

Eye size, fovea and foraging ecology in accipitriform raptors

Simon Potier^{a*}, Mindaugas Mitkus^{b#}, Francesco Bonadonna^a, Olivier Duriez^a, Pierre-François Isard^c, Thomas Dulaurent^c, Marielle Mentek^c and Almut Kelber^b

Supplementary material

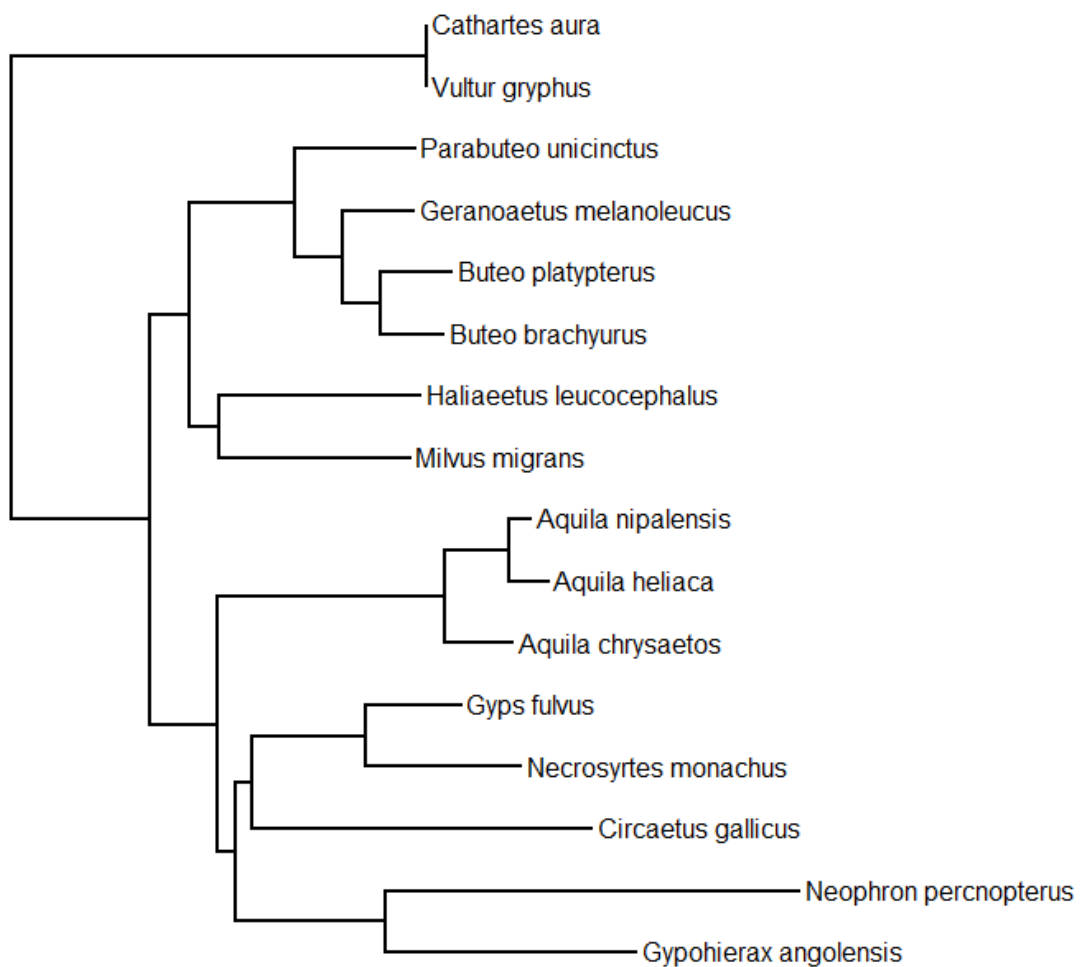


Figure S1: Phylogenetic tree for the species used for the fovea measurements; derived from Jiang et al. (2015).

