

RELATIVE KIDNEY SIZE IN NONPASSERINE BIRDS WITH FUNCTIONAL SALT GLANDS

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The problem of attaining sufficient water to meet their physiological requirements has been solved by some birds through the evolution of salt glands, which can eliminate ingested sodium chloride with little water loss. Species possessing functional salt glands have, then, two routes of sodium chloride excretion, the renal and the extrarenal routes. The size of the salt glands is determined by the salinity of the drinking water to which the bird is exposed (Schildmacher 1932; Holmes et al. 1961), but a similar study of the possible influence of salinity on kidney size has not been reported. Such an interrelationship might be anticipated from the conclusions of Benoit (1950) who found that avian kidney weight was larger in those species living near water or marshes, although Johnson (1968) was unable to substantiate this correlation. The present paper is an analysis of kidney size as a function of body weight in birds possessing active salt glands, in an attempt to evaluate the effect of an accessory osmoregulatory site on kidney size.

MATERIALS AND METHODS

The information reported in this paper is based on the kidney and body weights of 103 nonpasserine species representing 19 orders. Data on 26 African and North American species were taken from Quiring (1950:528-572). Data on 51 species, collected primarily in Arizona, Colorado, Minnesota, and North Dakota, were taken from the work of Johnson (1968). The remaining 36 species were collected by or for the author on the west coast of the United States and Canada, principally in Marin County, California. The five alcid species were collected on St. Lawrence Island, Alaska.

No details are available for the collecting or weighing techniques used by Quiring. The birds taken by Johnson were weighed to the nearest 0.1 g in the field. The kidneys, fixed in situ in the synsacra in either formalin or a mixture of acetic acid-formalin-alcohol (AFA), were subsequently dissected out, blotted on absorbent paper and weighed to the nearest 0.001 g in a sealed vial. The following procedure was employed for the remaining birds. The birds were shot, collected and, if small, placed in plastic bags to prevent desiccation. The birds were weighed to the nearest 0.1 g within hours of death; the kidneys were removed, blotted on absorbent paper, and weighed to the nearest 0.001 g on an analytical balance.

Kidney weight as a function of body weight was

analyzed and compared in 51 species in which hypertonic sodium chloride secretion from the salt glands had been demonstrated, or could be logically anticipated due to the presence of enlarged salt glands or the bird's mode of existence, and in 52 species in which salt secretion is not known to occur. Birds with marine affinities were assigned to the salt gland group, although extrarenal salt excretion has not been demonstrated in every species. No instance has been reported in which a marine bird was subjected to salt stress and failed to produce hypertonic salt gland secretion. The Ostrich, *Struthio camelus*, although nonmarine, is included in the group because hypertonic secretion has been elicited by heat stress (Schmidt-Nielsen et al. 1963). Although some raptors may secrete hypertonic sodium chloride (Cade and Greenwald 1966), of the species included in the present study, only *Aquila rapax* has been reported to do so and only this species is included in the active salt gland group.

RESULTS

A plot of log kidney weight against log body weight in figure 1 shows that birds possessing active salt glands have relatively larger kidneys than birds lacking active salt glands. Linear regressions were calculated and an analysis of covariance established, at the 0.01 level, that the two regressions had the same variance and slope (0.909), but were not coincident.

The slope of the line for birds with functional salt glands, $KW = 0.026 BW^{0.879}$, is slightly less than that of the line for birds lacking salt glands, $KW = 0.012 BW^{0.928}$. Both lines agree well with that reported by Johnson (1968): $KW = 0.016 BW^{0.913}$. The slope of the line calculated from the combined data in this study, 0.909, is in very close agreement with Johnson's value, but greater than that given by Brody (1964): $KW = 0.009 BW^{0.852}$.

The value (kidney weight/body weight) \times 100, was greater than 1.0 for species that have either complete or sporadic marine affinities, while species from nonmarine habitats generally have kidneys smaller than one per cent of the body weight (see table 1).

