Supplementary Material for Lapsansky, Warrick, & Tobalske 2022

*Phylogenetic Signal*

**Table S1: Blomberg’s K for body mass, wing area, and wing second moment of area (S2).** Here and for all following tables, values shown are mean ± standard deviation (lower 5% quantile – upper 95% quantile) of estimates for 100 trees from the Ericson or Hackett backbone. Column sets separate tests run on the full set of species (“All species”) and those on a subset of species represented by genetic data in birdtree.org phylogenies (“Species with genetic data”).

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**Table S2: Pagel’s λ for body mass, wing area, and wing second moment of area (S2).**



*Behavioral classification*

We reevaluated the aquatic habits of all avian groups (Table S3) through an exhaustive survey of published literature and video evidence (Table S4). We classified species reliant on diving to acquire food as obligate divers, whereas we classified species that dive for food only on rare occasions as facultative submergers (Rel.). Groups are also categorized based on their entry method into the water (*EM*) as surface diving (*S*) – meaning they enter the water after floating on the water’s surface – and/or plunge diving (*P*) – meaning they enter the water directly from the air and without first resting on the surface (Ashmole 1971; Ropert-Coudert et al. 2003; Chang et al. 2016). We have also noted the location of food taken as Benthic and/or Pelagic. We have included the surface habits of each group to give the reader a sense of those groups which regularly transit on water for reasons other than rare instances of predator evasion, but which may or may not dive for food. For both surface and submerged swimming categories, we note the reliance (Rel.) of said group on each form of aquatic locomotion as either obligate (*O*) or facultative (*F*). Finally, we have included columns for both terrestrial and aerial habits based on information in *Bird of the World* (Billerman et al. 2020) and *Handbook of Australian, New Zealand and Antarctic Birds* (Marchant and Higgins 1991)to allow quick comparisons to aquatic habits. It should be noted that considerable variation in terrestrial and aerial habits may exist within groups (Bruderer et al. 2010) which is outside the scope of the present analysis.

**Table S3:** **Locomotor habits of birds.** All orders of birds are considered with increased resolution to family, genera, and species levels where variation in aquatic behavior exists. The terrestrial (Terr.) habits of each group are categorized as either WR (walking/running) or IL (infrequent/labored). The aerial (Aerial) habits of each group are categorized as NV (non-volant), IF (infrequent flight), GS (gliding/soaring + flapping), CF (continuous flapping), or FB (flap-bounding). For both surface and submerged aquatic habits, the use of an appendage pair (FP – foot-propelled, WP – wing-propelled) for steady-state aquatic propulsion is indicated by a colored rectangle corresponding to that group. Colors (yellow, teal, and purple) are to ease visualization only. Gray rectangles indicate a lack of aquatic locomotion (surface or submerged) for that row. All diving and swimming groups are categorized according to their reliance on aquatic locomotion (Rel.) as either O (obligate; solid filled rectangles) or F (facultative; diagonal striped rectangles). In reliance columns, “?” indicates unknown reliance (*sensu* Ashmole 1971). In wing-propelled and foot-propelled columns, “?” indicates that the appendage pair may utilized for aquatic locomotion, but that concrete evidence is lacking. Taxonomic organization follows that of *Birds of the World* (Billerman et al. 2020).



