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Supporting Online Material for

Nocturnality in Dinosaurs Inferred from Scleral Ring and Orbit Morphology

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Material and methods

Proportions of photopic, mesopic, and scotopic amniotes in the extant biosphere: We estimated relative proportions of ocular image formation categories (in living mammals, squamates, and birds in order to obtain prior probabilities for discriminant analysis (*S1*, *S2*). The photopic group contains species with no activity in dim light levels (diurnal and diurnal+crepuscular). The scotopic group contains species that are never active in bright light conditions (nocturnal and nocturnal+crepuscular). The mesopic group, finally, features species that cope with varying, intermediate light levels (cathemeral and crepuscular). For example, cathemeral species have extended periods of activity in dim and bright light. This can include extended periods of activity in day and night on a diel or seasonal cycle. Crepuscular species are only active in twilight conditions and experience quickly changing light levels, ranging from dim to bright. Thus, crepusculars face optical challenges similar to cathemerals.

We combined two existing data sets (*S2, S3*) and added data from the Animal Diversity Web (http://animaldiversity.ummz.umich.edu/site/index.html; extracted on Oct. 7, 2010) for a total of 1,401 species (table S4). We adjusted the weight of the proportions of ocular image formation of squamates, avians, and mammals by correcting for their relative species richness since uneven sampling may bias the proportions. Specifically, we multiplied the counts for each clade (squamates, avians, and mammals) with the total number of species in the respective clade. Then, we divided the sum of these three numbers by the species number of squamates, avians, and mammals combined. Similarly, we adjusted the weight of the species-rich, largely nocturnal chiropterans and geckos, sub-clades of mammals and squamates, respectively. Total species counts for avians, squamates, mammals, chiropterans, and geckos are provided in reference *S4*.

Diel activity pattern and optics of the amniote eye: The timing of activity during the 24h cycle exposes species to substantially different light levels: diurnal species experience bright light, whereas nocturnal species cope with very dim light. Dim environments make it very difficult to produce an image of sufficient optical quality, because the number of photons reaching the retina is low and consequently the signal-to-noise ratio decreases (*S5*). Thus, nocturnal species benefit from improved light sensitivity, and modifications of the optical system can lead to better performance. For vision in dim light, amniotes need a large aperture (i.e., the size of the fully dilated pupil), which is controlled by the iris. Sensitivity can be maximized by increasing the size of the aperture, or fully dilated pupil, and simultaneously keeping the focal length constant, resulting in a low f-number (*S2, S3, S6*). Thus, the retinal image has the same size but is much brighter. Similarly, sensitivity is improved by maximizing aperture for the given size of the retina, because more light is captured by the same number of photoreceptors, assuming everything else stays constant (*S3*). Photopic species, active in bright ambient light levels, face the opposite problem: they need to protect the retina from too much incident light. Photopics minimize the amount of light entering the eye by keeping the aperture small. As the constriction of the pupil by the iris requires energy, the null point, or the maximum pupil diameter, is smaller than in scotopic species. Another benefit from a small maximum pupil diameter is a sufficient depth of focus without the requirement to contract the iris.We have used these optical predictions to form a ratio (aperture area / [focal length * retinal area]) that helps to delineate groups of different activity patterns, using both eye soft-tissue and hard-tissue traits as proxies for the optical variables (*S2, S3*). Discriminant analysis yields reliable distinction of different activity

patterns, where the multivariates axes reflect the optical ratio (axis 1) and overall eye size (axis 2) (*S2*, fig. S1). Coefficients of discriminant function 1, as found by phylogenetic flexible discriminant analysis at λ=0.08, are 0.32 for orbit length, -3.21 for external scleral ring diameter, and 4.38 for internal scleral ring diameter. Coefficients of discriminant function 2 are -5.2 for orbit length, 1.82 for external scleral ring diameter, and 3.51 for internal scleral ring diameter.

Measurements of scleral rings and orbits in fossil archosaurs: We measured orbit length, external, and internal scleral ring diameter of 33 Mesozoic archosaur species (table S1). In most cases we used digital calipers. However, some well-preserved specimens of the American Museum of Natural History are on display and protected by a glass-enclosing. We scanned these specimens with a NextEngine laser-scanner and measured dimensions digitally instead, because removal of the glass might damage the specimens. We supplemented these data with published dimensions, and also measured from published photographs and drawings (table S1).

Phylogeny: We performed phylogenetically informed discriminant analysis (pFDA) (*S2*) (fig. S2, see script below). The avian and squamates phylogeny is provided in reference *2*. We combined previously published topologies of phylogenetic hypotheses for fossil archosaurs (*S7-S10*). We estimated branch lengths based on stratigraphic occurrence (extracted from Paleobiology Database Oct. 22, 2010; http://paleodb.org/cgi-bin/bridge.pl; table S2) and minimized the lengths of ghost lineages. When several taxa (e.g., A, B, and C, with A the sistertaxon to (B, C)) had the same oldest stratigraphic appearance, we estimated the node age of the common ancestor of (A(B, C)) as one million years older than the first occurrence of A, B, and C. For branch lengths that we could not directly estimate by stratigraphic range of individual species, we assumed equal branch lengths scaled to the distance in-between the next closest node age estimates. The nexus file is provided below.

Script for phylogenetic discriminant analysis with separate training and test datasets: R scripts for phylogenetically informed discriminant analysis are attached to this file toward the end. There is also a step-by-step guide on how to use the scripts.

Fig. S1

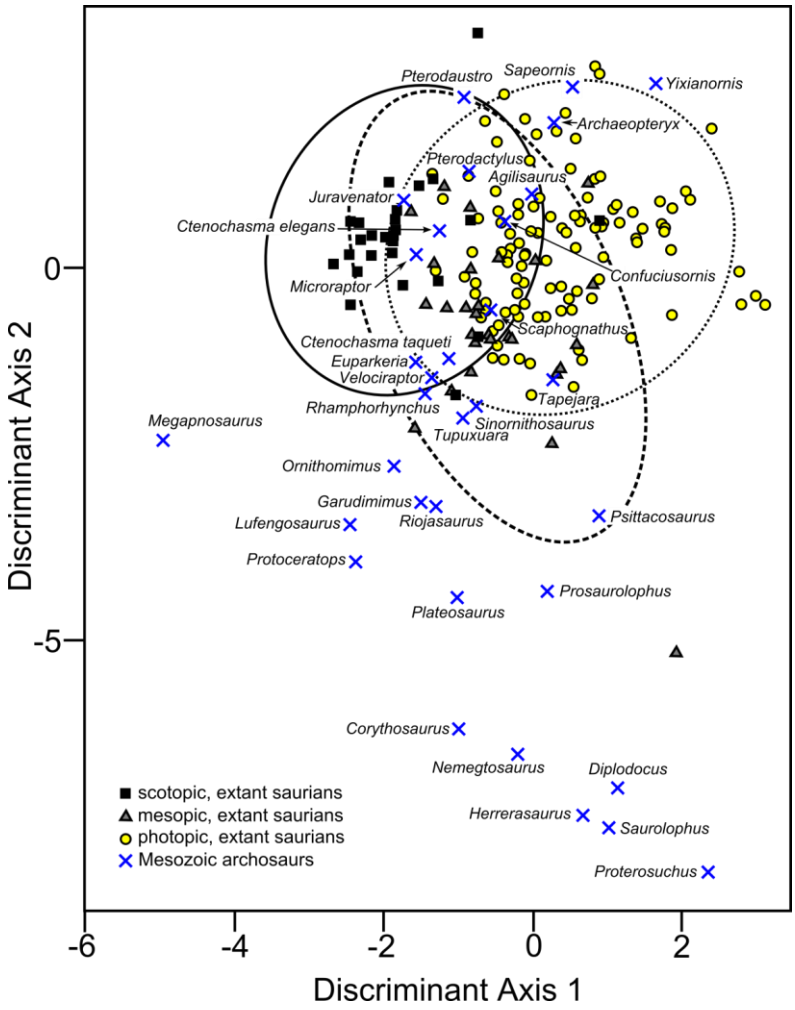

Fig. S1. Scatterplot of discriminant variates obtained from phylogenetic FDA. Discriminant axis 1 reflects the optical ratio, whereas scores on discriminant axis 2 are influenced by eye size. We plotted 95% confidence ellipses for each group of activity pattern as very approximate guidelines to help visualize the scatter of each pattern. These ellipses are not accurate representations of the discriminant method used.

Fig. S2

Fig. S2. Phylogeny and stratigraphic range of examined Mesozoic archosaurs. Neog., Neogene; Quart., Quaternary.

Table S1: Scleral Ring and Orbit Dimensions of Fossil Archosaurs

all dimensions in [mm]	OL	EXT	INT	collection #, reference
Basal archosaurs				
Euparkeria capensis	21.1	14.35	8.82	AMNH FR 29975 (cast)
Proterosuchus vanhoepeni	50	26.3	13.5	reference *S11**
Pterosaurs				
Ctenochasma elegans	9.97	6.82	5.14	ROM 52425
Ctenochasma taqueti	27	18.9	11.5	reference *S12**
*Pterodactylus antiquus***	12.35	9.56	5.84	BSP 1961 I 186, BSP AS V 29, BSP 1969 I 82, BSP AS XIX 3, BSP 1883 XVI I
Pterodaustro guinazui	14	13.45	6.73	AMNH FR 21483 (cast)
*Rhamphorhynchus muensteri***	25.15	16.7	11.29	JME SOS 2819, BSP 1867 II 2
Scaphognathus crassirostris	25	18	10	Goldfuss Museum Bonn 1304
Tapejara wellnhoferi	28.8	17.53	9.81	AMNH FR 24440
Tupuxuara sp.	43.25	29.5	16.7	BSP 1993 I 31
Ornithischian dinosaurs				
Agilisaurus louderbacki	32	26.5	11.3	reference *S13**, EXT given in text
Corythosaurus casuarius	146	63.2	45	AMNH FR 5338
Prosaurolophus maximus	148	77.6	37.4	AMNH FR 5386
Protoceratops andrewsi	93	59	40.5	AMNH FR 6466, reference *S14* (OL)
Psittacosaurus mongoliensis	40.2	18.7	11.52	AMNH FR 6254
Saurolophus osborni	269	92.6	51.7	AMNH FR 5220
Basal saurischian dinosaur				
Herrerasaurus ischigualestensis	69.3	33.94	19.77	reference *S15*, UCMP 177287, V98119
Sauropodomorph dinosaurs				
Diplodocus longus	148	63	33	ROM (cast) , reference *S16* (EXT and INT)
Lufengosaurus huenei	63	45	26	reference *S17**
Nemegtosaurus mongoliensis	205	88	52.2	reference *S18**
Plateosaurus longiceps	75	48.45	25.2	AMNH FR 6810, reference *S19** (OL)
Riojasaurus incertus	67	48.3	23.8	reference *S20*
Non-avian theropods				
Garudimimus brevipes	61.9	41.2	26.8	reference *S21*
Juravenator starki	18.11	15.78	9.75	JME Sch 200
Megapnosaurus kayentakatae	52	47.3	32.4	CSU Sacramento, Department of Geology, Teaching Collection (cast)
Microraptor gui	19.7	16.2	10.5	IVPP V 13352*

Ornithomimus edmontonicus	67	49.55	31.1	AMNH FR 6819
Sinornithosaurus sp.	30.3	19.74	13.09	AMNH FARB 30577
Velociraptor mongoliensis	39.83	30.2	18.56	UC Davis, Department of Geology, Teaching Collection (cast)
Avians				
Archaeopteryx lithographica	14	11.5	6	Berlin specimen, HMN 1880/1881
Confuciusornis sanctus	18	14.31	8.23	BSP 2000 I 5
Sapeornis chaoyangensis	15.84	14.64	6.5	IVPP V 13396
Yixianornis grabaui	10.65	8.31	3.9	IVPP V 12631

* measured from figure/photograph
** species average
Abbreviations: EXT, external scleral ring diameter; INT, internal scleral ring diameter; OL, orbit length.

Institutional Abbreviations: AMNH, American Museum of Natural History; BSP, Bayerische Staatssammlung für Paläontologie; CSU, California State University; HMN, Humboldt Museum für Naturkunde Berlin; IVPP, Institue of Vertebrate Paleontology and Paleoanthropology; JME, Jura-Museum Eichstätt; ROM, Royal Ontario Museum Toronto; UC, University of California; UCMP, University of California Museum of Paleontology.

Table S2: Stratigraphic Range of Examined Fossil Archosaurs

in [million years]	from	to
Basal archosaurs		
Euparkeria capensis	245	237
Proterosuchus vanhoepeni	251	249.7
Pterosaurs		
Ctenochasma elegans	150.8	145.5
Ctenochasma taqueti	150.8	145.5
Pterodactylus antiquus	150.8	145.5
Pterodaustro guinazui	125	99.6
Rhamphorhynchus muensteri	155.7	145.5
Scaphognathus crassirostris	150.8	145.5
Tapejara wellnhoferi	112	99.6
Tupuxuara sp.	112	99.6
Ornithischian dinosaurs		
Agilisaurus louderbacki	171.6	161.2
Corythosaurus casuarius	83.5	70.6
Prosaurolophus maximus	83.5	70.6
Protoceratops andrewsi	83.5	70.6
Psittacosaurus mongoliensis	125	112
Saurolophus osborni	83.5	65.5
Basal saurischian dinosaur		
Herrerasaurus ischigualestensis	228	216.5
Sauropodomorph dinosaurs		
Diplodocus longus	155.7	145.5
Lufengosaurus huenei	199.6	189.6
Nemegtosaurus mongoliensis	83.5	65.5
Plateosaurus longiceps	216.5	199.6
Riojasaurus incertus	216.5	203.6
Non-avian theropods		
Garudimimus brevipes	99.6	89.3
Juravenator starki	155.7	150.8
Megapnosaurus kayentakatae	199.6	175.6
Microraptor gui	125	112
Ornithomimus edmontonicus	83.5	65.5
Sinornithosaurus sp.	125	112
Velociraptor mongoliensis	85.8	70.6

Avians		
Archaeopteryx lithographica	150.8	145.5
Confuciusornis sanctus	130	112
Sapeornis chaoyangensis	125	112
Yixianornis grabaui	125	112

Table S3: Estimates of the Proportions of Ocular Image Formation Types in Extant Avians, Squamates, and Mammals

	mesopic	photopic	scotopic
Avians	41	301	33
Squamates	12	73	23
Mammals	156	276	486
All	209	650	542
in %, adjusted	14.4	58.5	27.1
Flyer	45	304	146
in %, adjusted	10.7	77.5	11.8
Terrestrial	164	346	396
in %, adjusted	17.3	41.4	41.3

Table S4: Types of Ocular Image Formation in Extant Squamates, Avians, and Mammals

	clade	OIF	source
Agkistrodon piscivorus	squamates	scotopic	ADW
Accipiter cooperii	avians	photopic	ADW
Accipiter gentilis	avians	photopic	*S2*
Accipiter striatus	avians	photopic	*S2*
Acerodon jubatus	mammals	scotopic	ADW
Aconaemys fuscus	mammals	scotopic	ADW
Acridotheres tristis	avians	photopic	ADW
Acrocephalus arundinaceus	avians	photopic	ADW
Actitis macularius	avians	photopic	ADW
Addax nasomaculatus	mammals	photopic	ADW
Aegithalos caudatus	avians	photopic	ADW
Aegolius acadicus	avians	scotopic	*S2*
Aegolius funereus	avians	scotopic	ADW
Aegotheles cristatus	avians	scotopic	*S2*
Aepyceros melampus	mammals	photopic	ADW
Aethia cristatella	avians	photopic	ADW
Agapornis roseicollis	avians	photopic	ADW
Agelaius phoeniceus	avians	photopic	ADW
Ailuroedus crassirostris	avians	photopic	ADW
Ailuropoda melanoleuca	mammals	scotopic	ADW
Ailurus fulgens	mammals	scotopic	ADW
Aimophila aestivalis	avians	photopic	ADW
Aimophila ruficeps	avians	photopic	ADW
Aix sponsa	avians	mesopic	*S2*
Akodon azarae	mammals	mesopic	ADW
Akodon philipmyersi	mammals	scotopic	ADW
Alauda arvensis	avians	photopic	ADW
Alcedo atthis	avians	photopic	ADW
Alces alces	mammals	mesopic	*S3*
Alectoris chukar	avians	photopic	ADW
Alethe choloensis	avians	photopic	ADW
Allactaga euphratica	mammals	scotopic	ADW
Allactodipus bobrinskii	mammals	scotopic	ADW
Alle alle	avians	photopic	ADW
Allenopithecus nigroviridis	mammals	photopic	ADW
Allocebus trichotis	mammals	scotopic	ADW
Alopochen aegyptiaca	avians	photopic	ADW
Alouatta belzebul	mammals	photopic	ADW
Alouatta caraya	mammals	photopic	ADW
Alouatta guariba	mammals	photopic	ADW

Alouatta pigra	mammals	photopic	ADW
Alouatta seniculus	mammals	photopic	ADW
Amandava amandava	avians	photopic	ADW
Amazilia tzacatl	avians	photopic	ADW
Amazona farinosa	avians	photopic	ADW
Amazona ochrocephala	avians	photopic	ADW
Amblysomus hottentotus	mammals	mesopic	ADW
Ameiva ameiva	squamates	photopic	*S2*
Ammodramus savannarum	avians	photopic	ADW
Ammotragus lervia	mammals	mesopic	*S3*
Amorphochilus schnablii	mammals	scotopic	ADW
Anas acuta	avians	mesopic	*S2*
Anas americana	avians	mesopic	*S2*
Anas discors	avians	photopic	ADW
Anas fulvigula	avians	photopic	ADW
Anas platyrhynchos	avians	mesopic	*S2*
Anas strepera	avians	photopic	*S2*
Anhima cornuta	avians	photopic	ADW
Anhinga anhinga	avians	photopic	ADW
Anodorhynchus hyacinthinus	avians	photopic	ADW
Anolis carolinensis	squamates	photopic	*S2*
Anolis equestris	squamates	photopic	ADW
Anolis sagrei	squamates	photopic	*S2*
Anomalurus beecrofti	mammals	scotopic	ADW
Anomalurus pusillus	mammals	scotopic	ADW
Anoura geoffroyi	mammals	scotopic	ADW
Anous minutus	avians	photopic	ADW
Anseranas semipalmata	avians	photopic	ADW
Antechinus swainsonii	mammals	scotopic	ADW
Anthropoides virgo	avians	photopic	ADW
Anthus cervinus	avians	photopic	ADW
Anthus spragueii	avians	photopic	ADW
Antilocapra americana	mammals	mesopic	ADW
Antilope cervicapra	mammals	mesopic	*S3*
Antrozous pallidus	mammals	scotopic	ADW
Aonyx capensis congica	mammals	scotopic	ADW
Aonyx cinerea	mammals	photopic	ADW
Aotus azarae	mammals	scotopic	ADW
Aotus lemurinus	mammals	scotopic	ADW
Aotus nancymaae	mammals	scotopic	ADW
Aotus nigriceps	mammals	scotopic	ADW
Aotus trivirgatus	mammals	scotopic	ADW
Aphelocoma coerulescens	avians	photopic	ADW

Aphelocorna californica	avians	photopic	*S2*
Aptenodytes patagonicus	avians	photopic	ADW
Apteryx australis	avians	scotopic	ADW
Apus apus	avians	mesopic	*S2*
Aquila audax	avians	mesopic	*S2*
Aquila chrysaetos	avians	mesopic	*S2*
Aquila clanga	avians	photopic	ADW
Aquila rapax	avians	photopic	ADW
Arborimus longicaudus	mammals	scotopic	ADW
Archilochus colubris	avians	photopic	ADW
Arctocebus calabarensis	mammals	scotopic	ADW
Arctocephalus australis	mammals	scotopic	ADW
Arctonyx collaris	mammals	scotopic	ADW
Ardea alba	avians	photopic	ADW
Ardea herodias	avians	mesopic	*S2*
Ardeotis kori	avians	photopic	ADW
Arenaria interpres	avians	photopic	ADW
Arvicanthis niloticus	mammals	photopic	ADW
Arvicola amphibius	mammals	mesopic	ADW
Asellia tridens	mammals	scotopic	ADW
Asio flammeus	avians	scotopic	ADW
Asio otus	avians	scotopic	*S2*
Asturina nitida	avians	photopic	*S2*
Atelerix frontalis	mammals	scotopic	ADW
Ateles belzebuth	mammals	photopic	ADW
Ateles fusciceps	mammals	photopic	ADW
Ateles geoffroyi	mammals	photopic	ADW
Ateles hybridus	mammals	photopic	ADW
Atelocynus microtis	mammals	mesopic	ADW
Athene cunicularia	avians	mesopic	*S3*
Atherurus macrourus	mammals	scotopic	ADW
Avahi laniger	mammals	scotopic	ADW
Aviceda madagascariensis	avians	photopic	ADW
Axis axis	mammals	photopic	ADW
Axis porcinus	mammals	scotopic	ADW
Aythya affinis	avians	photopic	ADW
Aythya valisineria	avians	photopic	ADW
Balaeniceps rex	avians	photopic	ADW
Balaenoptera physalus	mammals	mesopic	ADW
Balionycteris maculata	mammals	mesopic	ADW
Basiliscus basiliscus	squamates	photopic	*S2*
Basiliscus vittatus	squamates	photopic	*S2*
Bassaricyon gabbii	mammals	scotopic	ADW