DISCUSSION

Although the kidney size in birds varies from about one per cent to 2.6 per cent of the body weight (Benoit 1950), there has been little

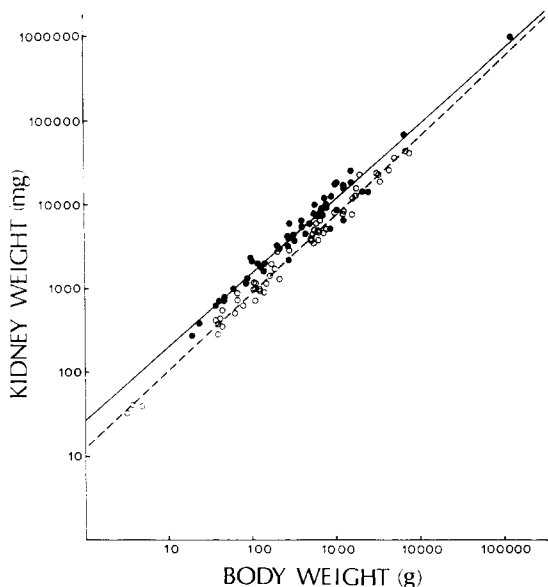


FIGURE 1. Logarithmic (base 10) plot of kidney weight as a function of the body weight in 103 species of nonpasserine birds. Dark circles (solid line) indicate birds with known or suspected hypertonic secretion from salt glands, while open circles (dashed line) indicate birds which lack active salt glands. The solid line is expressed by the equation: $\log \text{ kidney weight} = 0.879 \times \log \text{ body weight} - 1.586$; dashed line by the equation: $\log \text{ kidney weight} = 0.928 \times \log \text{ body weight} - 1.912$ (all weights in g).

attempt to assess possible physiological reasons for morphological differences. The kidneys of small birds are larger in proportion to their body weights than those of large birds (Rensch 1948). Johnson (1968) indicates that for body weights of 100–1000 g, the kidney weight closely approximates one per cent of the body weight, exceeding this value at lower body weights and falling below this value at higher body weights. In order to minimize the size factor in the present study (most of the birds fall within the 100–1000 g range) the passerine birds have been excluded. However, inclusion of 19 passerine species in a similar analysis did not alter the relationship of the two lines (fig. 1).

Most of the species in this study which have been placed in the "functional salt glands" category are birds which have marine affinities and are, therefore, exposed to hyperosmotic drinking water and food. There are two species, however, which are nonmarine and which have been shown to produce hypertonic salt secretion. These are the raptor *Aquila rapax*, which produces secretion in response to a high protein diet (Cade and Greenwald 1966), and the Ostrich, *Struthio camelus*, which produces secretion following heat stress (Schmidt-Niel-

sen et al. 1963). The kidney weight/body weight relationship of the Ostrich is best described by the solid line in fig. 1, but that of the raptor by the broken line.

Examination of the data in table 1 shows that, in orders containing mainly nonmarine species that have relatively smaller kidneys, the exceptions to the rule are species associated with saline habitats. For example, among the Ciconiiformes only the flamingo, *Phoeniconaias minor*, which sieves its food from marine muds, has relatively large kidneys. McFarland (1959) showed that another flamingo, *Phoenicopterus ruber*, has active salt glands. Among the Gruiformes, the Sora Rail (*Porzana carolina*) and the coot (*Fulica americana*), which may be found in brackish waters, have relatively larger kidneys. The coot has functional salt glands (Cooch 1964), but the rail has not been studied. Until more data are available on kidney size in nonmarine birds exhibiting extrarenal salt secretion, it will not be possible to determine whether larger kidney size is related to a specific causative agent, such as ingested hyperosmotic material, or whether it may be associated with extrarenal salt excretion in a more general way.

Salt gland size is an interspecifically variable and intraspecifically modifiable factor (Zaks and Sokolova 1961; Holmes et al. 1961). Salt gland size increases with exposure to salt stress in gulls (Holmes et al. 1961) and in ducks (Schmidt-Nielsen and Kim 1964). If kidney size is similarly modifiable, it is not unexpected that a large range of values for the per cent kidney weight should exist in orders, such as the Anseriformes, that contain species which are mainly marine, mainly fresh water, or which utilize both habitats intermittently (see table 1). It is noteworthy, though presently inexplicable, that those birds with supposedly active salt glands, but whose kidney weight to body weight relationship is better described by the line for birds lacking extrarenal excretion, are ducks (see fig. 1). It is probably unwise to assign all ducks to the same assemblage with respect to extrarenal excretion, since at least some require osmotic stress in order to realize their extrarenal excretory potential, and all are limited in their ability to form hypertonic secretion.

