Online Appendix  Justification of clock calibrations. The complete dataset of clock calibrations and associated biogeographic, paleontological and phylogenetic references are presented in the Supporting Online Dataset. Additional details of calibration points are presented here.

Anseridae: 1) A previous calibration using RFLP data used fossils of Branta which extend back to 5.0 Ma to calibrate the node connecting the sister genera Branta and Anser. Recently published fossils of Branta extend this date by approximately 2 million years. 2) A calibration was also obtained from ancient DNA for the extinct flightless giant goose (Branta sp.) from the Island of Hawaii and its sister species B. hyllobadistes which once inhabited the islands of Maui, Oahu and Kauai. Assuming immediate colonization of Hawaii as it formed, the age of Hawaii is used to calibrate the split between these sister species. 3) fossils assigned to Branta bernicla were used to date the split between B. bernicla and B. ruficollis. 4) The earliest Cygnus fossil used to date split between swans and geese. 5) The oldest mallard-like fossil was used to date split between mallard clade of Anas and other dabbling ducks. 6) Moa-Nalos are extinct flightless ducks from the main Hawaiian Islands. We used the age of the oldest main island (Kauai) to calibrate the split between Moa-Nalos and other ducks. 7) Histrionicus (Ocyplonessa) shortwelli was used to date the split between Histrionicus and Somateria.

Trochilidae: The uplift of the Talamanca highlands was used to date the Talamancan endemic Lampornis castaneoventris from its sister clade (L. sybillae and L. viridipallens) in northern Central America. Calibration of additional Talamancan endemic hummingbirds awaits further phylogenetic data.

Alcidae: A fairly well represented fossil record exists for this family (Olson 1985, Becker 1987). Many of the major extant lineages simultaneously appear in the fossil record between 9.5 and 11 Ma, consistent with the short branch lengths separating these lineages at the base of the Alcid phylogeny. Relationships between genera were based on a Bayesian phylogenetic analysis of several published datasets (Friesen et al 1996, Moum et al 2002). 1) The fossil auk Pinguinus alfrednewtoni was used to date the split between the sister genera Alca and Pinguinus. Because this fossil clearly belongs to Pinguinus, this calibration point is probably underestimated and the rate overestimated. 2) The split between Uria and its sister clade Alca, Allele and Pinguinus was dated using the Miocene Uria brodkorbi. 3) The lineage leading to Cepphus was dated using a Miocene Cepphus-like fossil. The exact relationship between Cepphus and other Alcid lineages is ambiguous in current phylogenetic reconstructions. Corrected sequence divergence between Cepphus and other lineages ranged between 18.13% and 20.33%. The average of these distances was used for the calibration. 4) The split between puffins (Fratercula and Cerorhinca) and auklets (Aethia and Ptychoramphus) was dated with a fossil assigned to Cerorhinca and the fossil Aethia rossmoort both from the late Miocene.
**Laridae**: The split between the two extant kittiwakes (*Rissa*) was dated with *R. estesi* believed to be on the lineage leading to *R. tridactyla* (Chandler 1990) and thus a crown group fossil.

**Sternidae**: 1) A fossil *Gelochelidon* was used to date the split between *G. nilotica* and its sister *Hydroprogne caspia*. 2) A North American fossil tern when compared to other North American terns was most similar to *Thalasseus maximus*. This fossil was used to date the split between a clade containing *Thalasseus maxima* and two Old World species (*T. bengalensis, T. bergii*) and a clade containing *T. sandvicensis* and *T. elegans*. Cross validation did not support this fossil calibration.

**Stercorariidae**: Several equally aged fossils most similar to *Stercorarius parasiticus* or *S. longicaudus* were used to date the split between this pair of sister species.