Table S1: Corneal diameter, axial length and body mass of raptors used for the eye size comparison

Family	Species scientific name	Corneal diameter (mm)	Number of individuals for corneal diameter measurements	Corneal diameter reference	Axial length* (mm)	Body mass# (g)	Number of individuals for body mass measurements	Ecology
Cathartidae	<i>Cathartes aura</i>	9.2/8.3	3/3	Ritland (1982)/present report	18.6	2006.0	130	C
	<i>Coragyps atratus</i>	8.8	1	Ritland (1982)	16.8	1640.0	50	C
	<i>Sarcoramphus papa</i>	11.8	4	Ritland (1982)	26.2	3400.0	28	C
	<i>Gymnogyps californianus</i>	11.2	1	Ritland (1982)	25.5	8450.0	?	C
	<i>Vultur gryphus</i>	10.8/11.8	1/1	Ritland (1982)/present report	23.7	10800.0	?	C
Pandionidae	<i>Pandion haliaetus</i>	12.4	4	Ritland (1982)	21.4	1485.5	24	P
Accipitridae	<i>Aviceda subcristata</i>	11.1	1	Ritland (1982)	22.8	327.0	19	P
	<i>Aviceda leuphotes</i>	10.2	1	Ritland (1982)	20.8	NA	NA	P
	<i>Chondrohierax uncinatus</i>	10.8	1	Ritland (1982)	17.4	NA	NA	P
	<i>Henicopernis longicauda</i>	11.6	1	Ritland (1982)	24.3	588.5	2	P
	<i>Pernis apivorus</i>	11.3	1	Ritland (1982)	21.5	758.0	18	P
	<i>Elanoides forficatus</i>	10.2	1	Ritland (1982)	20.3	442.0	14	P
	<i>Macheiramphus alcinus</i>	15.8	3	Ritland (1982)	24.4	650.0	1	P
	<i>Elanus leucurus</i>	10.6	2	Ritland (1982)	21.1	346.0	33	P
	<i>Elanus caeruleus</i>	10.1	1	Ritland (1982)	18.1	260.5	?	P
	<i>Elanus axillaris</i>	10.6	1	Ritland (1982)	19.8	271.0	16	P
	<i>Chelictinia riocourii</i>	7.3	1	Ritland (1982)	13.8	110.0	1	P
	<i>Rostrhamus sociabilis</i>	9.3	1	Ritland (1982)	17.4	420.0	13	P
	<i>Harpagus bidentatus</i>	9.8	2	Ritland (1982)	18.1	218.5	8	P
	<i>Ictinia plumbea</i>	9.4	1	Ritland (1982)	17.4	248.5	23	P

