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Author(s): Joseph W. Hinton and Michael J. Chamberlain
Source: Journal of Mammalogy, 95(4):855-861. 2014.
Published By: American Society of Mammalogists
DOI: http://dx.doi.org/10.1644/13-MAMM-A-202
URL: http://www.bioone.org/doi/full/10.1644/13-MAMM-A-202

Journal of Mammalogy, 95(4):855–861, 2014

Morphometrics of *Canis* taxa in eastern North Carolina

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We describe the external morphological characters of red wolves, coyotes, and their hybrids from North Carolina and assess if morphology could be an accurate discriminator among the 3 canid taxa. We used body measurements from 171 red wolves (*Canis rufus*), 134 coyotes (*Canis latrans*), and 47 hybrids in a polytomous logistic regression analysis to assess if they could be used to identify canids as red wolves, coyotes, or hybrids. Polytomous logistic regression analysis of 7 morphometric variables was able to correctly allocate 86% of canids to their a priori taxa groups. Using Akaike's information criterion, we judged hind-foot length, body mass, width of head, and tail length as variables to best separate taxa. Among the 3 sympatric *Canis* taxa in eastern North Carolina, red wolves are clearly the larger canid with hybrids intermediate to coyotes and red wolves in body size. Our results suggest that red wolves represent a unique *Canis* phenotype in the southeastern United States.

Key words: *Canis latrans*, *Canis rufus*, coyote, hybrid, morphology, red wolf

DOI: 10.1644/13-MAMM-A-202

Recent advances in science and technology have promoted molecular genetics as the primary tool for inferring the evolutionary and demographic past of North American wolves. In particular, the role of hybridization has become a predominant and contentious issue in the evolution and conservation of wolf populations in eastern North America. For example, the use of molecular markers bolstered the possible role coyotes (*Canis latrans*) played in the ancestry of wolves in eastern North America (Wayne and Jenks 1991; Wilson et al. 2000; Chambers et al. 2012). Despite leading to controversies surrounding the taxonomy of New World wolves, genetic markers have proven invaluable for conservation efforts by providing new insights into the evolution and ecology of *Canis* species (Chambers et al. 2012). Nevertheless, morphology is a fundamental component of biology (Nelson 1989; MacLeod 2004) and phylogenetic analysis is not possible without some method of describing the morphological variation between individuals, populations, and species (MacLeod and Forey 2004). Therefore, a complete synthesis of *Canis* species in eastern North America that leads to successful conservation requires studies from multiple disciplines involving ecological, evolutionary, molecular, and morphological analyses (Rutledge et al. 2012).

The Red Wolf Recovery Program (Recovery Program) of the United States Fish and Wildlife Service oversees the recovery of endangered red wolves (*Canis rufus*) and it currently manages the only wild population of red wolves on the Albemarle Peninsula in eastern North Carolina (Hinton et al. 2013). Since its inception during 1973, the Recovery Program has considered hybridization between red wolves and coyotes to be a primary threat to red wolf recovery efforts because hybridization can render the wild red wolf population unrecognizable within several generations (United States Fish and Wildlife Service 1989; Kelly et al. 1999; Rabon et al. 2013). During the initial stages of red wolf recovery efforts, morphometric data were used to identify individual red wolves captured from hybrid swarms in eastern Texas and western Louisiana, and these individuals were later used as founders for the captive and eastern North Carolina populations (United States Fish and Wildlife Service 1989). Additionally, the use of morphometric measurements alluded to issues of hybridization and coyote introgression into red wolf genetics before modern molecular approaches were developed (Nowak 1979). Therefore, morphometric data provide another method to differentiate among red wolves, coyotes, and red wolf–coyote hybrids (hereafter hybrids) that is essential to determine whether hybridization is occurring. Red wolves and coyotes are sympatric in eastern North Carolina and developing morphometric profiles for red wolves, coyotes, and hybrids in this region is necessary to develop practical approaches to address hybridization and enhance conservation.

An assessment of morphometric data for *Canis* taxa in eastern North Carolina can improve important areas necessary for red wolf recovery efforts. First, it allows tests to determine if morphometric measurements can be used to discriminate among red wolves, coyotes, and hybrids in the absence of molecular markers. If successful, this will permit an evaluation of which measurements are most useful to discriminate among the 3 *Canis* taxa. Such data can be extended to ecological studies to determine the limits of potential resource use and the relative efficiency of red wolves and coyotes to exploit resources within those limits (Wainwright 1996). Second, assessing morphometric measurements will allow the description of phenotypes of the 3 *Canis* taxa. Nowak (2002) observed the morphology of modern red wolves to be consistent with fossilized remains of small wolves in the eastern United States dating back to the Pleistocene. If this is true, regardless of the modern red wolf's evolutionary origins, the eastern North Carolina population may represent a *Canis* phenotype unique to the southeastern United States. Here we provide a systematic analysis of morphometric measurements currently collected by Recovery Program biologists from red wolves, coyotes, and hybrids and assess their reliability to describe and discriminate among the 3 taxa.