**Recurvirostriae**: *Himantopus olsoni* was used to date the split between *Himantopus* and *Recurvirostra*.

**Scolpanidae**: 1) The oldest *Philomachus* fossils were used to date the split between *Philomachus* and *Limicola*. 2) A fossil species (*Tringa antiqua*) is considered closely related to *Tringa solitarius* and dates to approximately 4.5 Ma. A second fossil similar to *ochropus* dates to approximately 4.5 Ma (Olson & Rasmussen 2001). 3) The oldest North America *Actitis*-like fossil was used to date the presence of *Actitis* in the New World. 4) Well supported phylogenies place *Limosa* as sister to everything else in the family except *Bartramia* and *Numenius*. Baker et al. (2007) incorrectly used the 33 million year old fossil *Montirallus gypsorum* to provide a minimum calibration of this split. *Montirallus gypsorum* was originally misclassified in *Limosa*, but its relation to living clades is uncertain and it has most recently been recognized as a rail (Olson 1985). This calibration incorrectly overestimated ages within the Scolpanidae in Baker et al’s study. Instead we date this split with the oldest recognized *Limosa* (*L. vanrossemi*), a calibration point supported by cross validation and which yielded a rate close to the traditional 2% 5) The fossil *Numenius antiquus* was used to calibrate the split between *Numenius* and *Bartramia* following Baker et al (2007). 6) The fossil *Micropalama hesternus* was used to date the split between *Micropalama* and *Trygnites*.

**Ardeidae**: 1) The fossil *Nycticorax fidens* was used to date the split between *Nycticorax* and *Nyctanassa*. These genera are sister in DNA hybridization trees and some but not all phylogenetic analysis using DNA sequences (see Sheldon et al. 2000). 2) The oldest *Egretta* fossil was used to calibrate the split between *Egretta* and its sister genus *Syrigma*.

**Ciconiidae** The mitochondrial based phylogenies available for this family are poorly resolved and additional sequence data is necessary to confirm relationships. For the purposes of this study we reconstructed a phylogeny using Bayesian analysis and the GTR-gamma model of sequence evolution. 1) The split between *Mycteria* and its sister clade comprising all other extant stork genera in our analysis was dated with the oldest fossil *Mycteria* from the Miocene. 2) *Ciconia* was sister to the entire stork radiation to the exclusion of *Mycteria* and we dated this split using the oldest recognized *Ciconia*. 3) A
fossil of *Ephippiorhynchus asiaticus* was used to date the split between this species and *E. senegalensis*.

**Psittacidae:** The oldest *Melopsittacus* fossil was used to date the split between this genus and its sister. To identify its sister we constructed a Bayesian phylogeny from Genbank sequences for Cytochrome b (GTR-gamma model) including representatives from most Australasian and New World genera. This phylogeny strongly supported *Psittaculirostris* as the immediate sister. Additional phylogenetic analysis using nuclear DNA datasets is needed to confirm this relationship.

**Spheniscidae:** 1) The earliest *Spheniscus* fossil was used to calibrate the split between *Spheniscus* and its sister *Eudyptula*. 2) The age of the Galapagos (based on the oldest exposed lavas) were used to calibrate the endemic *Spheniscus mendiculus* from its sister *S. humboldti* from coastal South America. Both *Spheniscus* calibrations were not supported by cross validation.

**Hydrobatidae:** Nunn & Stanley (1998) dated the crown group of extant *Oceanodroma* species with the earliest *Oceanodroma* fossil which they assumed belonged to the crown group. We provide this calibration here but confirmation of fossil placement is necessary.

**Diomedeidae:** 1) The sister genera *Thalassarche* and *Phoebetria* were dated using the oldest known fossil of *Thalassarche* (*T. thyridata*) dated at ~5.3 Ma. Nunn et al (1996) incorrectly used a date of 10 mya for this fossil calibration. 2) The split between the Ecuadorian endemic *Phoebastria irrorata* and its sister clade (*P. nigripes, immutabilis, and albatrus*) was dated with the age of the oldest terrestrial lavas for the Galapagos Archipelago. *Phoebastria irrorata* is essentially endemic to the Galapagos but a small colony of a few pairs of *P. irrorata* also occurs on a continental shelf island just off the coast of Ecuador. This latter island is of mid-Pleistocene age and thus post dates the age of the Galapagos islands used to date this species.

**Cuculidae:** *Coccyzus melacoryphus* endemic to the Galapagos was dated with the age of the Galapagos islands from its sister clade. A second calibration is possible for *C. ferrugineus* endemic to Cocos I, Costa Rica but sequences were not available.