<i>Milvus migrans</i>	10.5/10.7	3/4	Ritland (1982)/present report	20.0	567.0	96	C
<i>Milvus milvus</i>	10.4	2	Ritland (1982)	20.3	836.0	14	P
<i>Haliaeetus spheurus</i>	9.2	1	Ritland (1982)	18.5	753.0	452	P
<i>Haliaeetus indus</i>	10.2	1	Ritland (1982)	20.6	529.0	17	C
<i>Haliaeetus vocifer</i>	NA	NA	Ritland (1982)	21.6	3400.0	5	P
<i>Haliaeetus leucocephalus</i>	15.8/14.3	3/2	Ritland (1982)/present report	28.2	4740.0	72	P
<i>Gypohierax angolensis</i>	11.5/10.1	2/2	Ritland (1982)/present report	21.7	1600.0	6	C
<i>Neophron percnopterus</i>	10.2/9.9	3/3	Ritland (1982)/present report	22.1	2082.0	7	C
<i>Gypaetus barbatus</i>	14.8	2	Ritland (1982)	31.0	5680.0	15	C
<i>Gyps bengalensis</i>	10.8	1	Ritland (1982)	20.4	4385.0	29	C
<i>Gyps africanus</i>	11.0	1	Ritland (1982)	20.1	5433.0	44	C
<i>Sarcogyps calvus</i>	13.1	1	Ritland (1982)	27.3	NA	NA	C
<i>Torgos tracheliotos</i>	17.0	6	Spiegel et al. (2013)	NA	6969.0	21	C
<i>Aegyptius monachus</i>	18.1	1	present report	NA	9625.0	41	C
<i>Necrosyrtes monachus</i>	11.2/12.0	3/3	Ritland (1982)/present report	21.0	2043.0	7	C
<i>Gyps fulvus</i>	11.9	3	present report	NA	7436.0	15	C
<i>Circaetus gallicus</i>	15.3/17.4	2/1	Ritland (1982)/present report	32.5	1669.5	22	P
<i>Terathopius ecaudatus</i>	16.5	2	Ritland (1982)	32.8	2200.0	10	P
<i>Spilornis rufipectus</i>	13.3	1	Ritland (1982)	24.6	NA	NA	P
<i>Spilornis cheela</i>	14.0	2	Ritland (1982)	25.8	492.5	2	P
<i>Polyboroides typus</i>	9.1	1	Ritland (1982)	16.4	637.5	?	P
<i>Circus cyaneus</i>	9.5	2	Ritland (1982)	18.5	437.0	4	P
<i>Circus cinereus</i>	8.5	1	Ritland (1982)	17.6	405.5	8	P
<i>Circus macrourus</i>	9.4	1	Ritland (1982)	17.3	388.5	21	P
<i>Circus approximans</i>	10.7	1	Ritland (1982)	19.8	740.0	120	P
<i>Melierax metabates</i>	11.7	1	Ritland (1982)	21.0	NA	NA	P
<i>Micronisus gabar</i>	7.8	1	Ritland (1982)	13.1	NA	NA	P

<i>Accipiter gentilis</i>	11.9	1	Ritland (1982)	22.3	1027.5	180	P
<i>Accipiter melanoleucus</i>	10.8	1	Ritland (1982)	18.8	699.0	19	P
<i>Accipiter madagascariensis</i>	9.2	1	Ritland (1982)	16.0	212.0	10	P
<i>Accipiter gularis</i>	7.9	1	Ritland (1982)	13.1	121.5	22	P
<i>Accipiter virgatus</i>	11.1	1	Ritland (1982)	16.6	NA	NA	P
<i>Accipiter nisus</i>	NA	NA	Ritland (1982)	13.6	237.5	316	P
<i>Accipiter striatus</i>	7.5	4	Ritland (1982)	13.5	138.5	922	P
<i>Accipiter minullus</i>	6.9	1	Ritland (1982)	11.1	88.3	3	P
<i>Accipiter tachiro</i>	9.5	2	Ritland (1982)	16.8	202.0	4	P
<i>Accipiter trivirgatus</i>	11.8	1	Ritland (1982)	21.8	276.0	?	P
<i>Accipiter fasciatus</i>	10.5	1	Ritland (1982)	18.1	475.5	45	P
<i>Accipiter novaehollandiae</i>	10.2	1	Ritland (1982)	17.8	538.0	16	P
<i>Accipiter soloensis</i>	7.1	1	Ritland (1982)	13.3	165.5	4	P
<i>Accipiter badius</i>	9.0	1	Ritland (1982)	15.4	131.5	?	P
<i>Accipiter butleri</i>	7.3	1	Ritland (1982)	13.1	NA	NA	P
<i>Accipiter francesiae</i>	8.7	1	Ritland (1982)	14.2	198.5	17	P
<i>Accipiter cooperii</i>	10.5	1	Ritland (1982)	18.0	439.0	108	P
<i>Butastur rufipennis</i>	10.1	1	Ritland (1982)	19.4	335.0	?	P
<i>Butastur teesa</i>	10.8	1	Ritland (1982)	18.9	325.0	1	P
<i>Butastur indicus</i>	10.4	2	Ritland (1982)	19.4	415.0	?	P
<i>Kaupifalco monogrammicus</i>	10.2	1	Ritland (1982)	19.3	280.5	?	P
<i>Leucopternis melanops</i>	10.6	1	Ritland (1982)	20.3	312.0	9	P
<i>Buteogallus anthracinus</i>	12.0	1	Ritland (1982)	21.0	996.0	10	P
<i>Buteogallus urubitinga</i>	13.7	1	Ritland (1982)	23.5	1156.5	14	P
<i>Buteogallus meridionalis</i>	12.2	1	Ritland (1982)	23.0	808.0	8	P
<i>Busarellus nigricollis</i>	12.1	1	Ritland (1982)	20.8	785.0	8	P