Bassariscus astutus	mammals	scotopic	ADW
Bdeogale nigripes	mammals	scotopic	ADW
Beatragus hunteri	mammals	mesopic	ADW
Bettongia gaimardi	mammals	scotopic	ADW
Bettongia lesueur	mammals	scotopic	ADW
Bison bison	mammals	photopic	ADW
Bison bonasus	mammals	mesopic	*S3*
Bitis gabonica	squamates	scotopic	ADW
Blarina brevicauda	mammals	mesopic	ADW
Blarina carolinensis	mammals	scotopic	ADW
Blarina hylophaga	mammals	scotopic	ADW
Boa constrictor	squamates	scotopic	ADW
Bombycilla cedrorum	avians	photopic	ADW
Bombycilla garrulus	avians	photopic	ADW
Bos gaurus	mammals	mesopic	*S3*
Bos javanicus	mammals	mesopic	*S3*
Bos sauveli	mammals	scotopic	ADW
Bos taurus	mammals	photopic	ADW
Brachylagus idahoensis	mammals	photopic	ADW
Brachytarsomys albicauda	mammals	scotopic	ADW
Bradypodion fischeri	squamates	photopic	*S3*
Bradypus torquatus	mammals	mesopic	ADW
Branta canadensis	avians	photopic	ADW
Branta sandvicensis	avians	photopic	ADW
Bubalus bubalis	mammals	mesopic	ADW
Bubalus mindorensis	mammals	scotopic	ADW
Bubalus quarlesi	mammals	photopic	ADW
Bubo bubo	avians	scotopic	*S2*
Bubulcus ibis	avians	photopic	*S2*
Bucephala clangula	avians	photopic	ADW
Bucorvus abyssinicus	avians	photopic	ADW
Budorcas taxicolor	mammals	mesopic	*S3*
Bunolagus monticularis	mammals	scotopic	ADW
Bunopithecus hoolock	mammals	photopic	ADW
Buteo brachyurus	avians	photopic	ADW
Buteo buteo	avians	photopic	*S2*
Buteo jamaicensis	avians	photopic	*S2*
Buteo lagopus	avians	photopic	ADW
Buteo lineatus	avians	photopic	ADW
Buteo platypterus	avians	photopic	ADW
Buteo regalis	avians	mesopic	*S2*
Buteo swainsoni	avians	photopic	*S2*
Butorides sundevalli	avians	photopic	ADW

Butorides virescens	avians	photopic	ADW
Bycanistes subcylindricus	avians	photopic	ADW
Cabassous tatouay	mammals	scotopic	ADW
Cacajao calvus	mammals	photopic	ADW
Cacajao melanocephalus	mammals	photopic	ADW
Cacatua alba	avians	photopic	ADW
Cacatua galerita	avians	photopic	ADW
Caenolestes fuliginosus	mammals	scotopic	ADW
Calidris alba	avians	photopic	ADW
Callicebus cupreus	mammals	photopic	ADW
Callicebus moloch	mammals	photopic	ADW
Callicebus personatus	mammals	photopic	ADW
Callicebus torquatus	mammals	photopic	ADW
Callipepla californica	avians	photopic	*S2*
Callipepla gambeli	avians	photopic	*S2*
Callithrix argentata	mammals	photopic	ADW
Callithrix chrysoleuca	mammals	photopic	ADW
Callithrix jacchus	mammals	photopic	ADW
Callithrix kuhlii	mammals	photopic	ADW
Callithrix penicillata	mammals	photopic	ADW
Callithrix pygmaea	mammals	photopic	ADW
Callorhinus ursinus	mammals	mesopic	ADW
Callosciurus erythraeus	mammals	photopic	ADW
Callosciurus notatus	mammals	photopic	ADW
Callosciurus prevostii	mammals	mesopic	ADW
Calomyscus bailwardi	mammals	mesopic	ADW
Caluromys philander	mammals	scotopic	ADW
Calypte anna	avians	photopic	*S2*
Calyptophractus retusus	mammals	scotopic	ADW
Camelus bactrianus	mammals	photopic	ADW
Camelus dromedarius	mammals	photopic	ADW
Campephilus principalis	avians	photopic	ADW
Canis adustus	mammals	scotopic	ADW
Canis aureus	mammals	mesopic	ADW
Canis familiaris	mammals	mesopic	*S3*
Canis latrans	mammals	scotopic	ADW
Canis lupus	mammals	mesopic	ADW
Canis lupus dingo	mammals	scotopic	ADW
Canis lupus familiaris	mammals	mesopic	ADW
Canis mesomelas	mammals	mesopic	ADW
Canis rufus	mammals	scotopic	ADW
Canis simensis	mammals	mesopic	ADW
Capra caucasica	mammals	mesopic	*S3*

Capra cylindricornis	mammals	mesopic	*S3*
Capra falconeri	mammals	photopic	ADW
Capra hircus	mammals	photopic	ADW
Capra ibex	mammals	photopic	ADW
Capra nubiana	mammals	mesopic	ADW
Capra sibirica	mammals	photopic	ADW
Capra walie	mammals	mesopic	ADW
Capricornis crispus	mammals	mesopic	ADW
Caprimulgus carolinensis	avians	mesopic	*S2*
Caprimulgus europaeus	avians	scotopic	*S3*
Caprimulgus ridgwayi	avians	scotopic	*S2*
Caprimulgus rufigena	avians	scotopic	*S2*
Caprimulgus vociferus	avians	scotopic	*S2*
Caprolagus hispidus	mammals	scotopic	ADW
Caracal caracal	mammals	scotopic	ADW
Cardinalis cardinalis	avians	photopic	ADW
Cardiocranius paradoxus	mammals	scotopic	ADW
Cardioderma cor	mammals	scotopic	ADW
Carduelis tristis	avians	photopic	ADW
Carpodacus mexicanus	avians	photopic	ADW
Carpodacus purpureus	avians	photopic	*S2*
Castor canadensis	mammals	scotopic	ADW
Castor fiber	mammals	scotopic	ADW
Casuarius bennetti	avians	photopic	ADW
Casuarius casuarius	avians	photopic	ADW
Cathartes aura	avians	photopic	*S2*
Catharus guttatus	avians	photopic	*S2*
Catharus ustulatus	avians	photopic	*S2*
Catoptrophorus semipalmatus	avians	mesopic	*S2*
Catopuma badia	mammals	scotopic	ADW
Catopuma temminckii	mammals	scotopic	ADW
Cebus apella	mammals	photopic	ADW
Cebus capucinus	mammals	photopic	ADW
Cebus xanthosternos	mammals	photopic	ADW
Centurio senex	mammals	scotopic	ADW
Cephalophus niger	mammals	scotopic	ADW
Cephalophus rufilatus	mammals	photopic	ADW
Cephalophus silvicultor	mammals	scotopic	ADW
Cercartetus concinnus	mammals	scotopic	ADW
Cercocebus agilis	mammals	photopic	ADW
Cercopithecus ascanius	mammals	photopic	ADW
Cercopithecus cephus	mammals	photopic	ADW
Cercopithecus diana	mammals	photopic	ADW

Cercopithecus hamlyni	mammals	photopic	ADW
Cercopithecus mitis	mammals	photopic	ADW
Cercopithecus mona	mammals	photopic	ADW
Cercopithecus neglectus	mammals	photopic	ADW
Cercopithecus sclateri	mammals	photopic	ADW
Cercopithecus wolfi	mammals	photopic	ADW
Cerdocyon thous	mammals	scotopic	ADW
Certhia americana	avians	photopic	ADW
Cervus elaphus	mammals	mesopic	*S3*
Cervus nippon	mammals	scotopic	ADW
Ceryle rudis	avians	photopic	ADW
Cetartiodactyla	mammals	mesopic	ADW
Chaerephon pumilus	mammals	scotopic	ADW
Chaetodipus baileyi	mammals	scotopic	ADW
Chaetodipus californicus	mammals	scotopic	ADW
Chaetodipus fallax	mammals	scotopic	ADW
Chaetodipus formosus	mammals	scotopic	ADW
Chaetodipus nelsoni	mammals	scotopic	ADW
Chaetomys subspinosus	mammals	scotopic	ADW
Chaetophractus nationi	mammals	scotopic	ADW
Chaetophractus villosus	mammals	mesopic	ADW
Chaetura pelagica	avians	photopic	*S2*
Chalcophaps indica	avians	photopic	*S3*
Chamaeleo calyptratus	squamates	photopic	*S2*
Chamaeleo dilepsi	squamates	photopic	*S3*
Chamaeleo vulgaris	squamates	photopic	*S2*
Charadrius pecuarius	avians	photopic	ADW
Charadrius vociferus	avians	mesopic	*S2*
Charina trivirgata	squamates	mesopic	ADW
Cheirogaleus major	mammals	scotopic	ADW
Cheirogaleus medius	mammals	scotopic	ADW
Cheiromeles torquatus	mammals	scotopic	ADW
Chilonatalus micropus	mammals	scotopic	ADW
Chilonatalus tumidifrons	mammals	scotopic	ADW
Chinchilla chinchilla	mammals	scotopic	ADW
Chiropotes satanas	mammals	photopic	ADW
Chlamydosaurus kingii	squamates	photopic	*S3*
Chlorocebus aethiops	mammals	photopic	ADW
Chlorophanes spiza	avians	photopic	*S3*
Choeronycteris mexicana	mammals	scotopic	ADW
Choloepus didactylus	mammals	scotopic	ADW
Choloepus hoffmanni	mammals	scotopic	ADW
Chordeiles acutipennis	avians	mesopic	*S2*

Chordeiles minor	avians	mesopic	*S2*
Chrotogale owstoni	mammals	scotopic	ADW
Chrotopterus auritus	mammals	scotopic	ADW
Chrysocyon brachyurus	mammals	scotopic	ADW
Chrysolophus pictus	avians	photopic	*S2*
Chrysospalax trevelyani	mammals	scotopic	ADW
Ciccaba nigrolineata	avians	scotopic	ADW
Ciconia ciconia	avians	photopic	ADW
Ciconia nigra	avians	photopic	ADW
Cinclus cinclus	avians	photopic	ADW
Circus cyaneus	avians	photopic	ADW
Cistothorus platensis	avians	photopic	ADW
Cnemidophorus tigris	squamates	photopic	*S2*
Coccothraustes vespertinus	avians	photopic	*S2*
Coccyzus americanus	avians	photopic	*S2*
Coccyzus erythopthalmus	avians	photopic	ADW
Colaptes auratus	avians	photopic	ADW
Coleonyx brevis	squamates	scotopic	ADW
Colinus virginianus	avians	photopic	ADW
Colobus guereza	mammals	photopic	ADW
Colobus polykomos	mammals	photopic	ADW
Colobus vellerosus	mammals	photopic	ADW
Coluber constrictor	squamates	photopic	ADW
Condylura cristata	mammals	mesopic	ADW
Conepatus chinga	mammals	scotopic	ADW
Conepatus humboldtii	mammals	scotopic	ADW
Conepatus leuconotus leuconotus	mammals	scotopic	ADW
Conepatus semistriatus	mammals	scotopic	ADW
Connochaetes gnou	mammals	photopic	ADW
Contopus sordidulus	avians	photopic	ADW
Conuropsis carolinensis	avians	photopic	ADW
Coracias cyanogaster	avians	photopic	ADW
Coracias naevius	avians	photopic	*S3*
Corallus caninus	squamates	scotopic	ADW
Corallus hortulanus	squamates	mesopic	ADW
Cordylus cataphractus	squamates	photopic	ADW
Cordylus giganteus	squamates	photopic	*S2*
Corucia zebrata	squamates	scotopic	*S2*
Corvus brachyrhynchos	avians	photopic	*S2*
Corvus caurinus	avians	photopic	ADW
Corvus corax	avians	photopic	*S2*
Corynorhinus rafinesquii	mammals	scotopic	ADW
Corynorhinus townsendii	mammals	scotopic	ADW

Corythaeola cristata	avians	photopic	*S3*
Crateromys schadenbergi	mammals	scotopic	ADW
Cratogeomys neglectus	mammals	scotopic	ADW
Cricetomys gambianus	mammals	scotopic	ADW
Crocuta crocuta	mammals	photopic	ADW
Crossoptilon mantchuricum	avians	photopic	ADW
Crotalus molossus	squamates	mesopic	ADW
Crotalus unicolor	squamates	scotopic	ADW
Crotalus viridis	squamates	scotopic	ADW
Crotaphytes bicinctores	squamates	photopic	*S2*
Cryptoprocta ferox	mammals	scotopic	ADW
Cryptotis parva	mammals	mesopic	ADW
Crypturellus boucardi	avians	photopic	ADW
Ctenomys conoveri	mammals	photopic	ADW
Ctenomys talarum	mammals	photopic	ADW
Ctenosaura clarki	squamates	photopic	*S2*
Ctenosaura hemilopha	squamates	photopic	*S2*
Ctenosaura pectinata	squamates	photopic	*S2*
Cuculus canorus	avians	photopic	ADW
Cuniculus taczanowskii	mammals	scotopic	ADW
Cyanocitta cristata	avians	photopic	ADW
Cyanopsitta spixii	avians	photopic	ADW
Cygnus atratus	avians	scotopic	ADW
Cygnus columbianus	avians	mesopic	*S2*
Cygnus melancoryphus	avians	photopic	ADW
Cygnus olor	avians	photopic	ADW
Cynomys leucurus	mammals	photopic	ADW
Cynomys ludovicianus	mammals	photopic	ADW
Cynopterus brachyotis	mammals	scotopic	ADW
Cystophora cristata	mammals	photopic	ADW
Dactylopsila trivirgata	mammals	scotopic	ADW
Dama dama	mammals	mesopic	ADW
Damaliscus korrigum	mammals	mesopic	*S3*
Dasycercus cristicauda	mammals	mesopic	ADW
Dasyprocta leporina	mammals	photopic	ADW
Dasyprocta punctata	mammals	photopic	ADW
Dasyprocta ruatanica	mammals	photopic	ADW
Dasypus hybridus	mammals	scotopic	ADW
Dasypus novemcinctus	mammals	mesopic	ADW
Dasyurus maculatus	mammals	scotopic	ADW
Daubentonia madagascariensis	mammals	scotopic	ADW
Dendragapus obscurus	avians	mesopic	*S2*
Dendroaspis polylepis	squamates	photopic	ADW

Dendrocopos leucotos	avians	photopic	ADW
Dendrohyrax arboreus	mammals	scotopic	ADW
Dendroica caerulescens	avians	photopic	ADW
Dendroica petechia	avians	photopic	ADW
Dendroica virens	avians	photopic	ADW
Dendrolagus matschiei	mammals	photopic	ADW
Dendrolagus scottae	mammals	photopic	ADW
Dendromus mystacalis	mammals	scotopic	ADW
Dendrortyx barbatus	avians	photopic	ADW
Desmodus rotundus	mammals	scotopic	ADW
Diadophis punctatus	squamates	scotopic	ADW
Diaemus youngi	mammals	scotopic	ADW
Diceros bicornis	mammals	photopic	ADW
Diclidurus albus	mammals	scotopic	ADW
Dicrurus paradiseus	avians	photopic	ADW
Didelphis albiventris	mammals	scotopic	ADW
Didelphis aurita	mammals	scotopic	ADW
Didelphis marsupialis	mammals	scotopic	*S3*
Didelphis virginiana	mammals	scotopic	ADW
Diomedea epomophora	avians	mesopic	ADW
Diomedea exulans	avians	photopic	ADW
Diphyllodes magnificus	avians	photopic	ADW
Dipodomys californicus	mammals	scotopic	ADW
Dipodomys compactus	mammals	scotopic	ADW
Dipodomys deserti	mammals	scotopic	ADW
Dipodomys elator	mammals	scotopic	ADW
Dipodomys microps	mammals	scotopic	ADW
Dipodomys ordii	mammals	scotopic	ADW
Dipodomys venustus	mammals	scotopic	ADW
Dipsosaurus dorsalis	squamates	photopic	*S2*
Distoechurus pennatus	mammals	scotopic	ADW
Dorcopsis luctuosa	mammals	scotopic	ADW
Dorcopsulus macleayi	mammals	scotopic	ADW
Dromaius novaehollandiae	avians	mesopic	*S2*
Dromiciops gliroides	mammals	scotopic	ADW
Dryocopus pileatus	avians	photopic	*S2*
Dryomys nitedula	mammals	scotopic	ADW
Dumetella carolinensis	avians	photopic	ADW
Echimys semivillosus	mammals	scotopic	ADW
Eidolon helvum	mammals	scotopic	ADW
Eira barbara	mammals	photopic	ADW
Elanoides forficatus	avians	photopic	ADW
Elanus leucurus	avians	photopic	*S2*

Elaphe gloydi	squamates	photopic	ADW
Elaphe vulpina	squamates	photopic	ADW
Elaphodus cephalophus	mammals	mesopic	ADW
Elephantulus myurus	mammals	scotopic	ADW
Elephantulus rozeti	mammals	photopic	ADW
Elephantulus rufescens	mammals	scotopic	ADW
Elephas maximus	mammals	photopic	ADW
Eliomys quercinus	mammals	scotopic	ADW
Empidonax difficilis	avians	photopic	ADW
Eonycteris major	mammals	scotopic	ADW
Eonycteris spelaea	mammals	scotopic	ADW
Epomophorus gambianus	mammals	scotopic	ADW
Eptesicus fuscus	mammals	scotopic	ADW
Equus asinus	mammals	photopic	ADW
Equus burchellii	mammals	photopic	ADW
Equus caballus	mammals	mesopic	*S3*
Equus grevyi	mammals	photopic	ADW
Equus hemionus onager	mammals	mesopic	ADW
Equus kiang	mammals	scotopic	ADW
Equus zebra	mammals	photopic	ADW
Eremitalpa granti	mammals	scotopic	ADW
Erethizon dorsatum	mammals	scotopic	ADW
Erinaceus europaeus	mammals	scotopic	ADW
Erophylla sezekorni	mammals	scotopic	ADW
Erythrocebus patas	mammals	photopic	ADW
Eublepharis macularius	squamates	scotopic	*S3*
Eublepharis maculatus	squamates	scotopic	*S2*
Eublepharis sp	squamates	scotopic	*S2*
Euchoreutes naso	mammals	scotopic	ADW
Eudocimus ruber	avians	photopic	ADW
Eudorcas thomsonii	mammals	photopic	ADW
Eudyptes chrysocome	avians	photopic	ADW
Eudyptes chrysolophus	avians	photopic	ADW
Eudyptes robustus	avians	photopic	ADW
Eulemur coronatus	mammals	photopic	ADW
Eulemur fulvus	mammals	photopic	ADW
Eulemur macaco	mammals	photopic	ADW
Eulemur mongoz	mammals	mesopic	ADW
Eulemur rubriventer	mammals	photopic	ADW
Eumeces fasciatus	squamates	photopic	ADW
Eumops glaucinus	mammals	scotopic	ADW
Eumops perotis	mammals	scotopic	ADW
Eunectes notaeus	squamates	mesopic	ADW

Euoticus elegantulus	mammals	scotopic	ADW
Falco biarmicus	avians	photopic	ADW
Falco cherrug	avians	photopic	ADW
Falco eleonorae	avians	photopic	ADW
Falco mexicanus	avians	mesopic	*S2*
Falco peregrinus	avians	photopic	ADW
Falco rusticolus	avians	photopic	*S2*
Falco sparverius	avians	photopic	*S2*
Falco tinnunculus	avians	photopic	*S2*
Felis bieti	mammals	scotopic	ADW
Felis catus	mammals	mesopic	*S3*
Felis chaus	mammals	mesopic	ADW
Felis manul	mammals	scotopic	ADW
Felis margarita	mammals	scotopic	ADW
Felis nigripes	mammals	scotopic	ADW
Felis serval	mammals	mesopic	*S3*
Felis silvestris	mammals	scotopic	ADW
Feresa attenuata	mammals	photopic	ADW
Ficedula hypoleuca	avians	photopic	ADW
Fossa fossana	mammals	scotopic	ADW
Fregata andrewsi	avians	photopic	ADW
Fregata magnificens	avians	photopic	ADW
Fregata minor	avians	photopic	ADW
Fulica americana	avians	photopic	ADW
Fulmarus glacialis	avians	mesopic	ADW
Funambulus pennantii	mammals	photopic	ADW
Furcifer cephalolepis	squamates	photopic	*S2*
Furipterus horrens	mammals	scotopic	ADW
Galago alleni	mammals	scotopic	ADW
Galago demidoff	mammals	scotopic	ADW
Galago gabonensis	mammals	scotopic	ADW
Galago moholi	mammals	scotopic	ADW
Galago senegalensis	mammals	scotopic	ADW
Galago thomasi	mammals	scotopic	ADW
Galago zanzibaricus	mammals	scotopic	ADW
Galictis cuja	mammals	mesopic	ADW
Galidia elegans	mammals	photopic	ADW
Galidictis fasciata	mammals	scotopic	ADW
Galidictis grandidieri	mammals	scotopic	ADW
Gallinago gallinago	avians	mesopic	*S2*
Gallinula chloropus	avians	photopic	*S2*
Gallus gallus	avians	photopic	*S3*
Gambelia wislizenii	squamates	photopic	*S2*