**Table S4:** **References for Table S3.** Row numbers correspond to row numbers in Table S3.

|  |  |  |  |
| --- | --- | --- | --- |
| # | gROUP | DIVING Video Reference | Scientific References |
| 1 | Struthioniformes | - | - |
| 2 | Rheiformes | - | - |
| 3 | Tinamiformes | - | - |
| 4 | Casuariiformes | - | - |
| 5 | Apterygiformes | - | - |
| 6 | Anhimidae | - | - |
| 7 | *Anseranas semipalmata* | - | (Frith and Davies 1961) |
| 8 | *Dendrocynga* | <https://www.youtube.com/watch?v=yC6MhSSS2Ao>; [https://www.youtube.com/watch?v=2pTkHZ50i8g; https://www.youtube.com/watch?v=GsKM\_bbkaD8](https://www.youtube.com/watch?v=2pTkHZ50i8g;https://www.youtube.com/watch?v=GsKM_bbkaD8);  <https://www.youtube.com/watch?v=edowUtOZHPQ> | (Johnsgard 1967; W. Roy Siegfried 1973; Clark 1978) |
| 9 | *Thalassornis leuconotus* | <https://macaulaylibrary.org/asset/722862> | (Johnsgard 1967) |
| 10 | *Anser* | - | -­ |
| 11 | *Branta* | - | - |
| 12 | *Cereopsis novaehollandiae* | - | - |
| 13 | *Strictonetta naevosa* | - | - |
| 14 | *Cyanochen cyanoptera* | - | - |
| 15 | *Cygnus* | - | - |
| 16 | *Coscoroba coscoroba* | - | - |
| 17 | *Sarkidiornis* | - | - |
| 18 | *Pteronetta hartlaubii* | - | - |
| 19 | *Oressochen* | - | - |
| 20 | *Chleophaga* | - | - |
| 21 | *Radjah radjah* | - | - |
| 22 | *Alopochen aegyptiaca* | - | - |
| 23 | *Tadorna* | - | (Düttmann 1992) |
| 24 | *Plectropterus gambensis* | - | - |
| 25 | *Tachyeres patchonicus* | <https://macaulaylibrary.org/asset/201638591>; <https://macaulaylibrary.org/asset/201350781>; <https://macaulaylibrary.org/asset/201694131> | (Humphrey and Livezey 1982; Livezey and Humphrey 1983; Livezey and Humphrey 1986; Ryan et al. 1988) |
| 26 | *Tachyeres pteneres* | <https://macaulaylibrary.org/asset/200864671> |
| 27 | *Tachyeres brachypterus* | <https://macaulaylibrary.org/asset/201795571>; <https://macaulaylibrary.org/asset/201691341>; <https://macaulaylibrary.org/asset/201691351>; <https://macaulaylibrary.org/asset/201686251>; <https://macaulaylibrary.org/asset/201686241> |
| 28 | *Tachyeres leucocephalus* | - |
| 29 | *Lophonetta specularioides* | <https://macaulaylibrary.org/asset/201713901> | - |
| 30 | *Speculanas specularis* | - | - |
| 31 | *Cairina moschata* | - | - |
| 32 | *Nettapus pulchellus* | - | (Nye and Dickman 2005) |
| 33 | *Nettapus coromandelianus* | - | (Porte and Gupta 2019) |
| 34 | *Nettapus auratus* | - | (Johnsgard 1978) |
| 35 | *Callonetta leucophrys* | - | - |
| 36 | *Aix* | <https://www.youtube.com/watch?v=zNm6V7l5QqU>; <https://www.youtube.com/watch?v=TJDWn_SalpE>; <https://www.youtube.com/watch?v=PiTOi_lcSvw> | (Kear and Johnsgard 1968; Briggs 1978) |
| 37 | *Chenonetta* | <https://www.youtube.com/watch?v=u44QVK-OFKQ> | - |
| 38 | *Amazonetta brasilensis* | - | - |
| 39 | *Hymenolaimus malacorhynchos* | <https://macaulaylibrary.org/video/200914251>; <https://macaulaylibrary.org/video/200911091>; <https://macaulaylibrary.org/asset/201432891> | (Veltman et al. 1995; Collier and Wakelin 1996) |
| 40 | *Merganetta armata* | <https://macaulaylibrary.org/asset/248895471>;  <https://macaulaylibrary.org/asset/201015661>;  <https://macaulaylibrary.org/asset/201541621> | (Cerón and Trejo 2009) |
| 41 | *Salvadorina waigiuensis* | <https://macaulaylibrary.org/asset/201013481>; <https://macaulaylibrary.org/asset/457911>; <https://macaulaylibrary.org/asset/457910>; <https://macaulaylibrary.org/asset/457909> | (Johnsgard 1966) |
| 42 | *Sibirionetta Formosa* | - | - |
| 43 | *Spatula* | <https://www.youtube.com/watch?v=irPv6I0i7q0>; <https://www.youtube.com/watch?v=ZWyErx_kHLo> | (Kear and Johnsgard 1968) |
| 44 | *Mareca* | <https://www.youtube.com/watch?v=YE5nR6kUDno> | (Kear and Johnsgard 1968; Wishart 1983) |
| 45 | *Anas sp.* | <https://www.youtube.com/watch?v=i_xzhHoZ3_k>; <https://www.youtube.com/watch?v=-oTaLr1LZCY> | (Kutz 1940; Myline 1954; Kear and Johnsgard 1968; Miller 1983; Brodsky and Weatherhead 1985; Paulus 1988; McCanch 2012) |
| 46 | *Anas capensis* | - | (Kear and Johnsgard 1968; Winterbottom 1974) |
| 47 | *Anas aucklandica* | - | (Weller 1975) |
| 48 | *Anas nesiotis* | - | - |
| 49 | *Anas chlorotis* | <https://macaulaylibrary.org/asset/201072941> | (Weller 1974) |
| 50 | *Malacorhynchus membranaceus* | - | - |
| 51 | *Marmaronetta angustirostris* | - | (Green 1998) |
| 52 | *Rhodonessa caryophyllacea* | - | (Kear 2005) |
| 53 | *Asarcornis scutulata* | - | (Green 1993) |
| 54 | *Netta* | <https://macaulaylibrary.org/video/201121841>; <https://macaulaylibrary.org/asset/201915681>;  <https://macaulaylibrary.org/video/201922851> | (Amat 1984; Kear 2005) |
| 55 | *Aythya* | <https://macaulaylibrary.org/asset/227012291>; <https://macaulaylibrary.org/asset/305119421>;  <https://macaulaylibrary.org/asset/201012201> | (Cronan 1957; Siegfried 1976; Butler and Woakes 1979; Lalas 1983; Stephenson et al. 1986; Draidi et al. 2019) |