Materials and Methods

The Red Wolf Recovery Area (Recovery Area) was established on the Albemarle Peninsula in northeastern North Carolina during 1987. The area included 5 counties (Beaufort, Dare, Hyde, Tyrrell, and Washington) and consisted of approximately 6,800 km^2 of federal, state, and private lands (Fig. 1). The Albemarle Peninsula was composed of an intensively farmed agricultural–hardwood bottomland matrix in which approximately 30% of the landscape was driven by agricultural activity.

Red wolves, coyotes, and hybrids used in this study were captured by the Recovery Program during annual trapping within the designated Recovery Area from 1987 until 2011 (Rabon et al. 2013). Canids were captured using padded foothold traps (Victor no. 3 Softcatch; Woodstream Corporation, Lititz, Pennsylvania) and were sexed, measured, weighed, and aged by tooth wear (Gier 1968), and a blood sample was collected for genetic analysis. Ages of most red wolves were known and tooth-wear estimates mostly applied to coyotes and hybrids (Rabon et al. 2013). For this study, only animals captured between the months of November through March were used. This ensured that all pups used in the analysis were at or near full potential body size for the taxa. We aged individuals $>$ 2 years old as adults, 1–2 years old as juveniles, and 6–12 months old as pups. Microsatellite markers and other genetic information from the 14 founding individuals and other predefined red wolves were used to generate allele frequencies to reconstruct the pedigree of the red wolf population. Individuals used in this study were genotyped at 17 microsatellites and genetic analyses of blood samples followed the methods outlined in Adams (2006), Bohling et al. (2013), and Miller et al. (2003). Individuals were assigned to a species or hybrid group using the methods developed by Miller et al. (2003) to specifically identify red wolves, coyotes, and hybrids. During our study, these were the molecular methods used by the United States Fish and Wildlife Service for monitoring red wolf genetic ancestry (Bohling et al. 2013). Animal handling methods followed guidelines approved by the American Society of Mammalogists (Sikes et al. 2011) and were approved by the Louisiana State University Agricultural Center Institutional Animal Care and Use Committee (protocol AE2009-19).

Morphometric measurements were taken from live animals and measurements were followed as closely to standard anatomical reference points as possible. Body traits measured included body mass, ear length (edge of the external auditory canal to the tip of the ear), tail length (tip of the fleshy part of the tail to the tail base), body length (anterior tip of the nose pad to the tail base), hind-foot length (hock to the tip of the digital pads), shoulder height (tip of the scapula to tip of the digital pads), front- and hind-paw width (width across the cushiony pads at the widest points), front- and hind-paw length (base of the metacarpal pad to tip of the digital pads), length of head (edge of the premaxillary to the most posterior point of the occipital bone), and width of head (widest points across the zygomata). All animals measured were later identified as red wolves, coyotes, and hybrids by the Recovery Program using molecular methods.

We analyzed measurements of canids using univariate and multivariate statistical methods in Program R, version 3.0.2 (R Development Core Team 2013). We present statistics of measurements as the mean $\pm$ *SE*. To evaluate similarities between pairs of measurements, we used a correlation analysis. Individuals were included in the analysis only once to maintain independence. To remove redundancy, we used only 1 measurement from a set of strongly correlated measurements to represent that taxon in further analysis.

We used analysis of variance and *t*-tests to evaluate differences of measurements among and within taxa groups. We then used measurements in a polytomous logistic regression analysis to assess the reliability of morphometrics to identify canid taxa. Polytomous logistical regression is a logical extension of binary logistic regression that allows more than 2 categories of the dependent variable (Hosmer and Lemeshow 2000). The ability of the polytomous logistical regression to identify red wolves, coyotes, and hybrids using morphometric measurements was revealed as the percentage of individuals correctly reallocated to each taxon. The number of misclassified individuals indicated the degree of overlap between the groups. We used the Akaike information criterion (AIC) to compare models of morphometric measurements by calculating the AIC_C for each model and using ΔAIC_C and Akaike weights (w_is) to select the measurements that best delineated different canid categories (Burnham and Anderson 2002). We performed polytomous logistical regression and model selection using the polytomous and AIC functions from the polytomous and MuIN packages for Program R.

