Weather-based Indices of Parasitic Fly Activity and Abundance for the Bathurst Caribou Post-calving and Summer Range: Users Guide

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Abstract

The effects of climate change are occurring at an accelerated rate in the Arctic, with a warming of 4-7°C predicted over the coming century (ACIA 2004). Insect harassment is thought to be one of the most important causal links between warm summer temperatures and reduced body condition in caribou and reindeer (*Rangifer tarandus*) (Weladji et al. 2003); however, there is a paucity of information describing regional variation and the effects of changing environmental conditions on the activity and abundance of parasitic insects in the central Arctic. To gain a better understanding of insect-weather relationships on the post-calving/summer range of the Bathurst barren-ground caribou (*Rangifer tarandus groenlandicus*) herd, we recorded weather conditions and used carbon dioxide baited traps to monitor insect activity during 2007-2009. We used these data to generate indices representative of the activity levels of mosquitoes, black flies, and oestrid flies. Here, we describe the data requirements and calculations for generating the indices, as well as some perspective on the interpretation and application of the model predictions for future use. A full accounting of the methods and interpretation of the indices can be found in Witter (2010). This guidance is intended for biologists interested in monitoring current trends or predicting future levels of insect activity on the post-calving/summer range of the Bathurst caribou herd.

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Introduction

Caribou and reindeer (*Rangifer tarandus*) populations are thought to cycle over 40- to 70-year periods; however, the mechanisms of these patterns are not well understood (Gunn 2003, Zalatan et al. 2006). This is problematic given that many *Rangifer* herds across the circumpolar north are currently in the downward portion of the cycle, and, it is unclear whether natural recovery will be possible in the face of climate change, industrial development, and increased hunting pressure (Forchhammer et al. 2002, Vors and Boyce 2009). The decline of the Bathurst barren-ground caribou (*R.t. groenlandicus*) herd in the Northwest Territories and Nunavut, exemplifies this trend, with numbers dropping from a peak of 472,000 ± 72,000 (SE) in 1986 to 31,900 ± 5,300 in 2009 (Nishi et al. 2010).

One hypothesis for the decline in *Rangifer* populations is that warmer summer temperatures may have increased the intensity and duration of harassment by parasitic insects, including mosquitoes (Culicidae), black flies (Simuliidae), and oestrid flies (Oestridae) (Brotton and Wall 1997, Mörschel and Klein 1997, Weladji et al. 2003, Callaghan et al. 2004). In addition to the direct effects of blood loss and parasitic loading, the behavioural responses of *Rangifer* to abundant and persistent parasitic flies can result in significant energetic and nutritional costs (Downes et al. 1986, Mörschel and Klein 1997, Hagemoen and Reimers 2002, Colman et al. 2003). During times of high insect harassment, caribou/reindeer may reduce time spent foraging and increase time spent in walking, running, and insect avoidance behaviours (Russell et al. 1993, Toupin et al. 1996, Colman et al. 2003). Resulting changes in the pattern, quality, and quantity of forage intake can have multiplicative effects on *Rangifer* growth and survival (White 1983, Reimers 1997, Colman et al. 2003).

Our understanding of the potential consequences of climatic warming for the levels of insect harassment experienced by caribou is hampered by a paucity of information on the effects of changing environmental conditions on the activity/abundance of different families of parasitic insects in the central Arctic (Gunn and Skogland 1997, Whitfield and Russell 2005). Climatic changes, including warmer temperatures throughout the year, increased summer rains, and longer growing seasons, are already being reported in many areas of the Arctic (Dye 2002, IPCC 2007, Environment Canada 2009). Insect harassment experienced by caribou/reindeer may begin earlier in the summer season, last longer, and intensify as summer conditions warm (Brotton and Wall 1997, Callaghan et al. 2004). Temperature is consistently cited as a key driver of insect activity/abundance (Sommerman et al. 1955, Haufe and Burgess 1956, Danks 2004, Quinlan et al. 2005); however, the response of insect species to changed conditions will likely be more complex than often suggested (Danks 2004). Identification of trends in disease and parasites, as well as alterations in caribou behaviour in response to environmental change will contribute to understanding the interplay of factors (e.g. disease/parasites, climate change, industrial development, harvest pressure, predation) driving changes in the numbers of Bathurst caribou (Bathurst Caribou Management Planning Committee 2004, NWT CIMP 2007, Chen et al. 2009, TG and GNWT ENR 2010). Increased knowledge of summer range ecology is critical for developing sustainable harvest levels and management strategies for caribou.

To address gaps in our understanding of climate-insect-caribou interactions, we quantified relationships between weather parameters, activity/abundance levels of parasitic insects, and caribou behaviour. During 2007-2009, we recorded weather conditions, used carbon dioxide baited traps to systematically monitor insect activity, and observed caribou behaviour on the post-calving/summer range of the Bathurst herd. General objectives were to: (1) develop indices representing activity/abundance of parasitic insects (mosquitoes, black flies, oestrid flies) as products of weather and time, (2) develop a chronology of predicted insect levels since the 1950s, and (3) define fine scale functional relationships between caribou behaviour, insect activity/abundance, habitat, and time/date.

This report focuses on the first objective. We developed predictive indices of insect activity/abundance that can be easily applied by biologists interested in both examining past and monitoring future conditions of insect activity across the post-calving/summer range of Bathurst caribou. Here, we describe the methods used to develop the insect indices, data requirements and calculations necessary for application of the indices, and considerations relevant to interpretation of index predictions. A full accounting of the methods and interpretation of the indices, as well as details related to the other objectives of the study, can be found in Witter (2010).

Methods

Data Collection

During July-August of 2007-2009, we collected insect trap catch and weather data in the central to southwestern portion of the Bathurst post-calving/summer range (Figure 1). We used locations of collared female caribou to select sites for sampling during intensive sessions chosen to correspond with peak insect season (Roby 1978, Boertje 1981, Dau 1986, Russell et al. 1993). Intensive sessions occurred over a total of 33 days during 2007-2009.

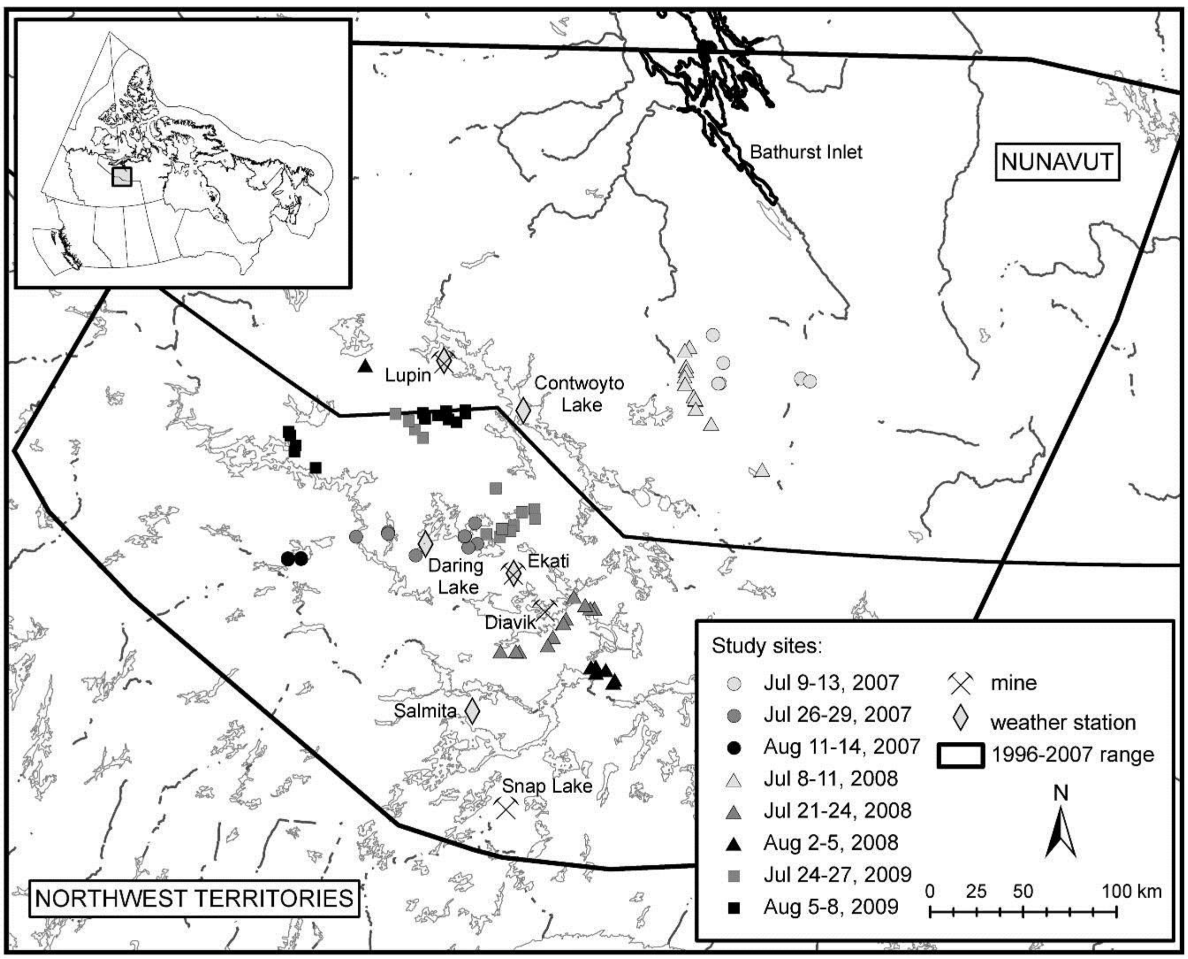

Figure 1. Post-calving/summer range of the Bathurst caribou herd 1996-2007. Point locations show mines, weather stations, Tundra Ecosystem Research Station at Daring Lake, and intensive session study sites from 2007-2009.

