26	0.72	5.61	5.33	6.39	3.06	5.50	1.00	1.33	1.83	7.06	4.44	4.72	4.06	2.94
27	8.78	12.78	11.72	10.22	6.83	9.39	6.33	7.83	7.72	9.78	8.28	11.56	9.94	8.67
28	9.11	11.72	11.17	10.61	8.83	9.28	7.39	8.83	9.00	10.44	9.78	10.89	9.61	10.22

(Continued on next page)

Table H.4: Continued

Day	18	19	20	21	22	23	24	25	26	27	28*	29	30	31
29	10.39	11.50	10.89	11.78	10.00	11.83	7.75	10.61	10.56	10.89	9.19	11.22	11.44	8.22
30	3.44	9.78	8.17	7.50	5.11	7.44	2.97	4.33	3.22	7.44	5.81	8.00	7.33	5.67
31	1.56	7.06	5.56	7.72	7.94	6.44	1.44	2.28	3.61	8.72	5.94	7.00	4.83	5.72
32	7.94	8.83	7.83	9.44	8.89	9.50	7.67	8.28	9.28	10.28	8.97	9.39	9.28	9.11
33	3.83	8.11	6.50	7.56	7.72	7.33	3.64	5.28	6.61	8.33	6.08	7.00	7.44	7.50
34	3.83	7.50	6.89	9.28	8.06	7.44	2.42	3.89	4.89	10.06	6.81	7.44	6.72	8.61
35	7.83	13.22	11.61	12.83	10.61	12.33	9.97	10.39	10.67	12.89	11.86	11.72	11.56	11.94
36	5.94	10.56	9.33	12.17	9.72	9.83	8.19	8.17	9.61	12.39	10.08	10.39	9.67	11.11
37	1.89	9.11	9.11	11.33	7.83	8.50	6.50	6.28	8.67	11.61	9.47	9.17	8.11	10.67
38	1.72	8.56	7.22	11.06	7.72	7.22	3.83	3.83	6.28	10.11	7.67	7.33	8.17	8.00
39	4.06	8.17	7.22	11.22	9.11	8.11	2.19	4.11	5.39	11.17	8.14	8.78	7.89	8.22
40	9.94	12.11	10.44	14.89	13.11	12.28	9.33	10.00	10.61	14.61	13.28	12.11	12.56	12.94
41	11.44	13.33	12.83	17.11	15.44	14.17	11.39	12.06	11.94	15.78	15.72	13.94	13.06	15.06
42	10.67	15.89	13.94	17.78	13.06	15.56	12.36	12.83	13.06	16.78	15.75	14.56	13.50	14.72
43	11.17	14.67	12.44	14.67	12.89	14.11	11.83	12.11	12.50	14.61	13.97	12.94	13.50	12.89
44	5.22	12.89	10.83	13.11	10.72	11.17	5.53	7.11	8.28	14.33	11.22	11.28	10.61	10.67
45	3.83	9.17	7.17	10.72	9.28	7.78	2.81	4.06	5.11	11.67	8.56	8.83	7.28	7.50
46	10.72	15.44	13.50	16.33	13.83	14.00	10.97	12.11	11.28	16.33	14.53	14.22	13.61	13.94
47	10.33	13.56	12.94	14.89	12.56	13.00	10.97	11.50	11.44	15.11	13.61	13.39	12.28	12.83
48	12.44	16.78	15.94	16.22	14.83	14.83	12.53	12.17	12.00	16.67	14.97	15.89	15.22	15.06
49	7.39	13.39	13.33	14.61	11.72	12.67	7.17	9.06	9.06	14.33	12.64	13.89	11.44	12.39
50	8.11	13.39	12.17	14.22	11.89	12.17	8.31	9.44	9.94	14.44	12.81	12.78	11.50	12.22
51	10.56	14.22	12.94	15.17	13.44	13.78	11.00	11.39	12.56	16.39	14.08	13.44	13.94	12.83
52	5.00	10.94	9.89	12.44	11.11	10.67	6.94	8.61	9.50	13.83	11.25	10.11	11.28	10.50
53	5.61	10.44	9.67	12.33	11.61	10.28	5.86	6.94	7.17	13.33	10.56	10.11	8.83	10.06
54	9.00	13.22	13.17	13.50	12.28	12.61	6.78	9.50	10.50	15.11	12.72	13.56	11.22	14.78
55	5.50	10.89	10.33	12.61	10.72	10.11	4.75	6.72	8.00	12.78	10.14	11.00	8.44	12.61
56	8.67	13.33	11.00	14.83	11.56	12.61	9.89	9.67	9.89	15.17	12.44	13.56	11.94	13.89
57	13.00	15.33	13.33	15.61	13.56	15.00	13.31	13.89	13.39	16.22	14.47	14.56	15.00	16.83

(Continued on next page)

Table H.4: Continued

Day	18	19	20	21	22	23	24	25	26	27	28*	29	30	31
58	12.00	14.67	13.11	15.06	13.61	14.22	13.00	13.44	13.39	16.11	14.42	13.94	13.67	15.22
59	8.50	13.56	11.11	15.11	13.22	13.11	8.28	10.39	10.44	15.22	13.50	13.83	12.50	16.83
60	7.06	10.94	8.11	12.56	12.33	10.00	6.33	8.44	7.61	13.44	11.08	10.94	9.06	16.83
61	7.11	11.39	10.28	14.17	11.33	11.50	7.75	9.28	9.17	14.22	12.39	12.22	9.94	18.61
62	8.22	13.61	9.39	14.72	11.22	11.89	5.92	9.44	8.61	15.44	13.31	12.17	12.50	17.17
63	7.67	10.78	7.11	13.39	11.28	10.83	6.44	7.44	7.06	14.17	12.92	10.28	10.56	15.22
64	12.78	14.94	12.11	15.22	13.44	13.50	12.36	12.61	11.72	15.56	15.11	14.33	13.50	16.50
65	13.22	17.22	14.78	18.11	15.83	16.72	15.47	15.89	15.50	17.94	18.33	16.28	15.28	19.17
66	9.56	14.11	11.61	17.22	11.17	13.78	9.00	12.17	9.61	16.78	14.33	13.72	12.89	19.11
67	8.44	14.39	10.17	15.83	10.67	13.06	8.75	11.22	9.50	15.39	13.86	12.78	11.78	17.61
68	7.11	12.56	8.50	13.50	10.44	10.72	7.00	9.06	7.78	13.39	11.72	10.50	10.28	15.00
69	7.83	14.28	11.17	15.33	10.39	12.00	8.14	10.17	8.94	14.50	12.94	3.06	11.11	15.89
70	7.61	11.78	10.00	13.06	9.83	10.28	7.17	8.39	7.39	13.39	11.22	10.67	9.72	13.94
71	14.06	16.28	14.44	16.89	15.33	16.06	14.61	15.33	14.11	17.17	17.03	15.83	15.72	17.50
72	14.28	18.28	16.50	16.67	16.00	16.50	15.31	15.78	14.28	17.44	16.92	16.72	16.17	17.72
73	12.44	17.61	14.78	17.22	14.50	16.61	14.33	15.00	14.44	17.94	16.69	15.67	15.61	19.67
74	13.83	15.17	13.83	15.56	14.17	15.83	13.50	14.44	13.56	16.67	15.64	14.33	15.50	17.72
75	11.17	16.28	13.39	16.28	14.44	14.44	11.44	12.94	13.17	17.28	15.44	14.67	14.33	17.72
76	8.78	14.39	11.22	15.06	12.33	13.17	10.39	11.50	11.78	15.00	12.86	12.67	13.50	17.06
77	9.06	13.39	9.83	14.50	12.11	13.06	10.03	11.44	10.89	14.89	12.75	12.67	10.94	17.94
78	9.72	14.50	11.17	16.00	13.56	13.67	9.39	12.78	11.00	15.72	13.53	13.22	11.83	18.17
79	11.33	15.56	12.11	16.61	14.17	14.89	12.31	14.56	13.61	16.50	16.00	14.33	13.44	19.00
80	9.11	13.56	10.44	14.94	13.83	13.56	8.94	11.44	10.39	15.94	13.78	12.17	11.39	19.11
81	16.06	18.56	16.61	19.22	17.00	17.89	16.44	17.28	16.39	19.17	19.08	17.61	17.28	20.67
82	12.78	18.89	15.44	20.61	15.28	18.33	13.42	16.06	14.39	19.17	18.42	16.94	15.94	23.06
83	9.72	16.22	13.11	17.72	13.89	15.50	11.06	13.06	13.06	17.39	15.53	14.72	14.06	20.61
84	7.94	14.17	10.50	15.94	12.28	13.56	8.97	10.89	10.28	15.56	14.22	12.00	11.22	18.67
85	14.83	17.83	15.50	18.61	16.06	17.22	15.00	15.33	15.50	18.83	18.33	16.28	17.22	19.11
86	11.56	15.06	12.56	16.28	14.33	15.00	10.94	13.17	13.28	16.50	16.08	14.11	14.44	17.22

(Continued on next page)