Garrulus glandarius	avians	photopic	*S2*
Gavia immer	avians	photopic	ADW
Gazella dorcas	mammals	mesopic	ADW
Gazella rufifrons	mammals	mesopic	*S3*
Gazella soemmeringii	mammals	mesopic	*S3*
Gekko gecko	squamates	scotopic	*S2*
Gekko ulikovskii	squamates	scotopic	*S2*
Genetta angolensis	mammals	scotopic	ADW
Geococcyx californianus	avians	photopic	ADW
Geogale aurita	mammals	scotopic	ADW
Gerbillus cheesmani	mammals	scotopic	ADW
Gerrhosaurus major	squamates	photopic	*S2*
Giraffa cameloperdalis	mammals	mesopic	*S3*
Glaucidium brasilianum	avians	photopic	ADW
Glaucidium gnoma	avians	photopic	*S2*
Glaucomys sabrinus	mammals	scotopic	ADW
Glaucomys volans	mammals	scotopic	ADW
Glironia venusta	mammals	scotopic	ADW
Glirulus japonicus	mammals	scotopic	ADW
Globicephala melas	mammals	mesopic	ADW
Glossophaga commissarisi	mammals	scotopic	ADW
Gorilla beringei	mammals	photopic	ADW
Gorilla gorilla	mammals	photopic	*S3*
Grus canadensis	avians	photopic	ADW
Grus leucogeranus	avians	photopic	ADW
Gulo gulo	mammals	mesopic	ADW
Gymnobelideus leadbeateri	mammals	scotopic	ADW
Gymnogyps californianus	avians	photopic	*S3*
Gyps bengalensis	avians	photopic	ADW
Gyps rueppellii	avians	photopic	*S3*
Halcyon smyrnensis	avians	photopic	ADW
Hapalemur aureus	mammals	mesopic	ADW
Hapalemur griseus	mammals	mesopic	ADW
Harpyionycteris whiteheadi	mammals	scotopic	ADW
Helarctos malayanus	mammals	scotopic	ADW
Heliosciurus gambianus	mammals	photopic	ADW
Hemibelideus lemuroides	mammals	scotopic	ADW
Hemicentetes semispinosus	mammals	photopic	ADW
Hemigalus derbyanus	mammals	scotopic	ADW
Hemitragus hylocrius	mammals	photopic	ADW
Hemitragus jayakari	mammals	photopic	ADW
Hemitragus jemlahicus	mammals	mesopic	ADW
Herpestes edwardsi	mammals	photopic	ADW

Herpestes ichneumon	mammals	mesopic	ADW
Herpestes javanicus	mammals	photopic	ADW
Heterodon nasicus	squamates	mesopic	ADW
Heterodon platirhinos	squamates	photopic	ADW
Heteronetta atricapilla	avians	photopic	ADW
Hexaprotodon liberiensis	mammals	scotopic	ADW
Hipposideros commersoni	mammals	scotopic	ADW
Hipposideros diadema	mammals	scotopic	ADW
Hipposideros fulvus	mammals	scotopic	ADW
Hippotragus equinus	mammals	mesopic	ADW
Hippotragus niger	mammals	scotopic	ADW
Hirundo rustica	avians	photopic	ADW
Holbrookia propinqua	squamates	photopic	ADW
Homo sapiens	mammals	photopic	*S3*
Hoplomys gymnurus	mammals	scotopic	ADW
Hydrochoerus hydrochaeris	mammals	mesopic	ADW
Hylobates agilis	mammals	photopic	ADW
Hylobates klossii	mammals	photopic	ADW
Hylobates lar	mammals	photopic	ADW
Hylobates moloch	mammals	photopic	ADW
Hylobates muelleri	mammals	photopic	ADW
Hylobates pileatus	mammals	photopic	ADW
Hylocichla mustelina	avians	photopic	ADW
Hylonycteris underwoodi	mammals	scotopic	ADW
Hypogeomys antimena	mammals	scotopic	ADW
Hypsignathus monstrosus	mammals	scotopic	ADW
Hystrix africaeaustralis	mammals	scotopic	ADW
Hystrix pumila	mammals	scotopic	ADW
Ichneumia albicauda	mammals	scotopic	ADW
Icterus abeillei	avians	photopic	ADW
Icterus cayanensis	avians	photopic	ADW
Icterus chrysater	avians	photopic	ADW
Icterus galbula	avians	photopic	ADW
Icterus graduacauda	avians	photopic	ADW
Icterus gularis	avians	photopic	ADW
Icterus icterus	avians	photopic	ADW
Icterus oberi	avians	photopic	ADW
Icterus pustulatus	avians	photopic	ADW
Icterus spurius	avians	mesopic	ADW
Ictinia mississippiensis	avians	photopic	ADW
Ictonyx striatus	mammals	scotopic	ADW
Idiurus macrotis	mammals	scotopic	ADW
Idiurus zenkeri	mammals	scotopic	ADW

Iguana iguana	squamates	photopic	*S3*
Indri indri	mammals	photopic	ADW
Irediparra gallinacea	avians	photopic	*S3*
Ixoreus naevius	avians	photopic	*S2*
Jabiru mycteria	avians	photopic	ADW
Jacana spinosa	avians	photopic	ADW
Jaculus jaculus	mammals	scotopic	ADW
Jaculus orientalis	mammals	scotopic	ADW
Junco hyemalis	avians	photopic	ADW
Kerivoula lanosa	mammals	scotopic	ADW
Kerodon rupestris	mammals	mesopic	ADW
Kobus ellipsiprymnus	mammals	mesopic	*S3*
Kobus megaceros	mammals	photopic	ADW
Kobus vardonii	mammals	scotopic	ADW
Lacerta sp	squamates	photopic	*S2*
Lagenorhynchus obscurus	mammals	photopic	ADW
Lagopus lagopus	avians	mesopic	*S2*
Lagorchestes hirsutus	mammals	scotopic	ADW
Lagostrophus fasciatus	mammals	scotopic	ADW
Lagothrix lagotricha	mammals	photopic	ADW
Lagurus lagurus	mammals	mesopic	ADW
Lama glama	mammals	photopic	ADW
Lama pacos	mammals	photopic	ADW
Lampropeltis getula	squamates	mesopic	ADW
Lampropeltis triangulum	squamates	mesopic	ADW
Lanius ludovicianus	avians	photopic	*S2*
Larus argentatus	avians	mesopic	*S2*
Larus californicus	avians	mesopic	*S2*
Larus canus	avians	mesopic	*S2*
Larus delawarensis	avians	photopic	ADW
Larus occidentalis	avians	photopic	*S2*
Larus philadelphia	avians	photopic	ADW
Lasionycteris noctivagans	mammals	scotopic	ADW
Lasiorhinus latifrons	mammals	mesopic	ADW
Lasiurus borealis	mammals	scotopic	ADW
Lasiurus cinereus	mammals	scotopic	ADW
Lasiurus seminolus	mammals	mesopic	ADW
Laterallus jamaicensis	avians	photopic	*S2*
Lavia frons	mammals	scotopic	ADW
Lemmiscus curtatus	mammals	mesopic	ADW
Lemur catta	mammals	photopic	ADW
Leontopithecus caissara	mammals	photopic	ADW
Leontopithecus chrysomelas	mammals	photopic	ADW

Leontopithecus rosalia	mammals	photopic	ADW
Leopardus colocolo	mammals	scotopic	ADW
Leopardus geoffroyi	mammals	scotopic	ADW
Leopardus guigna	mammals	mesopic	ADW
Leopardus jacobitus	mammals	scotopic	ADW
Leopardus pardalis	mammals	scotopic	ADW
Leopardus tigrinus	mammals	scotopic	ADW
Leopardus wiedii	mammals	photopic	ADW
Lepilemur leucopus	mammals	scotopic	ADW
Lepilemur mustelinus	mammals	scotopic	ADW
Lepilemur septentrionalis	mammals	scotopic	ADW
Leptailurus serval	mammals	mesopic	ADW
Leptonycteris nivalis	mammals	scotopic	ADW
Leptonycteris yerbabuenae	mammals	scotopic	ADW
Lepus alleni	mammals	scotopic	ADW
Lepus americanus	mammals	scotopic	ADW
Lepus callotis	mammals	scotopic	ADW
Lepus capensis	mammals	photopic	ADW
Lepus castroviejoi	mammals	scotopic	ADW
Lepus europaeus	mammals	scotopic	ADW
Lepus insularis	mammals	scotopic	ADW
Lepus nigricollis	mammals	mesopic	ADW
Lepus othus	mammals	mesopic	ADW
Lepus saxatilis	mammals	scotopic	ADW
Lepus timidus	mammals	scotopic	ADW
Lepus townsendii	mammals	scotopic	ADW
Lestodelphys halli	mammals	scotopic	ADW
Lialis burtoni	squamates	scotopic	*S2*
Limnogale mergulus	mammals	scotopic	ADW
Liochlorophis vernalis	squamates	photopic	ADW
Liolaemus belli	squamates	photopic	*S2*
Liolaemus bibronni	squamates	photopic	*S2*
Liolaemus buergeri	squamates	photopic	*S2*
Lipotes vexillifer	mammals	photopic	ADW
Litocranius walleri	mammals	photopic	ADW
Lobodon carcinophaga	mammals	scotopic	ADW
Lonchophylla thomasi	mammals	scotopic	ADW
Lontra felina	mammals	photopic	ADW
Lontra provocax	mammals	scotopic	ADW
Lophocebus albigena	mammals	photopic	ADW
Lophodytes cucullatus	avians	photopic	ADW
Lophophorus impeyanus	avians	photopic	*S2*
Lophura bulweri	avians	mesopic	*S2*

Loris tardigradus	mammals	scotopic	ADW
Loxia curvirostra	avians	photopic	ADW
Loxodonta africana	mammals	mesopic	ADW
Loxodonta cyclotis	mammals	mesopic	ADW
Luscinia megarhynchos	avians	mesopic	ADW
Lutreolina crassicaudata	mammals	scotopic	ADW
Lycalopex culpaeus	mammals	mesopic	ADW
Lycalopex fulvipes	mammals	mesopic	ADW
Lycalopex griseus	mammals	scotopic	ADW
Lycalopex gymnocercus	mammals	scotopic	ADW
Lycalopex vetulus	mammals	mesopic	ADW
Lycaon pictus	mammals	photopic	ADW
Lyncodon patagonicus	mammals	scotopic	ADW
Lynx canadensis	mammals	scotopic	ADW
Lynx lynx	mammals	mesopic	ADW
Lynx pardinus	mammals	scotopic	ADW
Lynx rufus	mammals	scotopic	ADW
Mabuya mabuya	squamates	photopic	*S2*
Macaca arctoides	mammals	photopic	ADW
Macaca cyclopis	mammals	photopic	ADW
Macaca fascicularis	mammals	photopic	ADW
Macaca fuscata	mammals	photopic	ADW
Macaca mulatta	mammals	photopic	ADW
Macaca nemestrina	mammals	photopic	ADW
Macaca radiata	mammals	photopic	ADW
Macaca silenus	mammals	photopic	ADW
Macaca sinica	mammals	photopic	ADW
Macaca sylvanus	mammals	photopic	ADW
Macroderma gigas	mammals	scotopic	ADW
Macroglossus sobrinus	mammals	scotopic	ADW
Macrophyllum macrophyllum	mammals	scotopic	ADW
Macropus agilis	mammals	scotopic	ADW
Macropus dorsalis	mammals	scotopic	ADW
Macropus eugenii	mammals	scotopic	ADW
Macropus giganteus	mammals	scotopic	ADW
Macropus parma	mammals	scotopic	ADW
Macropus rufus	mammals	scotopic	ADW
Macrotis lagotis	mammals	scotopic	ADW
Macrotus californicus	mammals	scotopic	ADW
Mandrillus leucophaeus	mammals	photopic	ADW
Mandrillus sphinx	mammals	photopic	ADW
Manis javanica	mammals	scotopic	ADW
Manis temminckii	mammals	scotopic	ADW

Marmaronetta angustirostris	avians	photopic	*S3*
Marmota bobak	mammals	mesopic	ADW
Marmota caligata	mammals	photopic	ADW
Marmota monax	mammals	photopic	ADW
Marmota olympus	mammals	photopic	ADW
Marmota vancouverensis	mammals	photopic	ADW
Martes americana	mammals	scotopic	ADW
Martes foina	mammals	scotopic	ADW
Martes melampus	mammals	scotopic	ADW
Martes pennanti	mammals	mesopic	ADW
Mazama gouazoubira	mammals	scotopic	ADW
Megaceryle alcyon	avians	photopic	ADW
Megaderma lyra	mammals	scotopic	ADW
Megadyptes antipodes	avians	photopic	ADW
Megaptera novaeangliae	mammals	photopic	ADW
Melanerpes carolinus	avians	photopic	ADW
Melanerpes erythrocephalus	avians	photopic	ADW
Meleagris gallopavo	avians	photopic	*S2*
Meleagris ocellata	avians	photopic	*S2*
Mellisuga helenae	avians	photopic	ADW
Melogale everetti	mammals	scotopic	ADW
Melogale moschata	mammals	scotopic	ADW
Melogale personata	mammals	scotopic	ADW
Melopsittacus undulatus	avians	photopic	ADW
Melospiza melodia	avians	photopic	*S2*
Melursus ursinus	mammals	scotopic	ADW
Mephitis mephitis	mammals	scotopic	ADW
Merganetta armata	avians	photopic	ADW
Mergus merganser	avians	photopic	ADW
Mergus serrator	avians	photopic	ADW
Meriones crassus	mammals	scotopic	ADW
Mesocricetus auratus	mammals	scotopic	ADW
Mesoplodon bidens	mammals	photopic	ADW
Mesoplodon carlhubbsi	mammals	photopic	ADW
Mesoplodon grayi	mammals	photopic	ADW
Mesoplodon layardii	mammals	photopic	ADW
Mesoplodon stejnegeri	mammals	photopic	ADW
Metachirus nudicaudatus	mammals	scotopic	ADW
Micrathene whitneyi	avians	scotopic	ADW
Microcavia australis	mammals	photopic	ADW
Microcebus murinus	mammals	scotopic	ADW
Microcebus rufus	mammals	scotopic	ADW
Microdipodops pallidus	mammals	scotopic	ADW

Microgale brevicaudata	mammals	mesopic	ADW
Microgale dryas	mammals	mesopic	ADW
Microgale longicaudata	mammals	scotopic	ADW
Microgale talazaci	mammals	mesopic	ADW
Microhierax caerulescens	avians	photopic	*S2*
Microlophus albemarlensis	squamates	photopic	ADW
Microlophus peruvianus	squamates	photopic	*S2*
Micropotamogale lamottei	mammals	scotopic	ADW
Micropotamogale ruwenzorii	mammals	scotopic	ADW
Micropteropus pusillus	mammals	scotopic	ADW
Microtus californicus	mammals	mesopic	ADW
Microtus longicaudus	mammals	scotopic	ADW
Microtus ochrogaster	mammals	mesopic	ADW
Microtus oeconomus	mammals	mesopic	ADW
Microtus pennsylvanicus	mammals	mesopic	ADW
Microtus pinetorum	mammals	mesopic	ADW
Milvus milvus	avians	photopic	*S2*
Mimon crenulatum	mammals	scotopic	ADW
Mimus polyglottos	avians	photopic	ADW
Miniopterus australis	mammals	scotopic	ADW
Miniopterus schreibersii	mammals	scotopic	ADW
Miopithecus talapoin	mammals	photopic	ADW
Mirounga angustirostris	mammals	mesopic	ADW
Mirounga leonina	mammals	mesopic	ADW
Mniotilta varia	avians	photopic	ADW
Moloch horridus	squamates	photopic	ADW
Monachus monachus	mammals	photopic	ADW
Monachus tropicalis	mammals	mesopic	ADW
Monodelphis brevicaudata	mammals	photopic	ADW
Monodelphis domestica	mammals	mesopic	ADW
Morus bassanus	avians	photopic	ADW
Morus capensis	avians	photopic	ADW
Moschus chrysogaster	mammals	scotopic	ADW
Moschus fuscus	mammals	scotopic	ADW
Moschus moschiferus	mammals	mesopic	*S3*
Mungotictis decemlineata	mammals	photopic	ADW
Muntiacus atherodes	mammals	photopic	ADW
Muntiacus feae	mammals	scotopic	ADW
Muntiacus gongshanensis	mammals	mesopic	ADW
Muntiacus reevesi	mammals	mesopic	ADW
Muntiacus vuquangensis	mammals	mesopic	ADW
Murina cyclotis	mammals	scotopic	ADW
Murina suilla	mammals	scotopic	ADW

Mus musculus	mammals	scotopic	*S3*
Muscardinus avellanarius	mammals	scotopic	ADW
Musonycteris harrisoni	mammals	scotopic	ADW
Mustela altaica	mammals	scotopic	ADW
Mustela erminea	mammals	scotopic	ADW
Mustela frenata	mammals	mesopic	ADW
Mustela kathiah	mammals	scotopic	ADW
Mustela nivalis	mammals	mesopic	ADW
Mustela putorius	mammals	scotopic	ADW
Mustela putorius furo	mammals	mesopic	ADW
Mustela sibirica	mammals	scotopic	ADW
Mydaus javanensis	mammals	scotopic	ADW
Myocastor coypus	mammals	scotopic	ADW
Myodes californicus	mammals	scotopic	ADW
Myodes gapperi	mammals	scotopic	ADW
Myodes glareolus	mammals	scotopic	ADW
Myodes rutilus	mammals	mesopic	ADW
Myoprocta acouchy	mammals	photopic	ADW
Myosciurus pumilio	mammals	photopic	ADW
Myotis auriculus	mammals	mesopic	ADW
Myotis austroriparius	mammals	scotopic	ADW
Myotis evotis	mammals	scotopic	ADW
Myotis grisescens	mammals	scotopic	ADW
Myotis keenii	mammals	scotopic	ADW
Myotis lucifugus	mammals	scotopic	ADW
Myotis myotis	mammals	scotopic	ADW
Myotis mystacinus	mammals	scotopic	ADW
Myotis septentrionalis	mammals	scotopic	ADW
Myotis sodalis	mammals	scotopic	ADW
Myotis yumanensis	mammals	scotopic	ADW
Myrmecophaga tridactyla	mammals	photopic	ADW
Mysateles prehensilis	mammals	mesopic	ADW
Mystacina robusta	mammals	scotopic	ADW
Mystromys albicaudatus	mammals	scotopic	ADW
Myzopoda aurita	mammals	scotopic	ADW
Naemorhedus caudatus	mammals	photopic	ADW
Naemorhedus goral	mammals	photopic	ADW
Nanger dama	mammals	mesopic	*S3*
Nanger granti	mammals	photopic	ADW
Nanonycteris veldkmapii	mammals	scotopic	ADW
Napaeozapus insignis	mammals	scotopic	ADW
Nasalis larvatus	mammals	photopic	ADW
Natalus stramineus	mammals	scotopic	ADW

Necromys lasiurus	mammals	mesopic	ADW
Neofelis nebulosa	mammals	mesopic	ADW
Neophron percnopterus	avians	photopic	ADW
Neopsephotus bourkii	avians	scotopic	ADW
Neotoma floridana	mammals	scotopic	ADW
Neotoma lepida	mammals	scotopic	ADW
Neotoma mexicana	mammals	scotopic	ADW
Neotomodon alstoni	mammals	scotopic	ADW
Neotragus moschatus	mammals	scotopic	ADW
Neovison vison	mammals	scotopic	ADW
Nerodia sipedon	squamates	photopic	ADW
Nesofregetta fuliginosa	avians	photopic	ADW
Nestor notabilis	avians	photopic	ADW
Ninox novaeseelandiae	avians	scotopic	*S2*
Nipponia nippon	avians	photopic	ADW
Noctilio albiventris	mammals	scotopic	ADW
Noctilio leporinus	mammals	scotopic	ADW
Nomascus concolor	mammals	photopic	ADW
Nomascus gabriellae	mammals	photopic	ADW
Nomascus leucogenys	mammals	photopic	ADW
Norops sagrei	squamates	photopic	ADW
Notomys alexis	mammals	scotopic	ADW
Numenius americanus	avians	photopic	*S2*
Nyctalus leisleri	mammals	scotopic	ADW
Nyctea scandiaca	avians	photopic	ADW
Nyctereutes procyonoides	mammals	mesopic	ADW
Nycteris grandis	mammals	scotopic	ADW
Nycteris hispida	mammals	scotopic	ADW
Nycteris thebaica	mammals	photopic	ADW
Nyctibius grandis	avians	scotopic	ADW
Nyctibius jamaicensis	avians	scotopic	*S2*
Nycticebus cougang	mammals	scotopic	*S3*
Nycticebus pygmaeus	mammals	scotopic	ADW
Nycticeius humeralis	mammals	scotopic	ADW
Nyctidromus albicollis	avians	scotopic	*S2*
Nyctiellus lepidus	mammals	scotopic	ADW
Nyctimene albiventer	mammals	scotopic	ADW
Nyctinomops macrotis	mammals	scotopic	ADW
Nymphicus hollandicus	avians	photopic	ADW
Ochotona cansus	mammals	photopic	ADW
Ochotona collaris	mammals	photopic	ADW
Ochotona curzoniae	mammals	photopic	ADW
Ochotona hyperborea	mammals	photopic	ADW

Ochotona macrotis	mammals	photopic	ADW
Ochotona pallasi	mammals	photopic	ADW
Ochotona pusilla	mammals	mesopic	ADW
Ochotona rufescens	mammals	mesopic	ADW
Ochotona rutila	mammals	mesopic	ADW
Octodon degus	mammals	photopic	ADW
Odocoileus virginianus	mammals	mesopic	ADW
Ondatra zibethicus	mammals	scotopic	ADW
Onychogalea fraenata	mammals	scotopic	ADW
Onychomys arenicola	mammals	scotopic	ADW
Ophisaurus ventralis	squamates	photopic	*S2*
Oporornis tolmiei	avians	photopic	ADW
Oreamnos americanus	mammals	photopic	ADW
Orthogeomys cavator	mammals	mesopic	ADW
Orthogeomys grandis	mammals	scotopic	ADW
Orthogeomys heterodus	mammals	mesopic	ADW
Orycteropus afer	mammals	scotopic	ADW
Oryctolagus cuniculus	mammals	scotopic	ADW
Oryx gazella	mammals	mesopic	ADW
Oryx leucoryx	mammals	photopic	*S3*
Oryzomys galapagoensis	mammals	scotopic	ADW
Oryzorictes hova	mammals	scotopic	ADW
Otaria flavescens	mammals	photopic	ADW
Otocyon megalotis	mammals	mesopic	ADW
Otolemur crassicaudatus	mammals	scotopic	ADW
Otolemur garnettii	mammals	scotopic	ADW
Otus asio	avians	scotopic	*S2*
Otus kennicottii	avians	scotopic	ADW
Otus trichopsis	avians	scotopic	ADW
Ovibos moschatus	mammals	photopic	ADW
Ovis ammon	mammals	photopic	ADW
Ovis aries orientalis	mammals	mesopic	*S3*
Ovis aries vignei	mammals	photopic	ADW
Ovis canadensis	mammals	photopic	ADW
Oxyura jamaicensis	avians	photopic	ADW
Pachyornis mappini	avians	photopic	ADW
Pachyuromys duprasi	mammals	scotopic	ADW
Paguma larvata	mammals	scotopic	ADW
Pan paniscus	mammals	photopic	ADW
Pan troglodytes	mammals	photopic	ADW
Pandion haliaetus	avians	photopic	ADW
Panthera leo	mammals	scotopic	ADW
Panthera onca	mammals	mesopic	ADW