We also collected insect and weather data at the Tundra Ecosystem Research Station at Daring Lake, NWT in 2008-2009.

We collected data on weather variables thought to influence insect activity. Barometric pressure (BP), relative humidity (RH), temperature, wind speed, and light intensity were recorded at 10 minute intervals (Kestrel 4500 on Kestrel Portable Vane Mount, Nielsen Kellerman, Boothwyn, PA; data-logging light meter, Sper Scientific, Scottsdale, AZ). We calculated mean values of weather variables over each two-hr trapping session for use in insect models. We used modified Malaise traps baited with carbon dioxide (Anderson et al. 2001) to collect insects. We monitored traps over the 24-hr period; with insects collected and counted at two-hr intervals. We sorted insect catches into female mosquitoes, black flies, oestrid flies, and other.

Model Development

We developed sets of statistical models to test hypotheses about the combinations of weather and time/date variables (Table 1) that best predicted mosquito, black fly, and oestrid fly levels (Witter 2010). For mosquitoes and black flies, we modeled four categories (no, low, moderate, and high) of relative activity/abundance based on hourly trap catch data. Hourly trap catch numbers corresponding to 33.33 and 66.67 centile values were used to determine categorical breaks between low/moderate and moderate/high insect activity (Table 2). We used multinomial logistic regression (mlogit; Long and Freese 2001) to model the effects of changes in weather and time on levels of insect activity. Mlogits can be thought of as series of comparisons between categorical outcomes (Long 1997). Each binary comparison examined the effect of environmental variables on the probability of a given insect activity level compared to another (e.g. probability of low vs. moderate insect activity). Due to low trap catches, we modeled oestrid presence and absence using logistic regression. We used Intercooled Stata 9.2 (Statacorp, College Station, TX) for all statistical analyses.

Table 1. Independent variables used in indices of mosquito and black fly activity/abundance and oestrid fly presence/absence.

Variable	Description
Weather	
temp	Mean air temperature (°C)
wind	Mean wind speed (m/s)
light	Mean light level (lux)
BP	Mean barometric pressure (in Hg)
RH	Mean relative humidity (%)
Time/date	
time	
dawn	1 hr before to 2 hrs after sunrise
morning	2 hrs after sunrise to local/solar noon
afternoon	Local/solar noon to 2 hrs before sunset
dusk	2 hrs before sunset to 1 hr after sunset
night	1 hr after sunset to 1 hr before sunrise
gdd	Growing degree days relevant to insect development
gdd^2	Quadratic term for growing degree days

Table 2. Mosquito and black fly categories used in multinomial logistic regression (mlogit) models of insect activity/abundance on the Bathurst caribou post-calving/summer range, Northwest Territories and Nunavut, 2007-2009.

Category[*]	Mosquitoes/hr	Black flies/hr
None (0)	0	0
Low (1)	0-3.5	0-1.5
Moderate (2)	3.5-42.9	1.5-5.5
High (3)	>42.9	>5.5

[*] For categories 1-3, categorical breaks are based on hourly trap catch numbers corresponding to 33.33 and 66.67 centile values.

Model Selection and Index Development

We employed an Information Theoretic Model Comparison (ITMC) approach (Anderson et al. 2000) to select the most parsimonious model from each set for use as a predictive index of insect activity/abundance. To assess the fit of the models selected for use as indices, we determined the difference between observed and predicted insect activity levels, and calculated Pearson's standardized residuals. During model development, we withheld 20% of the data for use in validation of the final models. We used area under the Receiver Operating Characteristic (ROC) curve (AUC) to assess predictive ability as poor (0.5-0.7), reasonable (0.7-0.9), or very good (0.9-1.0) (Swets 1988). All models were interpreted as predicting activity level or presence/absence relative to the trap catch. While this was reflective of insect levels in the environment, trap catches did not measure absolute activity levels or presence/absence.

Summary of Results

The models selected for use as mosquito and black fly indices contained predictor variables describing time of day, growing degree days (gdd^2), temperature, wind speed, light intensity, BP, and RH (Appendix A). The predictive abilities of both of these indices were reasonable to very good, as indicated by ROC scores ranging from 0.84-1.00 and 0.81-1.00 for the series of binary logistic regressions representing the four levels of insect activity for the mosquito and black fly index, respectively. The model selected for the oestrid index contained predictor variables describing temperature, wind speed, light intensity, BP, and RH (Appendix A). Predictive ability of the oestrid index was also reasonable (AUC=0.84).

Temperature had a positive effect on activity of all three insect families; oestrids were the least tolerant of low temperatures. Wind speed negatively affected all insect activity, but this effect was strongest for mosquitoes. The effects of light, BP, and RH on black fly and oestrid activity were insignificant. Mosquito activity, on the other hand, was positively related to BP and RH. Thus, the effects of temperature and wind on mosquito activity may be moderated by changes in BP or RH. Time of day and season also affected the activity/abundance of mosquitoes and black flies. The probability of high mosquito activity increased during dusk and night, while black flies were most active during morning, afternoon, and dusk. Both mosquito and black fly activity exhibited quadratic relationships with gdd. Mosquito activity peaked in early to mid-July, largely separate from the period of greatest black fly activity in late July to early August.

Index Calculation

a. Data Requirements

Mosquito and black fly indices require data describing time of day, growing degree days (gdd), temperature, wind speed, light intensity, BP, and RH. The oestrid index requires information on temperature, wind speed, light intensity, BP, and RH.

Temperature - these data are commonly available from meteorological stations. Use air temperature values in Celsius (°C) when calculating the index.

Wind Speed - these data are commonly available from meteorological stations. Use wind speed values in metres/second (m/s) when calculating the index.

Light Intensity - use light intensity measures in lux. AANDC weather records consist of incoming short wave radiation (Kw/m^2) data instead of light intensity measurements. Multiply incoming radiation values by 248,756 to get an approximation of lux (Skye Instruments Ltd 2009). Environment Canada records do not contain data on light intensity. Ideally, light meters could be installed at these locations. In the absence of this, lux measurements corresponding to average values by time category from the 2007-2009 field data can be substituted for missing light intensity values (Table 3); however there is a high amount of day to day variability in light conditions during any given time category.

Table 3. Mean and standard deviation of light intensity (lux) by time category from data collected on the Bathurst post-calving/summer range (Witter 2010) during 2007-2009.

Time category	Mean light intensity (lux)	Standard deviation
Dawn (n=129)	4,119	8,225
Morning (n=261)	34,828	21,848
Afternoon (n=274)	32,734	20,980
Dusk (n=126)	2,693	4,099
Night (n=98)	104	510

Barometric Pressure (BP) - no weather stations currently record BP. In the absence of station-specific data, the mean BP value from the 2007-2009 field measurements ($\bar{x}$ = 28.33 in Hg, SD = 0.21) could be used.

Relative Humidity (RH) - these data are commonly available from meteorological stations. Use percent (%) RH in index calculations.

Time of Day - Mosquito and black fly indices use categorical values for time of day. Note whether or not initial time values are in daylight savings time (DST). AANDC reports time in DST; Environment Canada does not. All times should be changed to DST before converting to categorical values. Time is divided into five categories (dawn, morning, afternoon, dusk, night) based on relation to sunrise/sunset (Table 1). Since sunrise/set times vary over the course of the post-calving/summer season, time category boundaries differ depending on date. Sunrise/set times at the four weather stations (Daring Lake, Ekati, Lupin, Salmita) differ by ≤ 20 min. Mean sunrise/set times for the four locations can be used to determine time category (Appendix B). For example, weather data recorded at 13:00 hr on June 30 would fall in the 'morning' time category; a value of 1 would be used for morning in index calculations and values of 0 would be used for all other time categories (i.e. dawn, afternoon, dusk, night).