There are two birds in which extrarenal salt secretion has not been observed, yet which have relatively large kidneys. These are the francolin, *Francolinus sephaena*, and the Sage Hen, *Centrocercus urophasianus* (fig. 1 and table 1). Hypertonic secretion in response to

TABLE 1. Kidney weight expressed as per cent body weight, in 103 species of nonpasserine birds.

Order and species	No. specimens*	\bar{x} weight (g)		% of body wt.	Source ^b
		Kidney	Body		
Struthioniformes					
<i>Struthio camelus</i>	1*	920.	123,000	0.8	Q
Caviiformes					
<i>Gavia stellata</i>	3*	25.2	1,549	1.6	Q
Podicipediformes					
<i>Podiceps caspicus</i>	2*	3.7	330	1.1	J
<i>Podilymbus podiceps</i>	2*	5.9	496	1.2	J
Procellariiformes					
<i>Puffinus griseus</i>	1*	3.2	268	1.2	Q
Pelecaniformes					
<i>Pelecanus erythrorhynchos</i>	2*	66.0	6,777	1.0	J
<i>Phalacrocorax pelagicus</i>	1*	16.9	1,300	1.3	H
Ciconiiformes					
<i>Ardea herodias</i>	1	15.8	1,840	0.9	J
<i>Nycticorax nycticorax</i>	2	6.7	657	1.0	J
<i>Botaurus lentiginosus</i>	2	4.7	625	0.7	J
<i>Ciconia ciconia</i>	3	23.0	3,350	0.7	Q
<i>Leptoptilos cruminiferus</i>	2	42.9	7,130	0.6	Q
<i>Casmerodius albus</i>	1	8.2	1,030	0.8	Q
<i>Mesophoyx intermedius</i>	1	3.7	525	0.7	Q
<i>Phoeniconaias minor</i>	5*	18.0	1,541	1.2	Q
Anseriformes					
<i>Chen caerulescens</i>	4*	13.8	2,155	0.6	J
<i>Anas platyrhynchos</i>	1*	6.5	1,305	1.3	H
<i>Anas acuta</i>	1*	5.1	862	0.6	J
<i>Anas carolinensis</i>	1*	2.2	285	0.8	H
<i>Anas discors</i>	2*	4.3	449	1.0	J
<i>Anas cyanoptera</i>	1*	4.4	319	1.4	H
<i>Aythya americana</i>	2*	8.4	1,055	0.8	J
<i>Aythya marila</i>	1*	9.1	787	1.2	Q
<i>Aythya affinis</i>	1*	18.1	1,041	1.7	Q
<i>Melanitta deglandi</i>	1*	12.4	910	1.4	H
<i>Oxyura jamaicensis</i>	1*	5.4	411	1.3	H
<i>Mergus serrator</i>	1*	9.7	700	1.3	Q
Falconiformes					
<i>Cathartes aura</i>	1	12.6	1,761	0.7	H
<i>Buteo jamaicensis</i>	1	7.6	1,225	0.6	J
<i>Buteo vulpinus</i>	1	3.4	500	0.6	Q
<i>Falco sparverius</i>	1	1.1	112	1.0	Q
<i>Aquila rapax</i>	3*	13.9	2,532	0.6	Q
<i>Pseudogyps africanus</i>	1	35.8	5,270	0.7	Q
<i>Haliaeetus vocifer</i>	1	18.4	3,500	0.5	Q
Galliformes					
<i>Bonasa umbellus</i>	2	4.9	577	0.8	J
<i>Lagopus lagopus</i>	5	6.0	602	1.0	J
<i>Pedioecetes phasianellus</i>	1	5.1	791	0.6	J
<i>Centrocercus urophasianus</i>	2	22.3	2,013	1.1	J
<i>Callipepla squamata</i>	2	1.4	168	0.8	J
<i>Lophortyx gambelii</i>	3	1.2	150	0.8	J
<i>Cyrotornyx montezumae</i>	2	1.3	212	0.6	J
<i>Phasianus colchicus</i>	4	8.2	1,283	0.6	J
<i>Perdix perdix</i>	2	3.8	521	0.7	J
<i>Francolinus sephaena</i>	1	2.7	208	1.3	Q
<i>Numida meleagris</i>	1	7.3	1,620	0.5	Q
<i>Gallus domesticus</i>	8	4.5	733	0.6	Q
Gruidiformes					
<i>Grus canadensis</i>	1	11.7	1,651	0.7	Q
<i>Balearica pavonina</i>	2	26.0	4,448	0.6	Q
<i>Ardeotis kori</i>	2	44.3	7,770	0.5	Q
<i>Porzana carolina</i>	1	0.9	670	1.3	J
<i>Fulica americana</i>	1*	9.0	699	1.3	H