Panthera pardus	mammals	scotopic	ADW
Panthera tigris	mammals	mesopic	ADW
Papio anubis	mammals	photopic	ADW
Papio cynocephalus	mammals	photopic	ADW
Papio hamadryas	mammals	photopic	ADW
Papio papio	mammals	photopic	ADW
Papio ursinus	mammals	photopic	ADW
Pappogeomys bulleri	mammals	mesopic	ADW
Parabuteo unicinctus	avians	photopic	ADW
Paradipus ctenodactylus	mammals	scotopic	ADW
Paraechinus aethiopicus	mammals	scotopic	ADW
Paraechinus micropus	mammals	scotopic	ADW
Parantechinus apicalis	mammals	mesopic	ADW
Paraxerus flavovittis	mammals	photopic	ADW
Pardofelis marmorata	mammals	mesopic	ADW
Parus bicolor	avians	photopic	ADW
Parus carolinensis	avians	photopic	ADW
Passer domesticus	avians	photopic	ADW
Passerella iliaca	avians	photopic	*S2*
Passerina cyanea	avians	photopic	ADW
Pavo pavo	avians	photopic	*S2*
Pecari tajacu	mammals	mesopic	ADW
Pelecanoides magellani	avians	mesopic	ADW
Pelecanoides urinatrix	avians	mesopic	ADW
Pelecanus erythrorhynchos	avians	photopic	ADW
Pelecanus philippensis	avians	photopic	ADW
Pentalagus furnessi	mammals	scotopic	ADW
Peponocephala electra	mammals	photopic	ADW
Perdix perdix	avians	mesopic	*S2*
Perisoreus canadensis	avians	photopic	*S2*
Perodicticus potto	mammals	scotopic	ADW
Perognathus amplus	mammals	scotopic	ADW
Perognathus fasciatus	mammals	scotopic	ADW
Perognathus flavescens	mammals	scotopic	ADW
Peromyscus attwateri	mammals	scotopic	ADW
Peromyscus aztecus	mammals	scotopic	ADW
Peromyscus boylii	mammals	scotopic	ADW
Peromyscus californicus	mammals	scotopic	ADW
Peromyscus eremicus	mammals	scotopic	ADW
Peromyscus gossypinus	mammals	scotopic	ADW
Peromyscus keeni	mammals	scotopic	ADW
Peromyscus leucopus	mammals	scotopic	ADW
Peromyscus maniculatus	mammals	scotopic	ADW

Peromyscus polionotus	mammals	scotopic	ADW
Peromyscus truei	mammals	scotopic	ADW
Peropteryx kappleri	mammals	scotopic	ADW
Peropteryx macrotis	mammals	scotopic	ADW
Petaurillus hosei	mammals	scotopic	ADW
Petaurista elegans	mammals	scotopic	ADW
Petaurista leucogenys	mammals	scotopic	ADW
Petauroides volans	mammals	scotopic	ADW
Petrochelidon pyrrhonata	avians	photopic	*S2*
Petrodromus tetradactylus	mammals	mesopic	ADW
Petrogale assimilis	mammals	scotopic	ADW
Petrogale concinna	mammals	scotopic	ADW
Petrogale penicillata	mammals	scotopic	ADW
Petromus typicus	mammals	photopic	ADW
Petromyscus collinus	mammals	scotopic	ADW
Petropseudes dahli	mammals	scotopic	ADW
Petrosaurus thalassinus	squamates	photopic	*S2*
Phacochoerus aethiopicus	mammals	photopic	ADW
Phacochoerus africanus	mammals	photopic	ADW
Phalacrocorax aristotelis	avians	photopic	ADW
Phalacrocorax auritus	avians	photopic	ADW
Phalacrocorax brasilianus	avians	photopic	ADW
Phalaenoptilus nuttallii	avians	scotopic	*S2*
Phalanger lullulae	mammals	scotopic	ADW
Phalanger orientalis	mammals	scotopic	ADW
Phaner furcifer	mammals	scotopic	ADW
Pharomachrus antisianus	avians	photopic	ADW
Phasianus colchicus	avians	photopic	*S2*
Phelsuma astriata	squamates	photopic	*S2*
Phelsuma cepediana	squamates	photopic	*S2*
Phelsuma madagascarensis	squamates	photopic	*S2*
Phelsuma sundbergi	squamates	photopic	*S2*
Pheucticus ludovicianus	avians	mesopic	ADW
Pheucticus melanocephalus	avians	photopic	ADW
Philantomba maxwellii	mammals	scotopic	ADW
Phloeomys cumingi	mammals	scotopic	ADW
Phodopus campbelli	mammals	scotopic	ADW
Phoebastria immutabilis	avians	mesopic	*S2*
Phoebastria nigripes	avians	scotopic	ADW
Phoebetria palpebrata	avians	photopic	ADW
Phoenicoparrus andinus	avians	photopic	ADW
Phoenicopterus chilensis	avians	photopic	ADW
Phrynocephalus mystaceus	squamates	photopic	*S2*

Phrynosoma cornutum	squamates	photopic	*S2*
Phrynosoma mcallii	squamates	photopic	*S2*
Phrynosoma solare	squamates	photopic	*S2*
Phymaturus palluma	squamates	photopic	*S2*
Physignathus cocincinus	squamates	photopic	*S2*
Physignathus lesueurii	squamates	photopic	*S2*
Pica nuttalli	avians	photopic	*S2*
Picoides pubescens	avians	photopic	ADW
Piliocolobus rufomitratus	mammals	photopic	ADW
Pinguinus impennis	avians	photopic	ADW
Pipilo maculatus	avians	photopic	*S2*
Pipistrellus hesperus	mammals	mesopic	ADW
Pipistrellus subflavus	mammals	scotopic	ADW
Piranga rubra	avians	photopic	ADW
Pithecia monachus	mammals	photopic	ADW
Pithecophaga jefferyi	avians	photopic	ADW
Pituophis catenifer	squamates	mesopic	ADW
Planigale ingrami	mammals	scotopic	ADW
Planigale tenuirostris	mammals	scotopic	ADW
Platacanthomys lasiurus	mammals	scotopic	ADW
Platanista gangetica	mammals	mesopic	ADW
Plecotus auritus	mammals	scotopic	ADW
Plectrophenax nivalis	avians	photopic	ADW
Plegadis chihi	avians	photopic	ADW
Pluvialis dominica	avians	photopic	ADW
Podargus strigoides	avians	scotopic	*S2*
Podiceps auritus	avians	photopic	ADW
Podilymbus podiceps	avians	photopic	ADW
Poecile gambeli	avians	photopic	*S2*
Poelagus marjorita	mammals	scotopic	ADW
Pogona barbarata	squamates	photopic	*S2*
Pogona vitticeps	squamates	photopic	*S3*
Poiana richardsonii	mammals	scotopic	ADW
Polihierax semitorquatus	avians	photopic	*S3*
Pongo abelii	mammals	photopic	ADW
Pongo pygmaeus	mammals	photopic	ADW
Porphyrio hochstetteri	avians	photopic	ADW
Porphyrio porphyrio	avians	photopic	*S2*
Potamochoerus larvatus	mammals	mesopic	ADW
Potamogale velox	mammals	scotopic	ADW
Potos flavus	mammals	scotopic	ADW
Presbytis melalophos	mammals	photopic	ADW
Presbytis thomasi	mammals	photopic	ADW

Priodontes maximus	mammals	scotopic	ADW
Prionailurus bengalensis	mammals	scotopic	ADW
Prionailurus iriomotensis	mammals	mesopic	ADW
Prionailurus planiceps	mammals	scotopic	ADW
Prionailurus rubiginosus	mammals	scotopic	ADW
Prionodon pardicolor	mammals	scotopic	ADW
Probosciger aterrimus	avians	photopic	ADW
Procapra gutturosa	mammals	photopic	ADW
Procolobus verus	mammals	photopic	ADW
Procyon cancrivorus	mammals	scotopic	ADW
Procyon lotor	mammals	scotopic	ADW
Profelis aurata	mammals	scotopic	ADW
Propithecus diadema	mammals	photopic	ADW
Propithecus perrieri	mammals	photopic	ADW
Propithecus tattersalli	mammals	photopic	ADW
Propithecus verreauxi	mammals	photopic	ADW
Proteles cristata	mammals	mesopic	ADW
Przewalskium albirostris	mammals	photopic	ADW
Psammomys obesus	mammals	photopic	ADW
Pseudochirops archeri	mammals	scotopic	ADW
Pseudochirulus canescens	mammals	scotopic	ADW
Pseudochirulus herbertensis	mammals	scotopic	ADW
Pseudomys higginsi	mammals	scotopic	ADW
Pseudoryx nghetinhensis	mammals	photopic	ADW
Psittacus erithacus	avians	photopic	ADW
Pteridophora alberti	avians	photopic	ADW
Pterodroma arminjoniana	avians	photopic	ADW
Pteroglossus torquatus	avians	photopic	ADW
Pteromys momonga	mammals	scotopic	ADW
Pteromyscus pulverulentus	mammals	scotopic	ADW
Pteronotus davyi	mammals	scotopic	ADW
Pteronotus parnellii	mammals	scotopic	ADW
Pteropus alecto	mammals	scotopic	ADW
Pteropus dasymallus	mammals	scotopic	ADW
Pteropus giganteus	mammals	scotopic	*S3*
Pteropus hypomelanus	mammals	scotopic	ADW
Pteropus livingstonii	mammals	scotopic	ADW
Pteropus mariannus	mammals	scotopic	ADW
Pteropus melanotus	mammals	photopic	ADW
Pteropus poliocephalus	mammals	scotopic	ADW
Pteropus rodricensis	mammals	scotopic	ADW
Pteropus rufus	mammals	scotopic	ADW
Pteropus samoensis	mammals	photopic	ADW

Pteropus tonganus	mammals	scotopic	ADW
Ptilinopus iozonus	avians	photopic	*S3*
Ptilopsis granti	avians	scotopic	*S3*
Puffinus auricularis	avians	photopic	ADW
Pulsatrix perspicillata	avians	mesopic	ADW
Puma concolor	mammals	scotopic	ADW
Puma yagouaroundi	mammals	mesopic	ADW
Pusa caspica	mammals	photopic	ADW
Pygathrix cinerea	mammals	photopic	ADW
Pygathrix nemaeus	mammals	photopic	ADW
Pygoscelis adeliae	avians	photopic	ADW
Python regius	squamates	scotopic	ADW
Python sebae	squamates	scotopic	ADW
Quiscalus quiscula	avians	photopic	ADW
Rallus limicola	avians	mesopic	*S2*
Ramphastos sulfuratus	avians	photopic	ADW
Rangifer tarandus	mammals	mesopic	*S3*
Raphicerus melanotis	mammals	scotopic	ADW
Raphicerus sharpei	mammals	scotopic	ADW
Rattus norvegicus	mammals	scotopic	*S3*
Rattus rattus	mammals	scotopic	ADW
Redunca arundinum	mammals	scotopic	ADW
Redunca fulvorufula	mammals	scotopic	ADW
Regina septemvittata	squamates	photopic	ADW
Regulus calendula	avians	photopic	*S2*
Reithrodon auritus	mammals	mesopic	ADW
Reithrodontomys megalotis	mammals	scotopic	ADW
Reithrodontomys raviventris	mammals	scotopic	ADW
Rhacodactylus auriculatus	squamates	scotopic	*S2*
Rhacodactylus ciliatus	squamates	scotopic	*S3*
Rhinolophus blasii	mammals	scotopic	ADW
Rhinolophus capensis	mammals	scotopic	ADW
Rhinolophus denti	mammals	scotopic	ADW
Rhinolophus euryale	mammals	scotopic	ADW
Rhinolophus ferrumequinum	mammals	scotopic	ADW
Rhinolophus hipposideros	mammals	scotopic	ADW
Rhinolophus megaphyllus	mammals	scotopic	ADW
Rhinophylla pumilio	mammals	mesopic	ADW
Rhombomys opimus	mammals	photopic	ADW
Rhynchocyon cirnei	mammals	mesopic	ADW
Rhyncholestes raphanurus	mammals	scotopic	ADW
Riparia riparia	avians	photopic	ADW
Rucervus duvaucelii	mammals	photopic	ADW

Rucervus eldii	mammals	mesopic	*S3*
Rungwecebus kipunji	mammals	photopic	ADW
Rusa alfredi	mammals	mesopic	ADW
Rusa timorensis	mammals	mesopic	*S3*
Rusa unicolor	mammals	scotopic	ADW
Rynchops niger	avians	mesopic	ADW
Saccostomus campestris	mammals	scotopic	ADW
Sagittarius serpentarius	avians	photopic	ADW
Saguinus bicolor	mammals	photopic	ADW
Saguinus geoffroyi	mammals	photopic	ADW
Saguinus graellsi	mammals	photopic	ADW
Saguinus imperator	mammals	photopic	ADW
Saguinus midas	mammals	photopic	ADW
Saguinus nigricollis	mammals	photopic	ADW
Saguinus tripartitus	mammals	photopic	ADW
Saimiri boliviensis	mammals	photopic	ADW
Saimiri oerstedii	mammals	photopic	ADW
Saimiri sciureus	mammals	photopic	ADW
Saimiri vanzolinii	mammals	photopic	ADW
Salpingotus pallidus	mammals	scotopic	ADW
Sarcophilus harrisii	mammals	scotopic	ADW
Sator angustus	squamates	photopic	*S2*
Sauromalus ater	squamates	photopic	*S2*
Scalopus aquaticus	mammals	scotopic	ADW
Scapanus townsendii	mammals	scotopic	ADW
Sceloporus occidentalis	squamates	photopic	*S3*
Sceloporus undulatus	squamates	photopic	*S2*
Sciurus carolinensis	mammals	photopic	ADW
Sciurus niger	mammals	photopic	ADW
Sciurus oculatus	mammals	photopic	ADW
Sciurus variegatoides	mammals	photopic	ADW
Sciurus vulgaris	mammals	photopic	ADW
Sekeetamys calurus	mammals	scotopic	ADW
Sericulus chrysocephalus	avians	photopic	ADW
Serinus mozambicus	avians	photopic	ADW
Sialia sialis	avians	photopic	ADW
Sigmodon arizonae	mammals	mesopic	ADW
Sigmodon hispidus	mammals	scotopic	ADW
Simias concolor	mammals	photopic	ADW
Sistrurus catenatus	squamates	photopic	ADW
Sitta canadensis	avians	photopic	ADW
Sitta carolinensis	avians	photopic	ADW
Solenodon cubanus	mammals	scotopic	ADW

Solenodon paradoxus	mammals	scotopic	ADW
Sorex araneus	mammals	scotopic	ADW
Sorex arcticus	mammals	mesopic	ADW
Sorex cinereus	mammals	scotopic	ADW
Sorex fumeus	mammals	mesopic	ADW
Sorex gaspensis	mammals	mesopic	ADW
Sorex hoyi	mammals	mesopic	ADW
Sorex merriami	mammals	scotopic	ADW
Sorex palustris	mammals	mesopic	ADW
Sorex tundrensis	mammals	mesopic	ADW
Sotalia fluviatilis	mammals	photopic	ADW
Spalax ehrenbergi	mammals	photopic	ADW
Speothos venaticus	mammals	photopic	ADW
Spermophilus annulatus	mammals	photopic	ADW
Spermophilus beecheyi	mammals	photopic	ADW
Spermophilus brunneus	mammals	photopic	ADW
Spermophilus elegans	mammals	photopic	ADW
Spermophilus madrensis	mammals	photopic	ADW
Spermophilus saturatus	mammals	photopic	ADW
Spermophilus spilosoma	mammals	photopic	ADW
Spermophilus tereticaudus	mammals	photopic	ADW
Spermophilus tridecemlineatus	mammals	photopic	ADW
Spermophilus variegatus	mammals	photopic	ADW
Spermophilus washingtoni	mammals	photopic	ADW
Spheniscus mendiculus	avians	photopic	ADW
Sphiggurus insidiosus	mammals	scotopic	ADW
Sphiggurus mexicanus	mammals	scotopic	ADW
Spilocuscus rufoniger	mammals	scotopic	ADW
Spizella arborea	avians	photopic	ADW
Spizella passerina	avians	photopic	ADW
Spizella pusilla	avians	photopic	ADW
Stagonopleura guttata	avians	photopic	ADW
Steatornis caripensis	avians	scotopic	*S2*
Stenella longirostris	mammals	scotopic	ADW
Stercorarius maccormicki	avians	mesopic	*S2*
Stercorarius parasiticus	avians	photopic	ADW
Sterna caspia	avians	photopic	ADW
Sterna forsteri	avians	photopic	ADW
Storeria dekayi	squamates	scotopic	ADW
Storeria occipitomaculata	squamates	mesopic	ADW
Streptopelia risoria	avians	photopic	*S3*
Streptoprocne zonaris	avians	photopic	*S2*
Strigocuscus celebensis	mammals	scotopic	ADW

Strigops habroptila	avians	scotopic	ADW
Strix aluco	avians	mesopic	*S3*
Strix occidentalis	avians	scotopic	*S2*
Strix varia	avians	scotopic	ADW
Strix virgata	avians	scotopic	ADW
Struthidea cinerea	avians	photopic	ADW
Struthio camelus	avians	mesopic	*S3*
Sturnella magna	avians	photopic	ADW
Sturnus vulgaris	avians	photopic	*S3*
Sula dactylatra	avians	photopic	ADW
Sula sula	avians	mesopic	ADW
Suncus murinus	mammals	scotopic	ADW
Sundasciurus hippurus	mammals	photopic	ADW
Surnia ulula	avians	scotopic	ADW
Sus celebensis	mammals	photopic	ADW
Sus scrofa	mammals	scotopic	ADW
Sus verrucosus	mammals	scotopic	ADW
Swynnertonia swynnertoni	avians	photopic	ADW
Sylvilagus aquaticus	mammals	scotopic	ADW
Sylvilagus brasiliensis	mammals	scotopic	ADW
Sylvilagus floridanus	mammals	scotopic	ADW
Sylvilagus nuttallii	mammals	mesopic	ADW
Sylvilagus palustris	mammals	scotopic	ADW
Symphalangus syndactylus	mammals	photopic	ADW
Synaptomys cooperi	mammals	scotopic	ADW
Syncerus caffer	mammals	mesopic	*S3*
Tachycineta bicolor	avians	photopic	ADW
Tadarida aegyptiaca	mammals	scotopic	ADW
Tadarida australis	mammals	scotopic	ADW
Tadarida brasiliensis	mammals	scotopic	ADW
Taeniopygia guttata	avians	photopic	ADW
Talpa europaea	mammals	scotopic	ADW
Tamandua mexicana	mammals	mesopic	ADW
Tamias alpinus	mammals	photopic	ADW
Tamias amoenus	mammals	photopic	ADW
Tamias canipes	mammals	photopic	ADW
Tamias cinereicollis	mammals	photopic	ADW
Tamias dorsalis	mammals	photopic	ADW
Tamias merriami	mammals	photopic	ADW
Tamias minimus	mammals	photopic	ADW
Tamias obscurus	mammals	photopic	ADW
Tamias palmeri	mammals	photopic	ADW
Tamias panamintinus	mammals	photopic	ADW

Tamias quadrimaculatus	mammals	photopic	ADW
Tamias quadrivittatus	mammals	photopic	ADW
Tamias senex	mammals	photopic	ADW
Tamias speciosus	mammals	photopic	ADW
Tamias striatus	mammals	photopic	ADW
Tamias umbrinus	mammals	photopic	ADW
Tamiasciurus douglasii	mammals	photopic	ADW
Tamiasciurus hudsonicus	mammals	photopic	ADW
Tapera naevia	avians	photopic	ADW
Taphozous mauritianus	mammals	scotopic	ADW
Taphozous melanopogon	mammals	scotopic	ADW
Taphozous melanopogon phillipinensis	mammals	scotopic	ADW
Taphozous nudiventris	mammals	scotopic	ADW
Tapirus bairdii	mammals	mesopic	ADW
Tapirus indicus	mammals	mesopic	*S3*
Tapirus pinchaque	mammals	mesopic	ADW
Tarentola chazaliae	squamates	scotopic	*S3*
Tarsius bancanus	mammals	scotopic	ADW
Tarsius dentatus	mammals	scotopic	ADW
Tarsius pumilus	mammals	scotopic	ADW
Tarsius syrichta	mammals	scotopic	ADW
Tarsius tarsier	mammals	scotopic	ADW
Tatera indica	mammals	scotopic	ADW
Taxidea taxus	mammals	mesopic	ADW
Tayassu pecari	mammals	mesopic	ADW
Teius teyou	squamates	photopic	*S2*
Tenrec ecaudatus	mammals	scotopic	ADW
Teratoscincus przewalskii	squamates	scotopic	*S2*
Teratoscincus sp.	squamates	scotopic	*S2*
Thamnophis butleri	squamates	mesopic	ADW
Thamnophis radix	squamates	mesopic	ADW
Thamnophis sauritus	squamates	photopic	ADW
Thamnophis sirtalis	squamates	photopic	ADW
Theropithecus gelada	mammals	photopic	ADW
Thomomys mazama	mammals	scotopic	ADW
Threskiornis aethiopicus	avians	photopic	ADW
Thryonomys swinderianus	mammals	scotopic	ADW
Thryothorus ludovicianus	avians	photopic	ADW
Thylogale billardierii	mammals	scotopic	ADW
Thylogale stigmatica	mammals	mesopic	ADW
Thylogale thetis	mammals	scotopic	ADW
Thyroptera discifera	mammals	scotopic	ADW
Thyroptera tricolor	mammals	scotopic	ADW

