A PRELIMINARY STUDY ON REGIONAL VARIATION IN SKULL MORPHOMETRICS OF *VULPES VULPES* IN THUNDER BAY, ON

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A PRELIMINARY STUDY ON REGIONAL VARIATION IN SKULL MORPHOMETRICS OF *VULPES VULPES* IN THUNDER BAY, ONTARIO

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An undergraduate thesis submitted in partial fulfillment of the requirements for
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Major Advisor	Second Reader

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ABSTRACT

The purpose of this study was to identify whether morphological differences occur between subsets of Red Fox (*Vulpes vulpes* L.) from different areas in Thunder Bay district. The goal was to examine the statistical output generated from measurements of Red Fox skulls to determine whether differences in cranial measurement ratios occur over a short distance. The first phase of the research was to complete a literature review to determine significant cranial relationships in mammals. The second phase of this research was the examination of skulls from Thunder Bay using a discriminant function analysis to determine which cranial relationships are significant in describing variation across skulls.

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INTRODUCTION AND OBJECTIVE

Subspecies are semi-permanent classifications that require management independent of other subspecies due to specific needs or functions. Variation in subspecies or populations can arise from numerous factors, including genotypic variation, phenotypic variation, and separate breeding populations (Morris and Lundberg, 2011). The objectives of this thesis were to determine whether regional variation occurs in Red Fox *(Vulpes vulpes* L.) skull morphometrics and to speculate whether differences are caused by climate or variations in habitat, because resource availability during juvenile years has a significant impact on the development of an individual (Hanken and Hall 1993). This research is intended to be preliminary and a basis for comparison of any set of Red Fox skulls.

Examples of genotypic variations are genetic change arising from mutations, genetic drift or selection, whereas phenotypic variation is natural selection acting upon certain genes, in which the phenotype is a result of the effect of the environment on the genotype or development on genotype. The inheritance of specific genes is dependent on the success of an individual's ancestors; therefore, it is essential to acknowledge that variation in the environment can have a profound role on gene expression.

It is important to determine the extent to which a species encompasses morphological differences, because differences provide evidence as to whether a population deserves a unique taxonomical classification, information essential in management and conservation of biodiversity. The Red Fox is one of the most widely distributed mammals in the world (Tesky,1995) occurring in vastly different ecosystems. Craniometrical data may provide the grounds for future genetic testing and improved understanding of divergence of species and the impact that environmental factors have on morphology and development. It is valuable to study the skulls manually as genetic testing is not a complete review of an individual and it is expensive. Here I present an application involving data from a collection of Red Fox skulls at Lakehead University.

Vulpes vulpes occurs as nine subspecies in North America (Tesky, 1995). In this thesis, several skulls of will be measured following methodology of a similar study in Japan; skull width, skull height, mastoid width, occipital condyle width, zygomatic arch and mandible length (Yosuke et al., 2015). Additional measures will be cranial length, braincase width, braincase height, width of palate of first molars, and snout length. These measurements were chosen as they are consistent across several studies. These measurements will be summarized using discriminant function analysis to predict categorical dependent variables by one or more continuous or binary independent variables. For the purpose of this thesis, breeding dynamics will be considered as a potential influence on populations as foxes are likely to disperse as a result of increased population density.

Three subspecies of Red Fox have the potential to occur in Thunder Bay, Ontario: *Vulpes vulpes fulvus*, *V. v. regalis*, and with a lower likelihood, *V. v* *rubricosa* (Figure 1). A northern breeding season occurs later than that in southern regions with an estrus lasting one to six days (Tesky, 1995). The region of origin of the trapped Red Fox individuals will also be considered in potential differences in skull morphology because climate conditions, habitat preferences and food preferences can be factors determining anatomical design and function. The purpose of this study was to analyze and interpret the morphology of a set of Red Fox skulls and subject the data to statistical testing to determine if climate or habitat are the cause of variance. I predict that cranial variance will occur between individuals trapped in close proximity to Lake Superior and those further away.

LITERATURE REVIEW

Evolution

Vulpes vulpes belongs to the order Carnivora, representing mammals with well developed and elongated canine and carnassial teeth that are designed for the mechanical process of ingesting flesh (Feldhamer et al., 2004). The Red Fox belongs to Canidae, a family of carnivores that diverged from dogs, wolves and other foxes approximately 50-60 million years ago. Within the same clade belong the Cape Fox, Fennec Fox, Kit Fox and Arctic Fox (Wayne, 1993).

Morphology

The Red Fox is a synapsid vertebrate with quadrupedal locomotion. It has heterodont dentition: canines and incisors tear food, and flattened molars and premolars are used for grinding and crushing. The temporalis muscle, attached to the mastoid, aids in jaw power. Precise occlusion is the connection and alignment of teeth in a closed jaw, requiring the jaw to be solidly structured (Gomes et al., 2016).