Table H.4: Continued

Day	18	19	20	21	22	23	24	25	26	27	28*	29	30	31
87	10.56	13.61	11.00	16.61	15.11	14.61	9.75	12.06	11.72	15.94	14.39	14.50	12.11	17.00
88	10.67	15.89	13.33	17.17	13.33	15.11	10.58	12.33	11.11	16.50	15.19	14.67	14.11	16.44
89	10.22	15.28	12.50	15.83	12.17	14.00	11.31	11.39	10.39	15.28	13.69	13.56	13.28	15.44
90	7.50	11.50	9.11	13.78	13.11	11.78	7.81	8.67	8.72	13.56	11.72	10.89	10.44	13.67
91	6.22	10.11	7.33	12.72	11.72	10.39	5.17	7.33	7.39	12.89	10.75	9.61	8.39	12.11
92	8.39	12.72	10.61	14.00	13.00	12.72	8.11	9.61	9.50	14.11	12.08	11.67	10.72	13.50
93	13.83	16.50	14.33	17.78	15.83	16.39	13.78	14.44	14.50	17.89	16.56	15.83	15.67	16.33
94	9.61	15.17	13.83	16.61	13.94	14.33	9.78	12.22	12.17	16.61	14.61	15.94	14.78	14.56
95	7.89	13.33	11.17	13.44	12.28	12.11	8.92	10.44	10.56	14.83	11.67	13.33	13.39	12.83
96	10.67	13.94	11.72	17.44	14.89	14.89	12.08	9.44	13.11	17.78	16.08	14.50	14.39	14.44
97	7.17	12.56	9.89	15.22	10.44	12.89	7.67	7.89	9.17	15.06	12.75	13.11	11.83	12.28
98	5.44	9.94	7.44	12.56	10.50	10.67	6.00	5.78	6.89	13.17	10.81	10.50	9.83	11.11
99	9.17	12.94	10.56	14.28	12.67	12.44	9.28	7.72	8.61	15.61	13.53	10.72	13.22	12.89
100	16.50	17.94	17.00	17.83	16.61	17.89	16.61	16.83	16.44	18.67	18.61	17.17	17.06	17.72
101	10.44	16.39	15.67	18.61	16.72	15.44	13.56	12.50	15.61	18.89	17.06	14.28	16.67	15.94
102	8.83	14.78	13.44	15.56	14.06	13.50	11.94	9.89	12.67	16.33	14.14	11.44	13.39	13.89
103	12.89	14.78	13.33	14.44	13.39	14.11	12.78	12.28	12.78	15.56	15.25	12.72	14.67	13.67
104	8.39	14.61	13.28	16.28	13.67	14.72	12.78	11.39	13.17	16.61	14.56	12.50	12.94	13.83
105	6.89	12.78	10.89	14.00	12.06	12.72	10.06	8.22	10.61	15.06	12.67	10.17	11.78	12.22
106	6.94	13.06	11.61	12.78	11.67	11.28	9.08	7.83	10.28	14.39	12.25	10.50	11.83	11.28
107	5.78	10.50	9.28	11.28	11.56	10.44	7.39	6.06	8.00	12.89	10.50	8.06	9.50	9.44
108	9.50	13.78	12.11	13.61	12.78	12.83	9.44	9.50	11.00	15.39	12.39	12.56	12.22	11.50
109	6.61	12.78	11.39	12.67	12.22	12.17	9.31	8.67	10.17	14.22	11.64	10.83	10.89	11.22
110	10.67	13.00	12.33	14.44	14.50	13.33	10.97	10.17	11.11	16.67	13.58	12.94	14.06	12.56
111	9.06	14.17	12.22	16.56	13.44	13.78	11.36	10.94	11.78	16.78	14.81	12.56	12.78	13.83
112	9.72	13.72	11.39	13.89	10.78	12.39	9.22	9.11	11.00	14.72	13.00	11.39	12.94	11.00
113	6.94	10.56	7.78	11.22	7.94	10.17	5.50	7.22	7.50	12.22	9.42	8.33	8.44	9.78
114	6.11	10.56	8.22	10.00	10.33	8.72	4.94	4.39	6.78	11.50	8.03	8.22	9.89	8.06
115	9.06	14.22	10.44	14.50	13.89	12.44	9.14	8.17	12.17	13.61	11.75	12.17	11.94	11.11

(Continued on next page)

Table H.4: Continued

Day	18	19	20	21	22	23	24	25	26	27	28*	29	30	31
116	7.17	13.61	12.00	13.22	12.72	12.56	10.08	6.83	9.67	15.44	14.11	11.39	12.94	13.17
117	7.17	12.11	8.67	12.94	11.89	11.94	10.42	7.28	10.17	14.06	13.03	10.11	11.67	11.67
118	8.17	12.28	8.83	12.39	11.67	11.61	9.00	8.94	9.33	13.33	11.53	10.78	10.39	11.50
119	6.39	11.56	9.00	12.28	10.78	11.78	7.67	7.83	9.00	13.22	10.72	10.67	11.17	9.22
120	3.50	9.06	7.22	8.11	8.44	8.22	4.06	3.78	6.00	9.83	6.58	7.28	8.06	6.56
121	7.28	12.17	10.78	13.33	14.28	11.78	8.42	8.94	10.39	15.06	11.47	10.94	11.61	11.61
122	3.22	8.67	6.11	10.06	8.33	8.50	6.00	3.78	5.44	10.39	7.53	6.83	7.28	7.78
123	5.28	9.44	6.83	10.89	11.72	9.44	6.47	5.61	7.11	12.11	9.06	8.39	8.56	8.39
124	10.44	12.00	10.33	13.44	12.44	12.61	9.75	10.61	10.22	14.83	12.89	11.28	12.67	12.28
125	12.06	13.89	12.28	14.89	14.61	14.06	12.86	12.67	13.28	15.78	14.92	12.78	14.11	13.94
126	14.22	17.28	15.22	18.22	17.33	16.72	15.44	15.83	15.28	17.72	16.36	15.89	16.89	16.67
127	6.56	11.17	9.06	12.89	9.44	11.61	8.47	7.50	8.61	13.78	11.86	9.28	10.67	10.17
128	7.33	10.89	9.89	11.83	10.06	10.78	8.22	7.94	8.50	13.06	11.22	9.72	10.06	10.17
129	6.22	9.22	6.33	10.06	7.94	9.61	6.72	5.28	7.50	11.83	9.64	9.72	8.89	8.89
130	6.72	8.78	6.28	11.72	10.89	9.78	5.81	6.56	7.44	13.00	10.17	8.17	8.56	9.89
131	5.78	6.28	5.39	9.33	10.22	8.83	5.25	5.44	6.33	11.44	7.92	6.83	9.11	8.78
132	3.22	6.72	4.94	8.11	8.33	6.39	3.36	2.33	4.78	10.50	6.69	5.94	6.94	6.67
133	3.94	9.11	7.39	9.50	8.56	8.72	5.19	5.39	5.89	11.78	8.72	7.44	8.67	9.17
134	1.78	6.00	3.44	7.39	6.94	5.94	2.11	1.50	3.61	9.94	6.31	4.83	6.33	5.50
135	4.00	8.11	6.39	8.72	9.00	8.00	3.72	3.61	5.50	11.17	7.50	6.17	8.28	6.67
136	6.44	8.67	6.94	8.72	9.22	8.44	5.81	5.50	8.39	10.78	8.67	6.61	9.39	7.67
137	0.89	5.28	1.83	2.72	2.83	2.83	-2.69	-1.83	0.61	5.83	1.53	1.83	5.56	0.89
138	1.22	3.39	1.17	5.50	5.56	4.61	0.06	0.67	3.78	7.78	4.11	2.06	4.56	2.56
139	5.50	7.61	5.78	9.33	9.17	7.89	5.11	5.44	6.06	10.56	7.44	6.56	8.22	6.94
140	1.00	5.56	2.28	9.33	6.89	7.11	1.89	2.28	4.22	10.44	6.92	4.28	5.39	5.06
141	0.94	4.06	1.61	6.94	7.61	5.56	1.44	1.28	3.33	9.61	5.61	3.56	4.83	4.22
142	16.06	17.17	17.22	16.11	13.33	16.78	16.58	16.61	16.28	17.06	16.25	17.00	17.06	16.61

* indicates positive (present) Dakota skipper site

Table H.5: Average daily temperature (°C) for study sites 1 to 17, with the exception of site 4, 5, and 8 (not redeemed). Temperature monitor data reflects daily measurements for the time interval of 1 May 2016 to 19 September 2016.