Growing Degree Days (gdd and gdd^2) - For mosquito and black fly indices, calculate growing degree days (gdd) relevant to insect development. Growing degree days are cumulative over the course of the growing season and represent the sum of mean daily temperature above 0°C (BC Centre for Disease Control 2009, University of California & California State Department of Agriculture & Natural Resources Integrated Pest

Management Program 2009). Ice-free date at Daring Lake can be used as the start date to begin accumulating gdds if ice-free data specific to a given weather station are not available. Alternatively, the mean ice-free date from 1996-2009 Daring Lake records (Julian day 169) can be used. Negative temperature values are set to zero during gdd calculation. The quadratic term, gdd^2, also needs to be generated for use in index calculations. To determine gdd^2, simply square the value calculated for gdd.

b. Weather Data and Future Analyses

Weather stations currently in operation on the Bathurst post-calving/summer range (Figure 1) include Daring Lake (GNWT ENR; Water Resources Division, Aboriginal Affairs and Northern Development Canada (AANDC)), Salmita (AANDC), and Ekati and LupinCS (Environment Canada).

With minor modifications, data from these weather stations can be used in the calculation of insect indices. If further short-term data are desired, temporary weather stations (e.g. Kestrel 4500 on Kestrel Portable Vane Mount, Nielsen Kellerman, Boothwyn, PA; data-logging light meter, Sper Scientific, Scottsdale, AZ) could be set up at additional locations across the range.

Values for insect indices can be calculated for each hourly weather record for the June 15 to September 1 time period. We combined weather data from a station previously in operation at Contwoyto Lake with the nearby LupinCS station to retrospectively calculate index values for the 1957-2008 post-calving/summer seasons (Witter 2010). For direct comparison with these retrospective Lupin/Contwoyto index values in the future, restrict Lupin index calculations to 06:00-18:00 hours DST. In all other cases, weather data for the complete 24-hr period should be used. Weather data are available from:

Environment Canada:
http://climat.meteo.gc.ca/climateData/canada_e.html
(Use ‘customized search’ by ‘station name’)

Aboriginal Affairs and Northern Development Canada:
Head, Water Management and Planning
Water Resources Division, Indian and Northern Affairs
Yellowknife, Northwest Territories
(Phone) 867-669-2661

c. Equations

Mosquito and black fly indices use multinomial logistic regression (mlogit; Long and Freese 2001) models to predict the probabilities of four levels (no, low, moderate, high) of insect activity (Table 2) for each hourly weather record. These levels of insect activity correspond with empirical trapping data collected from 2007-2009 (Witter 2010). The oestrid index is based on a logistic regression model, and predicts the probability of oestrid presence/absence for each hourly record. See Appendix C for sample index calculations.

Mosquito Index

The mosquito index predicts the probabilities of four levels (*m*) of insect activity (no (0), low (1), moderate (2), and high (3)) for each hourly weather data record. Using no mosquitoes (*m*=0) as a reference, for m=1, *m*:

$$\ln \frac{P(Y_i = m)}{P(Y_i = 0)} = \alpha_m + \sum_{k=1}^{K} \beta_{mk} x_{ik} = Z_{mi}$$

Here, *m* refers to the categorical level of insect activity and *k* refers to the independent variables (Williams 2009). Steps to calculate the mosquito index are as follows:

(1) Calculate Z_{mi} for *m*=1-3:

$\boldsymbol{Z_1}$=-20.04552+0.0054049*gdd-0.0000197*gdd^2+0.1551978*temp-0.7167382*wind+0.00000222*light+0.6793176*BP+0.0178509*RH-

0.6813476*dawn+0.2925948*morning-0.0385022*afternoon+0.5042725*dusk-0.0770176*night

$\boldsymbol{Z_2}$=-43.19938+0.0175277*gdd-0.0000606*gdd^2+0.1793057*temp-1.187834*wind-0.00000727*light+1.587921*BP-0.0000359*RH-0.4255667*dawn+0.0096408*morning-0.4136742*afternoon+0.1898509*dusk+0.6397492*night

$\boldsymbol{Z_3}$=-68.25537+0.0319474*gdd-0.0001338*gdd^2+0.3717478*temp-1.825519*wind-0.0000107*light+2.407874*BP+0.0126396*RH-0.4878346*dawn-0.5879428*morning-0.4953612*afternoon+0.7137365*dusk+0.8574021*night

(2) Next, the predicted probabilities of each mosquito activity level are calculated as:

$$P(Y_i = 0) = \frac{1}{1 + \exp(Z_1) + \exp(Z_2) + \exp(Z_3)}$$

$$P(Y_i = 1) = \frac{\exp(Z_1)}{1 + \exp(Z_1) + \exp(Z_2) + \exp(Z_3)}$$

$$P(Y_i = 2) = \frac{\exp(Z_2)}{1 + \exp(Z_1) + \exp(Z_2) + \exp(Z_3)}$$

$$P(Y_i = 3) = \frac{\exp(Z_3)}{1 + \exp(Z_1) + \exp(Z_2) + \exp(Z_3)}$$

(3) Compare the four probabilities calculated in Step 2. The predicted mosquito level is the category with the highest probability.

(4) Repeat Steps 1-3 for each hourly weather record.

(5) Across each season (June 15 - September 1), sum the number of hours with moderate-high predicted mosquito activity. These are calculated hourly values where the highest probability corresponds with either $P(Y_i=2)$ or $P(Y_i=3)$.

(6) Calculate the ratio of hours with moderate-high mosquito activity to the total number of hourly weather data records for the season. This ratio is the mosquito index value, and can be used to compare the intensity of mosquito activity across years.

Black Fly Index

Similar to the mosquito index, the black fly index predicts the probabilities of four levels of black fly activity using no activity as the reference level. Follow the steps below to calculate the black fly index:

(1) Calculate Z_{mi} for m=1-3:

$\boldsymbol{Z_1}$=2.548764+0.013693*gdd-0.0000181*gdd^2+0.2480225*temp-0.5195547*wind+0.00000604*light-0.2604663*BP+0.0048481*RH-0.4263185*dawn+0.2075883*morning+0.1175204*afternoon+0.5607764*dusk-0.4595666*night

$\boldsymbol{Z_2}$=-2.627903+0.0176196*gdd-0.0000275*gdd^2+0.6306475*temp-0.9051865*wind+0.0000116*light-0.3270503*BP+0.0278441*RH-0.8864531*dawn+0.4131525*morning+0.3046342*afternoon+0.7051569*dusk-0.5364905*night

$\boldsymbol{Z_3}$=2.712381+0.0455715*gdd-0.0000745*gdd^2+0.7681217*temp-1.42851*wind+0.00000221*light-0.6335725*BP+0.0151761*RH-0.8568974*dawn+0.8372642*morning+0.8321328*afternoon+0.9028336*dusk-1.715333*night

(2) Next, the predicted probabilities of each black fly activity level can be calculated as:

$$P(Y_i = 0) = \frac{1}{1 + \exp(Z_1) + \exp(Z_2) + \exp(Z_3)}$$

$$P(Y_i = 1) = \frac{\exp(Z_1)}{1 + \exp(Z_1) + \exp(Z_2) + \exp(Z_3)}$$

$$P(Y_i = 2) = \frac{\exp(Z_2)}{1 + \exp(Z_1) + \exp(Z_2) + \exp(Z_3)}$$

$$P(Y_i = 3) = \frac{\exp(Z_3)}{1 + \exp(Z_1) + \exp(Z_2) + \exp(Z_3)}$$

(3) Compare the four probabilities calculated in Step 2. The predicted black fly level is the category with the highest probability.

(4) Repeat Steps 1-3 for each hourly weather record.

(5) Across each season (June 15 - September 1), sum the number of hours with moderate-high predicted black fly activity. These are calculated hourly values where the highest probability corresponds with either $P(Y_i=2)$ or $P(Y_i=3)$.

(6) Calculate the ratio of hours with moderate-high black fly activity to the total number of hourly weather data records for the season. This ratio is the black fly index value, and can be used to compare the intensity of black fly activity across years.

Oestrid Index

The index for oestrid activity produces a value between 0 and 1 representing the probability of catching an oestrid fly during that hour. These values are calculated using logistic regression (Hosmer and Lemeshow 2000):

$$\ln \frac{P(Y_i = 1)}{1 - P(Y_i = 1)} = \alpha + \sum_{k=1}^{K} \beta_k x_{ik} = Z_i$$

Steps to calculate the oestrid index are as follows:

(1) Calculate Z_1:

$\boldsymbol{Z_1}$=16.70563+0.5971228*temp-0.5283295*wind+0.0000256*light-1.180306*BP+0.0626941*RH

(2) Then, calculate the probabilities of oestrid presence ($P(1)$):

$$P(1) = \frac{\exp(Z_1)}{1 + \exp(Z_1)}$$

(3) For each hourly weather record, the probability of oestrid presence is considered to be high if $P(1)>0.13$. This threshold represents the 95th centile value of predicted probabilities from the 2007-2009 trap catch data.

(4) Calculate the ratio of the number of hours with a high predicted probability of oestrid presence to the total number of hourly data records for each season. This ratio is the oestrid index value, and can be used to compare the intensity of oestrid activity across years.