Sexual dimorphism is the process by which sexes of the same species exhibit differences in appearance or morphology beyond their sexual organs (Gomes et al., 2016). Craniometrical analysis is a major component in studying variation in skull morphology that can result from differences in habitat, as well as characteristics of individuals and populations. Differences in skull morphology are apparent between ages and sex. A study originating in Wales was able to distinguish the sexes of Red Fox with an 88% accuracy using measurements of zygomatic width, greatest length, condylo-basal length and palatal length (Huson and Page, 1978). The same study was able to classify 66% of male skulls by region using occipto-nasal length, and for females using zygomatic width and condylo-basal length. Another study found that sexual variation may be recognized using total length, zygomatic width and mastoid width (Churcher, 1960). Lynch (1996) proposed a mathematical equation differentiating male and female Red Fox as $D = (2.114 \times GL) - (1.874 \times PO) - 27.478$, where D is the sex discriminant function, GL is the greatest longitudinal dimension in centimeters, and PO is the post orbital constriction, although it was to be effective only within a population or subspecies.

Post orbital constriction is the relationship of the narrowing of the cranium posterior of the orbital sockets, and in a Japanese study on the subspecies

Vulpes vulpes schrencki Kishida, this measure varied with climatic factors such as minimum mean monthly temperature and snowfall (Yosuke et al., 2015). Thus, specific climatic conditions and habitats are potential factors in the morphological differences in skulls from different geographical locations. Indeed, several factors are thought to affect the morphology of animals, such as population, access to resources, and climate. Bergmann's rule hypothesizes that in homeothermic animals body size will be larger in cooler climates than in warmer climates – a mechanism thought to be in response to heat conservation and heat dissipation (Bergmann, 1847). Another such hypothesis, Allen's rule, applies to shape rather than size – it states that body form is also affected by climate and that animals will adapt rounder forms in colder climates rather than linear forms in warm climates as another means of heat conservation (Allen, 1877).

Variances in skull structure during development are not only accountable by age, sex or adult body size. Additional variations are divided into three classes: gross malformations, epigenetic polymorphisms, and trophic polymorphisms. Gross malformations are defined by abnormalities in development or deformation. Epigenetic polymorphisms are the result of environmental effects on the genome. An example is in the Olympic salamander, *Rhyacotriton olympicus*, with variation in the presence of anatomical right and left nasal bones – some lacking the bone altogether. The last variation is trophic polymorphism – at least two coexisting cranial phenotypes existing independently within many individuals as an adaptation to environmental stress. An example is in the development of papilliform and molariform feeding structures in Mexican cichlid fish (Hanken and Hall 1993).

Biology and Population Dynamics of the Red Fox

The Red Fox's average life span is three to four years, and a female produces one litter per year (Tesky, 1995). Generally, the social hierarchy is limited to mating pairs and their offspring, but family groups may also include one adult male and several adult females. The presence of paired Red Fox trails in snow may signal mates, usually a single pair (Storm et al., 1976). In northern populations, estrus occurs later than it does in southern populations, and in both cases, it lasts between one and six days. Male Red Fox pups are the first to disperse from the den and have been shown to travel up to 29 km (in Iowa and Illinois) and 122 km (in Ontario), although most disperse approximately 30 km. Female postnatal dispersal is less than for males.

A study in central Italy proposed that the male Red Fox is larger and heavier than females, while differences in size with age were non-significant; greater size variation is due to population density rather than ecological factors (Cavallini, 1995). At higher densities, Red Fox populations exhibited smaller ranges and lower dispersal distances. Population density, however, may relate to ecological factors. Home ranges of Red Fox have been determined to be within a 4.0 x 2.4 km area for some families (Storm et al., 1976). A study of Red Fox populations in Yellowstone National Park demonstrated that elevational isolation of populations can between groups above 2,300 m and below 1,600 m (Swanson et al., 2005). This study was conducted by microsatellite loci.

The Red Fox occupies various ecosystems from tundra to semi-arid. They seem to excel in heterogenous landscapes. Habitat preferences are innately tied to season and food availability. In a study in Maine, Red Fox was shown to utilize all habitats, with a preference for softwood stands or open areas (Halpin et al., 1988). During times of deep snow, the Red Fox shifts habitat use to areas of softwood regeneration that support the Snowshoe Hare (*Lepus americana*). The Red Fox tends to avoid hardwood forests in the northern hemisphere, and are commonly found in boreal, coniferous, and deciduous forests, as well as tundra (Tesky, 1995). The Red Fox will opt for shrub filled areas over open tundra (Larivière and Pasitschniak-Arts, 1996).

Subspecies of Red Fox

Microsatellites are segments of genetic data that can be used to ascertain relatedness and population dynamics within a species. To differentiate the two possible subspecies in Thunder Bay, genetic testing would be pertinent. *Vulpes vulpes rubricosa* occurs in New Brunswick, Quebec, Ontario, as well as in a small portion of the north-eastern United States. *Vulpes vulpes regalis* occupies the remaining portion of Ontario, Manitoba, parts of Saskatchewan, Nunavut, and some of the mid-northern United States. The *regalis* subspecies is the largest in North America, golden-yellow in appearance with black feet and a long tail. The *rubricosa* subspecies is deeply coloured in appearance with a broad, large tail (Merriam, 1990).

The *regalis* subspecies is present in Thunder Bay and the *rubricosa* subspecies of Red Fox may be present in Thunder Bay, Ontario where the boreal and Great Lakes–St. Lawrence forests overlap (Figure 1) although it is unlikely.