**Columbidae:** 1) *Zenaida galapagoensis* from the Galapagos is sister to a clade containing *Z. auriculata, macroura* and *graysoni*. This split was dated using the age of the Galapagos Islands 2) *Z. graysoni* endemic to Socorro Island represents an Island form of the mainland *Z. macroura* and the date of Socorro Island was used to date this split. 3) The closest living know relative of the extinct flightless Dodo (*Raphus*) is the Nicobar Pigeon (*Caloenas*). I used the age of Mauritius Island to which the Dodo was endemic, to calibrate the split between this genus and *Caloenas*. Note: this split was previously estimated to much older (~43 million years) using an external calibration between Procellariiformes and penguins, however, the age of Mauritius was not rejected by the cross validation test while the this older date was.
**Odontophoridae**: We used *Callipepla (Lophorhynchus) shortwelli* to date the split between *Callipepla* and *Colinus*. Confirmation that this fossil belongs to or is closely related to *Callipepla* is needed.

**Gruidae**: Krajewski & King (1996) provided several fossil based calibrations for cranes but did not specify fossil identities or ages, or the nodes used for calibration. As such we were not able to include their calibrations in our analysis. Though other potential fossil calibration points may exist, we felt confident only to use the split between *Grus americana* and its sister clade (*G. grus, G. monachus, and G. nigricollis*). This split was dated using the oldest known fossil of *G. americana* and probably underestimates the true rate.

**Accipitridae**: The split between New World *Spizaetus* and *Oroaetus* and its Old World sister clade was dated with the earliest New World fossil of *Spizaetus* (*S. schultzi*).

**Falconidae**: The age of Mauritius was used to date the endemic *Falco punctatus* from its sister clade (*F. araea* and *F. newtoni*).

**Ramphastidae**: *Semnornis frantzii* is endemic to the Talamanca highlands of Costa Rica and Panama. Its sister, *S. ramphastinus* is endemic to the Choco slope of the Andes of Colombia and Ecuador. We dated the split between these species using the age of completion of the Central American landbridge.

**Picidae**: The split between *Sasia abnormis* from peninsular Malaysia and *S. ochracea* distributed north of the peninsula was previously calibrated with the formation of the temporary Kra Seaway that bisected the Malaysian peninsula. Other calibrations using this seaway will be possible when phylogenetic information becomes available.

**Dendrocolaptidae**: The split between the Central American clade of endemic species *Lepidocolaptes leucogaster* and *L. affinis* and their South American sister *L. lachrymosus* was dated with the completion of the Central American landbridge.

**Tyrannidae**: The split between the *Empidonax atriceps* endemic to the Talamanca and its Middle American sister *E. fulvifrons* was dated with uplift of the Talamanca.

**Dicruridae**: Though Cibois *et al* (2004) did not calibrate molecular rates, they did discuss the colonization history of *Pomarea* monarchs in the Marquesas islands and suggested that species colonized islands in a stepping stone fashion shortly after the intense volcanic activity on each island had subsided. Five calibrations are possible as presented in the Online Dataset. These can be dated either with the age of the oldest known lavas on the islands or with the ending of intense volcanic activity. We tested both under the cross validation procedure. Using dates of the cessation of volcanism as calibration points received much stronger support in the cross validation procedure than using dates of island origin (Online Dataset). Dates are taken from Cibois *et al* (2004) and references therein.
**Turdidae:** 1) *Catharus gracilirostris* endemic to the Talamanca highlands is sister to a clade of *Catharus* derived from the north that includes *C. occidentalis*, *guttatus*, *fuscuncens*, *minimus* and *bicknelli* (Outlaw 2003) and was dated with the uplift of the Talamanca. 2) The Hawaiian clade of *Myadestes* is endemic to the main Hawaiian islands. The split between the Hawaiian clade and its sister mainland clade (*M. unicolor*, *genibarbis*, *elisabeth* and *occidentalis*) was dated with the age of the main islands. 3) The pair of Central American species, *Myadestes melanops* endemic to Costa Rica and western Panama and *M. coloratus* of eastern Panama, are sister to the Andean *M. ralloides* and were dated with the age of the Central American landbridge.

**Sylviidae:** Three calibration points for *Sylvia* warblers are presented by Bohning-Gaese *et al.* (2006). However, DNA sequence data were available for only two of these. 1) *Sylvia ruepelli* endemic to the island of Cyprus and 2) *Sylvia balearica* endemic to the Balearic Islands are sister to the mainland forms *S. melanothorax* and *S. undata/deserticola* respectively. Both are believed to have formed after the end of the Messinian salinity crisis which had left the Mediterranean Sea dry.