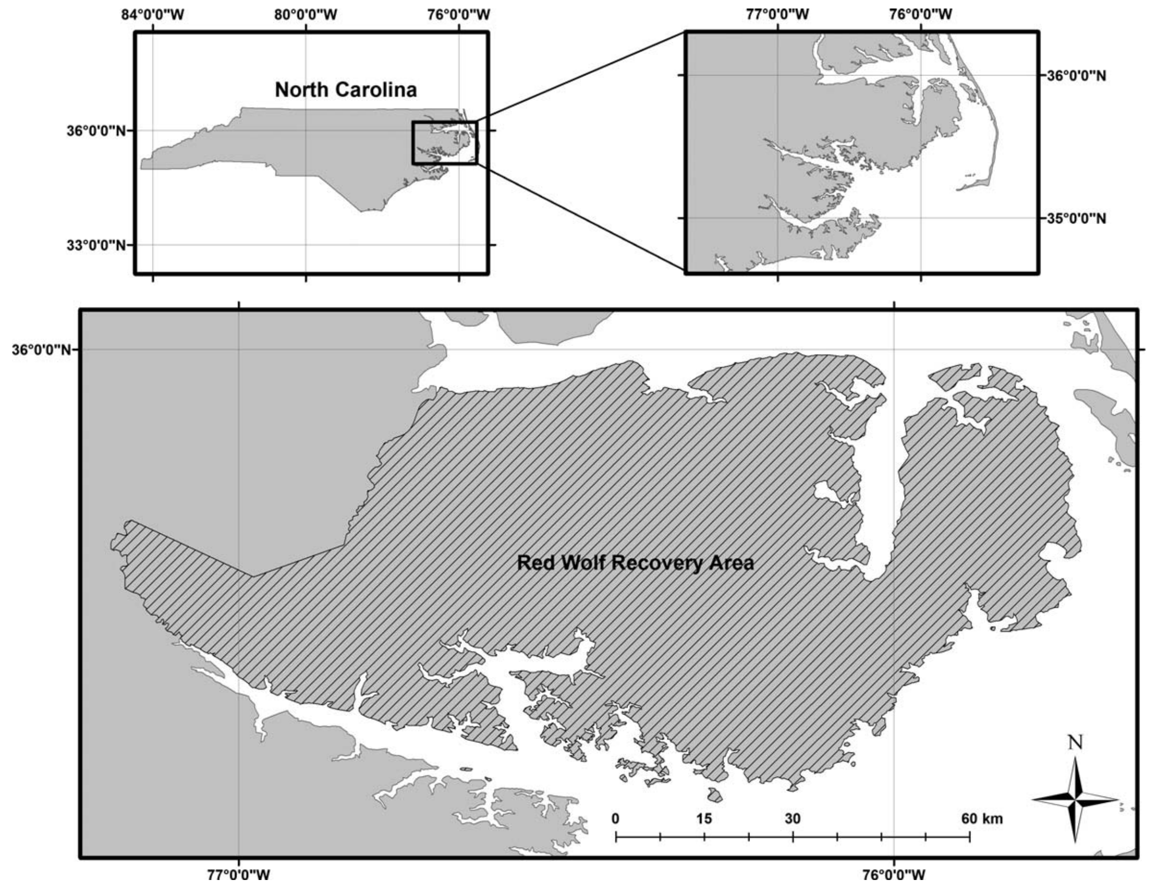

FIG. 1.—Outline map of North Carolina showing the location of the Red Wolf Recovery Area (hatched area) during the study in the northeastern portion of the state.

Sample sizes among measurements varied because it was not always possible to measure every variable for each individual. Only individual canids with all measurements were included in the polytomous logistical regression analysis. We used a Kolmogorov–Smirnov 1-sample test for each measurement to determine whether measurements for the subset of individuals used in the polytomous logistical regression analysis were biased when compared to the larger sample from which they were drawn.

RESULTS

From 1987 to 2011, 951 canids were captured and measured, including 528 red wolves (56%), 264 coyotes (28%), and 159 hybrids (17%) that were genetically identified. Measurements differed among red wolves, coyotes, and hybrids (Table 1) and hybrids were intermediate to red wolves and coyotes in all morphometric measurements.