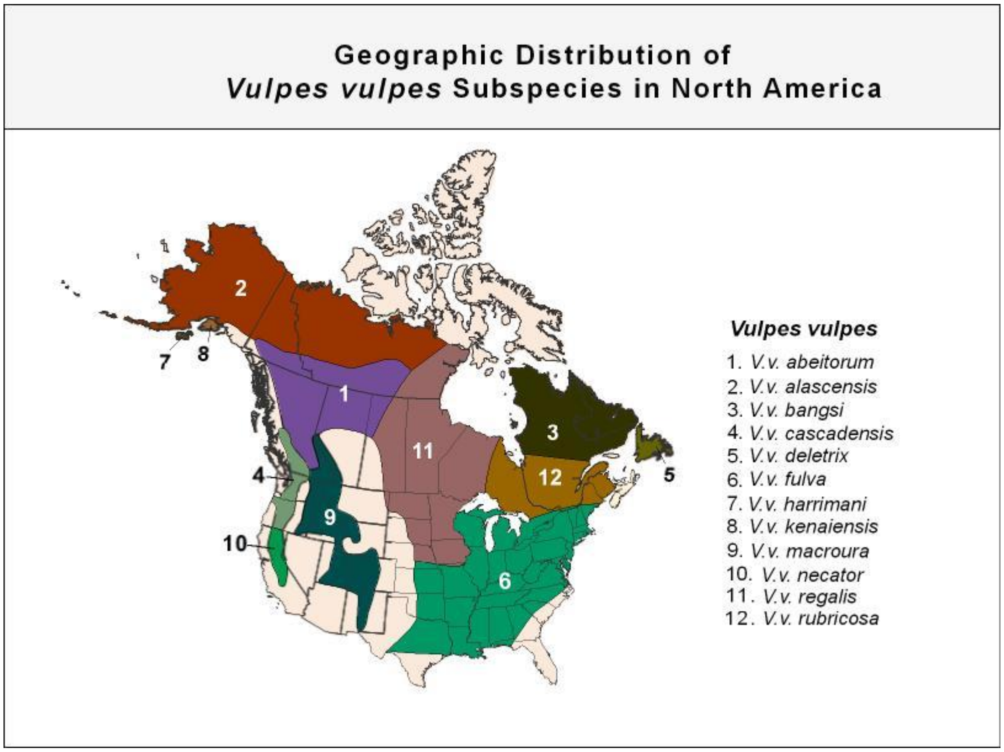

Figure. 1 Geographic distribution of *Vulpes vulpes* subspecies in North America (Ables, 1975).

MATERIALS AND METHODS

The reference collection for this study was *Vulpes vulpes* L. skulls (*n* = 112) collected by Thunder Bay area trappers in 1980 and 1981 and by licenced collector Mr. Don Barnes (former Lakehead University employee). The skulls were stored in individual paper bags. The cranial relationships were chosen for measurement for consistency across different studies, as well as to compensate for the condition of skulls, i.e. missing bone fragments made some measurements infeasible in the Lakehead University sample. They skulls were measured by one individual with a compass and a ruler along 12 dimensions (Figures 2-6); all dimensions were measured once and then verified with a second measurement before being recorded.

Location data existed for approximately 30 of the skulls in a Lakehead University thesis by Robert Janser (1980) as a trapline map of the Thunder Bay area. The skulls were sorted into three zones based on proximity to the moderating effects of Lake Superior, Zone 1 being the closest to the lake and Zone 3 being the furthest. Zone 3 was omitted due to lack of individuals (n=1). Zones 1 and 2 were then sorted as male and female due to significant variance between the sexes. Initially data was analyzed by calculating the mean of each significantly different cranial relationship between zones and sexes. Data were then interpreted by means of principal component analysis, as well as a discriminant function to convert possibly correlated observations (skull parameters) into linearly uncorrelated values and explain the maximum variance using the fewest number of components (Brownlee, 2018).

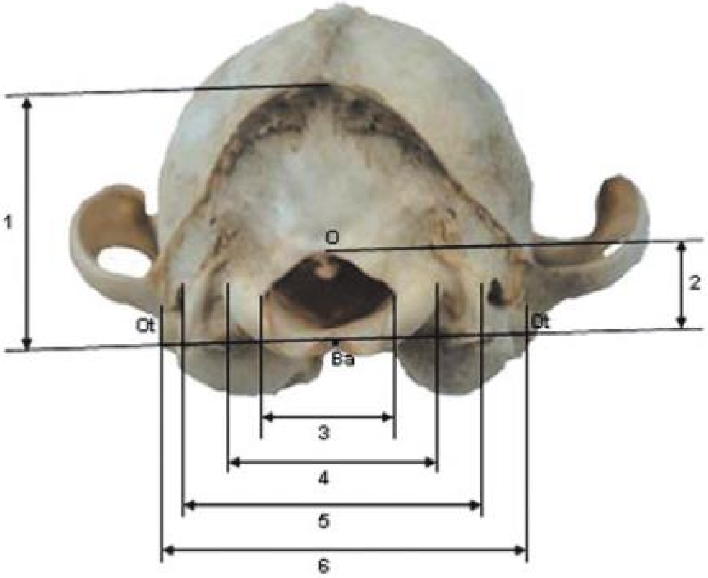

Figure 2. Occipital view of fox skull: 6. Greatest mastoid width. Source: Onar et al., 2005. *Measurements not listed were not used in this study.