| 56 | *Polysticta stelleri* | <https://macaulaylibrary.org/asset/201367751>; <https://macaulaylibrary.org/asset/201229011> | (Laubhan and Metzner 1999) |
| 57 | *Somateria* | <https://macaulaylibrary.org/asset/201817441>; <https://macaulaylibrary.org/asset/201374451>; <https://macaulaylibrary.org/asset/201369051> | (Bustnes and Lønne 1997; MacCharles 1997; Guillemette et al. 2004; Heath et al. 2006; Gough et al. 2015) |
| 58 | *Histrionicus histionicus* | <https://macaulaylibrary.org/asset/234548481>; <https://macaulaylibrary.org/asset/234546781>; <https://macaulaylibrary.org/asset/201845311>; <https://macaulaylibrary.org/asset/201827721>;  <https://vimeo.com/234936039> | (Townsend 1909; Mittelhauser et al. 2008; Goudie 2009) |
| 59 | *Melanitta perspicillata* | <https://macaulaylibrary.org/asset/286905701>; <https://macaulaylibrary.org/asset/216453321>; <https://www.youtube.com/watch?v=sufoZq2yHpc> | (Townsend 1909; Humphrey 1957; Humphrey 1957; Mullarney 1983; Beauchamp 1992; Lewis 2005; Kaiser et al. 2006; Lovvorn et al. 2013) |
| 60 | *Melanitta fusca* | <https://macaulaylibrary.org/asset/201494461>; <https://macaulaylibrary.org/asset/201427121>; <https://macaulaylibrary.org/asset/200835311>; |
| 61 | *Melanitta deglandi* | <https://macaulaylibrary.org/asset/276504641>; <https://macaulaylibrary.org/asset/201465151>; <https://www.youtube.com/watch?v=vvOvB_etaJ4> |
| 62 | *Melanitta stejnegeri* | <https://macaulaylibrary.org/asset/201380811> |
| 63 | *Melanitta nigra* | <https://macaulaylibrary.org/asset/271088361> |
| 64 | *Melanitta americana* | <https://macaulaylibrary.org/asset/282321981>; <https://macaulaylibrary.org/asset/275333321>; <https://macaulaylibrary.org/asset/201363501> |
| 65 | *Clangula hyemalis* | <https://www.youtube.com/watch?v=oQxtr3AMbw>; <https://www.youtube.com/watch?v=QbftwiB7m1g>; <https://macaulaylibrary.org/video/201365381> | (Snell 1984; Reynolds 1987) |
| 66 | *Bucephala* | <https://macaulaylibrary.org/asset/283243771>; <https://macaulaylibrary.org/asset/292734141>;  <https://macaulaylibrary.org/asset/312220431>;  <https://vimeo.com/379304392>;  <https://vimeo.com/383798494>;  https://vimeo.com/262668198 | (Bent 1919; Heintzelman 1963; Nilsson 1972; Beauchamp 1992) |
| 67 | *Mergellus albellus* | <https://macaulaylibrary.org/video/201946481>;  <https://macaulaylibrary.org/video/201376451>;  <https://macaulaylibrary.org/asset/417976> | (Nilsson 1970; Nilsson 1974; Savitskii and Matishov 2011) |
| 68 | *Lophodytes cucullatus* | <https://macaulaylibrary.org/asset/484408>; <https://macaulaylibrary.org/asset/475202>;  <https://macaulaylibrary.org/asset/306521581> | (Brooks 1945) |
| 69 | *Mergus* | <https://macaulaylibrary.org/asset/201082881>; <https://macaulaylibrary.org/asset/483951>; <https://macaulaylibrary.org/asset/479854>;  <https://macaulaylibrary.org/video/201481451> | (White 1957; Nilsson 1970) |
| 70 | *Heteronetta atricapilla* | - | (Weller 1968) |
| 71 | *Nomonyx dominicus* | <https://macaulaylibrary.org/asset/410587>; <https://macaulaylibrary.org/asset/410588> | (Jenni 1969; Jenni and Gambs 1974; Goodman et al. 2017) |
| 72 | *Oxyura* | <https://macaulaylibrary.org/asset/475156>; <https://macaulaylibrary.org/asset/400196>; <https://macaulaylibrary.org/asset/201413661> | (W. R. Siegfried 1973; Siegfried 1976; Lalas 1983; Tome and Wrubleski 1988) |
| 73 | *Biziura lobata* | <https://macaulaylibrary.org/video/201638021>; <https://macaulaylibrary.org/asset/244893131> | (Osterrieder et al. 2014) |
| 74 | Galliformes | - | - |
| 75 | Phoenicopteriformes | - | - |
| 76 | *Rollandia rolland* | <https://macaulaylibrary.org/asset/201287931>; <https://macaulaylibrary.org/asset/201287921>; <https://macaulaylibrary.org/asset/201287891> | (Livezey 1989; Roots 2006) |
| 77 | *Rollandia microptera* | <https://macaulaylibrary.org/video/201251181>; <https://macaulaylibrary.org/asset/201260961> | (Livezey 1989; Roots 2006) |
| 78 | *Tachybaptus* | <https://macaulaylibrary.org/asset/221972771>; <https://macaulaylibrary.org/asset/268994431>; <https://macaulaylibrary.org/asset/201939411> | (Ladhams 1968; Jenni 1969; Ropert-Coudert and Kato 2009) |
| 79 | *Podilymbus podiceps* | <https://macaulaylibrary.org/asset/292561231>; <https://macaulaylibrary.org/asset/287918701> | (Jenni and Gambs 1974; Bleich 1975) |
| 80 | *Podilymbus gigas* | - | (Livezey 1989; Roots 2006) |
| 81 | *Poliocephalus* | <https://macaulaylibrary.org/asset/257573401>; <https://macaulaylibrary.org/asset/201881751>; <https://macaulaylibrary.org/asset/201444461> | (Ropert-Coudert and Kato 2009) |
| 82 | *Podiceps sp.* | <https://macaulaylibrary.org/video/201701141>; <https://macaulaylibrary.org/asset/292561221> | (Dow 1964; Lalas 1983; Jehl 1988; Kloskowski 2004) |
| 83 | *Podiceps taczanowskii* | <https://macaulaylibrary.org/asset/200954771>; <https://macaulaylibrary.org/asset/201104471>; <https://macaulaylibrary.org/asset/201948661> |  |