The original dataset showed that the measurements were strongly correlated ($r = 0.75$–0.90). To reduce the number of variables, we used only 7 univariate estimates (body mass, ear length, tail length, body length, hind-foot length, shoulder height, and width of head) to characterize overall size because this subset most completely represented the various aspects of canid anatomy needed for analysis. Among red wolves all 7 measurement means increased ($F_{2,453} \geq 6.79$, $P < 0.001$) with age. Additionally, all 7 measurement means were greater ($t_{528} \geq 6.07$, $P < 0.001$) for males than for females. Among coyotes, body mass, ear length, body length, hind-foot length, shoulder height, and width of head were greater ($t_{264} \geq 2.98$, $P \leq 0.003$) for males than for females, but there was no difference in tail length ($t_{264} = 1.60$, $P = 0.11$). Ear length and tail length ($F_{2,159} \leq 1.72$, $P \geq 0.181$) did not differ among ages, but mass, body length, hind-foot length, shoulder height, and width of head ($F_{2,163} \geq 5.61$, $P \leq 0.004$) increased with age. Among hybrids, tail length and body length ($t_{159} \leq 1.78$, $P \geq 0.077$) did not differ between males and females, whereas body mass, ear length, hind-foot length, shoulder height, and width of head were larger for males than for females ($t_{159} \geq 2.06$, $P \leq 0.041$). Body mass, tail length, and shoulder height ($F_{2,56} \leq 4.77$, $P \geq 0.012$) increased with age, but ear length, body length, hind-foot length, and width of head ($F_{2,56} = 2.95$, $P = 0.060$) did not differ with age.

Included in the polytomous logistical regression analysis were 352 (171 red wolves, 134 coyotes, and 47 hybrids) canids for which all 7 measurements were completed. The subset used in the polytomous logistical regression analysis was not biased when compared to the larger samples of red wolves ($D = 0.10$, $P = 0.094$), coyotes ($D = 0.06$, $P = 0.925$), and hybrids ($D = 0.2$, $P = 0.110$). The polytomous logistical regression model

Table 1.—Means (± *SE*) and results of analysis of variance (ANOVA) for the morphological characters of red wolves, coyotes, and their hybrids in northeastern North Carolina, 1987–2011. Ranges for trait measurements are given in parentheses.

	Red wolf		Coyote		Hybrid		ANOVA	
Characters	n[a]	$\bar{X} \pm SE$	n[a]	$\bar{X} \pm SE$	n[a]	$\bar{X} \pm SE$	F	P
Weight (kg)	509	23.2 ± 0.23 (7.9–38.6)[b]	240	13.4 ± 0.12 (6.9–19.1)	147	17.0 ± 0.34 (6.4–27.5)	438.97	<0.0001
Ear length (cm)	458	11.0 ± 0.03 (9.0–12.9)	254	9.9 ± 0.04 (8.0–12.8)	153	10.5 ± 0.05 (8.5–12.5)	236.55	<0.0001
Tail length (cm)	456	36.4 ± 0.15 (25.8–48)	241	33.9 ± 0.20 (20.5–44.7)	151	35.7 ± 0.25 (24.5–43.5)	48.53	<0.0001
Body length (cm)	454	106.4 ± 0.33 (75.0–125.0)	246	90.0 ± 0.30 (64.0–105.0)	136	97.7 ± 0.60 (78.0–122.0)	497.72	<0.0001
Hind-foot length (cm)	460	22.3 ± 0.06 (17.0–27.0)	256	18.7 ± 0.06 (16.4–22.5)	153	20.4 ± 0.11 (17.0–25.1)	813.38	<0.0001
Shoulder height (cm)	455	66.9 ± 0.18 (52.3–77.2)	249	57.3 ± 0.02 (47.1–68.7)	140	62.2 ± 0.36 (50.3–79.9)	563.23	<0.0001
Front-paw length (cm)	407	7.1 ± 0.02 (5.0–8.7)	238	6.0 ± 0.03 (4.44–7.73)	148	6.5 ± 0.05 (4.3–7.8)	432.24	<0.0001
Front-paw width (cm)	406	5.0 ± 0.02 (3.4–6.3)	238	4.1 ± 0.02 (3.0–5.5)	148	4.6 ± 0.04 (3.3–6.3)	292.59	<0.0001
Hind-paw length (cm)	381	6.5 ± 0.02 (5.0–8.2)	227	5.5 ± 0.03 (4.2–6.6)	146	6.0 ± 0.04 (4.9–7.5)	364.41	<0.0001
Hind-paw width (cm)	380	4.5 ± 0.02 (3.0–5.9)	227	3.7 ± 0.02 (2.8–4.9)	146	4.1 ± 0.03 (3.2–5.1)	350.72	<0.0001
Length of head (cm)	183	22.2 ± 0.11 (19.0–26.0)	146	19.9 ± 0.08 (17.5–24.0)	50	21.0 ± 0.24 (17.5–24.5)	146.91	<0.0001
Width of head (cm)	182	11.9 ± 0.08 (9.5–14.5)	146	10.4 ± 0.05 (9.0–12.5)	51	11.1 ± 0.11 (9.5–12.5)	108.38	<0.0001

[a] Number of individuals measured in each taxon.