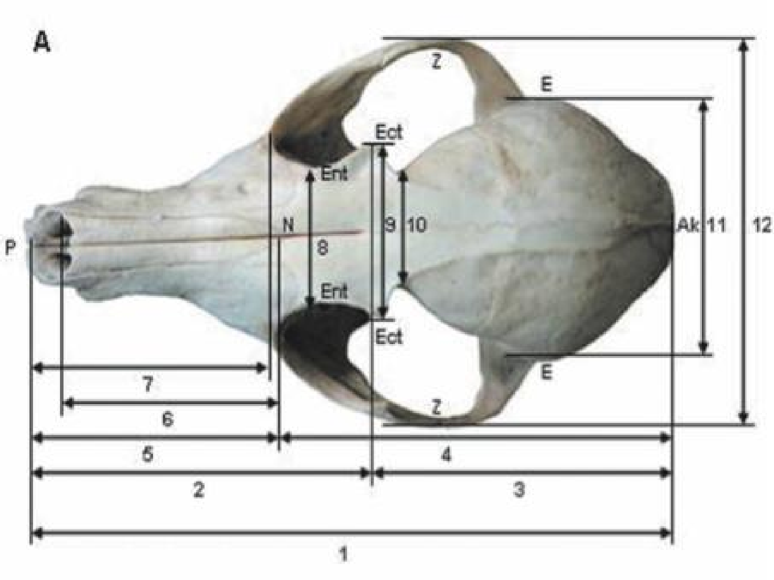

Figure 3. Dorsal view of fox skull: 1. Skull length, 4. Cranial length, 7. Snout length, 10. Post-orbital constriction, 11. Cranial width, 12. Width of zygomatic arch. Source: Onar et al., 2005. *Measurements not listed were not used in this study.

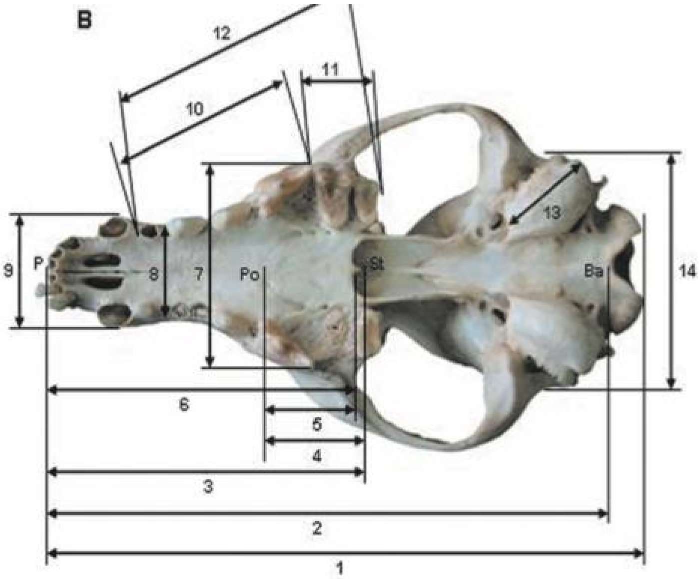

Figure 4. Ventral view: 1. Skull length, 3. Palate length, 8. Least palatal width. Source: Onar et al., 2005. *Measurements not listed were not used in this study.

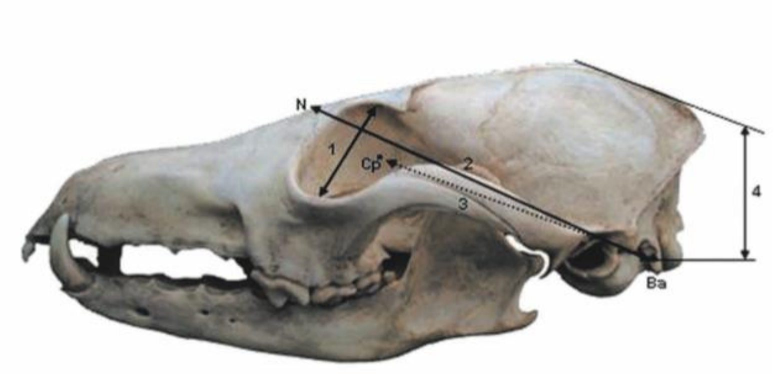

Figure 5. Left lateral view: 4. Skull height. Source: Onar et al., 2005. *Measurements not listed were not used in this study.