Day	1*	2	3	6*	7	9	10*	11	12	13	14	15	16	17*
1	15.25	12.71	11.58	13.69	16.16	14.59	13.57	14.47	13.93	13.76	14.33	11.07	8.82	14.28
2	17.13	15.96	13.86	15.20	19.06	15.33	15.93	15.06	15.69	14.25	16.10	15.96	11.00	16.51
3	20.43	17.57	16.21	18.32	21.55	19.84	20.48	18.92	18.74	19.86	19.05	18.79	15.44	19.14
4	20.16	18.19	16.11	17.68	21.83	18.74	19.19	17.77	18.29	18.19	18.80	18.79	14.37	18.58
5	21.90	20.48	18.69	21.72	23.89	21.01	21.25	19.61	20.65	20.24	21.64	21.53	17.39	21.34
6	25.77	24.84	22.45	24.45	26.86	23.82	24.36	22.93	24.07	24.84	25.57	25.81	20.38	24.54
7	18.85	17.97	16.32	17.57	19.86	18.41	17.63	16.84	17.82	18.32	18.15	17.76	15.80	18.39
8	18.95	17.51	15.43	16.48	20.71	16.98	18.19	15.58	16.77	16.47	18.55	17.77	14.02	17.30
9	20.27	18.14	17.87	19.28	20.72	20.08	20.53	17.75	19.01	18.93	19.25	20.87	17.00	19.48
10	20.11	19.11	18.51	20.24	21.10	20.83	20.37	19.88	19.80	21.95	20.25	20.34	17.95	20.13
11	11.11	10.65	10.46	10.81	11.19	11.78	11.10	10.91	11.21	11.17	11.04	10.69	10.89	11.13
12	7.43	6.74	6.87	6.40	7.51	6.84	7.05	7.30	7.64	6.20	6.99	6.19	6.46	7.40
13	6.99	5.79	5.92	5.79	6.67	5.24	6.13	6.67	6.72	4.76	5.87	5.48	4.94	6.99
14	11.70	9.01	9.06	9.17	12.84	9.12	9.17	10.99	11.47	9.47	9.66	8.08	7.32	10.77
15	12.97	11.82	10.50	11.35	13.31	10.45	11.88	11.95	11.98	10.47	11.87	11.11	9.23	11.81
16	16.06	14.86	13.52	14.08	17.38	13.69	15.58	13.85	14.78	14.06	15.12	14.67	12.06	15.51
17	17.99	16.72	14.56	16.93	19.00	17.35	17.65	15.47	16.42	17.72	18.04	16.46	14.89	17.80
18	18.70	18.98	16.97	18.60	21.24	18.86	21.21	16.96	18.08	18.10	19.89	21.19	17.21	19.88
19	21.60	21.33	18.97	20.86	22.05	20.91	22.29	19.26	19.96	20.39	21.70	22.07	18.93	20.91
20	22.12	22.15	20.44	22.51	23.45	23.30	23.87	21.33	21.00	23.45	24.18	24.18	20.49	22.93
21	21.34	21.72	20.23	21.74	23.22	22.51	22.67	20.90	21.05	23.49	23.71	21.55	19.23	22.93
22	21.63	22.07	20.35	21.53	22.91	21.82	22.43	20.87	20.84	22.55	23.50	21.34	19.15	23.02
23	25.67	27.10	24.70	24.64	25.60	23.80	24.96	22.50	22.93	23.86	26.68	24.59	21.67	26.75
24	20.21	22.13	19.60	18.26	20.39	17.80	19.62	16.73	17.63	17.01	21.84	18.87	16.74	20.64
25	17.64	19.49	18.11	16.87	18.32	17.18	19.60	14.74	17.16	15.86	20.32	18.11	16.30	19.67
26	12.08	11.62	11.19	11.84	12.20	13.16	12.02	11.20	11.58	11.46	12.60	11.70	11.69	11.82
27	15.06	14.45	13.95	13.93	14.36	13.46	12.54	13.05	12.80	13.04	16.41	12.21	12.38	14.88
28	18.66	16.65	15.02	15.95	18.24	16.74	16.17	15.96	14.39	15.29	17.45	15.47	15.57	16.11

(Continued on next page)

Table H.5: Continued

Day	1*	2	3	6*	7	9	10*	11	12	13	14	15	16	17*
29	16.67	16.07	14.68	15.19	16.02	16.14	15.69	15.66	14.80	16.13	18.60	14.95	15.52	16.93
30	22.42	22.37	20.01	20.14	23.08	18.40	21.60	18.65	18.74	18.67	23.22	20.14	18.25	23.62
31	15.44	16.53	14.88	14.99	16.00	14.30	16.15	14.01	14.24	14.35	16.29	15.55	14.20	15.96
32	12.42	11.99	11.57	11.59	12.62	11.46	11.66	11.80	11.67	11.40	12.62	11.00	10.98	12.21
33	20.00	17.85	16.62	17.88	21.97	16.67	20.86	17.13	17.29	17.99	20.67	18.08	16.28	19.31
34	20.55	19.95	18.30	20.16	21.56	19.27	22.17	18.72	18.54	19.65	20.80	21.32	19.67	21.11
35	22.88	20.91	20.58	20.46	23.72	18.42	22.85	20.73	19.74	20.43	23.47	19.54	19.07	23.66
36	24.30	22.86	21.44	21.73	25.79	20.58	24.59	21.79	21.86	22.56	24.76	22.45	20.98	23.97
37	23.40	22.53	20.74	20.73	24.66	19.88	23.64	20.52	20.86	21.42	23.59	21.65	19.88	22.81
38	20.02	21.02	18.44	19.57	21.50	19.78	22.90	18.42	19.25	20.03	21.49	19.95	19.40	19.85
39	22.02	22.07	21.48	22.68	24.96	22.75	24.55	20.65	20.91	22.86	23.91	24.18	21.83	23.28
40	24.79	24.08	22.23	24.45	26.90	24.35	27.54	23.32	23.97	25.29	25.88	26.92	24.69	25.79
41	26.46	26.75	24.50	26.48	28.23	24.86	28.30	24.97	24.67	26.20	27.28	27.67	25.08	27.33
42	27.34	26.16	24.20	24.41	27.93	23.94	27.64	23.42	23.86	25.59	27.06	26.36	24.14	26.57
43	22.07	19.35	19.12	19.39	21.84	21.50	20.30	19.28	19.15	20.36	23.56	18.84	19.59	21.62
44	21.30	20.00	18.31	19.18	21.73	20.82	21.76	18.50	19.06	19.91	22.99	20.89	20.13	20.66
45	23.13	22.89	21.04	21.83	25.11	20.71	24.16	19.78	21.33	21.52	24.83	22.64	20.02	23.29
46	21.83	20.19	18.45	20.54	23.10	21.76	22.56	20.17	20.61	22.24	22.41	22.44	22.10	21.02
47	26.41	25.64	23.31	23.26	27.86	22.42	26.39	23.16	22.98	24.74	27.82	24.33	22.33	25.81
48	23.34	22.22	20.03	21.94	23.02	22.38	22.92	20.15	20.40	22.19	25.89	23.51	22.58	23.17
49	25.95	24.95	23.54	22.17	25.74	21.87	25.52	22.05	22.52	23.94	27.82	23.88	22.61	25.32
50	26.09	24.44	22.92	24.26	27.22	25.09	26.53	23.91	23.63	25.97	28.49	26.12	24.75	25.62
51	25.58	23.32	21.83	21.88	23.33	21.28	24.27	21.50	21.93	23.95	26.05	22.53	21.65	24.10
52	24.77	22.94	19.89	21.03	23.89	20.74	24.07	21.16	20.55	23.29	25.89	22.06	20.30	23.42
53	23.49	22.67	19.91	21.08	23.70	20.96	23.79	20.53	20.36	22.25	25.71	22.21	20.44	22.32
54	22.58	20.01	16.74	19.23	22.60	21.15	21.07	18.76	17.94	20.52	24.08	19.37	20.81	20.65
55	23.87	22.45	19.55	22.11	25.18	22.70	24.58	20.48	20.41	23.02	25.78	23.09	22.88	22.79
56	26.09	24.25	21.85	23.97	26.15	24.47	25.38	23.26	22.22	24.90	28.33	23.42	24.02	25.27
57	22.33	20.18	19.23	18.84	19.82	17.17	20.98	18.26	19.04	20.21	21.94	18.07	17.80	21.53

(Continued on next page)