* = known or probable salt gland activity.

^b Q, Quiring 1950; J, Johnson 1968; H, Hughes.

TABLE 1 (Continued)

Order and species	No. specimens ^a	\bar{x} weight (g)		% of body wt.	Source ^b
		Kidney	Body		
Charadriiformes					
<i>Charadrius alexandrinus</i>	1*	0.6	37	1.7	H
<i>Charadrius vociferus</i>	3*	1.3	88	1.5	J
<i>Arenaria melanocephala</i>	1*	2.0	118	1.7	H
<i>Bartramia longicauda</i>	1*	1.6	141	1.1	J
<i>Actitis macularia</i>	2*	0.7	41	1.7	J
<i>Catoptrophorus semipalmatus</i>	1*	4.1	270	1.5	H
<i>Totanus melanoleucus</i>	2*	2.9	212	1.4	J
<i>Erolia melanotos</i>	2*	1.1	85	1.3	J
<i>Erolia minutilla</i>	1*	0.3	19	1.4	H
<i>Erolia ruficollis</i>	1*	0.8	46	1.7	H
<i>Limnodromus scolopaceus</i>	2*	1.8	130	1.4	J
<i>Ereunetes pusillus</i>	2*	0.4	23	1.6	J
<i>Limosa fedoa</i>	1*	6.4	388	1.7	H
<i>Steganopus tricolor</i>	3*	0.7	47	1.5	J
<i>Heteroscelus incanum</i>	1*	1.9	146	1.3	H
<i>Larus delawarensis</i>	4*	7.2	488	1.5	J
<i>Larus pipixcan</i>	2*	3.9	275	1.4	J
<i>Larus philadelphia</i>	1*	3.2	205	1.6	Q
<i>Larus heermanni</i>	1*	7.8	544	1.4	H
<i>Larus glaucescens</i>	1*	7.4	618	1.2	H
<i>Larus occidentalis</i>	2*	15.5	1,283	1.2	H
<i>Hydroprogne caspia</i>	1*	7.4	644	1.2	H
<i>Chlidonias nigra</i>	3*	1.0	60	1.6	J
<i>Aethia cristatella</i>	2*	6.0	289	2.1	H
<i>Aethia pusilla</i>	2*	2.3	96	2.4	H
<i>Lunda cirrhata</i>	1*	11.7	734	1.6	H
<i>Uria aalge</i>	1*	17.5	1,031	1.7	H
<i>Plautus alle alle</i>	2*	2.1	103	2.2	Q
<i>Fratercula corniculata</i>	2*	9.7	572	1.7	H
Columbiformes					
<i>Columba livia</i>	1	2.8	286	1.0	J
<i>Zenaida asiatica</i>	3	0.9	141	0.6	J
<i>Zenaidura macroura</i>	1	0.7	110	0.7	H
<i>Scardafella inca</i>	2	0.3	43	0.8	J
Psittaciformes					
<i>Melopsittacus undulatus</i>	6	0.3	39	0.7	J
Cuculiformes					
<i>Geococcyx californianus</i>	2	1.7	190	0.9	J
Strigiformes					
<i>Otus asio</i>	1	1.0	109	0.9	J
<i>Bubo virginianus</i>	1	3.7	635	0.4	H
<i>Micrathene whitneyi</i>	2	0.4	37	1.1	J
Caprimulgiformes					
<i>Chordeiles minor</i>	3	0.6	80	0.8	J
Apodiformes					
<i>Amazilia tzacotl</i>	1	0.04	5	0.8	Q
<i>Selasphorus platycercus</i>	2	0.03	3	1.0	J
<i>Selasphorus rufus</i>	1	0.04	4	1.1	J
Coraciiformes					
<i>Megaceryle alcyon</i>	2	2.2	173	1.2	J
<i>Bucorvus leadbeateri</i>	1	23.0	3,250	0.7	Q
Piciformes					
<i>Colaptes auratus</i>	1	1.0	126	0.8	J
<i>Colaptes cafer</i>	2	0.9	125	0.7	J
<i>Colaptes chrysoides</i>	2	1.0	116	0.8	J
<i>Centurus uropygialis</i>	3	0.7	68	1.1	J
<i>Melanerpes formicivorus</i>	2	0.5	63	0.8	J
<i>Sphyrapicus varius</i>	2	0.5	45	1.2	J
<i>Sphyrapicus thyroideus</i>	3	0.5	43	1.1	J
<i>Dendrocopos arizonae</i>	2	0.4	43	0.9	J