Index Interpretation and Application

Insect indices should be interpreted as the proportion of the post-calving/summer season during which conditions are favourable for insect activity. For mosquitoes and black flies, indices are representative of conditions favouring moderate to high activity levels. For oestrids, the index reflects the proportion of time during which the probability of oestrid presence is high. Index values give a rough approximation of the severity of insect harassment experienced by Bathurst caribou during the post-calving/summer season. Indices can be calculated using weather data from the current year, past weather records, or predictions of future weather conditions; allowing for both retrospective and prospective projections of trends over time.

All indices are simplifications of reality, and users of the indices should be aware of aspects of insect ecology that we were not able to account for in our models. Most importantly, we were not able to distinguish changes in insect abundance from variations in activity levels (Williams 2009). Insect abundance in any given year is affected by insect population size, weather conditions, and host abundance in the previous season, as well as by conditions affecting larval development. Additionally, we found mosquito activity levels to be variable across the post-calving/summer range of the Bathurst herd (Witter 2010). This implies that particular caution should be taken in interpreting mosquito indices calculated at a few points as reflective of range-wide conditions.

Our indices focused on changes in conditions faced by adult insects, but did not account for potential climate change effects on other life-cycle stages that are also important in determining species presence and abundance (Fallis 1964, Hogg and Williams 1996, Danks 2004). Generalization of the indices to areas outside the Bathurst range may be possible, but will depend on whether or not habitat and climate conditions favour the survival of egg and larval stages of a similar complement of parasitic species. Black flies may not be prevalent in all *Rangifer* habitats; relatively little is known about their distribution and abundance on caribou ranges in North America (Anderson and Nilssen 1996). Horse flies (Tabanidae) were uncommon on the Bathurst range, but have been reported to cause avoidance responses by *Rangifer* in other areas (Karter and Folstad 1989, Anderson and Nilssen 1998).

Despite limitations, indices are a means of gauging the potential effects of climate change at the local-scale and allowing adaptive management in the absence of perfect information. Insect indices can be used as simple and cost-effective tools to translate meteorological data that is collected on a regular basis on the Bathurst range into predictions about the degree to which environmental conditions favour insect activity. In the absence of historical data on insect activity, retrospective indices provide a means of estimating reference insect activity levels against which to compare changes over time (Niemi and McDonald 2004, Hardman-Mountford et al. 2005). Used in conjunction with measures of other potential stressors (e.g. industrial development, hunting pressure, range condition), predictive insect indices can inform ecologically-based management actions for the Bathurst herd. In Arctic ecosystems, parameters of interest cannot always be efficiently and inexpensively measured on a regular basis (McKelvey and Pearson 2001, Hopkins and Kennedy 2004). Thus, tools such as indices with a strong basis in functional ecological relationships are important for detecting trends and understanding the causes and impacts of change over time (McGeoch 1998, Niemi and McDonald 2004).

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Website Links

Environment Canada weather data:
http://climat.meteo.gc.ca/climateData/canada_e.html

Julian/ordinal date conversion:
www.fs.fed.us/raws/book/julian.shtml

Latitude/longitude conversion:
www.fcc.gov/mb/audio/bickel/DDDMMSS-decimal.html

Sunrise/sunset times:
www.nrc-cnrc.gc.ca/eng/services/hia/sunrise-sunset/angle-calculator.htm

APPENDIX A: Coefficients (β) and 95% Confidence Intervals (CI) from Multinomial Logistic Regression Models (mlogit) Selected for use as Indices of Mosquito and Black Fly Activity/Abundance; and from Logistic Regression Model Selected as Index of Oestrid Presence/Absence on the Bathurst Caribou Post-calving/Summer Range, Northwest Territories and Nunavut, Canada. Coefficients for Growing Degree Days (gdd2) and Light Scaled by a Factor of 1000.

Mosquito Index:

Model coefficients for all other mosquito activity levels relative to absence of mosquitoes:

	Low mosquitoes			Moderate mosquitoes			High mosquitoes		
	β	95% CI		β	95% CI		β	95% CI	
		Lower	Upper		Lower	Upper		Lower	Upper
Gdd	0.005	0.002	0.009	0.018	0.005	0.030	0.032	−0.001	0.065
Gdd^2	−0.020	−0.029	−0.011	−0.061	−0.095	−0.026	−0.134	−0.229	−0.039
Temp	0.155	0.065	0.245	0.179	−0.013	0.371	0.372	0.097	0.647
Wind	−0.717	−0.835	−0.598	−1.188	−1.403	−0.973	−1.826	−2.143	−1.508
Light	0.002	−0.013	0.018	−0.007	−0.026	0.011	−0.011	−0.032	0.011
BP	0.679	−0.757	2.115	1.588	−1.894	5.070	2.408	−1.641	6.456
RH	0.018	−0.007	0.043	<−0.001	−0.027	0.027	0.013	−0.014	0.039
Time									
dawn	−0.681	−1.167	−0.195	−0.426	−0.922	0.071	−0.488	−1.056	0.080
morning	0.293	−0.146	0.731	0.01	−0.590	0.609	−0.588	−1.133	−0.043
afternoon	−0.039	−0.564	0.487	−0.414	−1.138	0.311	−0.495	−1.418	0.427
dusk	0.504	0.124	0.884	0.190	−0.241	0.620	0.714	0.223	1.205
night	−0.077	−0.813	0.659	0.640	−0.212	1.492	0.857	−0.449	2.164
Intercept	−20.046	−60.999	20.908	−43.199	−144.356	57.957	−68.255	−185.778	49.267

Model coefficients for all other mosquito activity levels relative to low mosquito activity:

	No mosquitoes			Moderate mosquitoes			High mosquitoes		
	β	95% CI		β	95% CI		β	95% CI	
		Lower	Upper		Lower	Upper		Lower	Upper
Gdd	−0.005	−0.009	−0.002	0.012	0.001	0.023	0.027	−0.005	0.058
Gdd^2	0.020	0.011	0.029	−0.041	−0.070	−0.012	−0.114	−0.205	−0.023
Temp	−0.155	−0.245	−0.065	0.024	−0.154	0.203	0.217	−0.087	0.520
Wind	0.717	0.598	0.835	−0.471	−0.614	−0.328	−1.109	−1.393	−0.825
Light	−0.002	−0.018	0.013	−0.009	−0.025	0.006	−0.013	−0.029	0.003
BP	−0.679	−2.115	0.757	0.909	−1.597	3.414	1.729	−1.501	4.958
RH	−0.018	−0.043	0.007	−0.018	−0.050	0.014	−0.005	−0.039	0.028
Time									
dawn	0.681	0.195	1.167	0.256	−0.185	0.697	0.194	−0.425	0.812
morning	−0.293	−0.731	0.146	−0.283	−0.758	0.192	−0.881	−1.399	−0.362
afternoon	0.039	−0.487	0.564	−0.375	−0.968	0.218	−0.457	−1.117	0.204
dusk	−0.504	−0.884	−0.124	−0.314	−0.802	0.173	0.209	−0.171	0.590
night	0.077	−0.659	0.813	0.717	0.148	1.286	0.934	0.103	1.766
Intercept	20.046	−20.908	60.999	−23.154	−97.503	51.195	−48.210	−143.819	47.399

Model coefficients for all other mosquito activity levels relative to moderate mosquito activity:

	No mosquitoes			Low mosquitoes			High mosquitoes		
	β	95% CI		β	95% CI		β	95% CI	
		Lower	Upper		Lower	Upper		Lower	Upper
Gdd	−0.018	−0.030	−0.005	−0.012	−0.023	−0.001	0.014	−0.012	0.040
Gdd^2	0.061	0.026	0.095	0.041	0.012	0.070	−0.073	−0.148	0.001
Temp	−0.179	−0.371	0.013	−0.024	−0.203	0.154	0.192	−0.012	0.396
Wind	1.188	0.973	1.403	0.471	0.328	0.614	−0.638	−0.891	−0.384
Light	0.007	−0.011	0.026	0.009	−0.006	0.025	−0.003	−0.027	0.020
BP	−1.588	−5.070	1.894	−0.909	−3.414	1.597	0.820	−0.957	2.597
RH	<0.001	−0.027	0.027	0.018	−0.014	0.050	0.013	−0.011	0.036
Time									
dawn	0.426	−0.071	0.922	−0.256	−0.697	0.185	−0.062	−0.657	0.532
morning	−0.010	−0.609	0.590	0.283	−0.192	0.758	−0.598	−1.045	−0.151
afternoon	0.414	−0.311	1.138	0.375	−0.218	0.968	−0.082	−0.675	0.511
dusk	−0.190	−0.620	0.241	0.314	−0.173	0.802	0.524	−0.124	1.172
night	−0.640	−1.492	0.212	−0.717	−1.286	−0.148	0.218	−0.410	0.845
Intercept	43.199	−57.957	144.356	23.154	−51.195	97.503	−25.056	−76.932	26.820