Tiliqua occipitalis	squamates	photopic	*S2*
Tlacuatzin canescens	mammals	scotopic	ADW
Toxostoma rufum	avians	photopic	ADW
Trachypithecus auratus	mammals	photopic	ADW
Trachypithecus cristatus	mammals	photopic	ADW
Trachypithecus francoisi	mammals	photopic	ADW
Trachypithecus geei	mammals	photopic	ADW
Trachypithecus obscurus	mammals	photopic	ADW
Tragelaphus buxtoni	mammals	mesopic	ADW
Tragelaphus eurycerus	mammals	photopic	*S3*
Tragopan satyra	avians	photopic	*S2*
Tragulus napu	mammals	scotopic	ADW
Tremarctos ornatus	mammals	scotopic	ADW
Trichosurus arnhemensis	mammals	scotopic	ADW
Trichosurus caninus	mammals	scotopic	ADW
Trichys fasciculata	mammals	scotopic	ADW
Tringa flavipes	avians	photopic	ADW
Troglodytes aedon	avians	photopic	ADW
Troglodytes troglodytes	avians	photopic	ADW
Tropidurus torquatus	squamates	photopic	*S2*
Tupaia glis	mammals	photopic	ADW
Tupaia minor	mammals	photopic	ADW
Tupaia tana	mammals	photopic	ADW
Tupinambis merianae	squamates	photopic	*S2*
Turdus merula	avians	photopic	*S2*
Turdus migratorius	avians	photopic	*S2*
Tursiops truncatus	mammals	mesopic	ADW
Tylonycteris pachypus	mammals	scotopic	ADW
Tyrannus couchii	avians	photopic	ADW
Tyrannus melancholicus	avians	photopic	ADW
Tyrannus tyrannus	avians	photopic	ADW
Tyto alba	avians	scotopic	*S3*
Uncia uncia	mammals	scotopic	ADW
Urocyon cinereoargenteus	mammals	scotopic	ADW
Urocyon littoralis	mammals	mesopic	ADW
Uromastyx maliensis	squamates	photopic	*S2*
Urosaurus ornatus	squamates	photopic	ADW
Ursus americanus	mammals	mesopic	ADW
Ursus arctos	mammals	mesopic	*S3*
Ursus maritimus	mammals	photopic	ADW
Ursus thibetanus	mammals	scotopic	ADW
Vampyrum spectrum	mammals	scotopic	ADW
Varanus beccarii	squamates	photopic	*S2*

Varanus gouldii	squamates	photopic	ADW
Varanus komodoensis	squamates	photopic	ADW
Varecia rubra	mammals	photopic	ADW
Varecia variegata	mammals	photopic	ADW
Vermivora peregrina	avians	photopic	ADW
Vipera berus	squamates	mesopic	ADW
Viverricula indica	mammals	scotopic	ADW
Volatinia jacarina	avians	photopic	ADW
Vulpes bengalensis	mammals	scotopic	ADW
Vulpes cana	mammals	scotopic	ADW
Vulpes chama	mammals	scotopic	ADW
Vulpes corsac	mammals	mesopic	ADW
Vulpes macrotis	mammals	scotopic	ADW
Vulpes pallida	mammals	scotopic	ADW
Vulpes rueppellii	mammals	scotopic	ADW
Vulpes velox	mammals	scotopic	ADW
Vulpes vulpes	mammals	scotopic	ADW
Vulpes zerda	mammals	scotopic	ADW
Wilsonia pusilla	avians	photopic	*S2*
Xerus erythropus	mammals	photopic	ADW
Xerus inauris	mammals	photopic	ADW
Zaedyus pichiy	mammals	scotopic	ADW
Zapus hudsonius	mammals	scotopic	ADW
Zapus princeps	mammals	scotopic	ADW
Zenaida macroura	avians	photopic	ADW
Zenkerella insignis	mammals	photopic	ADW
Zonotrichia albicollis	avians	photopic	ADW
Zonotrichia atricapilla	avians	photopic	*S2*

Abbreviations: ADW, Animal Diversity Web; OIF, ocular image formation

Table S5: Paleolatitude of Examined Fossil Archosaurs

in [degrees]	maximal paleolatitude*
Basal archosaurs	
Euparkeria capensis	67.4S
Proterosuchus vanhoepeni	66.4S (Harrysmith Commonage, Induan)
Pterosaurs	
Ctenochasma elegans	40.1N
Ctenochasma taqueti	39.6N
Pterodactylus antiquus	40.1N
Pterodaustro guinazui	38.3S
Rhamphorhynchus muensteri	40.2N
Scaphognathus crassirostris	40.1N
Tapejara wellnhoferi	12.5S
Tupuxuara sp.	12.5S
Ornithischian dinosaurs	
Agilisaurus louderbacki	29.4N
Corythosaurus casuarius	58.2N
Prosaurolophus maximus	58.1N
Protoceratops andrewsi	41.8N
Psittacosaurus mongoliensis	47.0N
Saurolophus osborni	59.6N
Basal saurischian dinosaur	
Herrerasaurus ischigualestensis	40.9S
Sauropodomorph dinosaurs	
Diplodocus longus	37.6N (*Diplodocus* sp. 41.4)
Lufengosaurus huenei	34.4N
Nemegtosaurus mongoliensis	40.8N
Plateosaurus longiceps	48.5N
Riojasaurus incertus	37.0S
Non-avian theropods	
Garudimimus brevipes	45.4N
Juravenator starki	40.2N
Megapnosaurus kayentakatae	20.6N (*M. rhodoensis* 41.4S)
Microraptor gui	44.7N (*M. zhaoianus* 46.9N)
Ornithomimus edmontonicus	59.4N (*Ornithomimus* sp. 62.9N)
Sinornithosaurus sp.	44.7N
Velociraptor mongoliensis	41.8N
Avians	

Archaeopteryx lithographica	40.3N
Confuciusornis sanctus	44.7N (*Confuciusornis* sp. up to 46.9N)
Sapeornis chaoyangensis	46.9N
Yixianornis grabaui	44.9N

*extracted from Paleobiology Database Oct. 28, 2010

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EXT, external scleral ring diameter; **INT**, internal scleral ring diameter; **m**, mesopic; **OL**, orbit length; **OIF**, ocular image formation; **p**, photopic; **s**, scotopic; **u**, unknown. Dimensions of continuous variables are in [mm].

#NEXUS
[written Wed Nov 03 10:50:24 PDT 2010 by Mesquite version 2.72 (build 527)]

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DIMENSIONS NTAX=197;
TAXLABELS
'Accipiter_gentilis' 'Accipiter_striatus' 'Aegolius_acadicus' 'Aegotheles_cristatus' Agilisaurus 'Aix_sponsa' 'Ameiva_ameiva' 'Anas_acuta' 'Anas_americana' 'Anas_platyrhynchos' 'Anas_strepera' 'Anolis_carolinensis' 'Anolis_sagrei' 'Aphelocorna_californica' 'Apus_apus' 'Aquila_audax' 'Aquila_chrysaetos' Archaeopteryx 'Ardea_herodias' 'Asio_otus' 'Asturina_nitida' 'Athene_cunicularia' 'Basiliscus_basiliscus' 'Basiliscus_vittatus' 'Bubo_bubo' 'Bubulcus_ibis' 'Buteo_buteo' 'Buteo_jamaicensis' 'Buteo_regalis' 'Buteo_swainsoni' 'Callipepla_californica' 'Callipepla_gambeli' 'Calypte_anna' 'Caprimulgus_carolinensis' 'Caprimulgus_ridgwayi' 'Caprimulgus_rufigena' 'Caprimulgus_vociferus' 'Carpodacus_purpureus' 'Catharthes_aura' 'Catharus_guttatus' 'Catharus_ustulatus' 'Catoptrophorus_semipalmatus' 'Chaetura_pelagica' 'Chamaeleo_calyptratus' 'Chamaeleo_vulgaris' 'Charadrius_vociferus' 'Chlamydosaurus_kingii' 'Chordeiles_acutipennis' 'Chordeiles_minor' 'Chrysolophus_pictus' 'Cnemidophorus_tigris' 'Coccothraustes_vespertinus' 'Coccyzus_americanus' Confuciusornis 'Cordylus_giganteus' 'Corucia_zebrata' 'Corvus_brachyrhynchos' 'Corvus_corax' Corythosaurus 'Crotaphytes_bicinctores' 'Ctenochasma_elegans' 'Ctenochasma_taqueti' 'Ctenosaura_clarki' 'Ctenosaura_hemilopha' 'Ctenosaura_pectinata' 'Cygnus_columbianus' 'Dendragapus_obscurus' Diplodocus 'Dipsosaurus_dorsalis' 'Dromaius_novaehollandiae' 'Dryocopus_pileatus' 'Elanus_leucurus' 'Eublepharis_maculatus' 'Eublepharis_sp' Euparkeria 'Falco_mexicanus' 'Falco_rusticolus' 'Falco_sparverius' 'Falco_tinnunculus' 'Furcifer_cephalolepis' 'Gallinago_gallinago' 'Gallinula_chloropus' 'Gallus_gallus' 'Gambelia_wislizenii' 'Garrulus_glandarius' Garudimimus 'Gekko_gecko' 'Gekko_ulikovskii' 'Gerrhosaurus_major' 'Glaucidium_gnoma' Herrerasaurus 'Iguana_iguana' 'Ixoreus_naevius' Juravenator 'Lacerta_sp' 'Lagopus_lagopus' 'Lanius_ludovicianus' 'Larus_argentatus' 'Larus_californicus' 'Larus_canus' 'Larus_occidentalis' 'Laterallus_jamaicensis' 'Lialis_burtoni' 'Liolaemus_belli' 'Liolaemus_bibronni' 'Liolaemus_buergeri' 'Lophophorus_impeyanus' 'Lophura_bulweri' Lufengosaurus 'Mabuya_mabuya' Megapnosaurus 'Meleagris_gallopavo' 'Meleagris_ocellata' 'Melospiza_melodia' 'Microhierax_caerulescens' 'Microlophus_peruvianus' Microraptor 'Milvus_milvus' Nemegtosaurus 'Ninox_novaeseelandiae' 'Numenius_americanus' 'Nyctibius_jamaicensis' 'Nyctidromus_albicollis' 'Ophisaurus_ventralis' Ornithomimus 'Otus_asio' 'Passerella_iliaca' 'Pavo_pavo' 'Perdix_perdix' 'Perisoreus_canadensis' 'Petrochelidon_pyrrhonata' 'Petrosaurus_thalassinus' 'Phalaenoptilus_nuttallii' 'Phasianus_colchicus' 'Phelsuma_astriata' 'Phelsuma_cepediana' 'Phelsuma_madagascarensis' 'Phelsuma_sundbergi' 'Phoebastria_immutabilis' 'Phrynocephalus_mystaceus' 'Phrynosoma_cornutum' 'Phrynosoma_mcallii' 'Phrynosoma_solare' 'Phymaturus_palluma' 'Physignathus_cocincinus' 'Physignathus_lesueurii' 'Pica_nuttalli' 'Pipilo_maculatus' Plateosaurus 'Podargus_strigoides' 'Poecile_gambeli' 'Pogona_barbarata' 'Pogona_vitticeps' 'Porphyrio_porphyrio' Prosaurolophus Proterosuchus Protoceratops Psittacosaurus 'Pterodactylus_antiquus' Pterodaustro 'Rallus_limicola' 'Regulus_calendula' 'Rhacodactylus_auriculatus' 'Rhacodactylus_ciliatus' 'Rhamphorhynchus_muensteri' Riojasaurus Sapeornis 'Sator_angustus' Saurolophus 'Sauromalus_ater' Scaphognathus 'Sceloporus_occidentalis' 'Sceloporus_undulatus' Sinornithosaurus 'Steatornis_caripensis'

'Stercorarius_maccormicki' 'Streptoprocne_zonaris' 'Strix_occidentalis' 'Struthio_camelus' Tapejara 'Teius_teyou' 'Teratoscincus_przewalskii' 'Teratoscincus_sp' 'Tiliqua_occipitalis' 'Tragopan_satyra' 'Tropidurus_torquatus' 'Tupinambis_merianae' Tupuxuara 'Turdus_merula' 'Turdus_migratorius' 'Tyto_alba' 'Uromastyx_maliensis' 'Varanus_beccarii' Velociraptor 'Wilsonia_pusilla' Yixianornis 'Zonotrichia_atricapilla'
;

END;

BEGIN CHARACTERS;
TITLE Character_Matrix;
DIMENSIONS NCHAR=3;
FORMAT DATATYPE = CONTINUOUS GAP = - MISSING = ?;
CHARSTATELABELS
1 OL,
2 EXT,
3 INT ;
MATRIX
'Accipiter_gentilis' 29.1 21.3 13.08
'Accipiter_striatus' 15.48 11.61 7.58
'Aegolius_acadicus' 15.47 16.18 10.56
'Aegotheles_cristatus' 16.79 10.96 8.65
Agilisaurus 32.0 26.5 11.3
'Aix_sponsa' 20.52 14.85 9.99
'Ameiva_ameiva' 9.9 8.7 4.47
'Anas_acuta' 21.62 12.25 8.23
'Anas_americana' 18.25 11.74 8.77
'Anas_platyrhynchos' 19.5 13.65 9.6
'Anas_strepera' 18.82 12.56 8.6
'Anolis_carolinensis' 5.77 3.6 1.36
'Anolis_sagrei' 5.12 3.88 1.85
'Aphelocorna_californica' 15.0 10.89 7.18
'Apus_apus' 12.89 10.03 5.2
'Aquila_audax' 39.87 29.55 17.92
'Aquila_chrysaetos' 42.75 31.5 20.0
Archaeopteryx 14.0 11.5 6.0
'Ardea_herodias' 25.44 20.87 13.9
'Asio_otus' 18.42 19.2 11.24
'Asturina_nitida' 28.08 22.01 12.97
'Athene_cunicularia' 19.5 20.09 11.0
'Basiliscus_basiliscus' 14.75 9.84 5.54
'Basiliscus_vittatus' 12.28 8.74 4.52
'Bubo_bubo' 34.0 39.0 20.0
'Bubulcus_ibis' 16.39 12.82 8.53
'Buteo_buteo' 33.0 25.0 14.25
'Buteo_jamaicensis' 35.16 28.3 15.82
'Buteo_regalis' 34.3 28.8 16.2
'Buteo_swainsoni' 31.3 23.5 13.0
'Callipepla_californica' 13.92 9.28 6.0
'Callipepla_gambeli' 13.38 8.26 5.73

'Calypte_anna' 5.7 4.33 3.05
'Caprimulgus_carolinensis' 19.37 16.77 11.21
'Caprimulgus_ridgwayi' 14.45 14.17 11.12
'Caprimulgus_rufigena' 14.39 13.65 9.74
'Caprimulgus_vociferus' 15.54 14.04 10.46
'Carpodacus_purpureus' 10.16 5.81 4.03
'Catharthes_aura' 24.08 18.34 10.28
'Catharus_guttatus' 11.23 7.9 5.48
'Catharus_ustulatus' 11.65 8.39 5.48
'Catoptrophorus_semipalmatus' 15.7 11.8 7.7
'Chaetura_pelagica' 11.0 8.2 4.46
'Chamaeleo_calyptratus' 13.0 6.64 2.43
'Chamaeleo_vulgaris' 11.98 5.36 2.1
'Charadrius_vociferus' 14.6 10.85 7.8
'Chlamydosaurus_kingii' 20.33 13.09 5.32
'Chordeiles_acutipennis' 14.07 13.05 9.16
'Chordeiles_minor' 15.23 14.14 9.0
'Chrysolophus_pictus' 19.77 13.21 8.74
'Cnemidophorus_tigris' 6.45 4.88 2.33
'Coccothraustes_vespertinus' 10.07 7.7 5.6
'Coccyzus_americanus' 12.28 10.1 6.3
Confuciusornis 18.0 14.31 8.23
'Cordylus_giganteus' 13.24 9.7 4.2
'Corucia_zebrata' 13.09 9.28 3.9
'Corvus_brachyrhynchos' 22.95 14.1 9.51
'Corvus_corax' 30.25 18.38 11.89
Corythosaurus 146.0 63.2 45.0
'Crotaphytes_bicinctores' 9.82 6.5 2.8
'Ctenochasma_elegans' 9.97 6.82 5.14
'Ctenochasma_taqueti' 27.0 18.9 11.5
'Ctenosaura_clarki' 10.44 7.75 3.68
'Ctenosaura_hemilopha' 21.48 12.37 5.78
'Ctenosaura_pectinata' 13.68 8.08 4.1
'Cygnus_columbianus' 31.5 16.55 11.4
'Dendragapus_obscurus' 18.98 12.65 8.27
Diplodocus 148.0 63.0 33.0
'Dipsosaurus_dorsalis' 10.16 6.92 3.16
'Dromaius_novaehollandiae' 45.41 32.06 22.63
'Dryocopus_pileatus' 17.83 15.33 8.17
'Elanus_leucurus' 28.11 18.91 12.3
'Eublepharis_maculatus' 8.26 6.78 5.06
'Eublepharis_sp' 8.88 6.53 5.2
Euparkeria 21.1 14.35 8.82
'Falco_mexicanus' 25.0 20.0 13.0
'Falco_rusticolus' 29.0 20.67 12.83
'Falco_sparverius' 17.71 13.78 8.24
'Falco_tinnunculus' 20.1 14.9 7.65
'Furcifer_cephalolepis' 9.0 3.87 1.77
'Gallinago_gallinago' 11.6 9.5 6.5
'Gallinula_chloropus' 16.2 10.02 6.4
'Gallus_gallus' 19.23 12.85 8.33

'Gambelia_wislizenii' 8.5 5.75 2.67
'Garrulus_glandarius' 18.0 11.7 6.9
Garudimimus 61.9 41.2 26.8
'Gekko_gecko' 12.04 11.09 8.3
'Gekko_ulikovskii' 8.94 7.69 6.2
'Gerrhosaurus_major' 10.94 10.3 4.57
'Glaucidium_gnoma' 14.63 14.8 6.96
Herrerasaurus 69.3 33.94 19.77
'Iguana_iguana' 18.78 12.18 5.74
'Ixoreus_naevius' 12.64 10.13 6.42
Juravenator 18.11 15.78 9.75
'Lacerta_sp' 5.7 3.23 1.77
'Lagopus_lagopus' 18.83 10.69 7.05
'Lanius_ludovicianus' 14.0 10.0 6.5
'Larus_argentatus' 21.62 14.08 9.54
'Larus_californicus' 23.58 15.78 10.35
'Larus_canus' 21.7 14.57 10.22
'Larus_occidentalis' 23.6 15.3 10.8
'Laterallus_jamaicensis' 9.69 6.07 3.9
'Lialis_burtoni' 4.38 4.55 2.41
'Liolaemus_belli' 5.65 3.14 1.7
'Liolaemus_bibronni' 6.63 3.7 1.6
'Liolaemus_buergeri' 6.78 4.5 2.1
'Lophophorus_impeyanus' 25.2 17.01 10.01
'Lophura_bulweri' 22.7 15.75 11.01
Lufengosaurus 63.0 45.0 26.0
'Mabuya_mabuya' 5.9 4.95 2.05
Megapnosaurus 52.0 47.3 32.4
'Meleagris_gallopavo' 25.36 21.83 13.45
'Meleagris_ocellata' 22.05 16.56 10.7
'Melospiza_melodia' 9.25 6.36 4.28
'Microhierax_caerulescens' 12.76 9.9 6.46
'Microlophus_peruvianus' 7.33 4.3 1.8
Microraptor 19.7 16.2 10.5
'Milvus_milvus' 31.75 21.5 13.0
Nemegtosaurus 205.0 88.0 52.2
'Ninox_novaeseelandiae' 24.17 23.73 15.1
'Numenius_americanus' 19.8 14.55 8.85
'Nyctibius_jamaicensis' 28.08 26.3 19.07
'Nyctidromus_albicollis' 15.74 14.84 11.52
'Ophisaurus_ventralis' 5.1 4.2 1.8
Ornithomimus 67.0 49.55 31.1
'Otus_asio' 21.7 23.52 12.44
'Passerella_iliaca' 8.15 7.42 4.68
'Pavo_pavo' 24.0 19.43 11.87
'Perdix_perdix' 17.29 10.84 6.32
'Perisoreus_canadensis' 16.59 11.31 7.57
'Petrochelidon_pyrrhonata' 10.2 6.97 4.34
'Petrosaurus_thalassinus' 11.34 6.96 3.16
'Phalaenoptilus_nuttallii' 13.75 12.27 9.4
'Phasianus_colchicus' 28.0 15.75 9.85