<i>Buteo nitidus</i>	12.0	1	Ritland (1982)	21.0	528.5	30	P
<i>Rupornis magnirostris</i>	10.2	3	Ritland (1982)	19.0	269.0	16	P
<i>Buteo ridgwayi</i>	10.8	1	Ritland (1982)	19.6	NA	NA	P
<i>Buteo lineatus</i>	12.7	2	Ritland (1982)	23.1	607.0	46	P
<i>Buteo platypterus</i>	10.5	2	Ritland (1982)	20.3	455.0	27	P
<i>Buteo swainsoni</i>	10.0	1	Ritland (1982)	19.6	958.5	119	P
<i>Buteo galapagoensis</i>	10.8	1	Ritland (1982)	23.6	1357.5	137	P
<i>Buteo jamaicensis</i>	14.7	4	Ritland (1982)	27.8	1126.0	208	P
<i>Buteo buteo</i>	12.2	1	Ritland (1982)	20.8	875.0	480	P
<i>Buteo lagopus</i>	14.1	1	Ritland (1982)	27.1	956.0	271	P
<i>Buteo rufofuscus</i>	NA	NA	Ritland (1982)	20.1	1530.0	1	P
<i>Parabuteo unicinctus</i>	10.3	6	present report	NA	844.0	397	P
<i>Geranoaetus melanoleucus</i>	14.9	2	present report	NA	2445.0	6	P
<i>Harpia harpyja</i>	16.2	1	Ritland (1982)	32.3	4800.0	?	P
<i>Pithecophaga jefferyi</i>	18.6	2	Ritland (1982)	33.8	5232.0	?	P
<i>Clanga pomarina</i>	NA	NA	Ritland (1982)	26.8	1370.0	37	P
<i>Aquila rapax</i>	13.9	1	Ritland (1982)	27.8	NA	NA	P
<i>Aquila audax</i>	15.0	1	Ritland (1982)	27.3	3466.0	46	P
<i>Aquila nipalensis</i>	16.0	3	present report	NA	2745.5	9	P
<i>Aquila chrysaetos</i>	15.5/16.7	3/1	Ritland (1982)/present report	29.3	4263.5	48	P
<i>Aquila heliaca</i>	12.4	1	present report	NA	3215.0	10	P
<i>Hieraaetus pennatus</i>	11.8	1	Ritland (1982)	22.6	834.5	23	P
<i>Hieraaetus morphnoides</i>	12.5	1	Ritland (1982)	23.4	791.0	33	P
<i>Nisaetus cirrhatus</i>	15.0	1	Ritland (1982)	25.7	1480.0	?	P
<i>Nisaetus philippensis</i>	13.6	1	Ritland (1982)	26.2	1168.0	1	P
<i>Spizaetus ornatus</i>	13.4	1	Ritland (1982)	24.1	1215.0	9	P
<i>Stephanoaetus coronatus</i>	14.1	1	Ritland (1982)	28.7	3640.0	4	P

Sagittariidae	<i>Sagittarius serpentarius</i>	15.4	4	Ritland (1982)	30.5	4017.0	20	P
----------------------	---------------------------------	------	---	----------------	------	--------	----	---

* From Ritland (1982)

From Dunning (2007)

Ecology: P - Predator & C - Carrion eater

Table S2: Mean central fovea and retina measurements (or mean \pm S.E. if applicable) from the SD-OCT images (B-scans).