Model coefficients for all other mosquito activity levels relative to high mosquito activity:

	No mosquitoes			**Low mosquitoes**			**Moderate mosquitoes**		
	β	**95% CI**		**β**	**95% CI**		**β**	**95% CI**	
		Lower	**Upper**		**Lower**	**Upper**		**Lower**	**Upper**
Gdd	−0.032	−0.065	0.001	−0.027	−0.058	0.005	−0.014	−0.040	0.012
Gdd^2	0.134	0.039	0.229	0.114	0.023	0.205	0.073	−0.001	0.148
Temp	−0.372	−0.647	−0.097	−0.217	−0.520	0.087	−0.192	−0.396	0.012
Wind	1.826	1.508	2.140	1.109	0.825	1.393	0.638	0.384	0.891
Light	0.011	−0.011	0.032	0.013	−0.003	0.029	0.003	−0.020	0.027
BP	−2.408	−6.456	1.641	−1.729	−4.958	1.501	−0.820	−2.597	0.957
RH	−0.013	−0.039	0.014	0.005	−0.028	0.039	−0.013	−0.036	0.011
Time									
dawn	0.488	−0.080	1.056	−0.194	−0.812	0.425	0.062	−0.532	0.657
morning	0.588	0.043	1.133	0.881	0.362	1.399	0.598	0.151	1.045
afternoon	0.495	−0.427	1.418	0.457	−0.204	1.117	0.082	−0.511	0.675
dusk	−0.714	−1.205	−0.223	−0.209	−0.590	0.171	−0.524	−1.172	0.124
night	−0.857	−2.164	0.449	−0.934	−1.766	−0.103	−0.218	−0.845	0.410
Intercept	68.255	−49.267	185.778	48.210	−47.399	143.819	25.056	−26.820	76.932

Black Fly Index:

Model coefficients all other black fly activity levels relative to absence of black flies:

	Low black flies			**Moderate black flies**			**High black flies**		
	β	**95% CI**		**β**	**95% CI**		**β**	**95% CI**	
		Lower	**Upper**		**Lower**	**Upper**		**Lower**	**Upper**
Gdd	0.014	0.010	0.018	0.018	0.012	0.023	0.046	0.029	0.062
Gdd^2	−0.018	−0.024	−0.013	−0.028	−0.038	−0.017	−0.075	−0.099	−0.050
Temp	0.248	0.145	0.351	0.631	0.490	0.771	0.768	0.551	0.985
Wind	−0.520	−0.642	−0.397	−0.905	−1.077	−0.734	−1.429	−1.879	−0.978
Light	0.006	−0.011	0.023	0.012	−0.005	0.029	0.002	−0.024	0.028
BP	−0.260	−1.741	1.220	−0.327	−2.372	1.718	−0.634	−3.255	1.988
RH	0.005	−0.011	0.021	0.028	−0.003	0.059	0.015	−0.016	0.047
Time									
dawn	−0.426	−0.964	0.112	−0.886	−1.749	−0.024	−0.857	−1.813	0.099
morning	0.208	−0.208	0.624	0.413	−0.094	0.920	0.837	0.288	1.386
afternoon	0.118	−0.307	0.542	0.305	−0.179	0.788	0.832	−0.241	1.905
dusk	0.561	0.176	0.945	0.705	0.222	1.188	0.903	0.176	1.629
night	−0.460	−0.949	0.030	−0.536	−1.486	0.413	−1.715	−3.239	−0.191
Intercept	2.459	−40.811	45.908	−2.628	−63.470	58.215	2.712	−75.361	80.786

Model coefficients all other black fly activity levels relative to low black fly activity:

	No black flies			Moderate black flies			High black flies		
	β	95% CI		β	95% CI		β	95% CI	
		Lower	Upper		Lower	Upper		Lower	Upper
Gdd	−0.014	−0.018	−0.010	0.004	−0.002	0.010	0.032	0.015	0.049
Gdd^2	0.018	0.013	0.024	−0.009	−0.022	0.003	−0.056	−0.082	−0.030
Temp	−0.248	−0.351	−0.145	0.383	0.219	0.546	0.520	0.344	0.697
Wind	0.520	0.397	0.642	−0.386	−0.531	−0.240	−0.909	−1.316	−0.502
Light	−0.006	−0.023	0.011	0.006	−0.021	0.032	−0.004	−0.021	0.014
BP	0.260	−1.220	1.741	−0.067	−1.681	1.548	−0.373	−2.445	1.698
RH	−0.005	−0.021	0.011	0.023	−0.001	0.047	0.01	−0.014	0.035
Time									
dawn	0.426	−0.112	0.964	−0.460	−1.373	0.453	−0.431	−1.315	0.454
morning	−0.208	−0.624	0.208	0.206	−0.329	0.740	0.630	−0.039	1.299
afternoon	−0.118	−0.542	0.307	0.187	−0.295	0.669	0.715	−0.249	1.678
dusk	−0.561	−0.945	−0.176	0.144	−0.492	0.781	0.342	−0.216	0.900
night	0.460	−0.030	0.949	−0.077	−1.054	0.900	−1.256	−3.008	0.496
Intercept	−2.549	−45.908	40.811	−5.177	−53.086	42.733	0.164	−61.662	61.989

Model coefficients all other black fly activity levels relative to moderate black fly activity:

	No black flies			Low black flies			High black flies		
	β	95% CI		β	95% CI		β	95% CI	
		Lower	Upper		Lower	Upper		Lower	Upper
Gdd	−0.018	−0.023	0.012	−0.004	−0.010	0.002	0.028	0.014	0.042
Gdd^2	0.028	0.017	0.038	0.009	−0.003	0.022	−0.047	−0.067	−0.027
Temp	−0.631	−0.771	−0.490	−0.383	−0.546	−0.219	0.137	−0.044	0.319
Wind	0.905	0.734	1.077	0.386	0.240	0.531	−0.523	−0.913	−0.133
Light	−0.012	−0.029	0.005	−0.006	−0.032	0.021	−0.009	−0.039	0.021
BP	0.327	−1.718	2.372	0.067	−1.548	1.681	−0.307	−2.027	1.414
RH	−0.028	−0.059	0.003	−0.023	−0.047	0.001	−0.013	−0.033	0.007
Time									
dawn	0.886	0.024	1.749	0.460	−0.453	1.373	0.030	−0.664	0.723
morning	−0.413	−0.920	0.094	−0.206	−0.740	0.329	0.424	−0.207	1.055
afternoon	−0.305	−0.788	0.179	−0.187	−0.669	0.295	0.527	−0.368	1.423
dusk	−0.705	−1.188	−0.222	−0.144	−0.781	0.492	0.198	−0.666	1.061
night	0.536	−0.413	1.486	0.077	−0.900	1.054	−1.179	−2.874	0.516
Intercept	2.628	−58.215	63.470	5.177	−42.733	53.086	5.340	−45.180	55.860

Model coefficients all other black fly activity levels relative to high black fly activity:

	No black flies			Low black flies			Moderate black flies		
	β	95% CI		β	95% CI		β	95% CI	
		Lower	Upper		Lower	Upper		Lower	Upper
Gdd	−0.046	−0.062	−0.029	−0.032	−0.049	−0.015	−0.028	−0.042	−0.014
Gdd^2	0.075	0.050	0.099	0.056	0.030	0.082	0.047	0.027	0.067
Temp	−0.768	−0.985	−0.551	−0.520	−0.697	−0.344	−0.137	−0.319	0.044
Wind	1.429	0.978	1.879	0.909	0.502	1.316	0.523	0.133	0.913
Light	−0.002	−0.028	0.024	0.004	−0.014	0.021	0.009	−0.021	0.039
BP	0.634	−1.988	3.255	0.373	−1.698	2.445	0.307	−1.414	2.027
RH	−0.015	−0.466	0.016	−0.010	−0.035	0.014	0.013	−0.007	0.033
Time									
dawn	0.857	−0.099	1.813	0.431	−0.454	1.315	−0.030	−0.723	0.664
morning	−0.837	−1.386	−0.288	−0.630	−1.299	0.039	−0.424	−1.055	0.207
afternoon	−0.832	−1.905	0.241	−0.715	−1.678	0.249	−0.527	−1.423	0.368
dusk	−0.903	−1.629	−0.176	−0.342	−0.900	0.216	−0.198	−1.061	0.666
night	1.715	0.191	3.239	1.256	−0.496	3.008	1.179	−0.516	2.874
Intercept	−2.712	−80.786	75.361	−0.164	−61.989	61.662	−5.340	−55.860	45.180

Oestrid Index (Model Coefficients for Oestrid Presence Relative to Absence):

	β	95% CI	
Temp	0.597	0.330	0.864
Wind	−0.528	−1.498	0.441
Light	0.026	−0.035	0.086
BP	−1.180	−4.925	2.565
RH	0.063	0.012	0.113
Intercept	11.946	−93.952	117.844
Induration*	4.760	------	------

*Induration is an offset term to account for the average duration of the interval over which weather and insect trap catch data were collected (Witter 2010). In the oestrid index equation, the intercept and Induration are combined into a single constant term.