'Phelsuma_astriata' 4.85 3.73 2.1
'Phelsuma_cepediana' 4.89 4.38 2.45
'Phelsuma_madagascarensis' 9.07 7.94 4.81
'Phelsuma_sundbergi' 6.3 5.44 3.66
'Phoebastria_immutabilis' 65.05 21.24 14.56
'Phrynocephalus_mystaceus' 8.29 4.7 2.09
'Phrynosoma_cornutum' 8.02 4.5 2.0
'Phrynosoma_mcallii' 7.2 3.93 1.97
'Phrynosoma_solare' 9.4 4.15 1.76
'Phymaturus_palluma' 6.95 4.15 2.13
'Physignathus_cocincinus' 11.44 7.53 3.24
'Physignathus_lesueurii' 17.21 12.78 6.39
'Pica_nuttalli' 18.77 11.94 7.42
'Pipilo_maculatus' 11.35 7.58 5.48
Plateosaurus 75.0 48.45 25.2
'Podargus_strigoides' 29.1 26.13 15.41
'Poecile_gambeli' 8.1 5.7 3.97
'Pogona_barbarata' 12.51 7.28 2.86
'Pogona_vitticeps' 16.18 10.74 3.91
'Porphyrio_porphyrio' 21.72 12.69 7.92
Prosaurolophus 148.0 77.6 37.4
Proterosuchus 50.0 26.3 13.5
Protoceratops 93.0 59.0 40.5
Psittacosaurus 40.2 18.7 11.52
'Pterodactylus_antiquus' 12.35 9.56 5.84
Pterodaustro 14.0 13.45 6.73
'Rallus_limicola' 10.9 7.06 5.06
'Regulus_calendula' 7.7 4.84 3.55
'Rhacodactylus_auriculatus' 9.98 8.51 6.29
'Rhacodactylus_ciliatus' 9.66 7.98 6.35
'Rhamphorhynchus_muensteri' 25.15 16.7 11.29
Riojasaurus 67.0 48.3 23.8
Sapeornis 15.84 14.64 6.5
'Sator_angustus' 8.2 4.8 2.0
Saurolophus 269.0 92.6 51.7
'Sauromalus_ater' 11.66 8.03 3.69
Scaphognathus 25.0 18.0 10.0
'Sceloporus_occidentalis' 6.17 3.23 1.61
'Sceloporus_undulatus' 6.48 3.7 1.7
Sinornithosaurus 30.3 19.74 13.09
'Steatornis_caripensis' 20.6 12.65 10.88
'Stercorarius_maccormicki' 26.75 16.0 10.0
'Streptoprocne_zonaris' 16.28 12.17 7.46
'Strix_occidentalis' 26.59 29.8 17.92
'Struthio_camelus' 24.6 17.03 11.58
Tapejara 28.8 17.53 9.81
'Teius_teyou' 8.59 6.52 2.99
'Teratoscincus_przewalskii' 8.57 7.4 5.6
'Teratoscincus_sp' 8.11 6.77 5.16
'Tiliqua_occipitalis' 12.1 6.1 3.3
'Tragopan_satyra' 23.54 16.23 10.59

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        'Tropidurus_torquatus'       7.76 4.87 2.28
        'Tupinambis_merianae'        16.8 9.2 3.86
        Tupuxuara                   43.25 29.5 16.7
        'Turdus_merula'              13.2 10.35 6.3
        'Turdus_migratorius'         13.5 10.25 6.55
        'Tyto_alba'                 19.87 18.0 10.23
        'Uromastyx_maliensis'        13.09 8.4 3.23
        'Varanus_beccarii'           12.17 7.59 4.0
        Velociraptor                39.83 30.2 18.56
        'Wilsonia_pusilla'           7.21 5.48 3.71
        Yixianornis                 10.65 8.31 3.9
        'Zonotrichia_atricapilla'    9.89 6.77 4.68

;

END;
BEGIN CHARACTERS;
        TITLE  Character_Matrix_OIF;
        DIMENSIONS  NCHAR=2;
        FORMAT DATATYPE = STANDARD GAP = - MISSING = ? SYMBOLS = "  0 1 2 3 4 5 6 7 8
9 A B C D E F G H J K M N P Q R S T U V W X Y Z a b c d e f g h j k m n p q r s t u";
        CHARSTATELABELS
                1 OIF, 2 EXTINCT ;
        MATRIX
        'Accipiter_gentilis'        pN
        'Accipiter_striatus'        pN
        'Aegolius_acadicus'         sN
        'Aegotheles_cristatus'      sN
        Agilisaurus                uY
        'Aix_sponsa'                mN
        'Ameiva_ameiva'             pN
        'Anas_acuta'                mN
        'Anas_americana'            mN
        'Anas_platyrhynchos'        mN
        'Anas_strepera'             pN
        'Anolis_carolinensis'       pN
        'Anolis_sagrei'             pN
        'Aphelocorna_californica'   pN
        'Apus_apus'                 mN
        'Aquila_audax'              mN
        'Aquila_chrysaetos'         mN
        Archaeopteryx               uY
        'Ardea_herodias'            mN
        'Asio_otus'                sN
        'Asturina_nitida'           pN
        'Athene_cunicularia'        mN
        'Basiliscus_basiliscus'     pN
        'Basiliscus_vittatus'       pN
        'Bubo_bubo'                 sN
        'Bubulcus_ibis'             pN
        'Buteo_buteo'               pN
```

'Buteo_jamaicensis' pN
'Buteo_regalis' mN
'Buteo_swainsoni' pN
'Callipepla_californica' pN
'Callipepla_gambeli' pN
'Calypte_anna' pN
'Caprimulgus_carolinensis' mN
'Caprimulgus_ridgwayi' sN
'Caprimulgus_rufigena' sN
'Caprimulgus_vociferus' sN
'Carpodacus_purpureus' pN
'Catharthes_aura' pN
'Catharus_guttatus' pN
'Catharus_ustulatus' pN
'Catoptrophorus_semipalmatus'mN
'Chaetura_pelagica' pN
'Chamaeleo_calyptratus' pN
'Chamaeleo_vulgaris' pN
'Charadrius_vociferus' mN
'Chlamydosaurus_kingii' pN
'Chordeiles_acutipennis' mN
'Chordeiles_minor' mN
'Chrysolophus_pictus' pN
'Cnemidophorus_tigris' pN
'Coccothraustes_vespertinus' pN
'Coccyzus_americanus' pN
Confuciusornis uY
'Cordylus_giganteus' pN
'Corucia_zebrata' sN
'Corvus_brachyrhynchos' pN
'Corvus_corax' pN
Corythosaurus uY
'Crotaphytes_bicinctores' pN
'Ctenochasma_elegans' uY
'Ctenochasma_taqueti' uY
'Ctenosaura_clarki' pN
'Ctenosaura_hemilopha' pN
'Ctenosaura_pectinata' pN
'Cygnus_columbianus' mN
'Dendragapus_obscurus' mN
Diplodocus uY
'Dipsosaurus_dorsalis' pN
'Dromaius_novaehollandiae' mN
'Dryocopus_pileatus' pN
'Elanus_leucurus' pN
'Eublepharis_maculatus' sN
'Eublepharis_sp' sN
Euparkeria uY
'Falco_mexicanus' mN
'Falco_rusticolus' pN
'Falco_sparverius' pN

'Falco_tinnunculus' pN
'Furcifer_cephalolepis' pN
'Gallinago_gallinago' mN
'Gallinula_chloropus' pN
'Gallus_gallus' pN
'Gambelia_wislizenii' pN
'Garrulus_glandarius' pN
Garudimimus uY
'Gekko_gecko' sN
'Gekko_ulikovskii' sN
'Gerrhosaurus_major' pN
'Glaucidium_gnoma' pN
Herrerasaurus uY
'Iguana_iguana' pN
'Ixoreus_naevius' pN
Juravenator uY
'Lacerta_sp' pN
'Lagopus_lagopus' mN
'Lanius_ludovicianus' pN
'Larus_argentatus' mN
'Larus_californicus' mN
'Larus_canus' mN
'Larus_occidentalis' pN
'Laterallus_jamaicensis' pN
'Lialis_burtoni' sN
'Liolaemus_belli' pN
'Liolaemus_bibronni' pN
'Liolaemus_buergeri' pN
'Lophophorus_impeyanus' pN
'Lophura_bulweri' mN
Lufengosaurus uY
'Mabuya_mabuya' pN
Megapnosaurus uY
'Meleagris_gallopavo' pN
'Meleagris_ocellata' pN
'Melospiza_melodia' pN
'Microhierax_caerulescens' pN
'Microlophus_peruvianus' pN
Microraptor uY
'Milvus_milvus' pN
Nemegtosaurus uY
'Ninox_novaeseelandiae' sN
'Numenius_americanus' pN
'Nyctibius_jamaicensis' sN
'Nyctidromus_albicollis' sN
'Ophisaurus_ventralis' pN
Ornithomimus uY
'Otus_asio' sN
'Passerella_iliaca' pN
'Pavo_pavo' pN
'Perdix_perdix' mN

'Perisoreus_canadensis' pN
'Petrochelidon_pyrrhonata' pN
'Petrosaurus_thalassinus' pN
'Phalaenoptilus_nuttallii' sN
'Phasianus_colchicus' pN
'Phelsuma_astriata' pN
'Phelsuma_cepediana' pN
'Phelsuma_madagascarensis' pN
'Phelsuma_sundbergi' pN
'Phoebastria_immutabilis' mN
'Phrynocephalus_mystaceus' pN
'Phrynosoma_cornutum' pN
'Phrynosoma_mcallii' pN
'Phrynosoma_solare' pN
'Phymaturus_palluma' pN
'Physignathus_cocincinus' pN
'Physignathus_lesueurii' pN
'Pica_nuttalli' pN
'Pipilo_maculatus' pN
Plateosaurus uY
'Podargus_strigoides' sN
'Poecile_gambeli' pN
'Pogona_barbarata' pN
'Pogona_vitticeps' pN
'Porphyrio_porphyrio' pN
Prosaurolophus uY
Proterosuchus uY
Protoceratops uY
Psittacosaurus uY
'Pterodactylus_antiquus' uY
Pterodaustro uY
'Rallus_limicola' mN
'Regulus_calendula' pN
'Rhacodactylus_auriculatus' sN
'Rhacodactylus_ciliatus' sN
'Rhamphorhynchus_muensteri' uY
Riojasaurus uY
Sapeornis uY
'Sator_angustus' pN
Saurolophus uY
'Sauromalus_ater' pN
Scaphognathus uY
'Sceloporus_occidentalis' pN
'Sceloporus_undulatus' pN
Sinornithosaurus uY
'Steatornis_caripensis' sN
'Stercorarius_maccormicki' mN
'Streptoprocne_zonaris' pN
'Strix_occidentalis' sN
'Struthio_camelus' mN
Tapejara uY

```
        'Teius_teyou'               pN
        'Teratoscincus_przewalskii'  sN
        'Teratoscincus_sp'          sN
        'Tiliqua_occipitalis'       pN
        'Tragopan_satyra'           pN
        'Tropidurus_torquatus'      pN
        'Tupinambis_merianae'       pN
        Tupuxuara                   uY
        'Turdus_merula'             pN
        'Turdus_migratorius'        pN
        'Tyto_alba'                 sN
        'Uromastyx_maliensis'       pN
        'Varanus_beccarii'          pN
        Velociraptor                uY
        'Wilsonia_pusilla'          pN
        Yixianornis                 uY
        'Zonotrichia_atricapilla'   pN

;

END;
BEGIN TREES;
        Title Stored_Trees;
        LINK Taxa = Untitled_Block_of_Taxa;
        TRANSLATE
                1 'Accipiter_gentilis',
                2 'Accipiter_striatus',
                3 'Aegolius_acadicus',
                4 'Aegotheles_cristatus',
                5 Agilisaurus,
                6 'Aix_sponsa',
                7 'Ameiva_ameiva',
                8 'Anas_acuta',
                9 'Anas_americana',
                10 'Anas_platyrhynchos',
                11 'Anas_strepera',
                12 'Anolis_carolinensis',
                13 'Anolis_sagrei',
                14 'Aphelocorna_californica',
                15 'Apus_apus',
                16 'Aquila_audax',
                17 'Aquila_chrysaetos',
                18 Archaeopteryx,
                19 'Ardea_herodias',
                20 'Asio_otus',
                21 'Asturina_nitida',
                22 'Athene_cunicularia',
                23 'Basiliscus_basiliscus',
                24 'Basiliscus_vittatus',
                25 'Bubo_bubo',
                26 'Bubulcus_ibis',
```

27 'Buteo_buteo',
28 'Buteo_jamaicensis',
29 'Buteo_regalis',
30 'Buteo_swainsoni',
31 'Callipepla_californica',
32 'Callipepla_gambeli',
33 'Calypte_anna',
34 'Caprimulgus_carolinensis',
35 'Caprimulgus_ridgwayi',
36 'Caprimulgus_rufigena',
37 'Caprimulgus_vociferus',
38 'Carpodacus_purpureus',
39 'Catharthes_aura',
40 'Catharus_guttatus',
41 'Catharus_ustulatus',
42 'Catoptrophorus_semipalmatus',
43 'Chaetura_pelagica',
44 'Chamaeleo_calyptratus',
45 'Chamaeleo_vulgaris',
46 'Charadrius_vociferus',
47 'Chlamydosaurus_kingii',
48 'Chordeiles_acutipennis',
49 'Chordeiles_minor',
50 'Chrysolophus_pictus',
51 'Cnemidophorus_tigris',
52 'Coccothraustes_vespertinus',
53 'Coccyzus_americanus',
54 Confuciusornis,
55 'Cordylus_giganteus',
56 'Corucia_zebrata',
57 'Corvus_brachyrhynchos',
58 'Corvus_corax',
59 Corythosaurus,
60 'Crotaphytes_bicinctores',
61 'Ctenochasma_elegans',
62 'Ctenochasma_taqueti',
63 'Ctenosaura_clarki',
64 'Ctenosaura_hemilopha',
65 'Ctenosaura_pectinata',
66 'Cygnus_columbianus',
67 'Dendragapus_obscurus',
68 Diplodocus,
69 'Dipsosaurus_dorsalis',
70 'Dromaius_novaehollandiae',
71 'Dryocopus_pileatus',
72 'Elanus_leucurus',
73 'Eublepharis_maculatus',
74 'Eublepharis_sp',
75 Euparkeria,
76 'Falco_mexicanus',
77 'Falco_rusticolus',

78 'Falco_sparverius',
79 'Falco_tinnunculus',
80 'Furcifer_cephalolepis',
81 'Gallinago_gallinago',
82 'Gallinula_chloropus',
83 'Gallus_gallus',
84 'Gambelia_wislizenii',
85 'Garrulus_glandarius',
86 Garudimimus,
87 'Gekko_gecko',
88 'Gekko_ulikovskii',
89 'Gerrhosaurus_major',
90 'Glaucidium_gnoma',
91 Herrerasaurus,
92 'Iguana_iguana',
93 'Ixoreus_naevius',
94 Juravenator,
95 'Lacerta_sp',
96 'Lagopus_lagopus',
97 'Lanius_ludovicianus',
98 'Larus_argentatus',
99 'Larus_californicus',
100 'Larus_canus',
101 'Larus_occidentalis',
102 'Laterallus_jamaicensis',
103 'Lialis_burtoni',
104 'Liolaemus_belli',
105 'Liolaemus_bibronni',
106 'Liolaemus_buergeri',
107 'Lophophorus_impeyanus',
108 'Lophura_bulweri',
109 Lufengosaurus,
110 'Mabuya_mabuya',
111 Megapnosaurus,
112 'Meleagris_gallopavo',
113 'Meleagris_ocellata',
114 'Melospiza_melodia',
115 'Microhierax_caerulescens',
116 'Microlophus_peruvianus',
117 Microraptor,
118 'Milvus_milvus',
119 Nemegtosaurus,
120 'Ninox_novaeseelandiae',
121 'Numenius_americanus',
122 'Nyctibius_jamaicensis',
123 'Nyctidromus_albicollis',
124 'Ophisaurus_ventralis',
125 Ornithomimus,
126 'Otus_asio',
127 'Passerella_iliaca',
128 'Pavo_pavo',

129 'Perdix_perdix',
130 'Perisoreus_canadensis',
131 'Petrochelidon_pyrrhonata',
132 'Petrosaurus_thalassinus',
133 'Phalaenoptilus_nuttallii',
134 'Phasianus_colchicus',
135 'Phelsuma_astriata',
136 'Phelsuma_cepediana',
137 'Phelsuma_madagascarensis',
138 'Phelsuma_sundbergi',
139 'Phoebastria_immutabilis',
140 'Phrynocephalus_mystaceus',
141 'Phrynosoma_cornutum',
142 'Phrynosoma_mcallii',
143 'Phrynosoma_solare',
144 'Phymaturus_palluma',
145 'Physignathus_cocincinus',
146 'Physignathus_lesueurii',
147 'Pica_nuttalli',
148 'Pipilo_maculatus',
149 Plateosaurus,
150 'Podargus_strigoides',
151 'Poecile_gambeli',
152 'Pogona_barbarata',
153 'Pogona_vitticeps',
154 'Porphyrio_porphyrio',
155 Prosaurolophus,
156 Proterosuchus,
157 Protoceratops,
158 Psittacosaurus,
159 'Pterodactylus_antiquus',
160 Pterodaustro,
161 'Rallus_limicola',
162 'Regulus_calendula',
163 'Rhacodactylus_auriculatus',
164 'Rhacodactylus_ciliatus',
165 'Rhamphorhynchus_muensteri',
166 Riojasaurus,
167 Sapeornis,
168 'Sator_angustus',
169 Saurolophus,
170 'Sauromalus_ater',
171 Scaphognathus,
172 'Sceloporus_occidentalis',
173 'Sceloporus_undulatus',
174 Sinornithosaurus,
175 'Steatornis_caripensis',
176 'Stercorarius_maccormicki',
177 'Streptoprocne_zonaris',
178 'Strix_occidentalis',
179 'Struthio_camelus',

180 Tapejara,
181 'Teius_teyou',
182 'Teratoscincus_przewalskii',
183 'Teratoscincus_sp',
184 'Tiliqua_occipitalis',
185 'Tragopan_satyra',
186 'Tropidurus_torquatus',
187 'Tupinambis_merianae',
188 Tupuxuara,
189 'Turdus_merula',
190 'Turdus_migratorius',
191 'Tyto_alba',
192 'Uromastyx_maliensis',
193 'Varanus_beccarii',
194 Velociraptor,
195 'Wilsonia_pusilla',
196 Yixianornis,
197 'Zonotrichia_atricapilla';
TREE saurian1026 =
((((103:68.6,(164:34.3,163:34.3):34.3):76.0,((73:66.95,74:66.95):66.95,(((87:35.70666667,88:35.70666667):35.70666667,(182:35.70666667,183:35.70666667):35.70666667):35.70666667,(136:80.34,(137:53.56,(135:26.78,138:26.78):26.78):26.78):26.78):26.78):10.7):53.3,(((89:60.3,55:60.3):110.2,(110:113.6666666667,(56:56.83333333,184:56.83333333):56.83333333):56.83333333):17.8,((95:169.3,(187:126.975,(181:84.65,(7:42.325,51:42.325):42.325):42.325):42.325):10.4,((193:127.3,124:127.3):39.1,(((80:55.6666666667,(44:27.83333333,45:27.83333333):27.83333333):27.83333333,(140:71.57142857,(192:59.64285714,(145:47.71428571,(146:35.78571428,(47:23.85714286,(153:11.92857143,152:11.92857143):11.92857143):11.92857143):11.92857143):11.92857143):11.92857143):11.92857143):60.7,(((60:54.075,84:54.075):54.075,((116:45.0625,186:45.0625):45.0625,((23:36.05,24:36.05):36.05,(69:54.075,((92:18.025,170:18.025):18.025,(63:18.025,64:18.025,65:18.025):18.025):18.025):18.025):18.025):18.025):18.025,(((12:37.8525,13:37.8525):37.8525,(144:50.47,(104:25.235,105:25.235,106:25.235):25.235):25.235):25.235,((141:37.8525,142:37.8525,143:37.8525):37.8525,(132:50.47,168:50.47,(172:25.235,173:25.235):25.235):25.235):25.235):25.235):18.025):22.2):13.3):8.6):9.6):77.0[%triangled = on
],(156:1.3,(75:8.0,(((171:10.2,165:10.2):1.0,(159:9.725,((180:12.4,188:12.4):41.75,(160:52.675,(61:5.3,62:5.3):1.475):1.475):1.475):1.475):84.05,(((157:54.4,158:13.0):47.6,(5:10.4[%selected = on
],(59:13.9,(155:12.9,169:18.0):1.0):87.1):1.0):63.9,((166:13.9,(149:16.9,(109:10.0,(68:10.2,119:90.2):43.9):16.9):1.0):14.75,(91:11.5,(111:24.0,(94:4.9,((125:34.1,86:10.3):54.466666667,((194:55.4,(117:13.5,174:13.5):1.0):26.433333,(18:5.3,(54:18.0,(167:14.0,(196:13.0,((70:59.5,179:59.5):59.5,(((66:85.52,(6:64.14,((9:21.38,11:21.38):21.38,(10:21.38,8:21.38):21.38):21.38):21.38):21.38,((31:31.2,32:31.2):31.2,((83:24.96,128:24.96):24.96,((185:18.72,107:18.72):18.72,((67:12.48,96:12.48):12.48,(113:12.48,112:12.48):12.48,108:24.96,129:24.96,50:24.96,134:24.96):12.48):12.48):12.48):44.5):1.25,(((175:30.45,122:30.45):30.45,(150:58.3666666667,((123:44.6666666666,133:44.6666666666,(48:22.3333333333,49:22.3333333333):22.3333333333,(37:33.5,(34:22.3333333333,(35:11.16666667,36:11.16666667):11.16666667):11.16666667):11.16666667):11.16666667,(4:53.3,(33:47.5,(177:31.6666666667,(15:15.83333333,43:15.83333333):15.83333333):15.83333333):5.8):2.5333333333):2.5333333333):2.5333333333):36.4,(((53:45.0,((102:15.0,154:15.0):15.0,(82:15.0,161:15.0):15.0):15.0):15.0,(139:40.0,(26:20.0,19:20.0):20.0):20.0):35.9,((46:93.1,((121:59.0,(42:29.5,81:29.5):29.5):29.5,(176:68.0,(100:51.0,(101:34.0,(98:17.0,99:17.0):17.0):17.0):17.0):20.5):4.6):1.4,(((71:74.4,(191:71.1,(178:35.55,126:35.55,120:35.55,25:35.55,20:35.55,3:35.55,90:35.55,22:35.55):35.55):3.3):3.3,(39:76.3,(72:66.7625,((16:28.6125,17:28.6125):28.6125,(118:47.6875,((1:19.075,2:19.075):19.075,(21:28.6125,(28:19.075,30:19.075,(27:9.5375,29:9.5375):9.5375):9.5375):9.5375):9.5375):9.5375):9.5375):9.5375):1.4):3.3,((115:54.0,(79:40.5,(78:27.0,(76:13.5,77:13.5):13.5):13.5):13.5):13.5,((97:24.2,(130:20.1666666667,(14:16.1333333333,(85:12.1,(147:8.0666666666,(57:4.0333

3333,58:4.03333333):4.03333333):4.03333333):4.03333333):4.03333333):4.03333333):23.7,((131:39.0,151:39.0):1.8,((162:37.8,((189:14.175,190:14.175):14.175,(93:18.9,(40:9.45,41:9.45):9.45):9.45):9.45):1.4,((38:10.0,52:10.0):10.0,(195:16.7,((197:5.56666667,127:5.56666667):5.56666667,(114:5.56666667,148:5.56666667):5.56666667):5.56666667):3.3):19.2):1.6):7.1):19.6):13.5):13.5):1.4):1.4):10.85):10.85):6.0[%triangled = on
]):1.0):4.0):20.8):1.6333333333):1.6333333333):1.6333333333):43.9):28.4):4.25):4.25):4.25):4.25):6.0):23.9):1.0;

END;

R Scripts--phylo.fda.R

R Scripts that start from the next paragraph are necessary for running the phylogenetically informed discriminant analysis. Copy them into a text file and name it phylo.fda.R.