Table H.5: Continued

Day	1*	2	3	6*	7	9	10*	11	12	13	14	15	16	17*
58	20.78	19.61	17.99	18.10	19.02	18.72	19.75	17.46	17.46	18.54	20.38	18.85	17.58	20.74
59	20.71	19.81	17.64	19.01	20.71	19.92	20.30	18.28	17.82	19.95	21.98	20.64	20.25	20.56
60	23.70	23.59	21.04	21.91	25.01	21.58	25.13	19.97	20.29	21.97	25.33	24.14	21.76	22.58
61	24.92	23.86	21.16	21.74	25.83	21.83	25.20	21.00	20.71	23.00	25.33	23.16	21.12	22.28
62	24.19	22.18	19.41	20.98	24.13	22.57	23.68	19.97	19.67	22.94	25.82	21.42	21.45	22.00
63	20.94	19.67	17.29	19.10	20.27	20.46	19.87	17.96	17.42	19.55	21.48	18.96	18.50	20.72
64	23.48	21.94	19.77	21.80	22.85	23.81	24.11	22.01	21.21	23.77	24.29	24.56	23.60	22.97
65	21.58	20.99	19.20	20.50	21.70	22.42	22.81	20.44	20.22	22.15	23.75	23.20	22.58	21.74
66	26.76	24.93	21.10	22.89	26.60	24.07	26.18	22.14	21.84	24.51	26.66	24.39	23.27	24.11
67	23.69	22.60	19.61	20.66	23.74	22.28	24.24	21.15	20.72	23.20	25.60	22.92	21.38	22.27
68	24.56	23.61	21.70	20.75	25.63	21.03	23.65	20.80	20.26	22.10	26.85	23.11	20.63	22.98
69	19.39	18.04	16.98	17.07	19.69	18.95	19.82	16.88	16.91	17.37	21.09	19.72	17.60	17.97
70	24.06	22.38	19.94	21.20	25.33	22.46	23.99	20.91	20.40	23.93	26.70	24.32	22.40	22.47
71	23.51	21.87	20.04	21.80	24.18	24.04	24.50	21.12	20.44	23.25	25.79	24.61	23.97	22.83
72	26.41	25.81	23.16	23.22	26.24	21.74	23.63	22.70	22.09	24.55	28.39	23.11	21.83	25.21
73	25.99	23.55	21.53	21.98	24.28	21.56	24.51	20.98	21.30	23.36	25.49	23.32	22.67	25.25
74	22.51	19.88	18.69	18.41	19.65	19.75	20.44	18.67	18.50	19.95	20.36	19.35	18.77	20.99
75	21.73	18.93	17.99	18.64	20.12	20.32	21.34	19.55	18.87	20.64	20.68	20.41	19.25	19.64
76	23.43	21.52	19.52	19.52	23.61	19.84	23.82	20.24	19.81	22.56	24.47	22.30	20.64	21.94
77	23.19	22.52	20.42	19.47	23.20	20.33	21.70	19.54	18.92	21.46	27.00	22.20	20.26	22.02
78	21.31	18.97	17.06	18.95	20.55	21.62	22.47	19.31	18.62	20.60	23.53	22.29	21.58	19.29
79	25.55	23.55	21.75	21.79	25.05	21.66	24.49	22.24	21.59	24.31	27.85	23.05	21.44	24.48
80	25.27	24.40	21.95	23.02	25.39	23.70	25.30	21.87	21.73	24.34	26.86	25.38	23.40	24.03
81	28.88	26.78	24.46	25.23	29.13	26.32	29.02	25.32	24.13	28.44	31.00	28.85	25.98	27.17
82	29.39	28.34	25.64	26.68	29.48	26.41	28.95	25.85	25.09	28.54	32.08	28.40	26.01	28.20
83	27.34	26.70	23.90	23.44	27.57	24.43	27.04	22.80	23.70	26.03	29.73	26.53	23.15	25.92
84	25.22	25.22	22.46	22.51	25.20	23.78	24.47	22.05	21.84	24.38	27.70	25.39	22.60	24.44
85	25.09	22.43	21.03	22.37	23.51	23.93	25.33	21.33	21.97	24.68	25.32	24.50	21.73	23.66
86	26.39	25.18	22.08	21.81	25.05	23.53	25.47	21.68	22.18	24.66	27.41	24.84	20.75	25.02

(Continued on next page)

Table H.5: Continued

Day	1*	2	3	6*	7	9	10*	11	12	13	14	15	16	17*
87	26.85	26.60	23.05	23.95	26.87	25.27	26.78	22.82	23.01	26.83	29.83	27.68	23.16	25.68
88	25.26	26.87	22.47	22.96	25.05	22.30	22.69	21.76	21.20	23.95	28.12	23.84	20.97	24.82
89	24.06	25.12	21.73	21.86	22.68	20.27	21.11	20.34	20.33	22.01	25.84	22.26	19.74	24.45
90	23.94	25.07	20.66	22.01	24.52	22.44	22.98	20.12	20.47	22.68	26.81	23.81	20.06	23.27
91	22.39	24.69	20.82	20.45	23.79	21.72	23.76	18.68	20.13	21.64	26.72	24.05	19.69	22.33
92	25.95	27.44	23.07	24.96	27.38	23.94	26.46	22.28	22.67	25.08	29.50	26.53	21.84	25.72
93	25.23	26.21	23.56	25.21	25.96	25.49	26.78	23.23	23.34	25.27	29.59	27.11	24.00	26.13
94	25.65	24.17	20.67	23.31	25.95	24.20	26.27	21.10	21.60	23.26	28.06	24.62	21.65	24.16
95	26.05	26.09	21.67	24.41	26.36	23.84	26.98	20.85	22.49	23.65	29.61	25.39	20.77	24.88
96	24.56	25.32	21.91	25.09	25.67	24.77	26.07	22.86	23.47	24.67	27.67	25.79	22.18	24.86
97	23.49	23.39	19.73	22.58	23.42	22.45	24.35	21.15	20.89	22.50	25.78	21.63	19.43	23.03
98	22.90	23.03	20.87	22.46	24.96	22.85	24.69	20.25	21.01	22.93	26.86	22.93	19.64	22.52
99	24.77	26.00	22.13	24.77	25.10	24.78	25.32	22.42	22.19	23.68	28.21	23.78	20.35	24.92
100	23.58	22.30	20.21	24.32	23.82	24.39	25.60	22.33	21.92	23.68	26.45	24.81	23.10	23.07
101	26.34	24.84	22.60	27.65	26.12	25.42	28.00	24.38	24.30	25.00	29.42	26.50	22.74	25.73
102	23.63	22.28	19.73	23.05	23.21	23.04	24.04	21.22	20.32	21.36	24.45	21.31	19.70	22.15
103	21.70	21.40	19.43	21.64	21.45	22.80	23.04	20.63	19.98	21.03	25.60	21.93	19.61	21.87
104	23.95	23.19	20.59	23.61	23.42	22.11	23.83	20.74	21.49	21.99	26.69	22.24	19.00	23.03
105	21.98	22.57	18.76	21.63	21.98	20.86	24.36	19.36	20.40	20.36	24.40	20.93	18.02	20.82
106	23.28	22.15	19.00	22.06	23.15	21.65	25.01	20.39	20.64	20.86	26.27	20.65	17.40	21.56
107	24.45	23.63	20.71	24.16	24.55	22.84	26.13	20.63	21.58	21.98	28.05	24.23	18.73	22.57
108	26.14	25.79	22.33	25.87	26.20	25.00	27.32	23.02	23.17	24.34	30.33	24.95	20.05	24.69
109	24.79	25.52	21.62	24.78	25.00	24.88	26.74	21.55	23.07	23.17	29.08	24.16	19.38	23.18
110	27.14	27.39	23.64	27.89	27.02	26.10	27.97	23.61	24.21	26.52	31.23	26.71	20.95	25.97
111	22.79	22.83	19.55	21.38	22.63	21.16	23.97	19.15	19.97	20.98	25.42	20.94	17.87	21.83
112	20.72	20.07	17.10	19.38	20.18	17.73	20.92	17.16	17.52	17.48	22.20	18.29	16.13	19.31
113	20.18	19.99	15.70	18.19	20.65	19.14	22.66	16.70	17.36	19.01	23.22	18.40	15.29	18.81
114	24.06	23.90	19.85	23.38	23.68	21.94	25.85	19.64	20.94	22.24	26.11	22.28	17.44	21.53
115	27.62	27.74	23.84	27.03	26.90	25.28	28.70	23.10	23.88	25.24	29.75	26.31	20.41	25.21

(Continued on next page)

Table H.5: Continued

Day	1*	2	3	6*	7	9	10*	11	12	13	14	15	16	17*
116	19.83	21.23	18.37	17.64	19.12	20.93	20.72	16.07	18.12	18.58	22.79	19.25	16.90	20.53
117	17.67	17.36	16.05	15.08	16.78	16.95	16.87	14.90	15.49	15.36	19.27	15.94	13.88	17.90
118	22.41	22.05	17.71	20.59	22.16	20.64	24.17	18.40	18.90	19.88	24.84	19.83	15.64	20.67
119	19.72	19.34	17.83	18.82	19.66	19.56	21.40	17.28	18.08	18.78	20.89	18.88	16.42	19.55
120	21.27	19.92	16.44	21.09	21.62	20.91	22.95	16.58	18.04	19.64	23.92	19.84	14.42	18.74
121	22.24	21.48	19.15	22.65	22.96	22.62	23.52	20.20	20.32	21.89	25.01	22.33	17.88	21.06
122	21.66	21.56	16.20	20.62	22.05	20.28	22.19	16.69	18.05	18.54	24.41	18.38	13.98	19.12
123	21.29	21.02	17.48	21.53	22.03	21.80	22.30	18.10	19.51	19.86	23.58	19.80	15.63	19.94
124	18.90	18.06	16.71	18.36	19.74	22.26	21.91	18.56	19.82	20.25	20.06	19.96	17.37	18.73
125	23.59	23.05	21.24	23.27	23.39	24.10	24.65	21.44	22.46	22.59	25.04	23.85	20.17	23.02
126	22.00	21.79	21.01	22.06	21.84	24.14	23.63	20.56	21.78	22.16	23.22	23.64	20.79	22.02
127	18.91	19.50	17.32	17.35	18.86	18.51	18.48	16.23	16.77	16.86	19.67	17.73	16.64	18.62
128	16.72	17.16	15.79	15.63	16.86	16.09	16.66	14.49	14.88	15.23	17.30	15.51	13.77	16.53
129	13.26	13.57	12.56	12.82	13.88	13.49	13.44	12.83	12.84	12.71	14.06	12.73	12.36	13.00
130	16.32	16.12	13.26	15.44	17.17	16.42	19.10	14.03	14.97	15.20	18.13	15.23	13.36	14.98
131	10.80	11.47	10.81	11.63	12.58	13.79	12.78	11.16	12.12	12.05	11.21	11.80	11.14	10.79
132	13.41	13.58	12.27	12.69	13.95	13.40	14.31	11.45	13.01	13.07	14.26	12.84	11.69	13.41
133	16.13	16.24	13.62	14.77	16.19	15.47	18.58	12.76	14.11	13.59	17.53	14.16	11.95	15.18
134	15.54	14.42	12.65	13.70	15.90	13.86	16.00	12.00	13.81	13.40	16.56	13.95	11.41	13.71
135	17.06	15.54	13.93	15.65	16.47	14.51	17.21	14.06	15.12	14.48	16.44	14.71	12.18	14.74
136	13.96	13.33	11.47	12.54	14.14	11.77	13.50	12.34	12.05	11.50	14.59	10.83	9.68	13.29
137	14.22	12.25	9.75	12.54	14.24	11.12	13.95	10.37	11.70	10.56	15.41	8.61	6.47	11.54
138	15.05	12.81	11.08	14.01	15.11	13.87	16.29	11.78	13.75	13.23	14.82	12.40	9.69	12.01
139	15.99	15.03	13.24	15.85	16.28	15.07	16.62	14.95	15.01	15.26	16.04	14.63	12.55	14.65
140	14.83	14.21	12.06	14.75	15.61	16.13	15.90	12.90	14.04	13.69	15.08	13.65	11.78	13.66
141	14.40	14.51	14.11	16.07	17.20	17.31	19.04	15.58	17.18	15.90	14.69	16.78	12.25	14.18
142	19.37	19.11	19.08	19.09	19.12	19.33	18.16	19.27	19.25	19.07	19.28	19.15	17.35	19.26