**Nectariniidae:** Warren *et al.* (2003) used the mid to late Pleistocene aged islands from the Indian Ocean to date three endemic subspecies of *Nectarinia* sunbirds. Cytochrome b sequences were available for only two of these. 1) *N. sovimanga aldabrensis* from Aldabra Island is believed to have descended from *N. s. sovimanga* and is dated with the formation of Aldabra. Note that these two subspecies however are not reciprocally monophyletic rendering this calibration suspect. We took average sequence divergence as our estimate. However, correcting for ancestral polymorphism was problematic due to lack of monophyly and we were forced to apply the average correction from the rest of our dataset. 2) *Nectarinia humbloti humbloti* endemic to Grande Comore Island is sister to *N. h. mohelica* and is dated with the formation of Grande Comore. Both of these calibrations were highlighted by the cross validation test as highly incompatible with the rest of the dataset or with other calibrations less than 2 million years old and we do not recommend their further use.

**Emberizinae:** 1) Phylogenetic relationships within *Chlorospingus* bush-tanagers (which belong with New World sparrows not tanagers) are taken from Weir *et al.* (2008). *Chlorospingus pileatus* endemic to the Talamanca highlands is sister to a clade containing *C. ophthalmicus*, *tacarcunae*, *inornatus* and *semifuscus*. This split is dated with the uplift of the Talamanca highlands. *C. ophthalmicus* secondarily colonized the Talamanca highlands at a later date. 2) The earliest fossil of the following taxa were used to date the splits between those taxa and their sister clades: *Melospiza melodia*, *Zonotrichia albicollis* and *Junco*. 3) The earliest emberizid fossil was used to date the split between Emberizidae and its sister group. The exact relationship between Emberizidae and other nine-primaried oscine families are uncertain. We used the relationships in the Barker *et al.* 2004 phylogeny which suggest that Thraupidae and Icteridae together form the sister. However, calibrated rates are similar if Parulidae or
Thraupinae: 1) The completion of the Central American Landbridge was used to calibrate several sister species pairs in which one sister is endemic to Central America and the other to South America (see Supporting Online Dataset). 2) the node separating the Galapagos finches from their closest ancestors in the Caribbean (Tiaris fuliginosa, T. obscura, T. canora, T. bicolor, Melanospiza richardsoni and Loxigilla noctis; Burns 2002) was dated with the age of the Galapagos Archipelago (oldest exposed terrestrial lavas).

Parulidae: 1) The earliest fossil of Vermivora celata was used to date the split between this species and its sister clade. 2) Myioborus torquatus endemic to the Talamanca highlands was dated with the Central American Landbridge. Phylogenetic analysis suggest its exact sister is uncertain due to rapid divergence of Andean Myioborus in a narrow time period. The sister is either M. brunniceps or a larger clade of Andean species. Similar calibrations are obtained independent of which Andean sister was used.

3) The split between the endemic Parula gutturalis endemic to the Talamanca and its Middle American sister P. superciliosa was dated with uplift of the Talamanca. These taxa are similar genetically suggesting recent colonization of the Talamanca and cross validation highlighted this calibration as a poor predictor of other calibration points.

Icteridae: 1) Florida fossils of Sturnella most similar to S. magna extent back to 2 million years and were used to date the split between S. magna and S. neglecta. 2) An early Sturnella fossil from Nebraska was used to date the split between S. magna / neglecta (yellow meadowlark clade) from the South American red meadowlark clade. 3) Florida fossils of Euphagus cyanocephalus also extend to the same period and were used to date the split between E. carolinensis and E. cyanocephalus. 3) Earliest fossils of Agelaius phoenicius were used to date the split between this species and A. tricolor. 4) Earliest fossils of Molothrus ater were used to date the split between this species and its sister M. bonariensis. 5) Five pairs of sister species of blackbirds in which one species is endemic to Central America and the other to South America were dated with the formation of the Isthmus of Panama (Online Dataset).

Cardinalinae: The split between Passerina and Cyanocompsa buntings is dated with the earliest fossil Passerina.