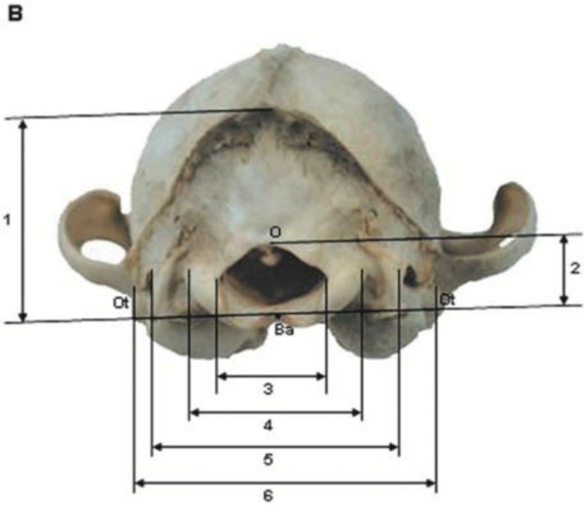

Figure 6. Occipital view: 6. Mastoid width. Source: Onar et al., 2005
*Measurements not listed were not used in this study.

RESULTS

Discriminating males and females was possible by the larger coefficients in the discriminant function: palate length (PL), zygomatic width (ZW), and cranial length (CL; Table 1). The set of three predictors is matched by stepwise entry of variables in a discriminant function (Table 2). Discriminant function analysis found no significant difference between skulls in Zones 1 and 2 and all skulls were grouped for subsequent analyses.

In a first principal component on all female skulls 19.6% of the variance was explained, and total length (TL) was after CL with PL close behind as factors forcing this component (Table 3). For the second principal component explaining17.6% of the variance, breadth of brain case (BBC) factored highest. Among males, the first principal component explained 23.7% of the variance and TL had the highest score in this component (Table 4). In the second principal

Table 1. Standardized canonical discriminant function coefficients in an analysis separating skulls by sex.

	Discriminant Function Coefficients
TL	0.04
MW	-0.03
ZW	0.48
CL	0.51
SL	0.28
POC	-0.01
PL	0.48
BBC	0.21
BP	0.00
HBC	0.04

Table 2. Stepwise entry of predictor variables canonical discriminant function coefficients in an analysis separating skulls by sex.

Step	Entered	F Statistic	df1	Statistic	Sig.
1	PL	20.9	1	20.92	0
2	ZW	15.6	2	15.62	0
3	CL	14.1	3	14.12	0

component, explaining 17.5% of the variance in male skull dimensions, CL and BBC factored highest. For the most meaningful dimensions, TL, ZW, CL and PL, skulls of female Red Fox from the Thunder Bay area sample were consistently and significantly smaller in every case (Tables 5, 6).

Table 3. Factor scores for principal components analysis of female skulls of *Vulpes vulpes* collected from the Thunder Bay area.

Cranial	Component	
Measurement	1	2
TL	0.60	-0.54
MW	-0.39	0.56
ZW	-0.25	-0.33
CL	0.80	-0.11
SL	0.37	0.08
POC	-0.02	0.50
PL	0.59	0.39
BBC	0.15	0.58
BP	0.21	0.48
HBC	0.43	0.26

Table 4. Factor scores for principal components analysis of male skulls of *Vulpes vulpes* collected from the Thunder Bay area.

Cranial	Component	
Measurement	1	2
TL	0.87	-0.11
MW	0.53	-0.40
ZW	0.30	0.16
CL	0.32	-0.75
SL	0.46	0.41
POC	-0.28	0.36
PL	0.75	0.34
BBC	-0.09	0.55
BP	0.40	0.53
HBC	0.34	-0.04

Table 5. Mean, standard deviation, and standard error calculated for the most important dimensions in skulls of male *Vulpes vulpes*.

Males (n=7)	Mean	Standard Deviation	Standard Error
TL	142.43	3.74	1.41
ZW	73.71	2.63	0.99
CL	80.14	4.66	1.76
PL	69.64	2.75	1.04

Table 6. Mean, standard deviation, and standard error calculated for the most important dimensions in skulls of female *Vulpes vulpes*.

Females (n=10)	Mean	Standard Deviation	Standard Error
TL	133.35	4.66	1.47
ZW	73.30	6.05	1.91
CL	76.25	3.57	1.13
PL	63.70	3.60	1.14

DISCUSSION

The goal of this thesis was to conduct preliminary research to observe how cranial measurements vary within the Thunder Bay Red Fox population. Principal components analysis on the skulls of males showed that most variance occurred in total length, cranial length, and palate length). Limiting measurements to these three could simplify future research by enabling efficient measurement of an increased number of individuals. Differences in diet may be the origin of differences in skull morphology, as food resource and availability have a large affect on the morphology of animals (Tilkens et al., 2007). Here, differences in morphology were undetectable over the short distances that traplines varied from Lake Superior and its moderating effect. The negative result may have been due to small sample size.

It is likely that the Red Fox studied were the subspecies *Vulpes vulpes regalis* and not *Vulpes vulpes rubricosa*. The geographic separation of the subspecies occurs approximately 220 km to the east, around Terrace Bay, Ontario. This is hypothesized because of information in the literature review that suggested genetic isolation could occur at elevational discrepancies of approximately 900 m, or because individuals rarely travel more than 8 km out of their territory before being considered dispersed, or because single Red Fox pups may disperse up to 122 km from the den in Ontario populations (Tesky, 1995), but not generally further. There is potential to overlap but it is difficult to determine whether two subspecies were present as mitochondrial haplotype studies are generally the source of identification. Only the cranial segment of skeleton was available for this study; thus, interpretation of subspecies based on appearance was not feasible.