[b] Ranges for trait measurements.

correctly classified 86% of the canids. Coyotes and red wolves were correctly classified 99% and 98% of the time, respectively. Hybrids were correctly classified 13% of the time. Hybrids were more likely to be misclassified as coyotes than as red wolves (61% versus 35%).

When red wolves were separated as pups (6–12 months old) and nonpups (adults and juveniles), all nonpups were correctly identified as red wolves and only 2 pups (1.8%) were misclassified as a coyote and a hybrid (Table 2). Only 2 coyotes (1.5%) were misclassified as red wolf pups and none were misclassified as hybrids. Most hybrids were misclassified as coyotes (53%) and red wolf pups (30%). Hybrids were 29% more likely to be misclassified as red wolf pups than as nonpups. This is likely because red wolf pups born in the spring overlap in body size with hybrids during summer and autumn as they approach adult body sizes in the winter.

The most useful measurements for separating red wolves, coyotes, and hybrids were hind foot length, body mass, width of head, and tail length (Table 3). Hind-foot length and body mass were the 2 most important measurements. Our findings (Table 4) suggest a reliable threshold that canids with hind-foot lengths > 21.5 cm, body mass > 21.5 kg, widths of heads > 10.5 cm, and tail lengths > 35 cm were most likely to be red wolves. Coyotes typically had hind-foot lengths < 19.5 cm, body mass < 19.5 kg, widths of heads < 10.5 cm, and tail lengths < 35 cm. Hybrid values for these 4 measurements would most likely overlap the minimum values for red wolves and maximum values for coyotes.

Discussion

Our results show that body-size measurements of red wolves and coyotes are distinct from one another, with hybrids representing an ambiguous intermediate size. Using measurements of hind-foot length, body mass, width of head, and tail length in a polytomous logistic regression analysis, we were able to correctly classify 86% of 352 canids into their correct taxa category with moderately high (80–90%) accuracy. Red wolves and coyotes were correctly classified 98% and 99% of the time, respectively. On the other hand, hybrids were more difficult to reassign and only 13% were correctly classified. Hybrids were more likely to be misclassified as either coyotes or red wolf pups. Despite the issue of morphological ambiguity, Recovery Program biologists still correctly classified canids as hybrids prior to genetic confirmation by identifying the morphological ambiguity and breeding status of hybrids. In other words, canids intermediate in size to red wolves and coyotes that have fully developed and active reproductive systems (e.g., males with enlarged testicles and females in estrus) are obviously adult hybrids, whereas those with underdeveloped and inactive reproductive systems are considered red wolf pups and confirmed with genetic analysis.

Of the 153 hybrids measured, only 2% (3 adult males) attained measurements above the minimum threshold values used by the Recovery Program to assign canids as red wolves. Nevertheless, the minimum values for red wolves reported in this study were estimated from the smallest adult females. Adult male red wolves are significantly larger than the minimum threshold reported. Interestingly, 20 of the 25 largest hybrids were captured and measured during 1998 through 2001. Since 2001, hybrids have been more coyote-like in their morphology and rarely exceed 20 kg in body mass. Coyotes did not fully colonize the Albemarle Peninsula until the mid-2000s (United States Fish and Wildlife Service 2007), so hybrids prior to this period may have been more red wolf–like because backcrosses were occurring within the smaller red wolf population. Once introgression was identified and management actions were used to reduce hybridization during the early 2000s (Kelly et al. 1999; Hinton et al. 2013; Rabon et al. 2013), hybrid backcrosses began to occur more often within the larger coyote population.

The Recovery Program uses sterilization of coyotes and hybrids as the primary management tool to prevent coyote introgression into the red wolf genome (Hinton et al. 2013; Rabon et al. 2013). After capture, sterilized canids are released back into the Recovery Area fitted with mortality-sensitive

Table 2.—Classification tables obtained from polytomous logistic regression for red wolves, coyotes, and hybrids in northeastern North Carolina, 1987–2011.