| 84 | *Aechmophorus* | <https://macaulaylibrary.org/asset/215105421>; <https://macaulaylibrary.org/asset/201754141>; <https://macaulaylibrary.org/asset/201450211> | (Lawrence 1950; Forbes and Sealy 1988) |
| 85 | Columbidae | - | - |
| 86 | Mesitornithidae | - | - |
| 87 | Pteroclidae | - | - |
| 88 | Otididae | - | - |
| 89 | Musophagidae | - | - |
| 90 | Cuculidae | - | - |
| 91 | Caprimulgiformes | - | - |
| 92 | *Opisthocomus hoazin* | <https://www.youtube.com/watch?v=wy7coZyvyW4>; <http://www.oiseaux-birds.com/card-hoatzin.html> | (Abourachid et al. 2019) |
| 93 | Sarothruridae | - | (Taylor 1994) |
| 94 | Rallidae sp. | <https://macaulaylibrary.org/asset/201796091>;  <https://macaulaylibrary.org/asset/435299> | (Wintle and Taylor 1993; Fournier and Krementz 2018) |
| 95 | *Fulica* | <https://macaulaylibrary.org/asset/222511281>; <https://macaulaylibrary.org/asset/220625601>; <https://macaulaylibrary.org/asset/201566061>; <https://macaulaylibrary.org/asset/261794001>; <https://macaulaylibrary.org/video/201537351>;  <https://vimeo.com/321106497> | (Dow 1964; Ryan and Dinsmore 1980; García et al. 2008; Conigliaro et al. 2011; Fortunati and Battisti 2011) |
| 96 | Heliornithidae | - | (Alvarez del Toro 1971) |
| 97 | *Aramus guaruana* | - | (Walkinshaw 1982) |
| 98 | Psophiidae | - | - |
| 99 | Gruiidae | <https://www.youtube.com/watch?v=EMEEclvmMuA>; <https://www.youtube.com/watch?v=p4MD_63_O3s> | - |
| 100 | *Chionis* | - | (Murphy 1936) |
| 101 | *Pluvianellus socialis* | - | - |
| 102 | Burhinidae | - | - |
| 103 | *Pluvianus aegyptius* | - | - |
| 104 | *Himantopus* | - | (Hamilton 1975) |
| 105 | *Cladorhynchus* | <https://macaulaylibrary.org/asset/201726521> | - |
| 106 | *Recurvirostra* | <https://www.youtube.com/watch?v=RZUeeE_xmV8>;  <https://macaulaylibrary.org/asset/201737631> | (Hamilton 1975; Gyug and Weir 2017) |
| 107 | *Ibidorhyncha struthersii* | - | (Ye et al. 2013) |
| 108 | Haematopodidae | <https://community.rspb.org.uk/chat/f/the-tea-rooms/106219/oystercatcher-swimming?pifragment-4313=1> | - |
| 109 | Charadriidae | <https://vimeo.com/351934031> | (1990: 929) |
| 110 | Pedionomidae | - | - |
| 111 | Thinocoridae | - | - |
| 112 | Rostratulidae | <https://www.10000birds.com/australian-painted-snipe-breeding-near-broome.htm>;  <https://macaulaylibrary.org/asset/71787301>;  <https://macaulaylibrary.org/asset/47796051> | (Hassell and Rogers 2002; Rogers et al. 2003; Thomas 2011) |
| 113 | Jacanidae | <https://macaulaylibrary.org/asset/479197>;  <https://macaulaylibrary.org/asset/264524381> | (Miller 1931; Tarboton and Fry 1986) |
| 114 | *Bartramia longicauda* | - | - |
| 115 | *Numenius* | - | - |
| 116 | *Limosa* | - | (Tufts 1986; Gratto-Trevor 2020; McCaffery and Gill 2020) |
| 117 | *Arenaria* | - | (Thompson 1973; John 1980) |
| 118 | *Prosobonia* | - |  |
| 119 | *Calidris* | - | (Wheeler 1962) |
| 120 | *Limnodromus* | <https://www.youtube.com/watch?v=BXOs647QA4M>;  <https://macaulaylibrary.org/asset/333067251> | - |
| 121 | *Limnocryptes minimus* | <https://samalij.wixsite.com/samsphotopoetry/single-post/2018/12/24/jack-snipe-swimming-on-the-sea> | - |
| 122 | *Scolopax* | - | - |
| 123 | *Coenocorypha* | - | - |
| 124 | *Gallingo* | - | (Bowles 1918) |
| 125 | *Xenus cinereus* | - | (Blokhin 2004) |
| 126 | *Phalaropus* | <https://macaulaylibrary.org/asset/320923421>;  <https://macaulaylibrary.org/asset/297998451>;  <https://macaulaylibrary.org/asset/320937541>;  <https://macaulaylibrary.org/asset/201470231> | (King 1971; Mercier and Gaskin 1985; Colwell and Oring 1988; Obst et al. 1996) |
| 127 | *Actitis* | - | (Sutton 1925; Murie 1934; Reed et al. 2020) |
| 128 | *Tringa* | <https://faculty.ucr.edu/~chappell/INW/birds2/willet.shtml>;  <https://macaulaylibrary.org/asset/192850971> | (Cadwalader 1938; Ingram and Salmon 1942; Northwood 1951) |
| 129 | Turnicidae | - | - |
| 130 | Dromadidae | - | - |
| 131 | Glareolidae | - | - |
| 132 | Stercocariidae | - | - |
| 133 | *Alle alle* | <https://macaulaylibrary.org/asset/201226671> | (Harding et al. 2009) |
| 134 | *Uria* | <https://elifesciences.org/articles/55774>; <https://macaulaylibrary.org/asset/201479271>; <https://macaulaylibrary.org/asset/270060251>; <https://www.youtube.com/watch?v=nbnJsc-GPaA> | (Wanless et al. 1988; Mehlum et al. 2001; Tremblay et al. 2003; Takahashi et al. 2008; Hedd et al. 2009; Evans et al. 2013) |
| 135 | *Alca torda* | <https://macaulaylibrary.org/asset/213447051>;  <https://macaulaylibrary.org/asset/201229751> | (Paredes et al. 2008 May 24; A Shoji et al. 2015) |
| 136 | *Cepphus* | <https://macaulaylibrary.org/asset/201298791>; <https://macaulaylibrary.org/asset/201483831> | (Duffy et al. 1987; Clowater and Burger 1994; Masden et al. 2013; Akiko Shoji et al. 2015) |
| 137 | *Brachyramphus* | <https://macaulaylibrary.org/asset/201438491>; <https://macaulaylibrary.org/asset/200871991>; <https://macaulaylibrary.org/asset/201469721>; <https://macaulaylibrary.org/asset/201469711> | (Thoresen 1989; Henkel et al. 2004) |