Species scientific name	Number of individuals	Central fovea				Ecology
		RetThiEdg (μm)	RetThiRim (μm)	RetThiPit (μm)	MaxFovDep (μm)	
<i>Gypohierax angolensis</i>	2	430	No rim	190	240	C
<i>Neophron percnopterus</i>	2	410	440	230	210	C
<i>Circaetus gallicus</i>	1	500	No rim	250	250	P
<i>Gyps fulvus</i>	3	420 \pm 0.00	No rim	200 \pm 8.82	230 \pm 6.67	C
<i>Necrosyrtes monachus</i>	2	450	No rim	230	220	C
<i>Aquila chrysaetos</i>	1	450	480	230	250	P
<i>Aquila heliaca</i>	1	460	No rim	230	230	P
<i>Aquila nipalensis</i>	1	430	440	180	260	P
<i>Milvus migrans</i>	3	390 \pm 6.67	410	210 \pm 20.28	210 \pm 31.80	C
<i>Haliaeetus leucocephalus</i>	3	430 \pm 6.67	460	210 \pm 8.82	260 \pm 15.27	P
<i>Geranoaetus melanoleucus</i>	1	440	480	-	-	P
<i>Parabuteo unicinctus</i>	7	440 \pm 5.22	470 \pm 3.69	180 \pm 10.46	290 \pm 10.43	P
<i>Buteo brachyurus</i>	1	470	500	250	250	P
<i>Buteo platypterus</i>	1	460	No rim	250	300	P
<i>Vultur gryphus</i>	1	400	430	170	260	C
<i>Cathartes aura</i>	3	380 \pm 0.00	400	190 \pm 11.55	210 \pm 11.55	C

RetThiEdg - retinal thickness at the foveal edge;

RetThiRim - retinal thickness at the foveal rim;

RetThiPit - retinal thickness at the centre of the pit

(see the Method section for explanation);

Ecology: P - Predator & C - Carrion eater

Table S2: Temporal fovea and retina measurements from the SD-OCT images (B-scans).

Species scientific name	Number of individuals	Temporal fovea				Ecology
		RetThiEdg (μm)	RetThiRim (μm)	RetThiPit (μm)	MaxFovDep (μm)	
<i>Gypohierax angolensis</i>	2	-	-	-	-	C
<i>Neophron percnopterus</i>	2	-	-	-	-	C
<i>Circaetus gallicus</i>	1	350	360	350	10	P
<i>Gyps fulvus</i>	3	-	-	-	-	C
<i>Necrosyrtes monachus</i>	2	-	-	-	-	C
<i>Aquila chrysaetos</i>	1	370	400	300	100	P
<i>Aquila heliaca</i>	1	380	No rim	370	10	P
<i>Aquila nipalensis</i>	1	370	No rim	320	50	P
<i>Milvus migrans</i>	3	-	-	-	-	C
<i>Haliaeetus leucocephalus</i>	3	350	No rim	340	10	P
<i>Geranoaetus melanoleucus</i>	1	360	380	350	30	P
<i>Parabuteo unicinctus</i>	7	350 \pm 6.15	No rim	330 \pm 6.15	30 \pm 11.25	P
<i>Buteo brachyurus</i>	1	370	410	290	120	P
<i>Buteo platypterus</i>	1	-	-	-	-	P
<i>Vultur gryphus</i>	1	-	-	-	-	C
<i>Cathartes aura</i>	3	-	-	-	-	C

RetThiEdg - retinal thickness at the foveal edge;

RetThiRim - retinal thickness at the foveal rim;

RetThiPit - retinal thickness at the centre of the pit

(see the Method section for explanation);