Sexual dimorphism in skull morphology was detected. Palate length, zygomatic width, cranial length and total length differed most between males and females, very similar to the outcome of the Welsh study (Huson and Page, 1978) and the older US study (Churcher, 1960). The result differs from the equation developed by Lynch (1996) to distinguish males and females within a population or subspecies as the fox are a different subspecies. Female Red Fox in the Thunder Bay area sample, as for most carnivores, had smaller skulls than males, likely corresponding to smaller overall body size.

A scan of skulls into a digital program would potentially aid this study if further research was conducted. Computed data (laser scanning for angular measurements) could also aid in eliminating variances due to fluctuating asymmetry; in future studies, flawed data can be avoided by measuring cranial traits on a left and right basis with accompanying variance analysis systems to determine if variance is caused by symmetry or a measurement error (Tomkins, 2001). Genetic marking would provide interesting insight on individuals if the required resources were available. If repetitions of this study are completed, it is suggested that a larger and homogenous sample be taken to obtain a stronger basis of data.

CONCLUSION

Vulpes vulpes is one of the most widespread carnivores in the world, adjusting to landscapes that vary from forested to arid due to their ability to adapt and disperse. Morphological adaptations must occur for the species to succeed in reaching adulthood and reproducing, and in this example, it was proposed that phenotypic expression influenced by climate and habitat (due to the moderating effects of large bodies of water, such as Lake Superior) could be a potential factor in craniometrical relationships. Variance may occur within the Thunder Bay area population and be expressed in palate length, cranial length, and total length, but there was insufficient information to support that resource availability, geographical and climate factors were the cause. Many other studies show that data for age, sex and population is too inconsistent to apply to a broad scale of study with many populations such as the studies of Huson and Page (1978) and Churcher (1960). At the beginning of this thesis, the geographical source of the data was unknown. Small sample size and geographic source of the skulls may have limited definitive statements on variation with climate in the Thunder Bay area – if individuals were sourced further from Lake Superior and at a higher sample size then it might be clearer. As the individuals were all sourced from a small area, it is unlikely that nutritional resources would have impacted the data unless individuals existed in areas of high population density and there was competition for resources.

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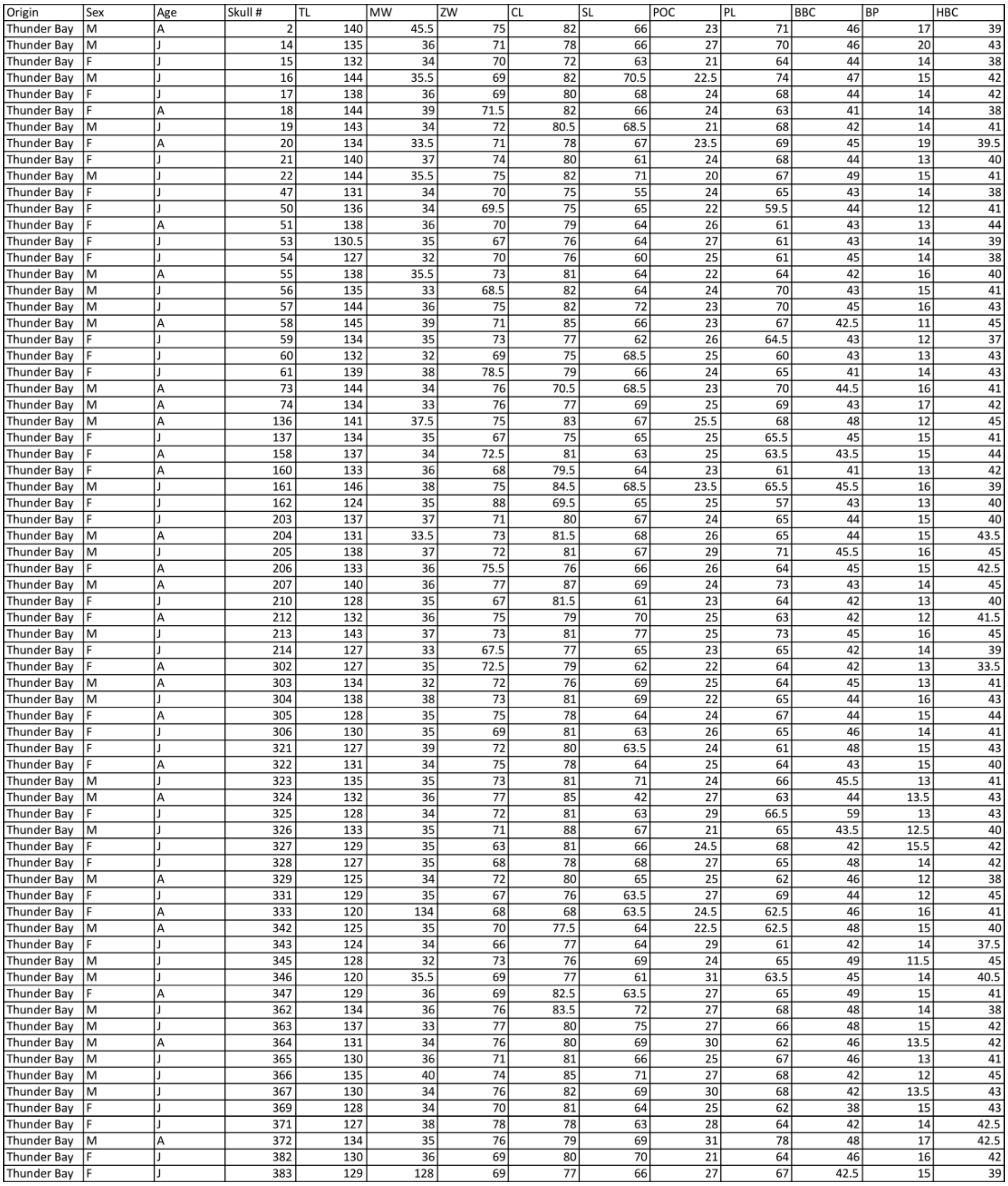
APPENDICES