APPENDIX B: Time of Day Corresponding to each of The Five Time Categories used in Mosquito and Black Fly Index Calculations. National Research Council Canada (2009) Online Tool 'Sunrise/Sunset/Sun Angle Calculator' was used to Determine Sunrise, Local Noon, and Sunset Times at Daring Lake, Ekati, Lupin, and Salmita Weather Stations. These Values Were Averaged to Generate Mean Sunrise, Local Noon, and Sunset Times to use in Time Category Generation. All Times are in Daylight Savings Time (DST).

Month	Day	Julian day*	Sunrise†	Local noon†	Sunset†	Dawn	Morning	Afternoon	Dusk	Night
June	15	166	2:41	13:25	0:10	1:41 — 4:41	4:41 — 13:25	13:25 — 22:10	22:10 — 1:10	1:10 — 1:41
June	16	167	2:40	13:25	0:11	1:40 — 4:40	4:40 — 13:25	13:25 — 22:11	22:11 — 1:11	1:11 — 1:40
June	17	168	2:39	13:25	0:12	1:39 — 4:39	4:39 — 13:25	13:25 — 22:12	22:12 — 1:12	1:12 — 1:39
June	18	169	2:39	13:26	0:13	1:39 — 4:39	4:39 — 13:26	13:26 — 22:13	22:13 — 1:13	1:13 — 1:39
June	19	170	2:38	13:26	0:13	1:38 — 4:38	4:38 — 13:26	13:26 — 22:13	22:13 — 1:13	1:13 — 1:38
June	20	171	2:38	13:26	0:14	1:38 — 4:38	4:38 — 13:26	13:26 — 22:14	22:14 — 1:14	1:14 — 1:38
June	21	172	2:38	13:26	0:14	1:38 — 4:38	4:38 — 13:26	13:26 — 22:14	22:14 — 1:14	1:14 — 1:38
June	22	173	2:39	13:26	0:14	1:39 — 4:39	4:39 — 13:26	13:26 — 22:14	22:14 — 1:14	1:14 — 1:39
June	23	174	2:39	13:27	0:14	1:39 — 4:39	4:39 — 13:27	13:27 — 22:14	22:14 — 1:14	1:14 — 1:39
June	24	175	2:40	13:27	0:13	1:40 — 4:40	4:40 — 13:27	13:27 — 22:13	22:13 — 1:13	1:13 — 1:40
June	25	176	2:41	13:27	0:12	1:41 — 4:41	4:41 — 13:27	13:27 — 22:12	22:12 — 1:12	1:12 — 1:41
June	26	177	2:42	13:27	0:11	1:42 — 4:42	4:42 — 13:27	13:27 — 22:11	22:11 — 1:11	1:11 — 1:42
June	27	178	2:43	13:27	0:10	1:43 — 4:43	4:43 — 13:27	13:27 — 22:10	22:10 — 1:10	1:10 — 1:43
June	28	179	2:45	13:28	0:09	1:45 — 4:45	4:45 — 13:28	13:28 — 22:09	22:09 — 1:09	1:09 — 1:45
June	29	180	2:47	13:28	0:07	1:47 — 4:47	4:47 — 13:28	13:28 — 22:07	22:07 — 1:07	1:07 — 1:47
June	30	181	2:48	13:28	0:05	1:48 — 4:48	4:48 — 13:28	13:28 — 22:05	22:05 — 1:05	1:05 — 1:48
July	1	182	2:51	13:28	0:04	1:51 — 4:51	4:51 — 13:28	13:28 — 22:04	22:04 — 1:04	1:04 — 1:51
July	2	183	2:53	13:28	0:02	1:53 — 4:53	4:53 — 13:28	13:28 — 22:02	22:02 — 1:02	1:02 — 1:53
July	3	184	2:55	13:29	0:00	1:55 — 4:55	4:55 — 13:29	13:29 — 22:00	22:00 — 1:00	1:00 — 1:55
July	4	185	2:58	13:29	23:58	1:58 — 4:58	4:58 — 13:29	13:29 — 21:58	21:58 — 0:58	0:58 — 1:58
July	5	186	3:00	13:29	23:56	2:00 — 5:00	5:00 — 13:29	13:29 — 21:56	21:56 — 0:56	0:56 — 2:00
July	6	187	3:03	13:29	23:53	2:03 — 5:03	5:03 — 13:29	13:29 — 21:53	21:53 — 0:53	0:53 — 2:03
July	7	188	3:06	13:29	23:51	2:06 — 5:06	5:06 — 13:29	13:29 — 21:51	21:51 — 0:51	0:51 — 2:06
July	8	189	3:09	13:29	23:48	2:09 — 5:09	5:09 — 13:29	13:29 — 21:48	21:48 — 0:48	0:48 — 2:09

Month	Day	Julian day*	Sunrise†	Local noon†	Sunset†	Dawn	Morning	Afternoon	Dusk	Night
July	9	190	3:12	13:30	23:45	2:12 — 5:12	5:12 — 13:30	13:30 — 21:45	21:45 — 0:45	0:45 — 2:12
July	10	191	3:15	13:30	23:42	2:15 — 5:15	5:15 — 13:30	13:30 — 21:42	21:42 — 0:42	0:42 — 2:15
July	11	192	3:17	13:30	23:40	2:17 — 5:17	5:17 — 13:30	13:30 — 21:40	21:40 — 0:40	0:40 — 2:17
July	12	193	3:20	13:30	23:37	2:20 — 5:20	5:20 — 13:30	13:30 — 21:37	21:37 — 0:37	0:37 — 2:20
July	13	194	3:23	13:30	23:34	2:23 — 5:23	5:23 — 13:30	13:30 — 21:34	21:34 — 0:34	0:34 — 2:23
July	14	195	3:27	13:30	23:31	2:27 — 5:27	5:27 — 13:30	13:30 — 21:31	21:31 — 0:31	0:31 — 2:27
July	15	196	3:30	13:30	23:28	2:30 — 5:30	5:30 — 13:30	13:30 — 21:28	21:28 — 0:28	0:28 — 2:30
July	16	197	3:33	13:30	23:25	2:33 — 5:33	5:33 — 13:30	13:30 — 21:25	21:25 — 0:25	0:25 — 2:33
July	17	198	3:37	13:31	23:22	2:37 — 5:37	5:37 — 13:31	13:31 — 21:22	21:22 — 0:22	0:22 — 2:37
July	18	199	3:40	13:31	23:19	2:40 — 5:40	5:40 — 13:31	13:31 — 21:19	21:19 — 0:19	0:19 — 2:40
July	19	200	3:43	13:31	23:16	2:43 — 5:43	5:43 — 13:31	13:31 — 21:16	21:16 — 0:16	0:16 — 2:43
July	20	201	3:46	13:31	23:12	2:46 — 5:46	5:46 — 13:31	13:31 — 21:12	21:12 — 0:12	0:12 — 2:46
July	21	202	3:50	13:31	23:09	2:50 — 5:50	5:50 — 13:31	13:31 — 21:09	21:09 — 0:09	0:09 — 2:50
July	22	203	3:53	13:31	23:06	2:53 — 5:53	5:53 — 13:31	13:31 — 21:06	21:06 — 0:06	0:06 — 2:53
July	23	204	3:56	13:31	23:02	2:56 — 5:56	5:56 — 13:31	13:31 — 21:02	21:02 — 0:02	0:02 — 2:56
July	24	205	4:00	13:31	22:59	3:00 — 6:00	6:00 — 13:31	13:31 — 20:59	20:59 — 23:59	23:59 — 3:00
July	25	206	4:03	13:31	22:56	3:03 — 6:03	6:03 — 13:31	13:31 — 20:56	20:56 — 23:56	23:56 — 3:03
July	26	207	4:06	13:31	22:52	3:06 — 6:06	6:06 — 13:31	13:31 — 20:52	20:52 — 23:52	23:52 — 3:06
July	27	208	4:10	13:31	22:49	3:10 — 6:10	6:10 — 13:31	13:31 — 20:49	20:49 — 23:49	23:49 — 3:10
July	28	209	4:13	13:31	22:46	3:13 — 6:13	6:13 — 13:31	13:31 — 20:46	20:46 — 23:46	23:46 — 3:13
July	29	210	4:16	13:31	22:43	3:16 — 6:16	6:16 — 13:31	13:31 — 20:43	20:43 — 23:43	23:43 — 3:16
July	30	211	4:20	13:31	22:39	3:20 — 6:20	6:20 — 13:31	13:31 — 20:39	20:39 — 23:39	23:39 — 3:20
July	31	212	4:23	13:31	22:36	3:23 — 6:23	6:23 — 13:31	13:31 — 20:36	20:36 — 23:36	23:36 — 3:23
Aug.	1	213	4:27	13:31	22:32	3:27 — 6:27	6:27 — 13:31	13:31 — 20:32	20:32 — 23:32	23:32 — 3:27
Aug.	2	214	4:30	13:31	22:29	3:30 — 6:30	6:30 — 13:31	13:31 — 20:29	20:29 — 23:29	23:29 — 3:30
Aug.	3	215	4:33	13:31	22:25	3:33 — 6:33	6:33 — 13:31	13:31 — 20:25	20:25 — 23:25	23:25 — 3:33
Aug.	4	216	4:37	13:30	22:22	3:37 — 6:37	6:37 — 13:30	13:30 — 20:22	20:22 — 23:22	23:22 — 3:37
Aug.	5	217	4:40	13:30	22:18	3:40 — 6:40	6:40 — 13:30	13:30 — 20:18	20:18 — 23:18	23:18 — 3:40
Aug.	6	218	4:43	13:30	22:15	3:43 — 6:43	6:43 — 13:30	13:30 — 20:15	20:15 — 23:15	23:15 — 3:43
Aug.	7	219	4:47	13:30	22:11	3:47 — 6:47	6:47 — 13:30	13:30 — 20:11	20:11 — 23:11	23:11 — 3:47
Aug.	8	220	4:50	13:30	22:08	3:50 — 6:50	6:50 — 13:30	13:30 — 20:08	20:08 — 23:08	23:08 — 3:50
Aug.	9	221	4:53	13:30	22:04	3:53 — 6:53	6:53 — 13:30	13:30 — 20:04	20:04 — 23:04	23:04 — 3:53
Aug.	10	222	4:56	13:30	22:01	3:56 — 6:56	6:56 — 13:30	13:30 — 20:01	20:01 — 23:01	23:01 — 3:56