Ecology: P - Predator & C - Carrion eater

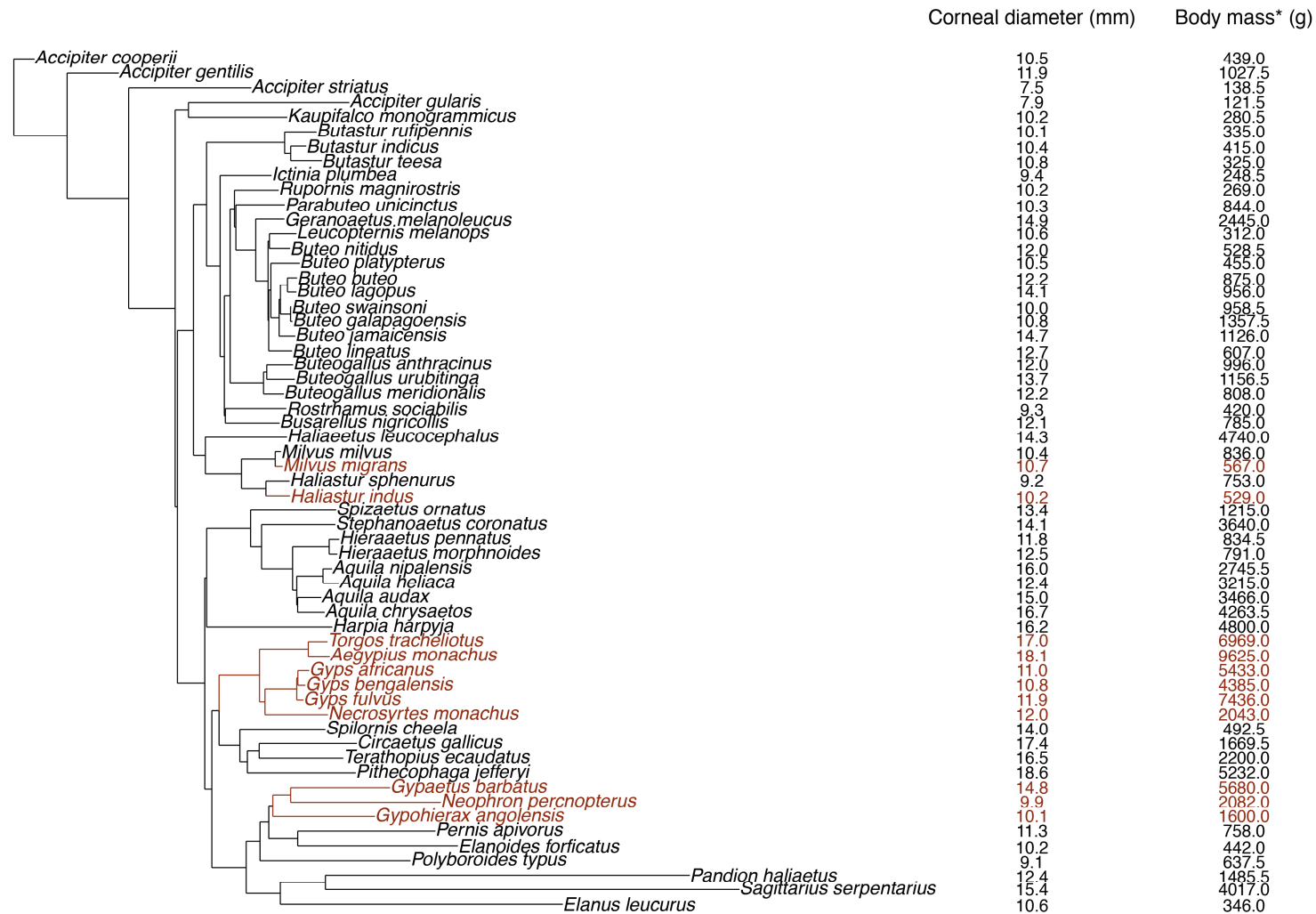


Figure S2: Phylogenetic tree used to estimate the relationship between corneal diameter and body mass; derived from Jiang et al. (2015). Predators are in black and carrion eaters in brown.