Appendix 1: Raw craniometrical data



Origin	Sex	Age	Skull #	TL	MW	ZW	CL	SL	POC	PL	BBC	BP	HBC
Thunder Bay	M	A	2	140	45.5	75	82	66	23	71	46	17	39
Thunder Bay	M	J	14	135	36	71	78	66	27	70	46	20	43
Thunder Bay	F	J	15	132	34	70	72	63	21	64	44	14	38
Thunder Bay	M	J	16	144	35.5	69	82	70.5	22.5	74	47	15	42
Thunder Bay	F	J	17	138	36	69	80	68	24	68	44	14	42
Thunder Bay	F	A	18	144	39	71.5	82	66	24	63	41	14	38
Thunder Bay	M	J	19	143	34	72	80.5	68.5	21	68	42	14	41
Thunder Bay	F	A	20	134	33.5	71	78	67	23.5	69	45	19	39.5
Thunder Bay	F	J	21	140	37	74	80	61	24	68	44	13	40
Thunder Bay	M	J	22	144	35.5	75	82	71	20	67	49	15	41
Thunder Bay	F	J	47	131	34	70	75	55	24	65	43	14	38
Thunder Bay	F	J	50	136	34	69.5	75	65	22	59.5	44	12	41
Thunder Bay	F	A	51	138	36	70	79	64	26	61	43	13	44
Thunder Bay	F	J	53	130.5	35	67	76	64	27	61	43	14	39
Thunder Bay	F	J	54	127	32	70	76	60	25	61	45	14	38
Thunder Bay	M	A	55	138	35.5	73	81	64	22	64	42	16	40
Thunder Bay	M	J	56	135	33	68.5	82	64	24	70	43	15	41
Thunder Bay	M	J	57	144	36	75	82	72	23	70	45	16	43
Thunder Bay	M	A	58	145	39	71	85	66	23	67	42.5	11	45
Thunder Bay	F	J	59	134	35	73	77	62	26	64.5	43	12	37
Thunder Bay	F	J	60	132	32	69	75	68.5	25	60	43	13	43
Thunder Bay	F	J	61	139	38	78.5	79	66	24	65	41	14	43
Thunder Bay	M	A	73	144	34	76	70.5	68.5	23	70	44.5	16	41
Thunder Bay	M	A	74	134	33	76	77	69	25	69	43	17	42
Thunder Bay	M	A	136	141	37.5	75	83	67	25.5	68	48	12	45
Thunder Bay	F	J	137	134	35	67	75	65	25	65.5	45	15	41
Thunder Bay	F	A	158	137	34	72.5	81	63	25	63.5	43.5	15	44
Thunder Bay	F	A	160	133	36	68	79.5	64	23	61	41	13	42
Thunder Bay	M	J	161	146	38	75	84.5	68.5	23.5	65.5	45.5	16	39
Thunder Bay	F	J	162	124	35	88	69.5	65	25	57	43	13	40
Thunder Bay	F	J	203	137	37	71	80	67	24	65	44	15	40
Thunder Bay	M	A	204	131	33.5	73	81.5	68	26	65	44	15	43.5
Thunder Bay	M	J	205	138	37	72	81	67	29	71	45.5	16	45
Thunder Bay	F	A	206	133	36	75.5	76	66	26	64	45	15	42.5
Thunder Bay	M	A	207	140	36	77	87	69	24	73	43	14	45
Thunder Bay	F	J	210	128	35	67	81.5	61	23	64	42	13	40
Thunder Bay	F	A	212	132	36	75	79	70	25	63	42	12	41.5
Thunder Bay	M	J	213	143	37	73	81	77	25	73	45	16	45
Thunder Bay	F	J	214	127	33	67.5	77	65	23	65	42	14	39
Thunder Bay	F	A	302	127	35	72.5	79	62	22	64	42	13	33.5
Thunder Bay	M	A	303	134	32	72	76	69	25	64	45	13	41
Thunder Bay	M	J	304	138	38	73	81	69	22	65	44	16	43
Thunder Bay	F	A	305	128	35	75	78	64	24	67	44	15	44
Thunder Bay	F	J	306	130	35	69	81	63	26	65	46	14	41
Thunder Bay	F	J	321	127	39	72	80	63.5	24	61	48	15	43
Thunder Bay	F	A	322	131	34	75	78	64	25	64	43	15	40
Thunder Bay	M	J	323	135	35	73	81	71	24	66	45.5	13	41
Thunder Bay	M	A	324	132	36	77	85	42	27	63	44	13.5	43
Thunder Bay	F	J	325	128	34	72	81	63	29	66.5	59	13	43
Thunder Bay	M	J	326	133	35	71	88	67	21	65	43.5	12.5	40
Thunder Bay	F	J	327	129	35	63	81	66	24.5	68	42	15.5	42
Thunder Bay	F	J	328	127	35	68	78	68	27	65	48	14	42
Thunder Bay	M	A	329	125	34	72	80	65	25	62	46	12	38
Thunder Bay	F	J	331	129	35	67	76	63.5	27	69	44	12	45
Thunder Bay	F	A	333	120	134	68	68	63.5	24.5	62.5	46	16	41
Thunder Bay	M	A	342	125	35	70	77.5	64	22.5	62.5	48	15	40
Thunder Bay	F	J	343	124	34	66	77	64	29	61	42	14	37.5
Thunder Bay	M	J	345	128	32	73	76	69	24	65	49	11.5	45
Thunder Bay	M	J	346	120	35.5	69	77	61	31	63.5	45	14	40.5
Thunder Bay	F	A	347	129	36	69	82.5	63.5	27	65	49	15	41
Thunder Bay	M	J	362	134	36	76	83.5	72	27	68	48	14	38
Thunder Bay	M	J	363	137	33	77	80	75	27	66	48	15	42
Thunder Bay	M	A	364	131	34	76	80	69	30	62	46	13.5	42
Thunder Bay	M	J	365	130	36	71	81	66	25	67	46	13	41
Thunder Bay	M	J	366	135	40	74	85	71	27	68	42	12	45
Thunder Bay	M	J	367	130	34	76	82	69	30	68	42	13.5	43
Thunder Bay	F	J	369	128	34	70	81	64	25	62	38	15	43
Thunder Bay	F	J	371	127	38	78	78	63	28	64	42	14	42.5
Thunder Bay	M	A	372	134	35	76	79	69	31	78	48	17	42.5
Thunder Bay	F	J	382	130	36	69	80	70	21	64	46	16	42
Thunder Bay	F	J	383	129	128	69	77	66	27	67	42.5	15	39