* indicates positive (present) Dakota skipper site

Table H.6: Average daily temperature (°C) for study sites 18 to 31. Temperature monitor data reflects daily measurements for the time interval of 1 May 2016 to 19 September 2016.

Day	18	19	20	21	22	23	24	25	26	27	28*	29	30	31
1	10.84	14.32	13.48	13.63	9.95	14.23	11.83	14.43	10.66	15.48	15.77	13.45	14.91	13.09
2	11.57	16.90	16.55	15.41	13.01	15.68	15.66	17.69	13.56	16.82	18.43	16.33	15.10	16.31
3	14.59	19.06	18.04	19.16	15.34	19.55	19.06	20.89	17.66	19.72	21.38	19.52	18.34	18.74
4	13.94	18.19	17.72	18.98	15.20	19.00	17.97	20.58	17.18	19.85	21.36	19.46	18.08	18.97
5	16.84	21.33	21.84	20.58	18.93	20.64	19.98	22.03	18.60	22.12	23.23	21.25	20.04	21.29
6	20.26	24.69	25.03	24.66	22.04	24.63	22.61	25.79	23.67	24.63	26.84	25.19	23.18	24.86
7	14.10	17.95	17.34	18.18	14.75	18.94	17.17	18.70	15.70	19.40	19.41	18.02	17.73	17.76
8	13.63	17.57	17.47	17.91	13.86	17.25	16.18	18.19	15.03	19.54	19.86	19.29	16.54	18.29
9	16.15	19.21	19.96	19.53	16.91	19.05	17.20	18.86	16.55	21.22	21.72	19.38	18.14	19.86
10	18.20	20.45	19.75	20.54	17.38	20.61	18.68	20.39	17.78	19.98	22.11	20.25	18.77	20.83
11	10.36	11.59	10.80	12.13	10.22	12.05	10.54	11.02	10.31	12.02	11.97	11.14	11.14	11.29
12	6.88	7.61	6.61	7.79	6.21	8.99	6.45	7.70	6.01	9.44	7.93	7.30	8.02	8.29
13	5.68	6.70	5.66	6.65	4.43	8.20	5.43	7.23	4.48	8.29	6.65	6.14	7.10	7.57
14	8.82	9.24	8.32	8.80	7.12	11.99	9.55	12.76	7.08	12.51	10.80	10.49	11.47	10.27
15	10.05	12.44	10.60	12.28	8.73	14.18	11.45	14.65	10.83	13.71	13.71	12.66	11.57	13.14
16	11.96	14.43	14.54	14.17	11.59	15.69	13.81	16.81	12.66	16.96	16.59	15.72	14.47	16.14
17	13.39	17.28	16.95	16.98	13.39	17.41	15.95	18.11	15.02	18.84	19.11	18.28	16.71	17.12
18	15.77	19.10	20.00	18.97	16.38	19.00	18.05	19.36	16.42	20.87	20.73	19.14	17.72	19.87
19	18.74	20.24	21.02	20.52	18.12	21.09	20.92	21.38	19.12	22.71	23.05	20.95	19.29	21.97
20	20.44	22.63	23.13	23.13	20.12	22.44	21.39	23.18	20.51	24.69	24.32	23.56	20.67	23.86
21	20.69	22.54	22.79	22.89	19.45	22.35	21.13	22.45	19.40	24.66	23.56	22.77	20.54	22.20
22	20.87	22.70	23.16	22.18	18.90	22.10	21.15	22.40	19.51	23.53	23.40	22.38	19.99	22.65
23	23.06	24.90	26.99	23.66	20.78	24.01	23.30	24.45	20.94	27.40	27.24	25.84	23.48	26.73
24	15.55	21.51	20.82	18.18	15.73	19.49	17.88	18.00	16.75	21.84	21.31	21.37	17.14	20.51
25	14.54	19.45	19.91	17.51	14.48	18.44	17.12	16.49	15.46	20.82	19.95	19.58	16.59	19.23
26	10.56	12.69	12.22	12.95	10.86	12.34	11.32	11.44	10.61	13.11	13.07	11.95	11.30	12.67
27	12.28	15.72	14.73	13.65	11.48	13.11	12.23	12.80	11.66	13.34	13.40	14.00	13.29	13.19
28	14.76	16.31	16.22	15.78	13.63	15.08	14.91	15.04	13.34	16.40	17.34	15.54	15.42	16.44

(Continued on next page)

Table H.6: Continued

Day	18	19	20	21	22	23	24	25	26	27	28*	29	30	31
29	14.68	17.09	16.61	15.88	13.31	15.44	14.90	15.65	13.61	15.05	15.94	15.77	14.54	15.17
30	18.46	21.43	22.79	18.62	15.73	19.55	19.46	20.70	16.82	21.22	21.73	22.49	18.52	20.61
31	13.32	16.23	16.62	15.44	13.71	15.31	14.24	15.25	13.50	15.49	15.47	16.18	14.29	15.88
32	11.22	12.17	11.63	11.95	11.17	12.05	11.38	11.65	11.24	12.60	12.18	12.33	12.18	11.92
33	16.76	17.66	18.33	17.48	14.84	18.25	18.52	20.01	16.30	19.55	20.11	20.52	17.96	17.86
34	19.06	20.43	21.36	20.25	17.29	20.14	19.94	20.67	19.02	20.15	22.03	20.87	17.93	19.82
35	20.42	21.09	21.98	20.31	18.33	21.84	20.86	22.93	19.18	21.93	22.67	23.07	20.86	21.38
36	21.02	21.86	23.16	21.87	19.55	22.86	22.91	24.10	21.85	23.82	23.99	25.09	22.31	22.18
37	19.42	21.10	22.24	21.36	19.06	22.24	21.72	22.58	20.81	22.93	23.51	23.76	22.45	22.40
38	17.33	19.47	19.91	20.77	18.12	20.37	20.72	20.51	19.88	22.52	22.75	22.05	19.76	22.06
39	21.37	22.59	24.06	22.37	20.32	22.30	22.18	22.23	20.70	23.55	24.10	23.55	21.30	24.52
40	24.31	24.38	25.73	23.60	22.63	24.89	25.17	24.74	23.08	25.85	26.66	26.07	23.88	27.80
41	25.56	25.86	28.37	25.86	23.87	26.30	25.78	26.68	24.64	25.99	27.96	27.72	24.75	29.07
42	23.86	25.32	26.83	24.34	21.74	25.64	25.45	26.54	22.97	26.62	27.58	28.25	24.48	29.03
43	19.88	21.87	21.19	19.91	17.19	19.96	19.53	18.85	17.77	20.87	21.90	21.11	18.43	20.01
44	18.67	20.51	21.52	18.72	17.26	20.25	20.06	19.86	17.06	21.69	23.06	21.57	18.21	21.22
45	21.40	22.83	24.83	20.85	19.49	22.16	21.32	21.92	20.29	22.58	24.04	24.42	20.28	23.89
46	21.61	21.42	22.83	20.64	19.19	21.07	20.96	21.30	19.14	20.76	22.16	22.86	19.37	21.37
47	24.25	23.79	27.26	22.39	18.73	23.96	24.02	25.69	22.96	23.98	26.00	27.44	23.21	25.56
48	21.32	23.94	24.70	21.09	18.37	20.56	21.35	21.32	19.53	21.38	23.06	23.03	20.05	22.31
49	23.65	23.89	26.44	21.66	19.22	23.39	22.92	23.69	21.96	24.42	25.93	26.25	22.52	25.41
50	25.49	25.05	27.99	23.07	20.69	24.34	24.83	24.72	23.14	25.06	27.48	26.51	22.38	26.36
51	22.81	23.33	24.75	21.16	18.06	24.11	21.95	23.61	20.22	23.61	25.32	24.75	22.30	23.21
52	22.00	21.27	23.67	20.39	18.27	22.81	21.18	22.63	21.03	23.79	24.51	24.88	22.65	24.53
53	21.91	22.85	23.86	22.23	19.22	22.57	20.88	22.54	22.15	22.08	24.26	24.79	21.04	23.88
54	20.07	20.07	23.85	19.07	15.82	19.94	19.67	21.64	18.08	20.94	22.95	22.06	18.92	20.58
55	23.02	22.39	25.69	21.16	19.87	22.85	22.06	24.05	20.66	23.48	25.09	24.73	20.02	22.82
56	25.71	24.77	26.76	23.84	21.83	24.55	23.55	26.20	23.18	24.68	27.54	26.74	22.52	24.33
57	20.36	20.64	21.70	18.26	16.50	21.09	18.42	21.16	18.05	21.06	21.30	21.89	20.24	19.56