	Predicted species					
Actual species	Red wolf pup	Red wolf nonpup	Coyote	Hybrid	Statistical error[a]	Biological error[b]
Red wolf pup[c] ($n = 112$)	94	16	1	1	0.16	0.02
Red wolf nonpup ($n = 59$)	23	36	0	0	0.39	0.00
Coyote ($n = 134$)	2	0	132	0	0.01	0.01
Hybrid ($n = 47$)	14	2	25	6	0.87	0.87

[a] Proportion of individuals misclassified statistically (e.g., adult red wolves misclassified as red wolf pups).
[b] Proportion of individuals misclassified taxonomically (e.g., hybrids misclassified as red wolves).
[c] Pups between 6 months and 12 months old.

radiocollars and monitored for the duration of their life. In the event that a red wolf pairs with a sterilized canid, the pair cannot produce hybrid litters. Although molecular markers ultimately confirm the taxa of canids captured, Recovery Program biologists routinely use morphometric measurements to prescreen, process, and rerelease individual canids into the wild before receiving genetic confirmation. Morphometric measurements are used to reduce holding times because this lowers the risk that captured canids would lose breeding mates and territories because of absence. Therefore, quick identification during the canid breeding season allows Recovery Program biologists to minimize disruptions to canid packs with excessive holding times while waiting for genetic confirmation. The accuracy of using morphometric measurements we observed confirms that morphological measurements could be used to prescreen canids for management decisions, while awaiting genetic confirmation. Ultimately, genetic assessments are necessary to effectively monitor, measure, and manage coyote introgression in the red wolf population.

Regardless of the ambiguity of hybrid measurements, our findings concerning morphometric measurements of red wolves and coyotes are consistent with the results of Nowak (1979, 2002), who demonstrated little to no overlap in red wolf and coyote cranial and dental measurements. Throughout North America, average coyote body mass reported in studies rarely exceed 18 kg (Leopold and Chamberlain 2001; Bekoff and Gese 2003; Way 2007). Additionally, examination of our data indicates that F_1 and F_2 hybrids are incapable of reaching body sizes of adult red wolves. This suggests that the red wolf represents a unique *Canis* phenotype in the southeastern United States. Differences in body-size measurements are highly suggestive of differences in ecological requirements, and this is particularly true for carnivores regarding diet (Gittleman 1985; Donadio and Buskirk 2006; Carbone et al. 2007), space use (Gittleman and Harvey 1982; Gompper and Gittleman 1991), and interspecific interactions (Rosenzweig 1966; Palomares and Caro 1999; Donadio and Buskirk 2006). The general relationship between morphology and ecology is well known (Hutchinson 1959; Arnold 1983; Wainwright 1996; Kishida et al. 2010), but effects of body size on the relative ability of red wolves and coyotes to successively hunt prey, acquire mates, and defend territories are not well known.

Among the 3 sympatric *Canis* taxa in eastern North Carolina, red wolves are clearly the largest canid, with hybrids

Table 3.—Results of the 10 best models for morphological characters for red wolves, coyotes, and hybrids in northeastern North Carolina, 1987–2011.

Model	K[a]	AIC_C	ΔAIC_C	w_i
Species ~ HF[b] + BM[c] + WH[d] + TA[e]	6	278.41	0	0.38
Species ~ HF + BM + TA	5	279.91	1.50	0.18
Species ~ HF + BM + BO[f] + TA	7	280.07	1.66	0.17
Species ~ HF + BM + BO + SH[g] + TA	8	281.88	3.47	0.07
Species ~ HF + BM + WH	5	282.20	3.79	0.06
Species ~ HF + BM + BO + WH	5	282.23	3.82	0.05
Species ~ HF + BM + WH + SH	6	283.92	5.51	0.02
Species ~ HF + BM + BO + SH + WH + TA	9	283.94	5.53	0.02
Species ~ HF + BM + BO + WH	6	284.06	5.65	0.02
Species ~ HF + BM + WH + EA[h]	6	284.20	5.79	0.02

[a] K represents number of parameters for each model.
[b] Hind-foot length.
[c] Body mass.
[d] Width of head.
[e] Tail length.
[f] Body length.
[g] Shoulder height.
[h] Ear length.

TABLE 4.—Means (± *SE*) and ranges for 4 morphological characters of red wolves, coyotes, and hybrids in northeastern North Carolina, 1987–2011.