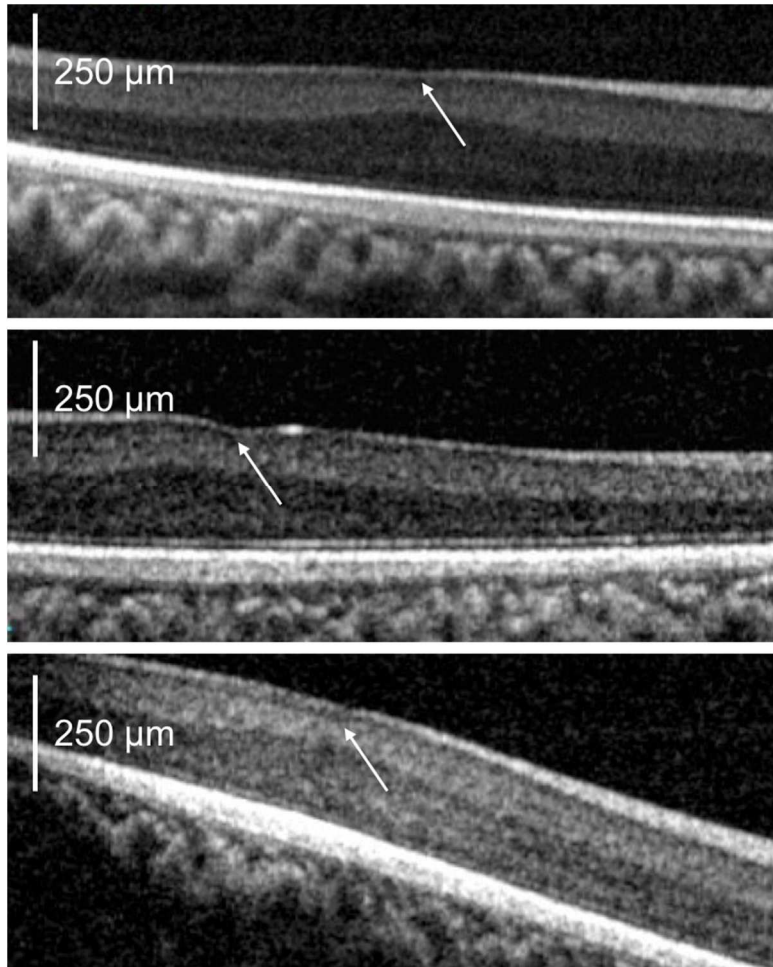


Figure S3: The shallow temporal fovea of three specimens of Bald eagle *Haliaeetus leucocephalus*. Please notice that there is no horizontal scale bar for the lateral dimension, only vertical scale bar for the axial dimension (thickness) of the retina, therefore foveal shape should not be evaluated mistakenly. The arrows point to the centre of the foveae.

Supplementary references

Dunning JB (2007): CRC Handbook of Avian Body Mass, 2nd edition. CRC Press, Cleveland.

Jiang L, Chen J, Wang P, Ren Q, Yuan J, Qian C, Hua X, Guo Z, Zhang L, Yang J (2015): The mitochondrial genomes of *Aquila fasciata* and *Buteo lagopus* (Aves, Accipitriformes): sequence, structure and phylogenetic analyses. *PloS one* **10**:e0136297.

Ritland SM (1982): The allometry of the vertebrate eye. Phd Thesis, University of Chicago, Department of Biology.

Spiegel O, Getz WM, Nathan R (2013) : Factors influencing foraging search efficiency: why do scarce lappet-faced vultures outperform ubiquitous whitebacked vultures? *Am Nat* **181**:E102-E115.