| 138 | *Synthliboramphus* | <https://macaulaylibrary.org/asset/298753421>; <https://macaulaylibrary.org/asset/201497541> | (Elliott et al. 2010) |
| 139 | *Ptychoramphus aleuticus* | - | (Elliott et al. 2010) |
| 140 | *Aethia* | <https://macaulaylibrary.org/asset/201387021>; <https://macaulaylibrary.org/asset/425993> |  |
| 141 | *Cerorhinca* | <https://macaulaylibrary.org/asset/201469941>; <https://macaulaylibrary.org/asset/449444> | (Kuroki et al. 2003) |
| 142 | *Fratercula* | <https://macaulaylibrary.org/asset/270051441>; <https://macaulaylibrary.org/asset/483751> | (Spencer 2012; A Shoji et al. 2015) |
| 143 | Laridae | <https://www.youtube.com/watch?v=n1woCgYPS8c>;  <https://www.youtube.com/watch?v=pbi-DNrbfPI>;  <https://www.youtube.com/watch?v=f0RSfoEFKvU> | (Verbeek 1977; Taylor 1983; Baptist and Leopold 2010) |
| 144 | *Rhynochetos jubatus* | - | - |
| 145 | *Eurypyga helias* | - | - |
| 146 | *Phaethon* | - | (Corre 1997; Sommerfeld and Hennicke 2010) |
| 147 | *Gavia* | <https://movie.biologists.com/video/10.1242/jeb.168831/video-1>;  <https://macaulaylibrary.org/asset/167382711>;  <https://macaulaylibrary.org/asset/168531151> | (Townsend 1924; Polak 2007; Clifton and Biewener 2018) |
| 148 | Spheniscidae | <https://macaulaylibrary.org/asset/201339311>; <https://macaulaylibrary.org/asset/281567361> | (Culik and Wilson 1994; Hull 2000: 200; Mills 2000; Tremblay and Cherel 2003; Sato 2004; Mattern et al. 2007; Ryan et al. 2007; Kato et al. 2008; Rey et al. 2013; Ropert-Coudert et al. 2018) |
| 149 | Diomedidae | <https://www.youtube.com/watch?v=tMTfr2NCvdY> | (Oatley 1979; Voisin 1981; Harper et al. 1985; Harper 1987; Harrison et al. 1991; Prince et al. 1994; 150Hedd et al. 1997; Huin and Prince 1997; Sakamoto et al. 2009; Kazama et al. 2019; Bentley et al. 2021) |
| 150 | Oceanitidae | - | (1990: 674) |
| 151 | Hydrobatidae | - | (Bried 2005; Flood et al. 2009; Albores‐Barajas et al. 2011) |
| 152 | *Macronectes* | - | (van den Hoff and Newbery 2006) |
| 153 | *Fulmarus* | <https://macaulaylibrary.org/asset/201220771> | (Hobson and Welch 1992; Garthe and Furness 2001) |
| 154 | *Thalassoica antarctica* | - | (Ainley et al. 1984; Spear and Ainley 1998) |
| 155 | *Daption capense* | <https://macaulaylibrary.org/asset/201437191>;  <https://vimeo.com/151211264> | (Harper et al. 1985; Harper 1987; Prince and Morgan 1987; Warham 1996) |
| 156 | *Pagodroma nivea* | - | (Harper et al. 1985; Prince and Morgan 1987; Spear and Ainley 1998) |
| 157 | *Aphrodroma brevirostris* | - | (Harper et al. 1985; Spear and Ainley 1998) |
| 158 | *Pterodroma* | - | (Harper et al. 1985; Spear and Ainley 1998; Rayner et al. 2008; Taylor 2008; Bester et al. 2011) |
| 159 | *Halobaena caerulea* | - | (Croxall and Prince 1980; Griffiths 1982; Chastel and Bried 1996; Navarro et al. 2013) |
| 160 | *Pachyptila* | <https://macaulaylibrary.org/asset/200905651>; | (Robinson 1961; Harper 1987; Chastel and Bried 1996; Cherel et al. 2002; Navarro et al. 2013) |
| 161 | *Bulweria* | - | (Mougin and Mougin 2000) |
| 162 | *Pseudobulweria* | - | (Spear and Ainley 1998; Ravache et al. 2020) |
| 163 | *Procellaria* | <https://macaulaylibrary.org/video/201430911> | (Brown et al. 1978; Huin 1994; Rollinson et al. 2016; Poupart et al. 2020) |
| 164 | *Calonectris* | <https://www.youtube.com/watch?v=1-bEtyhXKCA> | (Brown et al. 1978; Oka 1994; Burger 2001; Matsumoto et al. 2012; Grémillet et al. 2014; Cianchetti-Benedetti et al. 2017) |
| 165 | *Ardenna* | <https://macaulaylibrary.org/video/201317731>; <https://macaulaylibrary.org/asset/201467411>; <https://macaulaylibrary.org/asset/201451071>; <https://macaulaylibrary.org/asset/201431051> | (Skira 1979; Oka 1994; Weimerskirch and Sagar 1996; Taylor 2008; Ronconi et al. 2010; Dunphy et al. 2015; Shoji et al. 2016; Adams et al. 2019) |
| 166 | *Puffinus* | <https://macaulaylibrary.org/asset/201915491>; <https://macaulaylibrary.org/asset/201532811>; <https://macaulaylibrary.org/asset/201049721>; <https://macaulaylibrary.org/asset/201431021>; <https://macaulaylibrary.org/asset/200905951>; <https://www.youtube.com/watch?v=76WC1JNmFv0> | (Brown et al. 1978; Aguilar et al. 2003; Taylor 2008; Shaffer et al. 2009; Ronconi et al. 2010; Péron et al. 2013; Shoji et al. 2016; Bennet et al. 2020) |
| 167 | *Pelecanoides* | <https://macaulaylibrary.org/asset/201811631>; <https://macaulaylibrary.org/asset/200905541> | (Brown et al. 1978; Ryan and Nel 1999; Bocher et al. 2000; Taylor 2008; Navarro et al. 2014; Dunphy et al. 2015) |
| 168 | Ciconiidae | - | - |
| 169 | Fregatidae | - | - |
| 170 | Sulidae | <https://macaulaylibrary.org/asset/305748281>; <https://www.youtube.com/watch?v=IWbu6r-6VK8&t=20s;https://www.youtube.com/watch?v=mXXuK9eQVUw&t=1s>;  <https://www.youtube.com/watch?v=D8vaFl6J87s>;  <https://www.youtube.com/watch?v=w_h_KuIk_Vs> | (Garthe et al. 2000; Weimerskirch et al. 2005; Garthe et al. 2007; Zavalaga et al. 2007; Ropert‐Coudert et al. 2009; Grémillet et al. 2016) |