(Continued on next page)

Table H.6: Continued

Day	18	19	20	21	22	23	24	25	26	27	28*	29	30	31
58	17.86	19.21	19.98	18.51	16.97	19.98	18.42	20.02	16.70	20.80	21.08	19.00	18.22	19.04
59	19.04	20.87	22.21	19.19	17.74	19.64	18.98	20.11	17.94	20.44	21.56	20.77	18.38	21.42
60	22.67	22.82	25.86	22.32	21.15	23.00	21.24	25.05	20.80	22.70	24.40	25.31	20.65	24.53
61	22.93	21.89	23.84	22.05	21.21	23.80	21.94	25.37	22.25	23.87	24.84	25.29	22.41	24.69
62	22.51	22.48	24.36	21.59	20.13	22.59	20.78	23.71	21.21	23.15	25.08	24.25	21.42	23.61
63	20.11	19.84	20.97	18.56	16.45	19.58	18.07	19.36	16.50	20.67	21.77	20.03	18.49	20.07
64	23.98	23.11	23.94	22.58	19.62	23.36	22.77	24.67	22.32	23.70	25.93	24.71	20.94	23.36
65	20.80	22.42	22.57	21.66	19.73	21.01	21.28	22.38	19.85	22.08	22.88	22.99	19.34	23.12
66	23.50	22.54	26.86	23.44	21.91	25.44	22.82	26.19	22.76	26.55	26.69	27.55	22.66	25.25
67	23.13	22.03	24.77	21.89	18.61	23.50	21.05	24.53	21.13	24.53	24.55	25.51	20.69	24.01
68	23.61	22.42	25.50	22.13	20.03	23.16	21.19	25.01	21.29	23.77	23.88	26.33	21.77	22.97
69	16.55	20.07	18.87	19.28	16.08	17.46	16.24	18.45	16.11	19.34	19.99	18.89	17.61	20.83
70	22.54	22.56	25.80	22.19	19.78	22.26	21.40	24.70	21.49	24.03	25.20	25.10	20.39	23.38
71	22.25	22.97	25.07	22.68	19.90	22.77	22.31	24.33	21.06	23.72	25.96	24.46	20.41	24.60
72	24.22	24.93	28.02	22.92	19.88	22.77	21.82	25.71	21.78	22.35	23.94	27.84	22.40	24.24
73	23.49	23.54	27.34	21.67	19.43	24.79	22.11	24.37	21.18	22.32	25.75	25.25	22.44	22.95
74	19.38	19.55	21.69	18.41	16.75	21.29	18.81	21.64	16.86	20.55	21.59	20.47	19.56	20.75
75	19.86	19.69	19.41	19.42	17.30	20.90	18.89	21.97	17.48	21.26	21.77	21.77	19.25	20.71
76	21.65	21.00	23.96	21.29	18.61	21.78	20.73	24.36	20.44	21.92	22.39	24.12	21.10	21.96
77	20.52	22.48	24.82	21.30	17.80	20.59	19.62	23.01	19.28	21.81	22.65	24.26	20.38	22.57
78	19.89	21.50	21.27	21.55	18.40	21.38	20.39	21.58	19.27	21.82	23.56	21.00	18.46	22.69
79	24.55	22.88	25.88	21.74	19.05	24.24	22.09	26.19	20.82	24.68	24.89	25.63	23.32	24.46
80	23.44	23.62	27.93	23.05	20.91	24.10	22.43	26.15	22.47	24.43	25.60	25.87	22.11	24.31
81	27.72	26.12	30.47	26.30	24.75	27.48	26.30	30.08	26.48	27.94	29.41	30.12	25.77	26.50
82	27.84	28.03	31.45	27.08	24.60	27.88	25.99	30.22	26.08	27.85	28.52	30.11	26.15	27.55
83	25.44	25.40	29.01	24.77	22.87	26.18	23.48	27.82	24.61	27.14	27.49	28.51	24.67	25.90
84	23.24	24.33	27.85	24.05	21.52	23.85	22.07	25.99	22.87	24.84	25.57	26.40	22.49	23.92
85	23.23	22.98	25.73	22.85	20.44	25.28	22.21	25.92	21.44	26.27	27.07	24.95	21.72	23.89
86	23.61	22.42	26.05	22.64	21.03	24.93	21.85	26.96	22.45	26.63	26.48	25.82	23.38	22.98

(Continued on next page)

Table H.6: Continued

Day	18	19	20	21	22	23	24	25	26	27	28*	29	30	31
87	25.21	25.32	29.55	25.29	23.66	25.97	23.06	28.31	25.06	27.17	26.93	28.38	23.58	24.91
88	22.23	24.76	26.70	23.36	19.76	23.05	21.40	25.05	21.31	23.83	23.82	24.91	23.83	22.76
89	21.13	24.34	25.78	22.59	19.26	22.42	20.69	24.05	20.59	21.81	21.58	23.56	21.69	21.43
90	21.94	24.16	26.75	22.55	21.35	23.69	20.71	25.18	21.59	23.90	24.51	24.41	21.01	22.47
91	20.36	24.16	25.59	22.22	20.79	23.81	20.37	24.29	20.70	23.42	23.17	23.31	19.52	22.74
92	23.86	26.07	30.00	24.04	23.36	25.69	23.40	28.06	23.86	24.86	26.13	26.50	23.51	24.11
93	25.49	27.03	28.52	24.70	23.89	25.12	24.11	27.06	24.25	27.16	28.28	27.61	22.95	25.31
94	23.05	23.92	27.73	23.42	21.27	24.81	22.57	26.79	22.46	26.45	26.60	25.95	21.89	25.21
95	23.47	24.22	27.49	22.98	22.55	24.67	22.35	26.98	23.41	26.73	25.86	26.02	22.81	25.09
96	24.54	24.82	26.74	24.05	23.03	25.14	22.60	25.90	23.19	26.62	26.54	25.53	23.29	24.98
97	22.02	20.75	23.90	21.32	19.09	23.98	20.08	24.73	20.02	25.14	24.61	23.54	21.65	22.44
98	21.42	22.27	24.42	21.68	20.44	22.91	21.00	23.59	21.10	24.92	24.65	25.41	21.30	23.17
99	24.40	24.68	27.46	23.69	21.76	24.83	22.22	25.06	22.66	25.92	26.98	26.54	23.00	24.76
100	23.73	24.16	25.31	23.02	21.02	24.23	23.21	26.13	21.70	26.23	26.46	25.69	21.33	24.73
101	26.11	26.64	28.03	24.54	24.19	26.81	25.14	28.33	24.99	28.42	28.05	28.43	24.40	27.13
102	21.70	21.34	23.80	22.00	19.76	23.69	21.04	23.56	21.11	24.27	25.04	23.73	21.62	22.79
103	20.98	22.58	23.01	21.95	19.07	22.53	20.63	22.84	20.11	23.62	24.30	23.11	20.30	22.81
104	22.28	23.60	24.97	21.73	20.43	22.33	21.29	25.21	20.81	24.11	24.34	24.99	21.68	24.04
105	19.80	21.23	22.31	20.87	19.62	21.30	20.25	24.21	20.00	23.85	23.17	23.59	20.51	23.25
106	21.26	21.54	24.10	21.03	19.40	22.39	20.61	24.65	19.70	25.12	23.52	25.25	21.74	23.66
107	22.68	23.80	25.59	22.34	22.40	23.57	23.00	26.32	22.48	25.48	24.72	26.79	22.05	25.51
108	24.51	26.11	27.34	23.89	22.63	25.38	24.04	28.50	23.50	27.04	26.47	29.40	23.99	26.50
109	22.72	23.94	25.89	23.32	22.02	24.62	23.57	26.83	22.77	26.16	26.30	28.43	23.42	26.16
110	25.70	26.85	29.38	24.74	24.26	26.67	25.54	29.37	24.60	27.10	27.50	29.98	25.12	28.28
111	19.74	21.85	23.41	21.15	17.57	22.47	20.96	25.73	18.70	24.02	23.34	23.51	20.24	22.41
112	17.92	18.50	20.30	18.37	16.51	19.71	18.15	22.45	17.13	20.39	19.96	20.16	19.31	19.93
113	18.61	18.51	21.66	18.81	16.84	19.55	17.04	22.82	17.53	22.07	21.45	21.55	18.42	20.54
114	22.13	22.17	25.01	21.15	21.01	22.84	21.20	26.28	21.59	24.78	24.16	24.27	21.52	23.79
115	24.83	25.84	28.68	24.81	24.21	26.36	23.61	29.36	25.76	26.90	27.37	28.09	24.75	26.60