Month	Day	Julian day*	Sunrise†	Local noon†	Sunset†	Dawn	Morning	Afternoon	Dusk	Night
Aug.	11	223	4:59	13:30	21:57	3:59 — 6:59	6:59 — 13:30	13:30 — 19:57	19:57 — 22:57	22:57 — 3:59
Aug.	12	224	5:03	13:29	21:53	4:03 — 7:03	7:03 — 13:29	13:29 — 19:53	19:53 — 22:53	22:53 — 4:03
Aug.	13	225	5:06	13:29	21:50	4:06 — 7:06	7:06 — 13:29	13:29 — 19:50	19:50 — 22:50	22:50 — 4:06
Aug.	14	226	5:09	13:29	21:46	4:09 — 7:09	7:09 — 13:29	13:29 — 19:46	19:46 — 22:46	22:46 — 4:09
Aug.	15	227	5:13	13:29	21:43	4:13 — 7:13	7:13 — 13:29	13:29 — 19:43	19:43 — 22:43	22:43 — 4:13
Aug.	16	228	5:16	13:29	21:39	4:16 — 7:16	7:16 — 13:29	13:29 — 19:39	19:39 — 22:39	22:39 — 4:16
Aug.	17	229	5:19	13:28	21:35	4:19 — 7:19	7:19 — 13:28	13:28 — 19:35	19:35 — 22:35	22:35 — 4:19
Aug.	18	230	5:22	13:28	21:32	4:22 — 7:22	7:22 — 13:28	13:28 — 19:32	19:32 — 22:32	22:32 — 4:22
Aug.	19	231	5:25	13:28	21:28	4:25 — 7:25	7:25 — 13:28	13:28 — 19:28	19:28 — 22:28	22:28 — 4:25
Aug.	20	232	5:28	13:28	21:25	4:28 — 7:28	7:28 — 13:28	13:28 — 19:25	19:25 — 22:25	22:25 — 4:28
Aug.	21	233	5:31	13:27	21:21	4:31 — 7:31	7:31 — 13:27	13:27 — 19:21	19:21 — 22:21	22:21 — 4:31
Aug.	22	234	5:34	13:27	21:17	4:34 — 7:34	7:34 — 13:27	13:27 — 19:17	19:17 — 22:17	22:17 — 4:34
Aug.	23	235	5:38	13:27	21:14	4:38 — 7:38	7:38 — 13:27	13:27 — 19:14	19:14 — 22:14	22:14 — 4:38
Aug.	24	236	5:41	13:27	21:10	4:41 — 7:41	7:41 — 13:27	13:27 — 19:10	19:10 — 22:10	22:10 — 4:41
Aug.	25	237	5:44	13:26	21:07	4:44 — 7:44	7:44 — 13:26	13:26 — 19:07	19:07 — 22:07	22:07 — 4:44
Aug.	26	238	5:47	13:26	21:03	4:47 — 7:47	7:47 — 13:26	13:26 — 19:03	19:03 — 22:03	22:03 — 4:47
Aug.	27	239	5:50	13:26	20:59	4:50 — 7:50	7:50 — 13:26	13:26 — 18:59	18:59 — 21:59	21:59 — 4:50
Aug.	28	240	5:53	13:26	20:56	4:53 — 7:53	7:53 — 13:26	13:26 — 18:56	18:56 — 21:56	21:56 — 4:53
Aug.	29	241	5:56	13:25	20:52	4:56 — 7:56	7:56 — 13:25	13:25 — 18:52	18:52 — 21:52	21:52 — 4:56
Aug.	30	242	5:59	13:25	20:49	4:59 — 7:59	7:59 — 13:25	13:25 — 18:49	18:49 — 21:49	21:49 — 4:59
Aug.	31	243	6:02	13:25	20:45	5:02 — 8:02	8:02 — 13:25	13:25 — 18:45	18:45 — 21:45	21:45 — 5:02
Sept.	1	244	6:05	13:24	20:41	5:05 — 8:05	8:05 — 13:24	13:24 — 18:41	18:41 — 21:41	21:41 — 5:05

*For Julian day in a leap year, add 1.

†Mean of sunrise, local noon, and sunset times from Daring Lake, Ekati, Lupin, and Salmita. Times at the different weather station differ by ≤ 20 minutes.

APPENDIX C: Example Calculations of Mosquito, Black Fly, and Oestrid Indices using Weather Data from Daring Lake Weather Station (GNWT ENR; Water Resources Division, Aboriginal Affairs and Northern Development Canada (AANDC)), 10:00 hr July 9, 2003.

Raw Data

gdd = 221.6

gdd^2 = 221.6 * 221.6 = 49,106.56

temp = 16.8°C

wind = 1.223 m/s

light = 86,878.11 lux

BP = 28.33 in Hg

RH = 65.54%

julian day = 190

time = 10:00 hr

Use Table 2 to determine time category. 10:00 falls between 5:12 and 13:30, thus morning takes on a value of 1 and all other time categories take on values of 0.

dawn = 0

morning = 1

afternoon = 0

dusk = 0

night = 0

Mosquito Index

The mosquito index predicts the probabilities of four levels (*m*) of insect activity (no (0), low (1), moderate (2), high (3)) for each hourly weather data record. Steps to calculate the mosquito index are as follows:

(1) Calculate Z_{mi} for m=1-3:

$\boldsymbol{Z_1}$=-20.04552+0.0054049*gdd-0.0000197*gdd^2+0.1551978*temp-0.7167382*wind+0.00000222*light+0.6793176*BP+0.0178509*RH-0.6813476*dawn+0.2925948*morning-0.0385022*afternoon+0.5042725*dusk-0.0770176*night

$\boldsymbol{Z_1}$=-20.04552+(0.0054049*221.6)+(-0.0000197*49,106.56)+(0.1551978*16.8)+(-0.7167382*1.223)+(0.00000222*86,878.11)+(0.6793176*28.33)+(0.0178509*65.54)+(-0.6813476*0)+(0.2925948*1) + (-0.0385022*0) + (0.5042725*0) + (-0.0770176*0)

$\boldsymbol{Z_1}$ = 2.816038628

$\boldsymbol{Z_2}$=-43.19938+0.0175277*gdd-0.0000606*gdd^2+0.1793057*temp-1.187834*wind-0.00000727*light+1.587921*BP-0.0000359*RH-0.4255667*dawn+0.0096408*morning-0.4136742*afternoon+0.1898509*dusk+0.6397492*night

$\boldsymbol{Z_2}$=-43.19938+(0.0175277*221.6)+(-0.0000606*49,106.56)+(0.1793057*16.8)+(-1.187834*1.223)+(-0.00000727*86,878.11)+(1.587921*28.33)+(-0.0000359*65.54)+(-0.4255667*0)+(0.0096408*1)+(-0.4136742*0)+(0.1898509*0)+(0.6397492*0)

$\boldsymbol{Z_2}$ = 3.630001546

$\boldsymbol{Z_3}$=-68.25537+0.0319474*gdd-0.0001338*gdd^2+0.3717478*temp-1.825519*wind-0.0000107*light+2.407874*BP+0.0126396*RH-0.4878346*dawn-0.5879428*morning-0.4953612*afternoon+0.7137365*dusk+0.8574021*night