| 171 | Anhingidae | <https://macaulaylibrary.org/asset/201336971>; <https://macaulaylibrary.org/asset/227853371> | (Lalas 1983) |
| 172 | Phalacrocoraxidae sp. | <https://www.youtube.com/watch?v=rF5gAUJUZXA>;  <https://macaulaylibrary.org/asset/402027> | (Stonehouse 1967; Lalas 1983; Cooper 1986; Trayler et al. 1989; Frere et al. 2002; Ribak 2005) |
| 173 | *Nannopterum harrisi* | <https://macaulaylibrary.org/asset/193115251>;  <https://macaulaylibrary.org/asset/193125281> | - |
| 174 | *Pelecanus* | - | (Hall 1925; Skinner 1925; Duffy 1983; Carl 1987; Schreiber and Clapp 1987; Arnqvist 1992; Zavalaga et al. 2007) |
| 175 | *Balaeniceps rex* | - | - |
| 176 | *Scopus umbretta* | - | - |
| 177 | Ardeidae | <https://www.youtube.com/watch?v=ekGYwcYi4b4>; <https://www.youtube.com/watch?v=msgyPyzGedA>; <https://www.youtube.com/watch?v=1g6ODG2sqzQ> | - |
| 178 | Threskiornithidae | - | - |
| 179 | Cathartidae | - | - |
| 180 | Accipitriformes | - | - |
| 181 | Pandionidae | <https://www.youtube.com/watch?v=nMw-PspfdkQ&t>;  <https://www.youtube.com/watch?v=428L7cR4AMU&t> | (Winkler et al. 2020a) |
| 182 | Strigiformes | - | - |
| 183 | Collidae | - | - |
| 184 | *Leptosomus discolor* | - | - |
| 185 | Trogonidae | - | - |
| 186 | Bucerotiformes | - | - |
| 187 | Todidae | - | - |
| 188 | Momotidae | - | - |
| 189 | *Alcedo* | <https://macaulaylibrary.org/asset/201516191>;  <https://macaulaylibrary.org/asset/201494131>;  <https://macaulaylibrary.org/asset/201279521>;  <https://www.youtube.com/watch?v=lNcpMauEzMU>;  <https://www.youtube.com/watch?v=sLSQ-XDf_wQ> | (Forshaw 1983; Woodall 1991; Vilches et al. 2012; Vilches et al. 2013) |
| 190 | *Ceyx* | <https://macaulaylibrary.org/asset/201649161>;  <https://macaulaylibrary.org/asset/201651961>;  <https://macaulaylibrary.org/asset/201651941> | (Forshaw 1983; Barker and Vestjens 1989; Woodall 1991; Burnett 1996) |
| 191 | *Corythornis* | <https://macaulaylibrary.org/asset/201254641>;  <https://macaulaylibrary.org/asset/201594541> | (Reyer et al. 1988; Libois and Laudelout 2004) |
| 192 | *Corythornis madagascariensis* |  | (Woodall 1991; Woodall 2020) |
| 193 | *Ispindina* |  |  |
| 194 | *Lacedo pulchella* |  |  |
| 195 | *Dacelo* |  |  |
| 196 | *Clytoceyx rex* |  |  |
| 197 | *Cittura cyanotis* |  |  |
| 198 | *Pelargopsis* | <https://www.youtube.com/watch?v=5OajTIgbluM>;  <https://www.youtube.com/watch?v=5d40TDAyjRs> | (Biswas et al. 2014; Biswas et al. 2015) |
| 199 | *Halycon* | <https://macaulaylibrary.org/asset/201676381>;  <https://www.youtube.com/watch?v=doYxrSjfHHg>;  <https://www.youtube.com/watch?v=-CgrNok5k4M>;  <https://www.youtube.com/watch?v=C9DHCsyL4Zc> | (Woodall 1991; Naher and Sarker 2014) |
| 200 | *Todiramphus* | <https://www.youtube.com/watch?v=vbfLMXVnw_E>;  <https://www.youtube.com/watch?v=-gN_WXNGqvs> | (Fitzsimons and Thomas 2011) |
| 201 | *Caridonax fulgidus* | - | (Woodall and Kirwan 2020) |
| 202 | *Melidora macrorrhina* | - | - |
| 203 | *Actenoides* | - | - |
| 204 | *Syma* | - | - |
| 205 | *Tanysiptera* | - | - |
| 206 | *Megaceryle* | <https://macaulaylibrary.org/asset/201472031>;  <https://macaulaylibrary.org/asset/201344031>;  <https://www.youtube.com/watch?v=wF0Xxy61cBI> | (Arkell 1979; Kasahara and Katoh 2008; Brush 2020; Kelly et al. 2020) |
| 207 | *Ceryle rudis* | <https://www.youtube.com/watch?v=1Kh5CGvEj9o>;  <https://www.youtube.com/watch?v=HgJJ4l4ScNM> | (Labinger et al. 1991; Katzir and Camhi 1993) |
| 208 | *Chloroceryle* | <https://macaulaylibrary.org/asset/309727341> | (Willard 1985; Remsen 1991) |
| 209 | Meropidae | - | - |
| 210 | Coraciidae | - | - |
| 211 | Brachypteraciidae | - | - |
| 212 | Galbuliformes | - | - |
| 213 | Piciformes | - | - |
| 214 | Cariama sp. | - | - |
| 215 | Falconidae | - | - |
| 216 | Psittaciformes | - | - |
| 217 | *Strigops habroptila* | - | - |
| 218 | Passeriformes sp. | - | - |
| 219 | *Cinclus cinclus* | <https://macaulaylibrary.org/asset/294873831>; <https://macaulaylibrary.org/video/201119371>; <https://www.youtube.com/watch?v=uKHR8PJMj-Q> | (Crisp 1865; Dewar 1938; Ingram 1938; Ingram et al. 1938; Holmes 1939; Brownlow 1949; Jones and King 1952; Tyler and Ormerod 1994) |
| 220 | *Cinclus pallasii* | <https://macaulaylibrary.org/asset/201361231>; <https://macaulaylibrary.org/asset/201345451>; <https://www.youtube.com/watch?v=wEUM8G0bAeY> | (Eguchi 1990; Tyler and Ormerod 1994) |
| 221 | *Cinclus mexicanus* | <https://macaulaylibrary.org/asset/201668521>; <https://macaulaylibrary.org/asset/201668551>; <https://www.youtube.com/watch?v=cV6IDY1TSC0>;  <https://vimeo.com/111911128> | (Goodge 1957; Goodge 1959; Murrish 1970; Tyler and Ormerod 1994) |
| 222 | *Cinclus leucocephalus* | <https://macaulaylibrary.org/asset/107415681> | (Tyler and Ormerod 1994) |
| 223 | *Cinclus schulzii* | - | (Tyler and Ormerod 1994) |