(Continued on next page)

Table H.6: Continued

Day	18	19	20	21	22	23	24	25	26	27	28*	29	30	31
116	15.29	20.65	21.41	19.54	17.95	19.00	18.09	19.58	16.81	22.47	21.82	20.47	16.99	20.44
117	14.88	17.23	18.31	16.01	14.70	17.23	15.45	17.17	14.47	18.24	18.71	17.45	16.27	16.71
118	19.73	18.92	23.04	19.09	18.50	21.22	19.05	25.10	18.06	23.69	23.25	23.03	20.22	22.35
119	17.54	18.99	20.92	18.37	17.10	19.18	17.38	20.48	16.70	21.12	20.99	20.44	18.10	19.36
120	18.36	19.42	22.68	19.23	19.09	20.20	17.93	24.19	18.83	23.30	22.63	22.32	18.97	22.07
121	20.61	21.93	22.64	21.49	20.35	20.97	19.69	22.86	19.05	23.82	23.09	23.51	21.04	21.95
122	17.61	19.30	22.59	18.98	18.37	20.26	18.23	23.71	18.01	22.70	22.11	22.93	18.68	20.38
123	19.47	21.04	22.92	20.26	19.83	20.90	19.18	23.40	18.32	22.89	22.74	23.07	18.65	21.22
124	19.59	18.86	19.19	20.63	19.02	20.81	19.80	22.56	18.59	22.66	23.86	21.26	18.48	21.75
125	22.21	22.96	24.56	23.27	22.10	23.62	23.03	26.28	21.78	24.41	25.56	23.56	21.45	24.74
126	20.21	22.40	22.83	23.43	21.71	22.14	22.52	24.60	21.30	24.33	24.45	21.92	20.66	23.64
127	16.07	18.79	19.92	18.34	15.90	17.91	16.73	18.17	15.62	19.47	19.04	19.39	17.09	17.89
128	14.72	16.56	17.38	16.15	14.26	16.14	14.88	16.75	13.63	17.67	17.33	17.07	15.41	16.92
129	12.24	13.73	13.02	13.78	12.74	13.60	12.62	13.37	12.19	14.81	14.29	13.98	13.37	13.60
130	15.16	15.23	17.79	15.75	15.06	17.21	15.43	21.57	14.01	18.30	18.04	18.42	14.90	17.09
131	11.07	11.80	11.28	13.21	12.50	12.23	11.17	11.59	11.00	14.41	12.90	12.18	12.06	13.10
132	11.41	13.60	14.42	13.11	12.19	13.04	12.49	13.55	11.41	15.00	13.95	14.30	12.37	13.63
133	12.78	14.89	17.61	14.58	14.02	16.96	14.84	20.30	12.69	17.96	16.99	16.51	13.64	15.87
134	12.19	15.31	16.10	13.86	13.45	15.09	13.35	16.97	12.65	15.87	15.74	15.13	13.83	15.08
135	14.58	15.55	16.18	14.83	15.05	16.42	14.30	18.77	13.64	16.16	15.77	16.79	14.99	16.25
136	12.33	12.68	13.48	11.98	11.41	14.16	11.00	15.15	11.17	14.22	13.64	14.65	12.60	12.61
137	11.58	11.92	14.47	10.71	11.25	13.17	9.99	17.04	10.44	14.20	13.80	14.36	12.63	12.15
138	13.29	13.35	15.42	13.49	13.30	15.09	12.23	18.84	12.14	15.58	15.72	14.81	13.38	14.73
139	15.68	15.04	16.15	15.61	15.08	16.43	14.32	18.03	13.41	16.06	15.74	16.79	15.06	15.35
140	13.63	14.24	15.05	15.23	13.65	15.46	13.53	16.84	12.79	17.42	17.08	16.09	13.51	14.71
141	16.97	15.07	15.11	17.17	17.33	18.55	16.90	21.62	15.98	18.36	19.39	17.59	15.83	19.26
142	18.85	19.19	19.18	19.31	18.21	19.03	19.44	18.92	19.05	19.30	19.23	19.33	19.30	19.54

* indicates positive (present) Dakota skipper site

Appendix I: Site photos

Figure I.1: A female Dakota skipper observed on *Echinacea angustifolia*, displays her dorsal wings (Photo by K. Seidle).

Figure I.2: A female Dakota skipper observed on *Monarda fistulosa*, a potential nectaring plant of the Dakota skipper (Photo by K. Seidle).

Figure I.3: A female Dakota skipper observed on *Echinacea angustifolia,* a potential nectaring plant of the Dakota skipper (Photo by K. Seidle).

Figure I.4: Dakota skipper (Figure I.1) observed at the base of a south facing native prairie slope, in an actively grazed pasture, dominated by *Pediomelum argophyllum* (Photo by K. Seidle).

Figure I.5: A female and male Dakota skipper caught mating mid-flight display their ventral wings (Photo by K. Seidle).

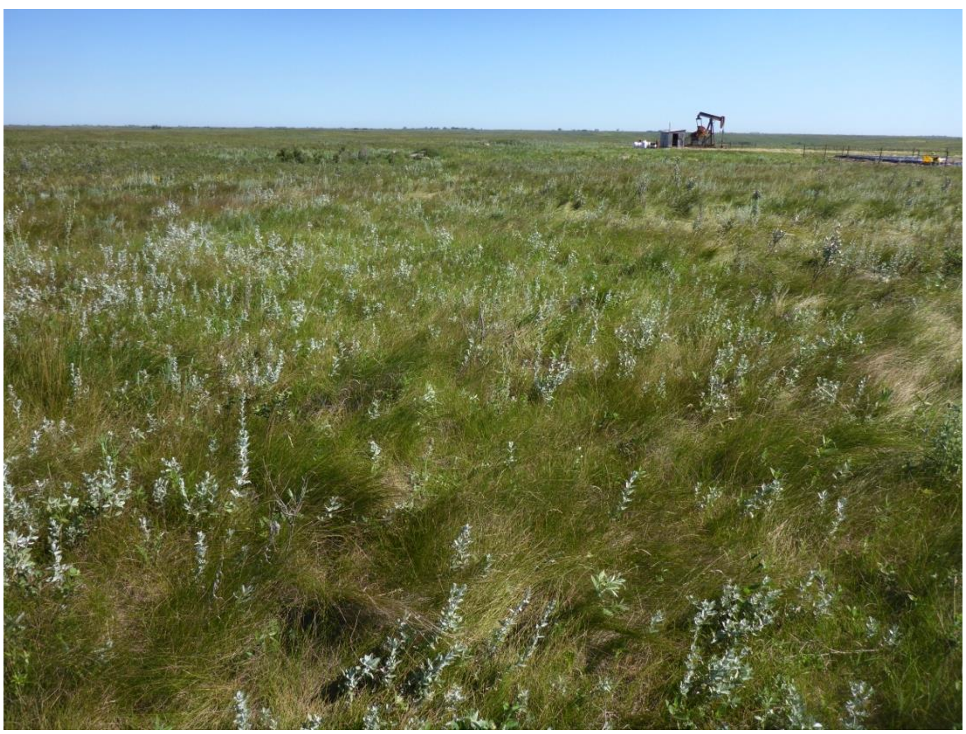

Figure I.6: Three Dakota skipper butterflies found in the Coalfield Community Pasture observed just down from a functioning oil pumpjack on a steep northwest facing slope. This pasture remains native prairie due to rocky soil that is not suitable for agriculture (Photo by K. Seidle).

Figure I.7: A Dakota skipper positive site (same site as Figure I.6) contains a large amount of *Pediomelum argophyllum*, a significant forb to Dakota skipper presence (Photo by K. Seidle).

Figure I.8: A male Dakota skipper is found just beyond a large gravel pit on a west facing slope. The site is dominated by *Pediomelum argophyllum*, a significant forb to Dakota skipper presence (Photo by K. Seidle).

Figure I.9: A Dakota skipper site (same site as Figure I.8) is experiencing *Bromus inermis* invasion and succession further down slope (Photo by K. Seidle).

Figure I.10: A negative Dakota skipper site experiencing succession of *Elaeagnus commutate*, a common occurrence now that wildfires have been suppressed within the mesic mixed-grass prairie (Photo by K. Seidle).