	Hind-foot length (cm)			Body mass (kg)			Width of head (cm)			Tail length (cm)		
Species	*n*[a]	$\bar{X}$	Range	*n*	$\bar{X}$	Range	*n*	$\bar{X}$	Range	*n*	$\bar{X}$	Range
Red wolf	460	22.3 ± 0.1	17.0–27.0	509	23.7 ± 0.2	10.1–38.6	182	11.9 ± 0.1	9.5–14.5	456	36.4 ± 0.2	25.8–48.0
Male	238	22.9 ± 0.1	19.6–27.0	260	25.1 ± 0.3	10.2–38.6	89	12.3 ± 0.1	10.0–14.5	234	37.3 ± 0.2	25.8–48.0
Pup[b]	122	22.6 ± 0.1	19.6–26.0	128	22.8 ± 0.4	10.2–34.0	54	11.9 ± 0.1	12.0–14.5	120	36.9 ± 0.3	29.4–46.0
Juvenile	47	22.9 ± 0.2	21.0–25.4	52	25.9 ± 0.5	18.6–31.8	20	12.6 ± 0.2	11.0–14.5	46	36.9 ± 0.5	29.0–48.0
Adult	69	23.4 ± 0.1	20.7–27.0	80	29.1 ± 0.4	21.4–38.6	15	13.4 ± 0.2	12.0–14.5	68	38.1 ± 0.5	25.8–46.0
Female	222	21.7 ± 0.1	17.0–24.5	249	21.2 ± 0.3	7.9–34.7	93	11.5 ± 0.1	9.5–14.4	222	35.4 ± 0.2	28.0–44.0
Pup	119	21.5 ± 0.1	18.0–24.0	124	19.2 ± 0.3	10.1–28.6	63	11.1 ± 0.1	9.5–12.8	120	35.1 ± 0.2	28.0–43.0
Juvenile	48	21.8 ± 0.2	19.7–24.0	54	22.7 ± 0.4	18.2–30.0	21	12.2 ± 0.2	11.0–14.4	48	35.6 ± 0.3	31.0–43.0
Adult	55	22.1 ± 0.2	17.0–24.5	71	25.1 ± 0.3	19.9–34.7	9	12.1 ± 0.3	11.0–13.5	54	36.2 ± 0.4	29.0–44.0
Coyote	256	18.7 ± 0.1	16.4–22.5	240	13.4 ± 0.1	6.9–19.1	146	10.5 ± 0.1	9.0–12.5	241	33.9 ± 0.2	20.5–44.7
Male	127	19.0 ± 0.1	16.5–22.0	122	14.0 ± 0.2	9.0–19.1	73	10.7 ± 0.1	9.5–12.5	118	34.3 ± 0.3	20.5–43.0
Pup	17	18.5 ± 0.2	17.0–20.1	15	12.4 ± 0.7	6.9–17.0	8	10.3 ± 0.2	10.0–11.0	16	34.0 ± 0.9	29.0–43.0
Juvenile	28	18.6 ± 0.1	17.3–19.9	27	13.7 ± 0.3	11.4–18.2	24	10.6 ± 0.1	9.5–11.5	28	33.5 ± 0.7	20.5–40.0
Adult	36	19.1 ± 0.2	16.5–20.5	34	14.5 ± 0.3	10.5–18.2	21	10.8 ± 0.2	9.5–12.0	34	35.3 ± 0.4	31.0–42.5
Unknown[c]	46	19.2 ± 0.1	17.5–22.0	46	14.2 ± 0.2	11.5–19.1	20	10.7 ± 0.1	9.5–12.5	40	34.0 ± 0.5	25.0–38.0
Female	129	18.4 ± 0.1	16.4–22.5	118	12.8 ± 0.1	8.9–16.5	73	10.2 ± 0.1	9.0–11.5	123	33.6 ± 0.3	27.0–44.7
Pup	23	17.9 ± 0.2	16.4–20.0	23	11.6 ± 0.3	8.9–15.0	13	10.0 ± 0.2	9.0–11.0	23	34.5 ± 0.8	28.0–44.7
Juvenile	35	18.3 ± 0.2	17.2–21.5	32	12.8 ± 0.2	10.0–15.4	26	10.1 ± 0.1	9.5–11.0	35	33.4 ± 0.5	27.0–41.2
Adult	27	18.4 ± 0.2	16.8–22.5	25	13.1 ± 0.3	9.7–16.3	15	10.4 ± 0.1	10.0–11.0	26	33.3 ± 0.5	29.4–43.0
Unknown	44	18.6 ± 0.1	17.0–21.9	38	13.3 ± 0.2	11.4–16.5	19	10.4 ± 0.1	9.5–11.5	39	33.5 ± 0.5	28.5–40.1
Hybrid	153	20.4 ± 0.1	16.4–25.1	147	17.0 ± 0.3	6.4–27.5	51	11.1 ± 0.1	9.5–12.5	151	35.7 ± 0.25	24.5–43.5
Male	85	20.6 ± 0.2	17.3–25.1	83	17.6 ± 0.5	6.4–27.5	32	11.3 ± 0.1	9.5–12.5	83	36.0 ± 0.36	24.5–43.5
Pup	4	19.5 ± 0.5	18.5–21.0	6	9.9 ± 1.2	6.4–14.5	1	10.8 ± N/A[d]	N/A[d]	3	31.5 ± 1.80	29.0–35.0
Juvenile	12	19.9 ± 0.3	17.3–21.6	10	15.9 ± 1.5	10.1–22.4	9	11.3 ± 0.2	10.5–12.5	12	35.6 ± 0.72	32.5–41.4
Adult	18	21.2 ± 0.2	18.8–21.5	18	17.8 ± 0.9	10.2–25.9	12	11.4 ± 0.2	9.5–12.0	18	36.4 ± 0.54	32.3–40.5
Unknown	51	21.0 ± 0.2	17.8–25.1	49	18.9 ± 0.6	12.0–27.5	10	11.2 ± 0.2	10.5–12.0	50	36.3 ± 0.51	24.5–43.5
Female	68	20.2 ± 0.2	17.0–22.5	64	16.1 ± 0.4	7.3–23.2	19	10.8 ± 0.2	9.5–12.5	68	35.2 ± 0.34	27.0–41.5
Pup	5	19.3 ± 0.6	16.4–20.0	5	13.0 ± 1.9	7.3–17.3	13	10.8 ± 1.3	9.5–12.0	5	33.1 ± 1.52	29.5–37.0
Juvenile	14	19.6 ± 0.4	17.0–21.9	13	15.1 ± 0.9	10.2–20.9	26	10.8 ± 0.3	9.5–12.0	14	35.4 ± 0.93	31.2–41.5
Adult	6	19.7 ± 0.5	18.3–21.7	6	14.9 ± 0.5	11.8–23.2	15	10.0 ± 0.5	9.5–11.0	6	35.4 ± 0.89	32.0–38.0
Unknown	43	20.5 ± 0.2	17.8–22.5	40	17.0 ± 0.5	11.8–23.2	3	11.5 ± 0.6	10.5–12.5	43	35.4 ± 0.38	27.0–41.0