Appendix 2. Trapline Map.

Appendix 3. Geographically sorted data

Zone 1	Origin	Sex	Age	Skull #	TL	MW	ZW	CL	SL	POC	PL	BBC	BP	HBC
	Thunder Bay	M	A	2	140	45.5	75	82	66	23	71	46	17	39
	Thunder Bay	M	J	16	144	35.5	69	82	70.5	22.5	74	47	15	42
	Thunder Bay	F	A	20	134	33.5	71	78	67	23.5	69	45	19	39.5
	Thunder Bay	F	J	59	134	35	73	77	62	26	64.5	43	12	37
	Thunder Bay	M	A	73	144	34	76	70.5	68.5	23	70	44.5	16	41
	Thunder Bay	F	A	158	137	34	72.5	81	63	25	63.5	43.5	15	44
	Thunder Bay	M	J	161	146	38	75	84.5	68.5	23.5	65.5	45.5	16	39
	Thunder Bay	F	J	162	124	35	88	69.5	65	25	57	43	13	40

Zone 2	Origin	Sex	Age	Skull #	TL	MW	ZW	CL	SL	POC	PL	BBC	BP	HBC
	Thunder Bay	M	J	14	135	36	71	78	66	27	70	46	20	43
	Thunder Bay	F	J	15	132	34	70	72	63	21	64	44	14	38
	Thunder Bay	F	J	21	140	37	74	80	61	24	68	44	13	40
	Thunder Bay	M	J	22	144	35.5	75	82	71	20	67	49	15	41
	Thunder Bay	F	J	47	131	34	70	75	55	24	65	43	14	38
	Thunder Bay	F	J	53	130.5	35	67	76	64	27	61	43	14	39
	Thunder Bay	M	J	57	144	36	75	82	72	23	70	45	16	43
	Thunder Bay	F	J	60	132	32	69	75	68.5	25	60	43	13	43
	Thunder Bay	F	J	61	139	38	78.5	79	66	24	65	41	14	43

Zone 3	Origin	Sex	Age	Skull #	TL	MW	ZW	CL	SL	POC	PL	BBC	BP	HBC
	Thunder Bay	F	J	50	136	34	69.5	75	65	22	59.5	44	12	41

(TL = total length, MW = mastoid width, ZW = zygomatic width, CL = cranial length, SL = snout length, POC= post-orbital constriction, PL = palate length, BBC = breadth of brain case, BP = breadth of palate, HBC = height of brain case)

Appendix 4: *Vulpes vulpes* skull

Appendix 5: Skull with detached mandibles

Appendix 6: Skulls of varying condition