$\boldsymbol{Z_3}$=-68.25537+(0.0319474*221.6)+(-0.0001338*49,106.56)+(0.3717478*16.8)+(-1.825519*1.223)+(-0.0000107*86,878.11)+(2.407874*28.33)+(0.0126396*65.54)+(-0.4878346*0)+(-0.5879428*1)+(-0.4953612*0)+(0.7137365*0)+(0.8574021*0)

$\boldsymbol{Z_3}$=3.792400642

(2) Next, the predicted probabilities of each mosquito activity level are calculated as:

$$P(Y_i = 0) = \frac{1}{1 + \exp(Z_1) + \exp(Z_2) + \exp(Z_3)}$$

$$P(Y_i = 0) = \frac{1}{1 + \exp(2.816038628) + \exp(3.630001546) + \exp(3.792400642)}$$

$$P(Y_i = 0) = 0.010021429$$

$$P(Y_i = 1) = \frac{\exp(Z_1)}{1 + \exp(Z_1) + \exp(Z_2) + \exp(Z_3)}$$

$$P(Y_i = 1) = \frac{\exp(2.816038628)}{1 + \exp(2.816038628) + \exp(3.630001546) + \exp(3.792400642)}$$

$$P(Y_i = 1) = 0.167463316$$

$$P(Y_i = 2) = \frac{\exp(Z_2)}{1 + \exp(Z_1) + \exp(Z_2) + \exp(Z_3)}$$

$$P(Y_i = 2) = \frac{\exp(3.630001546)}{1 + \exp(2.816038628) + \exp(3.630001546) + \exp(3.792400642)}$$

$$P(Y_i = 2) = 0.377936894$$

$$P(Y_i = 3) = \frac{\exp(Z_3)}{1 + \exp(Z_1) + \exp(Z_2) + \exp(Z_3)}$$

$$P(Y_i = 3) = \frac{\exp(3.792400642)}{1 + \exp(2.816038628) + \exp(3.630001546) + \exp(3.792400642)}$$

$$P(Y_i = 3) = 0.444578361$$

(3) Compare the four probabilities calculated in Step 2. The predicted mosquito level is the category with the highest probability.

$$0.444578361 > 0.377936984 > 0.167463316 > 0.010021429$$

$P(Y_i = 3)$ is highest. Thus, the predicted mosquito level is Category 3 or ‘high’.

(4) If calculating index values for an entire season, repeat Steps 1-3 for each hourly weather record. Then, across each season (June 15 - Sept 1), sum the number of hours with moderate-high predicted mosquito activity. These are calculated hourly values where the highest probability corresponds with either $P(Y_i=2)$ or $P(Y_i=3)$. Calculate the ratio of hours with moderate-high mosquito activity to the total number of hourly weather data records for the season. This ratio is the mosquito index value, and can be used to compare the intensity of mosquito activity across years.

Black Fly Index

Similar to the mosquito index, the black fly index predicts the probabilities of four levels of black fly activity using no activity as the reference level. Follow the steps below to calculate the black fly index:

(1) Calculate Z_{mi} for m=1-3:

$\boldsymbol{Z_1}$=2.548764+0.013693*gdd-0.0000181*gdd^2+0.2480225*temp-0.5195547*wind+0.00000604*light-0.2604663*BP+0.0048481*RH-0.4263185*dawn+0.2075883*morning+0.1175204*afternoon+0.5607764*dusk-0.4595666*night

$\boldsymbol{Z_1}$=2.548764+(0.013693*221.6)+(-0.0000181*49,106.56)+(0.2480225*16.8)+(-0.5195547*1.223)+(0.00000604*86,878.11)+(-0.2604663*28.33)+(0.0048481*65.54)+(-0.4263185*0)+(0.2075883*1)+(0.1175204*0)+(0.5607764*0)+(-0.4595666*0)

$\boldsymbol{Z_1}$=1.896732945

$\boldsymbol{Z_2}$=-2.627903+0.0176196*gdd-0.0000275*gdd^2+0.6306475*temp-0.9051865*wind+0.0000116*light-0.3270503*BP+0.0278441*RH-0.8864531*dawn+0.4131525*morning+0.3046342*afternoon+0.7051569*dusk-0.5364905*night

$\boldsymbol{Z_2}$=-2.627903+(0.0176196*221.6)+(-0.0000275*49,106.56)+(0.6306475*16.8)+(-0.9051865*1.223)+(0.0000116*86,878.11)+(-0.3270503*28.3)+(0.0278441*65.54)+(-0.8864531*0)+(0.4131525*1)+(0.3046342*0)+(0.7051569*0)+(-0.5364905*0)

$\boldsymbol{Z_2}$=3.394510762

$\boldsymbol{Z_3}$=2.712381+0.0455715*gdd-0.0000745*gdd^2+0.7681217*temp-1.42851*wind+0.00000221*light-0.6335725*BP+0.0151761*RH-0.8568974*dawn+.8372642*morning+0.8321328*afternoon+0.9028336*dusk-1.715333*night

$\boldsymbol{Z_3}$=2.712381+(0.0455715*221.6)+(-0.0000745*49,106.56)+(0.7681217*16.8)+(-1.42851*1.223)+(0.00000221*86,878.11)+(-0.6335725*28.33)+(0.0151761*65.54)+(-0.8568974*0)+(0.8372642*1)+(0.8321328*0)+(0.9028336*0)+(-1.715333*0)

$\boldsymbol{Z_3}$=4.384761002

(2) Next, the predicted probabilities of each black fly activity level can be calculated as:

$$P(Y_i = 0) = \frac{1}{1 + \exp(Z_1) + \exp(Z_2) + \exp(Z_3)}$$

$$P(Y_i = 0) = \frac{1}{1 + \exp(1.896732945) + \exp(3.394510762) + \exp(4.384761002)}$$

$$P(Y_i = 0) = 0.008497389$$

$$P(Y_i = 1) = \frac{\exp(Z_1)}{1 + \exp(Z_1) + \exp(Z_2) + \exp(Z_3)}$$

$$P(Y_i = 1) = \frac{\exp(1.896732945)}{1 + \exp(1.896732945) + \exp(3.394510762) + \exp(4.384761002)}$$

$$P(Y_i = 1) = 0.05662734$$

$$P(Y_i = 2) = \frac{\exp(Z_2)}{1 + \exp(Z_1) + \exp(Z_2) + \exp(Z_3)}$$

$$P(Y_i = 2) = \frac{\exp(3.394510762)}{1 + \exp(1.896732945) + \exp(3.394510762) + \exp(4.384761002)}$$

$$P(Y_i = 2) = 0.253222796$$

$$P(Y_i = 3) = \frac{\exp(Z_3)}{1 + \exp(Z_1) + \exp(Z_2) + \exp(Z_3)}$$

$$P(Y_i = 3) = \frac{\exp(4.384761002)}{1 + \exp(1.896732945) + \exp(3.394510762) + \exp(4.384761002)}$$

$$P(Y_i = 3) = 0.681652475$$

(3) Compare the four probabilities calculated in Step 2. The predicted black fly level is the category with the highest probability.

$$0.681652475 > 0.253222796 > 0.05662734 > 0.008497389$$

$P(Y_i = 3)$ is highest. Thus, the predicted black fly level is Category 3 or 'high'.

(4) If calculating index values for an entire season, repeat Steps 1-3 for each hourly weather record. Then, across each season (June 15 - September 1), sum the number of hours with moderate-high predicted black fly activity. These are calculated hourly values where the highest probability corresponds with either $P(Y_i=2)$ or $P(Y_i=3)$.

Calculate the ratio of hours with moderate-high black fly activity to the total number of hourly weather data records for the season. This ratio is the black fly index value, and can be used to compare the intensity of black fly activity across years.

Oestrid Index

The index for oestrid activity produces a value between 0 and 1 representing the probability of catching an oestrid fly during that hour. Steps to calculate the oestrid index are as follows:

(1) Calculate Z_1:

Z_1=16.70563+0.5971228*temp-0.5283295*wind+0.0000256*light-1.180306*BP+0.0626941*RH

Z_1=16.70563+(0.5971228*16.8)+(-0.5283295*1.223)+(0.0000256*86,878.11)+(-1.180306*28.33)+(0.0626941*65.54)

Z_1=-1.013871989

(2) Then, calculate the probabilities of oestrid presence ($P(1)$):

$$P(1) = \frac{\exp(Z_1)}{1 + \exp(Z_1)}$$

$$P(1) = \frac{\exp(-1.013871989)}{1 + \exp(-1.013871989)}$$

$$P(1) = 0.26622278$$

(3) For each hourly weather record, the probability of oestrid presence is considered to be high if $P(1)>0.13$. In this example, $P(1)=0.266$, and oestrid presence is considered high.

(4) If calculating index values for an entire season, repeat Steps 1-3 for each hourly weather record. Calculate the ratio of the number of hours with a high predicted probability of oestrid presence to the total number of hourly data records for each season. This ratio is the oestrid index value, and can be used to compare the intensity of oestrid activity across years.