```
require(nnet)
require(mda)
require(ape)
require(geiger)
require(lattice)

###-------------------------------------------------------------------------
### Internal function from the package mda
###-------------------------------------------------------------------------

"contr.fda" <-
function (p = rep(1, d[1]), contrast.default = contr.helmert(length(p)))
{
   d <- dim(contrast.default)
   sqp <- sqrt(p/sum(p))
   x <- cbind(1, contrast.default) * outer(sqp, rep(1, d[2] +
      1))
   qx <- qr(x)
   J <- qx$rank
   qr.qy(qx, diag(d[1])[, seq(2, J)])/outer(sqp, rep(1, J -
      1))
}

###-------------------------------------------------------------------------
### Associated functions modified from the package mda
###-------------------------------------------------------------------------

"predict.phylo.fda" <-
function (object, newdata, type = c("class", "variates", "posterior",
   "hierarchical", "distances"), prior, dimension = J - 1, ...)
{
   dist <- function(x, mean, m = ncol(mean)) (scale(x, mean,
      FALSE)^2) %*% rep(1, m)
   type <- match.arg(type)
   means <- object$means
   Jk <- dim(means)
   J <- Jk[1]
   k <- Jk[2]
   if (type == "hierarchical") {
      if (missing(dimension))
         dimension.set <- seq(k)
      else {
         dimension.set <- dimension[dimension <= k]
         if (!length(dimension.set))
            dimension.set <- k
         dimension <- max(dimension.set)
      }
   }
```

```
else dimension <- min(max(dimension), k)
if (missing(newdata))
    y <- predict(object$fit)
else {
    if (inherits(newdata, "data.frame") || is.list(newdata)) {
        Terms <- delete.response(terms(object))
        attr(Terms, "intercept") <- 0
        newdata <- model.matrix(Terms, newdata)
    }
    y <- predict(object$fit, newdata)
}
y <- y %*% object$theta[, seq(dimension), drop = FALSE]
lambda <- object$values
alpha <- sqrt(lambda[seq(dimension)])
sqima <- sqrt(1 - lambda[seq(dimension)])
newdata <- scale(y, FALSE, sqima * alpha)
if (missing(prior))
    prior <- object$prior
else {
    if (any(prior < 0) | round(sum(prior), 5) != 1)
        stop("innappropriate prior")
}
means <- means[, seq(dimension), drop = FALSE]
switch(type, variates = return(newdata), class = {
    n <- nrow(newdata)
    prior <- 2 * log(prior)
    mindist <- dist(newdata, means[1, ], dimension) - prior[1]
    pclass <- rep(1, n)
    for (i in seq(2, J)) {
        ndist <- dist(newdata, means[i, ], dimension) - prior[i]
        l <- ndist < mindist
        pclass[l] <- i
        mindist[l] <- ndist[l]
    }
    ## 2001-10-27: Need to provide levels or else if we get an error
    ## if the predicted classes do no contain all possible classes.
    ## Reported by Greg Jefferis <jefferis@stanford.edu>, fix by
    ## Bj/orn-Helge Mevik <bjorn-helge.mevik@matforsk.no>.
    return(factor(pclass, levels = seq(J),
                  labels = dimnames(means)[[1]]))
}, posterior = {
    pclass <- matrix(0, nrow(newdata), J)
    for (i in seq(J)) pclass[, i] <- exp(-0.5 * dist(newdata, means[i,
        ], dimension)) * prior[i]
    dimnames(pclass) <- list(dimnames(newdata)[[1]], dimnames(means)[[1]])
    return(pclass/drop(pclass %*% rep(1, J)))
}, hierarchical = {
    prior <- 2 * log(prior)
    Pclass <- vector("list", length(dimension.set))
    names(Pclass) <- paste("D", dimension.set, sep = "")
    for (ad in seq(along = dimension.set)) {
        d <- dimension.set[ad]
        dd <- seq(d)
```

```
        mindist <- dist(newdata[, dd, drop = FALSE], means[1, dd, drop = FALSE],
            d) - prior[1]
        pclass <- rep(1, nrow(newdata))
        for (i in seq(2, J)) {
            ndist <- dist(newdata[, dd, drop = FALSE], means[i, dd,
              drop = FALSE], d) - prior[i]
            l <- ndist < mindist
            pclass[l] <- i
            mindist[l] <- ndist[l]
        }
        levels(pclass) <- dimnames(means)[[1]]
        Pclass[[ad]] <- pclass
      }
      rownames <- dimnames(newdata)[[1]]
      if (is.null(rownames))
        rownames <- paste(seq(nrow(newdata)))
      return(structure(Pclass, class = "data.frame", row.names = rownames,
        dimensions = dimension.set))
    }, distances = {
      dclass <- matrix(0, nrow(newdata), J)
      for (i in seq(J)) dclass[, i] <- dist(newdata, means[i, ],
        dimension)
      dimnames(dclass) <- list(dimnames(newdata)[[1]], dimnames(means)[[1]])
      return(dclass)
    })
}
"predict.polyreg.modified" <-
function (object, newdata, ...)
{
    if (missing(newdata)) {
        z <- fitted(object)
        if (is.null(z))
            stop("need to supply newdata")
        else return(z)
    }
    degree <- object$degree
    monomial <- object$monomial
    newdata %*% object$coef
}
"polyreg.modified" <-
function (x, y, w, degree = 1, monomial = FALSE, ...)
{
    #x <- polybasis(x, degree, monomial)
    y <- as.matrix(y)                  # just making sure ...
    if (iswt <- !missing(w)) {
        if (any(w <= 0))
            stop("only positive weights")
        w <- sqrt(w)
        y <- y * w
        x <- x * w
    }
    qrx <- qr(x)
    coef <- as.matrix(qr.coef(qrx, y))
```

```
    fitted <- qr.fitted(qrx, y)
    if ((df <- qrx$rank) < ncol(x))
        coef[qrx$pivot, ] <- coef
    if (iswt)
        fitted <- fitted/w
    structure(list(fitted.values = fitted, coefficients = coef,
        degree = degree, monomial = monomial, df = df), class = "polyreg.modified")
}

"print.phylo.fda" <-
function (x, ...)
{
    if (!is.null(cl <- x$call)) {
        cat("Call:\n")
        dput(cl)
    }
    cat("\nDimension:", format(x$dimension), "\n")
    cat("\nPercent Between-Group Variance Explained:\n")
    print(round(x$percent, 2))
    error <- x$confusion
    df <- x$fit
    if (!is.null(df))
        df <- df$df
    if (!is.null(df)) {
        cat("\nDegrees of Freedom (per dimension):", format(sum(df)),
            "\n")
    }
    if (!is.null(error)) {
        n <- as.integer(sum(error))
        error <- format(round(attr(error, "error"), 5))
        cat("\nTraining Misclassification Error:", error, "( N =",
            n, ")\n")
    }
    invisible(x)
}

"plot.phylo.fda" <- function(pfdamodel,gfactor=pfdamodel$g,prdfactor=pfdamodel$prd)
{
  pfdavar <- predict(pfdamodel, type="variate")
  lim1x <- c(min(pfdavar[,1]),max(pfdavar[,1]))
  lim1y <- c(min(pfdavar[,2]),max(pfdavar[,2]))
  m1 <- 4;m2 <- 1
  oldpar<-
par(no.readonly=FALSE);on.exit(par(oldpar));x11(height=8,width=14);par(mfrow=c(1,2),mar=c(m1,m1,m1,
m2),oma=c(m2,m2,m2,m2));
  matplot(pfdavar[gfactor==levels(gfactor)[1],1], pfdavar[gfactor==levels(gfactor)[1],2],
xlab="pFDA1",ylab="pFDA2", xlim=lim1x, ylim=lim1y, pch=1, col=1, main="True
Classes",sub=paste("lambda = ",pfdamodel$val," intrcpt=",pfdamodel$intercept,"
eqprior=",pfdamodel$eqprior,sep=""))
  for (i in 2:nlevels(gfactor)) matplot(pfdavar[gfactor==levels(gfactor)[i],1],
pfdavar[gfactor==levels(gfactor)[i],2], add=TRUE, pch=i, col=i)
  legend(min(lim1x),max(lim1y),levels(gfactor), pch=1:nlevels(gfactor), col=1:nlevels(gfactor))
```

```
  legend(min(lim1x),min(lim1y)+(max(lim1y)-min(lim1y))*0.1,paste("lambda = ",pfdamodel$val,"
intrcpt=",pfdamodel$intercept,"  eqprior=",pfdamodel$eqprior,"   ",sep=""))
  addEllipseGrp(pfdavar[,1],pfdavar[,2],gfactor, pval=0.95, num=30)
  matplot(pfdavar[prdfactor==levels(prdfactor)[1],1], pfdavar[prdfactor==levels(prdfactor)[1],2],
xlab="pFDA1",ylab="pFDA2", xlim=lim1x, ylim=lim1y, pch=1, col=1, main="Predicted
Classes",sub=paste("lambda = ",pfdamodel$val," intercept=",pfdamodel$intercept,"
eqprior=",pfdamodel$eqprior,sep=""))
  for (i in 2:nlevels(prdfactor)) matplot(pfdavar[prdfactor==levels(prdfactor)[i],1],
pfdavar[prdfactor==levels(prdfactor)[i],2], add=TRUE, pch=i, col=i)
  legend(min(lim1x),max(lim1y),levels(prdfactor), pch=1:nlevels(prdfactor), col=1:nlevels(prdfactor))
  legend(min(lim1x),min(lim1y)+(max(lim1y)-min(lim1y))*0.1,paste(levels(prdfactor),"=",pfdamodel$prior,"
",sep=""))
  legend(max(lim1x)-(max(lim1x)-min(lim1x))*0.2,max(lim1y),signif(attr(pfdamodel$confusion,"error"),4))
  invisible()
}

###-------------------------------------------------------------------------
### Main pFDA function with training data only
###-------------------------------------------------------------------------

"phylo.fda" <-function (data,grp,tretre,val=1,treetrans=lambdaTree,
    dimension = J - 1, eps = .Machine$double.eps,
    keep.fitted = (n * dimension < 1000), method=polyreg.modified,intercept=TRUE,eqprior=FALSE,priin=1)
{
    this.call <- match.call()
if(intercept) data <- cbind(Intercept=rep(1,nrow(data)),data)
data <- as.matrix(data)
tretre <- treetrans(tretre,val)
g <- as.factor(grp)
ng <- nlevels(g)
W <- vcv.phylo(tretre)
invW<-solve(W)
invW.eig <- eigen(invW)
N <- invW.eig$vectors %*% diag(sqrt(invW.eig$values)) %*% solve(invW.eig$vectors)
divnum <-det(N)^(1/nrow(N))
N <- N/divnum
DATA <- N%*%data #Rao (4,57); transforming the data to linear
n <- nrow(DATA)
y <- matrix(0,nrow(data),ng)
for (i in 1:nrow(data)){y[i,g[i]] <- 1}
Y <- N%*%y  #Dummy matrix with phylo bias removed
    x <- DATA
    fg <- factor(g)
prior <- colSums(Y)/sum(colSums(Y))
if(eqprior)   prior <- c(rep(1/ng,ng))
if(priin != 1) prior<-priin
    cnames <- levels(fg)
    g <- as.numeric(fg)
    J <- length(cnames)
    weights <- rep(1, n)
    dp <- tapply(weights, g, sum)/n
    theta <- contr.helmert(J)
    theta <- contr.fda(dp, theta)
```

```
Theta <- Y%*%theta #fda p.7, above eq2
   fit <- method(x, Theta, weights)
rss <- t(Theta-fit$fitted) %*% (Theta-fit$fitted)
   ssm <- t(Theta) %*% fitted(fit)/n
   ed <- svd(ssm, nu = 0)
   thetan <- ed$v
   lambda <- ed$d
   lambda[lambda > 1 - eps] <- 1 - eps
   discr.eigen <- lambda/(1 - lambda)
   pe <- (100 * cumsum(discr.eigen))/sum(discr.eigen)
   dimension <- min(dimension, sum(lambda > eps))
   if (dimension == 0) {
      warning("degenerate problem; no discrimination")
      return(structure(list(dimension = 0, fit = fit, call = this.call),
                  class = "phylo.fda"))
   }
   thetan <- thetan[, seq(dimension), drop = FALSE]
   pe <- pe[seq(dimension)]
   alpha <- sqrt(lambda[seq(dimension)])
   sqima <- sqrt(1 - lambda[seq(dimension)])
   vnames <- paste("v", seq(dimension), sep = "")
   means <- scale(theta %*% thetan, FALSE, sqima/alpha)
   dimnames(means) <- list(cnames, vnames)
   names(lambda) <- c(vnames, rep("", length(lambda) - dimension))
   names(pe) <- vnames
frml <- "grp~"
nc <- ncol(data)
varnam <- colnames(data)
for(i in 1:(nc-1)) frml <- paste(frml,varnam[i],"+", sep="")
frml <- paste(frml,varnam[nc], sep="")
frml <- as.formula(frml)
dset <- as.data.frame(cbind(grp,DATA))
Terms <- as.call(fda(formula = frml, data = dset, weights = weights))
   obj <- structure(list(percent.explained = pe, values = lambda,
      means = means, theta.mod = thetan, dimension = dimension,
      prior = prior, fit = fit, call = this.call, terms = Terms),
      class = "phylo.fda")
   obj$confusion <- confusion(predict(obj), fg)
   obj$prd <- predict(obj)
obj$g <- as.factor(grp)
obj$val <- val
obj$rss <- sum(diag(rss))
obj$intercept <- intercept
obj$eqprior <- eqprior
   if (!keep.fitted)
      obj$fit$fitted.values <- NULL
   obj
}

###-------------------------------------------------------------------------
### Main pFDA function with training and test data
###-------------------------------------------------------------------------
```

```
"phylo.fda.pred" <-function (dataA,grpA,taxtaxA,tretreA,testlistn,val=1,treetrans=lambdaTree,
    method=polyreg.modified,sbcls=floor(table(grp)/4),
    dimension = J - 1, eps = .Machine$double.eps, keep.fitted = (n * dimension <
1000),intercept=TRUE,eqprior=FALSE,priin=1)
{
## Preparing data
this.call <- match.call()
  if(intercept) dataA <- cbind(Intercept=rep(1,nrow(dataA)),dataA)
  dataA <- as.data.frame(dataA)
  nA <- nrow(dataA)
  testlist <- taxtaxA[testlistn]
  traininglist <- taxtaxA[-testlistn]
  rownames(dataA) <- taxtaxA
  tretre <- drop.tip(tretreA,testlistn)
  grp <- grpA[-testlistn]
  grp <- grp[grp %in% names(table(grp))[table(grp) > 0], drop=TRUE]
  g <- as.factor(grp)
  ng <- nlevels(g)
  grpA <- as.factor(grpA)
  ntest <- length(testlist)
  dataA <- as.matrix(dataA)
  tretreA <- treetrans(tretreA,val)
  W <- vcv.phylo(tretreA)
  invW<-solve(W)
   invW.eig <- eigen(invW)
   N <- invW.eig$vectors %*% diag(sqrt(invW.eig$values)) %*% solve(invW.eig$vectors)
divnum <-det(N)^(1/nrow(N))
N <- N/divnum
  invN <- solve(N)
  y <- matrix(0,nA,nlevels(grpA))
  for (i in 1:nA){y[i,grpA[i]] <- 1}
  Y <- N%*%y  #Dummy matrix with phylo bias removed
  Y <- Y[-testlistn,1:ng]
  DATAA <- N%*%as.matrix(dataA) #Rao (4,57); transforming the data to linear
  DATA <- DATAA[-testlistn,]
  DATAtest <- DATAA[testlistn,]
  n<-nrow(DATA)
  m<-nrow(DATAtest)
  x <- DATA
    fg <- factor(g)
prior <- colSums(Y)/sum(colSums(Y))
if(eqprior)   prior <- c(rep(1/ng,ng))
#prior <- c(0.305, 0.237, 0.458)      # Mammalian Prior
#prior <- c(0.288, 0.558, 0.154)      # Avian Prior
if(priin != 1) prior<-priin
    cnames <- levels(fg)
    g <- as.numeric(fg)
    J <- length(cnames)
    weights <- rep(1, n)
    dp <- tapply(weights, g, sum)/n
    theta <- contr.helmert(J)
    theta <- contr.fda(dp, theta)
    Theta <- Y%*%theta #fda p.7, above eq2
```

```
    fit <- method(x, Theta, weights)
rss <- t(Theta-fit$fitted) %*% (Theta-fit$fitted)
    ssm <- t(Theta) %*% fitted(fit)/n
    ed <- svd(ssm, nu = 0)
    thetan <- ed$v
    lambda <- ed$d
    lambda[lambda > 1 - eps] <- 1 - eps
    discr.eigen <- lambda/(1 - lambda)
    pe <- (100 * cumsum(discr.eigen))/sum(discr.eigen)
    dimension <- min(dimension, sum(lambda > eps))
    if (dimension == 0) {
        warning("degenerate problem; no discrimination")
        return(structure(list(dimension = 0, fit = fit, call = this.call),
                    class = "fda"))
    }
    thetan <- thetan[, seq(dimension), drop = FALSE]
    pe <- pe[seq(dimension)]
    alpha <- sqrt(lambda[seq(dimension)])
    sqima <- sqrt(1 - lambda[seq(dimension)])
    vnames <- paste("v", seq(dimension), sep = "")
    means <- scale(theta %*% thetan, FALSE, sqima/alpha)
    dimnames(means) <- list(cnames, vnames)
    names(lambda) <- c(vnames, rep("", length(lambda) - dimension))
    names(pe) <- vnames
frml <- "grp~"
nc <- ncol(dataA)
varnam <- colnames(dataA)
for(i in 1:(nc-1)) frml <- paste(frml,varnam[i],"+", sep="")
frml <- paste(frml,varnam[nc], sep="")
frml <- as.formula(frml)
dset <- as.data.frame(cbind(grp,DATA))
Terms <- as.call(fda(formula = frml, data = dset, weights = weights))
    obj <- structure(list(percent.explained = pe, values = lambda,
        means = means, theta.mod = thetan, dimension = dimension,
        prior = prior, fit = fit, call = this.call, terms = Terms),
        class = "phylo.fda")
    obj$confusion <- confusion(predict(obj), fg)
    obj$prd <- predict(obj)
obj$x<-x
obj$g <- as.factor(grp)
obj$val <- val
obj$rss <- sum(diag(rss))
obj$intercept <- intercept
obj$eqprior <- eqprior
obj$DATAtest <- DATAtest
obj$DATA <- DATA
tpred <- predict(obj,DATAtest)
tpredn <- as.numeric(tpred)
tpred <- as.matrix(tpred)
rownames(tpred) <- testlist
obj$testprediction <- tpred
obj$testprediction_numeral <- tpredn
  if (!keep.fitted)
```

```
      obj$fit$fitted.values <- NULL
   obj
}

###-------------------------------------------------------------------------
### Function for optimal lambda value search
###-------------------------------------------------------------------------