Figure I.11: A negative Dakota skipper site is severely overgrazed, contains little vegetation cover, and has exposed soils. The Souris River Valley contains sandy, gravelly, and stony soils, which have been exposed on this site (Photo by K. Seidle).


Figure I.12: A negative Dakota skipper site containing steep slopes demonstrating how pristine native prairies occur throughout the Souris River Valley as they are too steep to be cultivated (Photo by K. Seidle).

Figure I.13: A Dakota skipper positive site contains steep slopes and a dominant population of *Schizachyrium scoparium,* a significant plant species to Dakota skipper presence (Photo by K. Seidle).

Figure I.14: A Dakota skipper negative site contains a large population of *Echinacea angustifolia* and *Monarda fistulosa,* potential nectaring plants for the Dakota skipper butterfly (Photo by K. Seidle).

Figure I.15: A negative Dakota skipper site contains a large population of *Lilium philadelphicum* and *Campanula rotundifolia*, potential nectaring plants for the Dakota skipper butterfly (Photo by K. Seidle).

Figure I.16: An abandoned painted turtle (S3) shell found within the Souris River valley. The mesic mixed-grass prairie is host to a large variety of at-risk species (Photo by K. Seidle).

Figure I.17: The mesic mixed-grass prairie is host to the SARA listed northern leopard frog, which is locally abundant in the native prairies of the Souris River Valley; listed as an S3 special concern in Saskatchewan (Photo by K. Seidle).

Appendix J: Digital soil mapping variables

Table J.1: Digital soil mapping predictor variable definitions and citations.

Predictor Variable	Definition	Citation
Topographic wetness index	An index of expected moisture accumulation that considers catchment area and slope angle.	Beven and Kirkby 1979
SAGA wetness index	Similar to the topographic wetness index defined above but considers a modified catchment area.	Boehner *et al*. 2002
Slope height	Elevation above the nearest stream channel.	Boehner and Selige 2006
Normalized height	A measure of a grid cell's relative position in the local landscape.	Boehner and Selige 2006
Standardized height	The normalized height multiplied by the absolute elevation.	Boehner and Selige 2006
Valley depth	Elevation below the nearest ridge.	Boehner and Selige 2006
Mid-slope position	The elevation above or below the mid-slope position of a local hill-slope.	Boehner and Selige 2006
Specific dispersal area	The total area of land that a grid cell contributes flow towards per unit contour; calculated based on the catchment area.	Costa-Cabral and Burges 1994
Mutli-resolution ridge top flatness index	A calculation that determines flat valley bottoms based on elevation and slope.	Gallant and Dowling 2003
Mutli-resolution valley bottom flatness index	A complementary calculation to the valley bottom index that determines flat hill tops using a similar approach.	Gallant and Dowling 2003
Convergence index	An index reflecting if the slopes of adjacent grid cells face the target grid cell.	Koethe and Lehmeier 1996
Slope length and steepness factor	A calculation which accounts for slope length and slope gradient.	Moore *et al*. 1991
Catchment area	The total area of land that contributes flow to a grid cell; calculated using a multiple flow direction algorithm which considers that water may flow more than one direction from a grid cell.	Quinn *et al*. 1991

(Continued on next page)

Table J.1: Continued

Predictor Variable	Definition	Citation
Specific catchment area	The total area of land that contributes flow to a grid cell per unit contour; calculated based on the catchment area.	Quinn *et al*. 1991
Terrain ruggedness index	An index that quantifies topographic heterogeneity based on the total change in elevation of a grid cell compared to its adjacent cells.	Riley *et al*. 1999
Aspect	Direction of the slope face.	Zevenbergen and Thorne 1987
Slope	Angle of inclination relative to the horizontal plane.	Zevenbergen and Thorne 1987
General Curvature	A summary of curvature of the entire grid's surface.	Zevenbergen and Thorne 1987
Plan Curvature	The curvature along the horizontal plane. This is often referred to as the contour slope as it reflects the curvature along a hypothetical contour line.	Zevenbergen and Thorne 1987
Profile Curvature	The curvature in the direction of the steepest slope.	Zevenbergen and Thorne 1987
Tangential Curvature	The curvature perpendicular to the steepest slope gradient.	Zevenbergen and Thorne 1987

Appendix K: References

Ashworth, J. and Mrazek, K. 1995. “Modified kelowna” test for available phosporus and potassium in soil. Communications in Soil Science and Plant Analysis, **26**: 731–739. https://doi.org/10.1080/00103629509369331.

Beven, K.J. and Kirkby, M.J. 1979. A physically based, variable contributing area model of basin hydrology. Hydrological Sciences Journal, **24**: 43–69. https://doi.org/10.1080/02626667909491834.

Boehner, J. and Selige, T. 2006. Spatial prediction of soil attributes using terrain analysis and climate regionalisation. *In* Boehner, J., McCloy, K.R., and Strobl, J. SAGA - analysis and modelling applications. Goettinger Geographische Abhandlungen. Pp. 13–27.

Boehner, J., Koethe, R., Conrad, O., Gross, J., Ringeler, A., and Selige, T. 2002. Soil regionalisation by means of terrain analysis and process parameterisation. *In* Micheli, E., Nachtergaele, F., and Montanarella, L. Soil classification 2001. European Soil Bureau, Research Report No. 7, EUR 20398 EN, Luxembourg. Pp. 213–222.

Costa-Cabral, M.C. and Burges, S.J. 1994. Digital elevation model networks (DEMON): a model of flow over hillslopes for computation of contributing and dispersal areas. Water Resources Research, **30**: 1681–1692. https://doi.org/10.1029/93WR03512.

Ellert, B., VandenBygaart, A.J., Janzen, H., and Bremer, E. 2007. Measuring change in soil organic carbon storage. *In* Carter, M. and Gregorich, E. Soil sampling and methods of analysis. 2nd ed. CRC Press Taylor and Francis Group, Boca Raton, Florida. Pp. 25–38.

Gallant, J.C. and Dowling, T.I. 2003. A multiresolution index of valley bottom flatness for mapping depositional areas. Water Resources Research, **39**: 1347–1359. https://doi.org/10.1029/2002WR001426.

Hao, X., Ball, B.C., Culley, J.L.B., Carter, M.R., and Parkin, G.W. 2008. Soil density and porosity. *In* Carter, M.R. and Gregorich, E.G. Soil sampling and methods of analysis. 2nd ed. CRC Press Taylor and Francis Group, Boca Raton, Florida. Pp. 743–759.

Hendershot, W.H., Lalande, H., and Duquette, M. 2008. Soil reaction and exchangeable acidity. *In* Carter, M.R. and Gregorich, E.G. Soil sampling and methods of analysis. 2nd ed. CRC Press Taylor and Francis Group, Boca Raton, Florida. Pp. 173–178.

Indorante, S.J., Hammer, R.D., and Koenig, P.G., and Follmer, L. R. 1990. Particle-size analysis by a modified pipette procedure. Soil Science Society of America Journal, **54**: 560–563. doi:10.2136/sssaj1990.03615995005400020047x.

Koethe, R. and Lehmeier, F. 1996. SARA-system zur automatischen relief-analyse, benutzerhandbuch, 2. Goettingen University [unpublished].

Maynard, D., Kalra, Y., and Crumbaugh, J. 2008. Nitrate and exchangeable ammonium nitrogen. *In* Carter, M.R. and Gregorich, E.G. Soil sampling and methods of analysis. 2nd ed. CRC Press Taylor and Francis Group, Boca Raton, Florida. Pp. 71–80.

Miller, J.J. and Curtin, D. 2008. Electrical conductivity and soluble ions. *In* Carter, M.R. and Gregorich, E.G. Soil sampling and methods of analysis. 2nd ed. CRC Press Taylor and Francis Group, Boca Raton, Florida. Pp. 161–171.

Moore, I.D., Grayson, R.B., and Ladson, A.R. 1991. Digital terrain modelling: a review of hydrological, geomorphological, and biological applications. Hydrological Processes, **5**: 3–30. https://doi.org/10.1002/hyp.3360050103.

Quinn, P.F., Beven, K.J., Chevallier, P., and Planchon, O. 1991. The prediction of hillslope flow paths for distributed hydrological modelling using digital terrain models. Hydrological Processes, **5**: 59-79. https://doi.org/10.1002/hyp.3360050106.

Riley, S.J., DeGloria, S.D., and Elliot, R. 1999. A terrain ruggedness index that quantifies topographic heterogeneity. Intermountain Journal of Science, **5**: 23–27.

Skjemstad, J.O. and Baldock, J.A. 2008. Total and organic carbon. *In* Carter, M.R. and Gregorich, E.G. Soil sampling and methods of analysis. 2nd ed. CRC Press Taylor and Francis Group, Boca Raton, Florida. Pp. 225–237.

Zevenbergen, L.W. and Thorne, C.R. 1987. Quantitative analysis of land surface topography. Earth Surface Processes and Landforms, **12**: 47-56. https://doi.org/10.1002/esp.3290120107.

Ziadi, N. and Sen Tran, T. 2008. Mehlich 3-extractable elements. *In* Carter, M.R. and Gregorich, E.G. Soil sampling and methods of analysis. 2nd ed. CRC Press Taylor and Francis Group, Boca Raton, Florida. Pp. 81–88.