high temperature has been observed in another galliform bird, the Desert Partridge, *Am-moperdix heyi*, (Schmidt-Nielsen et al. 1963). The present results suggest that extrarenal salt secretion might also be found in the francolin and the Sage Hen.

The present findings agree with those of Johnson (1968), who found no differences in kidney size between the sexes or attributable to diet.

The paucity of data on kidney size and extrarenal excretion in nonmarine birds makes generalizations unwise. It may be said with some certainty, however, that the presence of active salt glands, having the ability to regulate the sodium and chloride content of the body fluids, does not exercise a sparing effect on the amount of renal tissue. On the contrary, more renal tissue is found in birds with functional salt glands and the total amount of osmoregulatory tissue in these birds is much greater than in birds lacking active salt glands.

SUMMARY

The kidney weight/body weight relationship was analyzed in 51 species of birds having functional salt glands and in 52 species lacking extrarenal salt excretion. The presence of functional salt glands appears to be associated with increased weight of the renal mass.

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LITERATURE CITED

- BENOIT, J. 1950. Organes Uro-génitaux. p. 341-377. In P. P. Grasse [ed.] *Traité de Zoologie*, Tome XV, Oiseaux. Masson and Co., Paris.
- BRODY, S. 1964. Bioenergetics and growth with special reference to the efficiency complex in domestic animals. Hafner Publ. Co., New York.
- CADE, T. J., AND L. GREENWALD. 1966. Nasal salt secretion in falconiform birds. *Condor* 68:338-350.
- COOCH, F. G. 1964. A preliminary study of the survival value of a functional salt gland in prairie Anatidae. *Auk* 81:380-393.
- HOLMES, W. N., D. G. BUTLER, AND J. G. PHILLIPS. 1961. Observations on the effect of maintaining Glaucous-winged Gulls (*Larus glaucescens*) on fresh and sea water for long periods. *J. Endocrinol.* 23:53-61.
- JOHNSON, O. W. 1968. Some morphological features of avian kidneys. *Auk* 85:216-228.
- McFARLAND, L. Z. 1959. Captive marine birds possessing a functional lateral nasal gland (salt gland). *Nature* 184:2030-2031.
- QUIRING, D. P. 1950. Functional anatomy of vertebrates. McGraw-Hill, New York.
- RENSCH, B. 1948. Organproportionen und Körpergrösse bei Vögeln und Säugetieren. *Zool. Jahrb.* 61:337-412.
- SCHILDMACHER, H. 1932. Über den Einfluss des Salzwassers auf die Entwicklung der Nasendrüsen. *J. Ornithol.* 80:293-299.
- SCHMIDT-NIELSEN, K., A. BORUT, P. LEE, AND E. CRAWFORD, JR. 1963. Nasal salt excretion and the possible function of the cloaca in water conservation. *Science* 142:1300-1301.
- SCHMIDT-NIELSEN, K., AND Y. T. KIM. 1964. The effect of salt intake on size and function of the salt gland of ducks. *Auk* 81: 160-172.
- ZAKS, N. G., AND M. M. SOKOLOVA. 1961. Ontogenetic and specific features of the nasal gland in some marine birds. *Sechenov Physiol. J. U.S.S.R.* 47:120-127.

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