[a] Number of individuals measured from each taxon.
[b] Pups between 6 and 12 months old.
[c] Age class unknown.
[d] N/A = not available.

intermediate to coyotes and red wolves in body size. Although this is a commonly held opinion, there is no significant previous literature comparing the morphometrics of red wolves, coyotes, and hybrids. Nowak (1979, 2002) assessed measurements from skulls of prehistoric and 20th century red wolves, gray wolves (*Canis lupus*), and coyote specimens and concluded red wolves to be a species intermediate in size to gray wolves and coyotes. The United States Fish and Wildlife Service (1989) reported only minimum measurements used to distinguish male and female red wolves from non–red wolf canids in southeastern Texas and southwestern Louisiana during the 1970s. The 1999 Population Habitat and Viability Assessment for red wolves stated the need to develop a morphological profile for red wolves, coyotes, and hybrids for quick identification in the field (Kelly et al. 1999). Therefore, this study represents an initial comparison of sympatric red wolves, coyotes, and their hybrids. Our analysis has shown morphometrics to be valuable in exploring morphological variation among closely related and sympatric *Canis* taxa. Further examination of morphological characters between red wolves and coyotes could detect patterns of phenotypic discreteness that could highlight opportunities for analysis of traits that may have genetic, evolutionary, and ecological importance. Therefore, we recommend examining the effects of morphology on red wolf and coyote ecology and interactions that may facilitate hybridization between the 2 species.

ACKNOWLEDGMENTS

This research was funded by the Red Wolf Recovery Program, Warnell School of Forestry and Natural Resources at the University of Georgia, and the United States Fish and Wildlife Service. The data for this study were acquired from the Red Wolf Recovery Program. We appreciate support of the Red Wolf Recovery Program, specifically R. Bartel, A. Beyer, C. Lucash, F. Mauney, M. Morse, R. Nordsven, and D. Rabon. We also thank R. Nowak, D. Cobb, R. Powell, and 2 anonymous reviewers for their constructive comments. The findings and conclusions in this article are those of the authors and do not necessarily represent the views of the United States Fish and Wildlife Service.

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Submitted 19 August 2013. Accepted 8 April 2014.

Associate Editor was Roger A. Powell.