Fringillidae: Three Hawaiian honeycreeper calibrations were presented by Fleischer et al (1998) and are included here.

Additional Literature Cited


Bohrson WA, Reid MR (1997) Genesis of silicic peralkaline volcanic rocks in an ocean island setting by crustal melting and open-system processes: Socorro Island, Mexico. J. Petrol., 38, 1137-1166.


Castillo P, Batiza R, Vanko D et al. (1988) Anomalously young volcanoes on old hot-
spot traces: I. geology and petrology of Cocos-Island. Geol. Soc. Am. Bull., 100,
1400-1414.

Chandler RM (1990) Fossil birds of the San Diego Formation, late Pliocene, Blanca,
San Diego County, California, Part 2. Pp. 73–171 in Recent advances in the
study of Neogene fossil birds. Ornithol. Monogr. No. 44.


(Aves: Stercorariidae). Proceedings of the Royal Society of London Series B-
Biological Sciences, 264, 181-190.

Crowe TM, Bowie RCK, Bloomer P et al. (2006) Phylogenetics, biogeography and
classification of, and character evolution in, gamebirds (Aves : Galliformes):
effects of character exclusion, data partitioning and missing data. Cladistics, 22,
495-532.

based on mitochondrial DNA analysis. Molecular Phylogenetics and Evolution, 23,
339-356.

Emslie SD (2007) Fossil passerines from the early Pliocene of Kansas and the evolution

(Charadriiformes: Aves) inferred from total molecular evidence. Mol. Biol. Evol.,
13, 359-367.

and diversification among Lampornis hummingbirds: A Mesoamerican taxon.
Molecular Phylogenetics and Evolution, 38, 488-498.

Gohlich UB (2007) The oldest fossil record of the extant penguin genus Spheniscus - a
new species from the Miocene of Peru. Acta Palaeontologica Polonica, 52, 285-
298.

Groombridge JJ, Jones CG, Bayes MK et al. (2002) A molecular phylogeny of African
kestrels with reference to divergence across the Indian Ocean. Molecular
Phylogenetics and Evolution, 25, 267-277.

Hall ML (1983) Origin of Espanola-Island and the age of terrestrial life on the
Galapagos-Islands. Science, 221, 545-547.

monophyly. Systematics and Biodiversity, 4, 483-488.


Nunn GB, Cooper J, Jouventin P, Robertson CJR, Robertson GG (1996) Evolutionary relationships among extant albatrosses (Procellariformes: Diomedeidae) established from complete cytochrome-b
10

Nunn GB, Stanley SE (1998) Body size effects and rates of cytochrome b evolution in

*Condor*, 93, 1004-1006.

Olson SL, Rasmussen PD (2001) Miocene and Pliocene birds from the Lee Creek Mine,
North Carolina. 233-365 in Ray, C. E. & Bohaska, D. J., (eds.): Geology and
paleontology of the Lee Creek Mine, North Carolina, Vol. III. Smithsonian
Contributions to Paleobiology: No. 90, iii-365.

orioles (Icterus): The importance of dense taxon sampling. Molecular
Phylogenetics and Evolution, 12, 224-239.


Pons JM, Hassanin A, Crochet PA (2005) Phylogenetic relationships within the Laridae
(Charadriiformes: Aves) inferred from mitochondrial markers. Molecular
Phylogenetics and Evolution, 37, 686-699.


Sheldon FH, Jones CE, McCracken KG (2000) Relative patterns and rates of evolution in
heron nuclear and mitochondrial DNA. Molecular Biology and Evolution, 17,
437-450.

Sorenson MD, Cooper A, Paxinos EE et al (1999) Relationships of the extinct moa-
nalos, flightless Hawaiian waterfowl, based on ancient DNA. *Proc. R. Soc. Lond.
B*, 266, 2187-2193.

Club, Cambridge, Mass.

phylogeography reveals island colonization history and diversification of western
67-85.

mitochondrial genomes of White-crowned (Zonotrichia leucophrys) and Golden-
crowned (Z-atricapilla) sparrows: Pseudogenes, hybridization, or incomplete
lineage sorting?. *Auk*, 118, 231-236.

Wilkinson HE (1969) Description of an upper Miocene albatross from Beaumaris,
Victoria, Australia, and a review of fossil Diomedaeidae. *Memoirs of the National