**Comments on Tables S3 & S4:**

As illustrated in Table S3, the following orders contain diving members: Anseriformes, Podecipidiformes, Gruiformes, Charadriiformes, Phaethontiformes, Gaviiformes, Sphenisciformes, Procellariformes, Suliformes, Pelecaniformes, Accipitriformes, Coraciiformes, and Passeriformes. The following comments are based on Table S3 and the references in Table S4.

In the order Anseriformes (ducks, geese, and swans), divers rely on either their hindlimbs or both their hindlimbs and forelimbs for aquatic propulsion. This order contains non-diving species, as well as obligate divers and facultative submergers. All members of the order Podecipidiformes (grebes) are diving and are exclusively foot-propelled during steady-state aquatic locomotion. Though many members of the Gruiformes will dive to avoid predators (Wintle and Taylor 1993; Fournier and Krementz 2018), only those in the genus *Fulica* (coots), are obligate divers. However, given their strong association with water and the difficulty of studying rails and finfoots, it is conceivable that most species in the order Gruiformes are facultative submergers (Alvarez del Toro, 1971; Taylor, 1998). All members of the family *Alcidae* (auks) dive with their wings, and species in the genus *Cepphus* (guillemots) will also use their feet to hover while feeding on benthic prey, which they seem to do more often than other alcids. They do not, however, use their feet during steady-state locomotion in open water, as far as we can tell. The few species in the order Phaethontiformes (tropicbirds) apparently dive to considerable depths after entering the water from a plunge (Corre, 1997; Sommerfeld and Hennicke, 2010), but their mechanism of propulsion underwater is unknown. The five species in the order Gaviiformes (loons, sometimes referred to as “divers”) are foot-propelled, obligate divers. All members of Sphenisciformes (penguins) are non-volant and forage exclusively through wing-propelled diving. As with Anseriformes, a great deal of variation exists within the Procellariformes (albatrosses, shearwaters, and allies), with all families containing either facultative submergers or obligate divers. Most seem to use both the feet and wings for aquatic propulsion, but species in the genus *Pelecanoides* (diving petrels) apparently use only their wings, though we are unable to find any visual evidence to support this widespread view. In the order Suliformes, species in the order Sulidae (gannets and boobies) use both the feet and wings for aquatic propulsion, whereas those in Anhingidae and Phalacrocoraxidae (anhingas and cormorants, respectively) are exclusively foot propelled. Finally, the order Passeriformes contains three wing-propelled divers in the family Cinclidae, genus *Cinclus* (White-throated, Brown, and American dippers). Again, these categories apply only to healthy birds during steady-state aquatic locomotion.

Plunge divers in the orders Accipitriformes, Pelecaniformes, and Coraciiformes, and in the family Laridae (Order: Charadriiformes) illustrate the limitations of our definition of “diving”. At least some species in all four groups plunge into water as a critical component of their foraging strategy, but none descend in water using their appendages. Instead, they rely on momentum gained in the air to overcome the drag and buoyancy of water (Ashmole 1971; Ropert-Coudert et al. 2003; Chang et al. 2016). However, diving species within these groups may use their appendages to ascend in water following a plunge, thereby exhibiting aquatic locomotion and, potentially, associated morphological modifications. Ospreys (Order: Accipitriformes, Family: Pandionidae, Genus: *Pandion*) forage almost exclusively by plunging into water, but rarely submerge. Still, they use their wings (and, perhaps, their feet when not holding prey) to launch themselves out of the water following a plunge. Gulls and terns (Family: Laridae) also plunge dive, submerging on occasion, but do not contact the water with their wings to ascend. The same is true of pelicans (Order: Pelecaniformes, Family: Pelecanidae), though submergence by these species is apparently exceedingly rare (Hall 1925; Skinner 1925). Finally, kingfishers (Order: Coraciiformes, Family: Alcedinidae) exhibit dramatic interspecific variation in foraging behavior (Woodall 1991). Some species reach multiple body-lengths below the surface through plunge diving and use their wings to ascend; others feed entirely on terrestrial fauna. Others, still, are presumed to eat fish and other aquatic prey (Barker and Vestjens 1989), but their foraging behavior is poorly documented. Species in this final group might take aquatic prey by skimming the surface of the water or, perhaps, through plunges which may or may not result in complete submergence.