"phylo.RSS"<-function (datain,grp,tretre,val=1,treetrans=lambdaTree)
{
 datainO <- as.matrix(datain)
 datainI <- cbind(Intercept=rep(1,nrow(datainO)),datainO)
 tretre <- treetrans(tretre,val)
 n <- nrow(datain)
 g <- as.factor(grp)
 ng <- nlevels(g)
 W <- vcv.phylo(tretre)
 invW<-solve(W)
 y <- matrix(0,n,ng)  #Dummy matrix without phylo bias
 for (i in 1:n){y[i,g[i]] <- 1}
 invW.eig <- eigen(invW)
 N <- invW.eig$vectors %*% diag(sqrt(invW.eig$values)) %*% solve(invW.eig$vectors)
 Y <- N %*% y # Pretending that there is no phylogenetic bias in y; otherwise Y <- N%*%y
 DATAI <- N%*%datainI
#   BHAT <- solve(t(DATA)%*%DATA)%*%t(DATA)%*%Y
#   YHAT <- DATA%*%BHAT
 bhatI <- solve(t(datainI)%*%invW%*%datainI)%*%t(datainI)%*%invW%*%y #Rohlf (9) -- data biased still
Rao (4,64)
 yhatI <- datainI%*%bhatI  #Rohlf (11)
 RSSyI <-  t(y-yhatI) %*% invW %*% (y-yhatI) #Martins and Hansen 1997 (9)
 l0I<- lm(Y~DATAI-1)
#   RSSY <- t(Y-YHAT) %*% (Y-YHAT)
 list(RSS=sum(diag(RSSyI)),lLY=logLik(l0I),AICY=AIC(l0I),l0I=l0I)
}

#dataA=XA;grpA=gA;taxtaxA=taxaA;tretreA=treA;testlistn=testtaxan;val=0;treetrans=lambdaTree
"phylo.RSS.pred" <-function (dataA,grpA,taxtaxA,tretreA,testlistn,val=1,treetrans=lambdaTree)
{
 dataA <- as.data.frame(dataA)
 nA <- nrow(dataA)
 testlist <- taxtaxA[testlistn]
 traininglist <- taxtaxA[-testlistn]
 rownames(dataA) <- taxtaxA
 tretre <- drop.tip(tretreA,testlistn)
 grp <- grpA[-testlistn]
 grp <- grp[grp %in% names(table(grp))[table(grp) > 0], drop=TRUE]
 g <- as.factor(grp)
 ng <- nlevels(g)
 grpA <- as.factor(grpA)
 icptA <- rep(1,nA)
 dataA <- cbind(icptA,dataA)
 ntest <- length(testlist)
 tretreA <- treetrans(tretreA,val)
```

```
 W <- vcv.phylo(tretreA)
 invW<-solve(W)
 invW.eig <- eigen(invW)
 N <- invW.eig$vectors %*% diag(sqrt(invW.eig$values)) %*% solve(invW.eig$vectors)
 invN <- solve(N)
 y <- matrix(0,nA,nlevels(grpA))
 for (i in 1:nA){y[i,grpA[i]] <- 1}
 Y <- N%*%y  #Dummy matrix with phylo bias removed
 Y <- Y[-testlistn,1:ng]
 DATAA <- N%*%as.matrix(dataA) #Rao (4,57); transforming the data to linear
 DATA <- DATAA[-testlistn,]
 BHAT <- solve(t(DATA)%*%DATA)%*%t(DATA)%*%Y
 YHAT <- DATA%*%BHAT
 l0<- lm(Y~DATA-1)
 RSSY <- t(Y-YHAT) %*% (Y-YHAT)
 list(RSS=sum(diag(RSSY)),lLY=logLik(l0),AICY=AIC(l0))
}

#measurements=X;grps=g;mytree=tre;idc=filename_stem
"optLambda" <- function(measurements,grps,mytree,idc="default",sstep=0.01,srange=c(0,1),fldr="./")
{
 lambdalist <- seq(min(srange),max(srange),sstep)
 segnum <- length(lambdalist)
 rslt<-matrix(,segnum,3)
 colnames(rslt) <- c("Lambda","RSS","logLik")
 for(i in 1:segnum){
  lambdaval <- lambdalist[i]
  rss <- phylo.RSS(X,grps,mytree,val=lambdaval)
  rslt[i,] <- c(lambdaval,rss$RSS,rss$lLY)
 }
 optlambda <- matrix(,1,2);colnames(optlambda)<- c("RSS","logLik")
 optlambda[1,1]<-max(rslt[which(rslt[,2]==min(rslt[,2])),1])
 optlambda[1,2]<-max(rslt[which(rslt[,3]==max(rslt[,3]),1)])
 x11();matplot(rslt[,1],rslt[,2],type="l",xlab=expression(lambda),ylab="RSS",main="RSS",lty=1,col=1)
 abline(v=optlambda[1,1],col=2,lty=2);mtext(paste("Optimal Lambda = ",optlambda[1,1],sep=""))
 x11();matplot(rslt[,1],rslt[,3],type="l",xlab=expression(lambda),ylab="log
Likelihood",main="logLik",lty=1,col=1)
 abline(v=optlambda[1,2],col=2,lty=2);mtext(paste("Optimal Lambda = ",optlambda[1,2],sep=""))
 pdf(height=11,width=6,file=paste(fldr,idc,".optLambda.pdf",sep=""));layout(matrix(c(1,2),2,1))
  matplot(rslt[,1],rslt[,2],type="l",xlab=expression(lambda),ylab="RSS",main="RSS",lty=1,col=1)
  abline(v=optlambda[1,1],col=2,lty=2);mtext(paste("Optimal Lambda = ",optlambda[1,1],sep=""))
  matplot(rslt[,1],rslt[,3],type="l",xlab=expression(lambda),ylab="log
Likelihood",main="logLik",lty=1,col=1)
  abline(v=optlambda[1,2],col=2,lty=2);mtext(paste("Optimal Lambda = ",optlambda[1,2],sep=""))
 dev.off()
 list(optlambda=optlambda,rslt=rslt)
}
# optLambda(X,grps, mytree, "LSSoft2_1000",0.001,c(0,0.2))
# optLambda(X,grps, mytree, "SHF_1000",0.001,c(0,1))

#measurementsA=XA;grpsA=gA;mytreeA=treA;testn=testtaxan;idc=filename_stem
"optLambda.pred" <-
function(measurementsA,grpsA,taxaA,mytreeA,testn,idc="default",sstep=0.01,srange=c(0,1),fldr="./")
```

```
{
 lambdalist <- seq(min(srange),max(srange),sstep)
 segnum <- length(lambdalist)
 rslt<-matrix(,segnum+1,3)
 colnames(rslt) <- c("Lambda","RSS","logLik")
 for(i in 1:segnum){
  lambdaval <- lambdalist[i]
  rss <- phylo.RSS.pred(measurementsA,grpsA,taxaA,mytreeA,testn,val=lambdaval)
  rslt[i,] <- c(lambdaval,rss$RSS,rss$lLY)
 }
 optlambda <- matrix(,1,2);colnames(optlambda)<- c("RSS","logLik")
 optlambda[1,1]<-max(rslt[which(rslt[,2]==min(rslt[,2])),1])
 optlambda[1,2]<-max(rslt[which(rslt[,3]==max(rslt[,3]),1)])
 x11();matplot(rslt[,1],rslt[,2],type="l",xlab=expression(lambda),ylab="RSS",main="RSS",lty=1,col=1)
 abline(v=optlambda[1,1],col=2,lty=2);mtext(paste("Optimal Lambda = ",optlambda[1,1],sep=""))
 x11();matplot(rslt[,1],rslt[,3],type="l",xlab=expression(lambda),ylab="log
Likelihood",main="logLik",lty=1,col=1)
 abline(v=optlambda[1,2],col=2,lty=2);mtext(paste("Optimal Lambda = ",optlambda[1,2],sep=""))
 pdf(height=11,width=6,file=paste(fldr,idc,".optLambda.pred.pdf",sep=""));layout(matrix(c(1,2),2,1))
  matplot(rslt[,1],rslt[,2],type="l",xlab=expression(lambda),ylab="RSS",main="RSS",lty=1,col=1)
  abline(v=optlambda[1,1],col=2,lty=2);mtext(paste("Optimal Lambda = ",optlambda[1,1],sep=""))
  matplot(rslt[,1],rslt[,3],type="l",xlab=expression(lambda),ylab="log
Likelihood",main="logLik",lty=1,col=1)
  abline(v=optlambda[1,2],col=2,lty=2);mtext(paste("Optimal Lambda = ",optlambda[1,2],sep=""))
 dev.off()
 list(optlambda=optlambda,rslt=rslt)
}

###---------------------------------------------------------------------
### Utility functions for plotting
###---------------------------------------------------------------------

addEllipseSer <- function(x, y, series=2, pval=0.95, num=30)
    {
        acc <- num
        alpha <- 1-pval
        vx <- var(x)
        vy <- var(y)
        vxy <- var(x, y)
        lambda <- eigen(var(cbind(x, y)))$values
        a <- sqrt(vxy^2/((lambda[2]-vx)^2+vxy^2))
        b <- (lambda[2]-vx)*a/vxy
        theta <- atan(a/b)
        k <- sqrt(-2*log(alpha))
        l1 <- sqrt(lambda[1])*k
        l2 <- sqrt(lambda[2])*k
#         x2 <- seq(-l1, l1, l1/acc)
        pvec <- 0:num
        x2right <- sin((pi*pvec)/(num*2))*l1
        x2 <- c(-rev(x2right), x2right )
        tmp <- 1-x2^2/l1^2
        y2 <- l2*sqrt(ifelse(tmp < 0, 0, tmp))
        x2 <- c(x2, rev(x2))
```

```
        y2 <- c(y2, -rev(y2))
        s0 <- sin(theta)
        c0 <- cos(theta)
        xx <- c0*x2+s0*y2+mean(x)
        yy <- -s0*x2+c0*y2+mean(y)
        #polygon(xx, yy, border=series)
        matplot(xx,yy,xlim=range(x), ylim=range(y), type="l", add=TRUE, col=series, cex=1)
        epp <- cbind(xx,yy)
        return(epp)
    }

addEllipseGrp <- function(x,y,grp, pval=0.95, num=30)
{
 gnum <- nlevels(grp)
 gnames <- levels(grp)
 xrange <- cbind(min(x),max(x))
 yrange <- cbind(min(y),max(y))
 dset <- cbind(grp,x,y)
 epnts <- 1:((num+1)*4)
 for (i in 1:gnum)
 {
  dset1 <- dset[grp==gnames[i],]
  if(is.vector(dset1)==TRUE){x1 <- dset1[2]; y1 <- dset1[3]} else{x1 <- dset1[,2]; y1 <- dset1[,3]}
  epnts2 <- addEllipseSer(x1,y1,i,pval,num)
  epnts <- cbind(epnts, epnts2)
 }
}
```

Step-by-Step Guide to R Script Usage

Step 1. Prepare your data set.

Prepare your data using your spreadsheet software. Your data should be similar to below:

taxon	measure1	measure2	…	measureN	groups
Gen1_sp1	2.8	8.13	…	4.53	nocturnal
Gen2_sp2	1.41	8.34	…	6.56	unknown
Gen3_sp3	2.36	8.44	…	3.53	nocturnal
Gen4_sp4	1.33	7.87	…	3.6	diurnal
Gen5_sp5	2.72	6.5	…	5.79	diurnal
Gen6_sp6	4.83	9.34	…	4.79	diurnal
Gen7_sp7	1.62	8.09	…	4.39	unknown
…	..	…	…	…	…
GenM_spM	4.8	9.26	…	5.17	diurnal

taxon: Species names or equivalents. **Do not** use space. They should be in the order in which they appear in the phylogeny (i.e., NEXUS file).
measure1 ... : Continuous variables representing measurements, such as "eyeball_diameter" or "lens_ diameter".
groups: A categorical variable of interest. In the example above, diel activity pattern is used.

Step 2: Start R and get it ready

Start R, load relevant libraries (especially the packages ape and geiger), set the working directory if necessary. You also need to load functions in the **phylo.fda.R**, which is supplied earlier in this supporting online material.

Step 3. Input Phylogeny

Use Mesquite or some other software to prepare your phylogenetic tree. Make sure that branch lengths are specified. We recommend using divergence time to calculate branch lengths. Also, it is critical to have the taxa in this file arranged in the same sequence as they appear in the data set in Step 1. To reanalize our data, use the Nexus file attached in this supporting online material. Then:

```
treA <- read.nexus("your_file_name.nex")
```

Note that "your_file_name" should include the folder location if your NEXUS file is not in the working directory. The current working directory can be found by the command getwd(), and set by setwd(). Next, check if the tree is binary. If not, force it to be binary.

```
if(!is.binary.tree(treA)) treA <- multi2di(treA, random = TRUE)
```

Finally, if relevant, check if the tree is ultrametric. This would be irrelevant if your tree has fossil taxa.

```
is.ultrametric(treA)
```

Step 4: Input your data and prepare them

4-1: Copy the data from spreadsheet
If you are a Windows user, type the following command in R:

```
ddA <- as.data.frame(read.delim("clipboard"))
```

Copy the relevant area of the spreadsheet into the clipboard and then hit enter. If you use Mac OS X or Linux, you need to save the spreadsheet as a .csv file (say, data.csv), move it to the working directory of R (you can find where it is by typing getwd() and hitting enter in R), and load the file using the command:

```
ddA <- read.csv("data.csv",quote="")
```

Confirm that the data were correctly read into R by typing:

```
ddA
```

If you are not sure about the taxon order being identical between your tree and data set, you can run the following command:

```
rownames(ddA) <- ddA$taxon
ddA <- ddA[treA$tip.label,]
```

If you ran these two lines, then make sure that the rows sorted correctly (i.e., type "ddA" , hit return, and go through the matrix that is displayed). If the commands above gave you NAs in the data, that means the taxon names do not match exactly between the tree and spreadsheet.

4-2: Extract group categories
If your spreadsheet had a heading "groups" for categories as in the example in Step 1, then:

```
gA <- ddA$groups
```

4-3: Extract taxon names
If your spreadsheet had a heading "taxon" for the taxon names, then:

```
taxaA <- ddA$taxon
rownames(ddA) <- taxaA       # for later convenience
```

Make sure that taxon names are in the same order between the spreadsheet and the NEXUS file that will be used in Step 4.

4-4: Extract the measurements and transform(?)
If your measurements are in the second to fourth columns of ddA, then:

```
XA <- ddA[,2:4]
```

If you need to log transform your measurements, then:

```
XA <- log10(XA)
```

4-5: Identifies the taxa that are to be used in test data

If you identified test data taxa as "unknown" in your dataset, as in the example in Step 1, then use the following commands:

```
testtaxa <- rownames(ddA[gA=="unknown",])
testtaxan <- row(ddA)[gA=="unknown",1]
trainingtaxa <- rownames(ddA[-testtaxan,])
X <- XA[-testtaxan,]
dd <- ddA[-testtaxan,]
g <- gA[-testtaxan]
g <- g[g %in% names(table(g))[table(g) > 0], drop=TRUE]
```

4-6. Extract training data part of the tree

```
tre <- drop.tip(treA, testtaxa)
```

Step 5: Find the optimal λ value.

You need to find the strength of phylogenetic noise in your data in terms of Pagel's □. You can find this optimal λ value, as defined in Motani and Schmitz (in press), in two alternative ways. You can choose to find this value based on training data set only, or based on the entire data set. Either way, only the training part of the data set is used for most of the calculations. The only difference would be whether the phylogenetic noise in the training taxa is evaluated with some influence from test data set or not.

Comment [L1]: We can update this once it is published.

5-1. Find the optimal λ value using training data only

Run the commands below. It takes time (several minutes?) for the second line to be processed.

```
filename_stem <- "NameOfYourChoice"
ol1 <- optLambda(X,g,tre,idc=filename_stem)
ol1$optlambda
```

Take a note of the optimal λ value for "logLik". Also, a PDF file is generated automatically to record the graphs that appear. The file is named according to the filename_stem that you specify, and saved in the working directory.

5-2. Find the optimal λ value using training data, with influence from test data

Run the commands below. It takes time (several minutes?) for the second line to be processed.

```
filename_stem <- "NameOfYourChoice"
ol2<-optLambda.pred(XA,gA,taxaA,treA,testtaxan,idc=filename_stem)
ol2$optlambda
```

Take a note of the optimal λ value for "logLik". Also, a PDF file is generated automatically to record the graphs that appear. The file is named according to the filename_stem that you specify, and saved in the working directory.

Step 6: Run phylogenetic discriminant analysis

6-1. Simplest analysis

```
optl <- 0.08 #replace with the optimal lambda value from Step 5
pfda <- phylo.fda.pred(XA,gA,taxaA,treA,testtaxan,val=optl)
pfda$testprediction
```

6-2. Using specific prior probabilities

Pior probabilities have a substantial effect on the outcome of phylogenetic fda. When appropriate values can be estimated, it is best to supply these values. Otherwise, the proportion that is found in the training data set is used by default. Specify the prior probabilities for the categories in *g* (defined in Step 4-5), in the order as they appear in *g* (usually alpha-numerally sorted). The numbers below is based on the estimated proportions among cathemeral, diurnal, and nocturnal species among extant amniotes.

```
pri  <- c(0.1427,0.5864,0.2709)
```

Note that *pri* as defined above only works if your *g* has three categories. Run the commands below. Note the slight difference in the second line compared to 6-1. The commands below were written for the data set provided in supporting online material.

```
optl <- 0.08 #replace with the optimal lambda value from Step 5
pfda <- phylo.fda.pred(XA,gA,taxaA,treA,testtaxan,val=optl,priin=pri)
pfda$testprediction
```

You should receive a warning from the second line but you can ignore it.

6-3. Finding results across a range of λ values

The script below would only work with our data set, which is provided as online supporting material. Given that the estimation of the optimal λ value may involve errors, it is worthwhile to check how changing the λ value may affect the outcome of phylogenetic fda. We first calculate the outcome across a range of λ values, in this case 0, 0.01,0.02,...,1.00. It should take some time to process these commands.

```
lambdalist <- c(0:100)/100
nlambda <- length(lambdalist)
lmbd <- 0
pfp <- phylo.fda.pred(XA,gA,taxaA,treA,testtaxan,lmbd,priin=pri)
outcome<-pfp$testprediction
for(i in 1:(nlambda-1)){
  lmbd <- lambdalist[i+1]
  pfp <- phylo.fda.pred(XA,gA,taxaA,treA,testtaxan,lmbd,priin=pri)
  outcome<-cbind(outcome,pfp$testprediction)
}
```

We then convert the outcome to numbers and add names to rows and columns so that it is easier to plot.

```
outcomen<- matrix(0,nrow(outcome),ncol(outcome))
for(i in 1:ncol(outcome)){
  for(j in 1:nrow(outcome)){
    if(outcome[j,i]=="diurnal") outcomen[j,i]<-3
    if(outcome[j,i]=="cathemeral") outcomen[j,i]<-2
    if(outcome[j,i]=="nocturnal") outcomen[j,i]<-1
  }
}
colnames(outcome) <- lambdalist
colnames(outcomen) <- lambdalist
rownames(outcomen) <- rownames(outcome)
```

You can save the outcome to keep record.

```
dataname <- "DinoPrediction"
dname <- paste("./",dataname,sep="")
dput(outcomen,paste(dname,"_num",sep=""))
dput(outcome,paste(dname,"_char",sep=""))
```

We then make a plot for easier visualization. First, specify the colors to be used for categories, and give the category names to appear on the plot.

```
dapcol <- c("black","blue","yellow")
lgd <- c("Nocturnal","Cathemeral/Crepuscular","Diurnal")
```

If you would rather have a grayscale plot, then use:

```
dapcol <- c("black","gray","white")
```

We then set parameters that are necessary for plotting.

```
yLabels <- rownames(outcomen); xLabels <- colnames(outcomen)
reverse <- nrow(outcomen):1;  yLabels <- yLabels[reverse]
routcomen <- outcomen[reverse,]
m1 <- 5; m2 <- 0
```

Then run the following commands to display a plot on screen.

```
x11(width=11,height=8.5)
par(mfrow=c(1,1),mar=c(m1,10,6,m1),oma=c(1,m2,m2,m2))
image(c(1:length(xLabels)), c(1:length(yLabels)), z=t(routcomen),
      col=dapcol,xlab=expression(lambda),ylab="",axes=FALSE, main=
      dataname, sub=paste("Optimum = ", optl, sep=""))
axis(BELOW<-1, at=1:length(xLabels), labels=xLabels, cex.axis=0.7)
axis(LEFT <-2, at=1:length(yLabels), labels=yLabels, font=3, las=
      HORIZONTAL<-1,  cex.axis=0.7)
abline(v=c(which(xLabels==optl)),col=c(2));
abline(h=c(0:(length(yLabels)+1))-0.5); box()
par(xpd=NA)
legend(x=-20,y=42,lgd,fill=dapcol,bg="white")
```

You can save the plot as a PDF file by running the commands below. You may need to adjust the position of the legend to suit your machine's setting by changing x and y values in the penultimate line.

```
pdf(paste(dname,".pdf",sep=""),width=11,height=8.5);
par(mfrow=c(1,1),mar=c(m1,10,6,m1),oma=c(1,m2,m2,m2))
image(c(1:length(xLabels)), c(1:length(yLabels)), z=t(routcomen),
      col=dapcol,xlab=expression(lambda),ylab="",axes=FALSE, main=
      dataname, sub=paste("Optimum = ", optl, sep=""))
axis(BELOW<-1, at=1:length(xLabels), labels=xLabels, cex.axis=0.7)
axis(LEFT <-2, at=1:length(yLabels), labels=yLabels, font=3, las=
      HORIZONTAL<-1,  cex.axis=0.7)
abline(v=c(which(xLabels==optl)),col=c(2));
abline(h=c(0:(length(yLabels)+1))-0.5); box()
par(xpd=NA)
legend(x=-20,y=39,lgd,fill=dapcol,bg="white")
dev.off()
```

Supporting references and notes

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