Researchers should consider their specific questions when classifying species in these latter four groups. For example, if the goal is to explore the effects of aquatic locomotion on the osteology of the bones in the wing, then it might be most appropriate to classify terns as non-diving, as the wings occupy a passive role in plunging and submergence is rare. However, if the investigation instead focuses on the osteology of the cervical vertebrae, then terns might be better classed as divers, as they experience similar force regimes as other plunge divers even though submergence is rare.

In addition, researchers should carefully consider classifications of species in the Procellariformes, as our knowledge of diving in this group is incomplete (Dunphy et al. 2015; Shoji et al. 2016). This is especially true of the species in the genus *Pterodroma*, the gadfly petrels. Traditionally, gadfly petrels have been considered either non-diving or rarely-diving (Ashmole 1971; Harper et al. 1985; Prince and Morgan 1987), but recent studies utilizing capillary tube depth gauges have documented dive depths of greater than 20 meters in some species (Rayner et al. 2008; Taylor 2008). Still, the frequency of these dives relative to other foraging methods is largely unknown. Dive behavior may vary considerably between *Pterodroma* species, or depend on food availability or locality (Warham 1996). Hopefully, new technologies and methods of analysis (e.g., Cianchetti-Benedetti et al., 2017) will reveal the diving habits of these species.

For the sake of brevity, we will not further explore each group in Table 1, but we will comment on three interesting cases of interspecific variation which warrant more focused study.

First, the family Cinclidae contains five species, only three of which dive. These three species use their wings to dive in fast-flowing streams to feed on macroinvertebrates, fish, and other animal prey; *Cinclus* *cinclus* in Eurasia, *Cinclus pallasii* in Asia, and *Cinclus mexicanus* in North and Central America (Winkler et al. 2020b). The other two species, *Cinclus leucocephalus* and *Cinclus schulzii*, reside in South America but forage in similar environments and for similar prey as their relatives (Winkler et al. 2020b). For unknown reasons, the South American dippers do not dive, instead remaining firmly attached to the substrate while foraging (Tyler and Ormerod, 1994). Whether this variation in behavior is reflected in the morphology of these species is largely unknown, though there does appear to be variation in feather microstructure which may be adaptive for submerged swimming (Rijke and Jesser 2010).

Second, the genus *Melanitta* (scoters) contains two species which are exclusively foot-propelled divers – *Melanitta* *nigra* and *Melanitta* *americana*– and three species – *Melanitta* *perspecillata*, *Melanitta* *fusca*, & *Melanitta* *deglandi* – which will also use their wings for a proportion of their dives (Mullarney, 1983). The diving strategy in the sixth species in the genus, *Melanitta* *stejnegeri*, is apparently unknown. All six species occupy similar habitats, are of similar sizes, and dive to forage on benthic invertebrates (Winkler et al. 2020c). Again, whether this variation in behavior is reflected in the morphology of these species is unknown.

Finally, as noted above, the family Alcedinidae exhibits dramatic interspecific variation in foraging behavior (Woodall 1991). This variation has already proved fruitful for research (e.g., Crandell et al., 2019; Eliason et al., 2020), but many questions remain unanswered. Research on the foraging behavior and morphology of species in the genera *Ceyx*, *Halcyon*, *Todiramphus*, and *Caridonax* would be especially valuable. As present, many species which are said to feed on fish have received almost no behavioral study.

Minor comments

* Cape Teal (*Anas capensis*) reportedly dive more than other species in the genus *Anas* (according to Birds of the World entry, 19% of feeding activities), but we found no photos or videos.
* Marled Teal (*Marmaronetta angustirostris*) reportedly dives but no photo or video evidence found. The SeaWorld website (<https://seaworld.org/animals/facts/birds/marbled-teal/>) states that this species only dives to avoid predators.
* Maned Duck (*Chenonetta jubata*) marked as non-diver despite YouTube video (<https://www.youtube.com/watch?v=u44QVK-OFKQ>). This is presumably a captive-raised animal.
* Sandpipers (*Actitis*) reported to swim for food by no images found and no direct references.
* *Halobaena caerulea* classed as a facultative submerger after re-reading evidence, as many of the diving references for seabirds are made from fishing ships, in which birds might be more prone to dive to grab big pieces of food. The same is true of ducks if you provide large volumes of food (e.g. Kutz 1940).

*Phylogenetic Comparative Methods*

**Table S5: F statistics and P Values of tests for allometric differences in wing area [cm2] vs. body mass [g] between volant and flightless species.** There was consistent support for unique intercepts (scaling coefficients), but not unique slopes (scaling exponents).

Table

Description automatically generated

**Table S6: F statistics and P Values of tests for allometric differences in wing area vs. body mass between wing-propelled and exclusively foot-propelled divers.** There was no support for unique intercepts.

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**Table S7: F statistics and P Values of tests for allometric differences in wing area vs. body mass between exclusively wing-propelled and exclusively foot-propelled divers.** There was no support for unique intercepts.

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**Table S8: F statistics and P Values of tests for allometric differences in wing area vs. body mass between volant divers and volant non-divers.** There was consistent support for unique intercepts, but not unique slopes. **Table

Description automatically generated**

**Table S9: F statistics and P Values of tests for allometric differences in wing second moment of area vs. wing area between diving and non-divers.** There was no support for unique intercepts.

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**Table S10: T statistics and P Values of tests for phylogenetic generalized least squares regressions including residuals of wing area vs. body mass (WL – wing loading) and diving method (DM) as predictors for the residual of mean dive duration vs. body mass.**

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**Table S11: T statistics and P Values of tests for a significant relationship between the residuals of wing area vs. body mass and mean dive duration vs. body mass.** There was consistent support for a relationship between these two parameters.

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**Figure S1: Body mass versus mean dive duration for 127 species of birds.** Facultative submergers are indicated with cross marks. Color indicates taxonomic order.

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