Birds as Osmoregulators: Adaptations for Harsh Environments

Eldon J. Braun
Department of Physiology
University of Arizona

Overview of Presentation

- ❖Organs contributing to osmoregulation
- ❖Avian Renal and Gastrointestinal Anatomy
- ❖Renal Function: urine concentration
- ❖Uric Acid as an End-product of Nitrogen Metabolism
- ❖Integration of Renal and Gastrointestinal systems in osmoregulation
- ❖Comparison of small mammals and birds in the desert

Birds Osmoregulated Well

Birds inhabit all environments

- Aquatic
  - Fresh water
  - Marine
  - Estuaries
- Terrestrial
  - Polar
  - Temperate
  - Desert

In terms of osmoregulation, mammals are the unusual group of vertebrates

- Kidneys are the only osmoregulatory organ
- Osmoregulation among other vertebrates
  - Fish, amphibians, reptiles, and birds
  - Multiple organs function in osmoregulation

Presence of Osmoregulatory organs of vertebrates

Organ	Fish	Amphibians	Reptiles	Birds	Mammals
Kidney	X	X	X	X	X
Intestine	X	X	X	X	
Bladder	X	X	X		
Gills	X	X			
Salt Glands			X	X	
Skin		X			

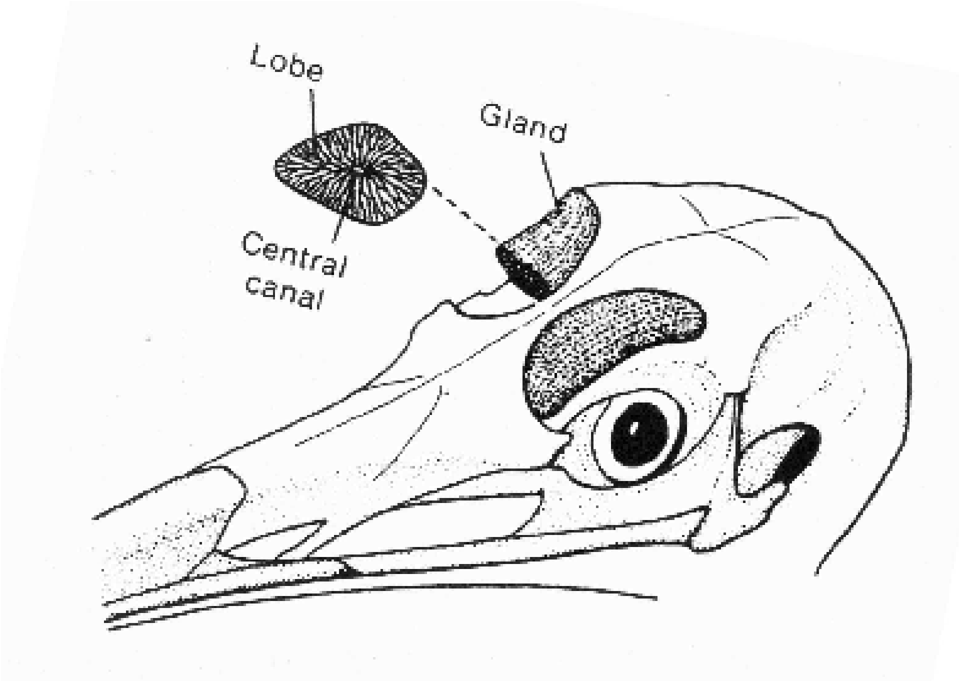
Osmoregulation by birds: Organs involved

Salt glands

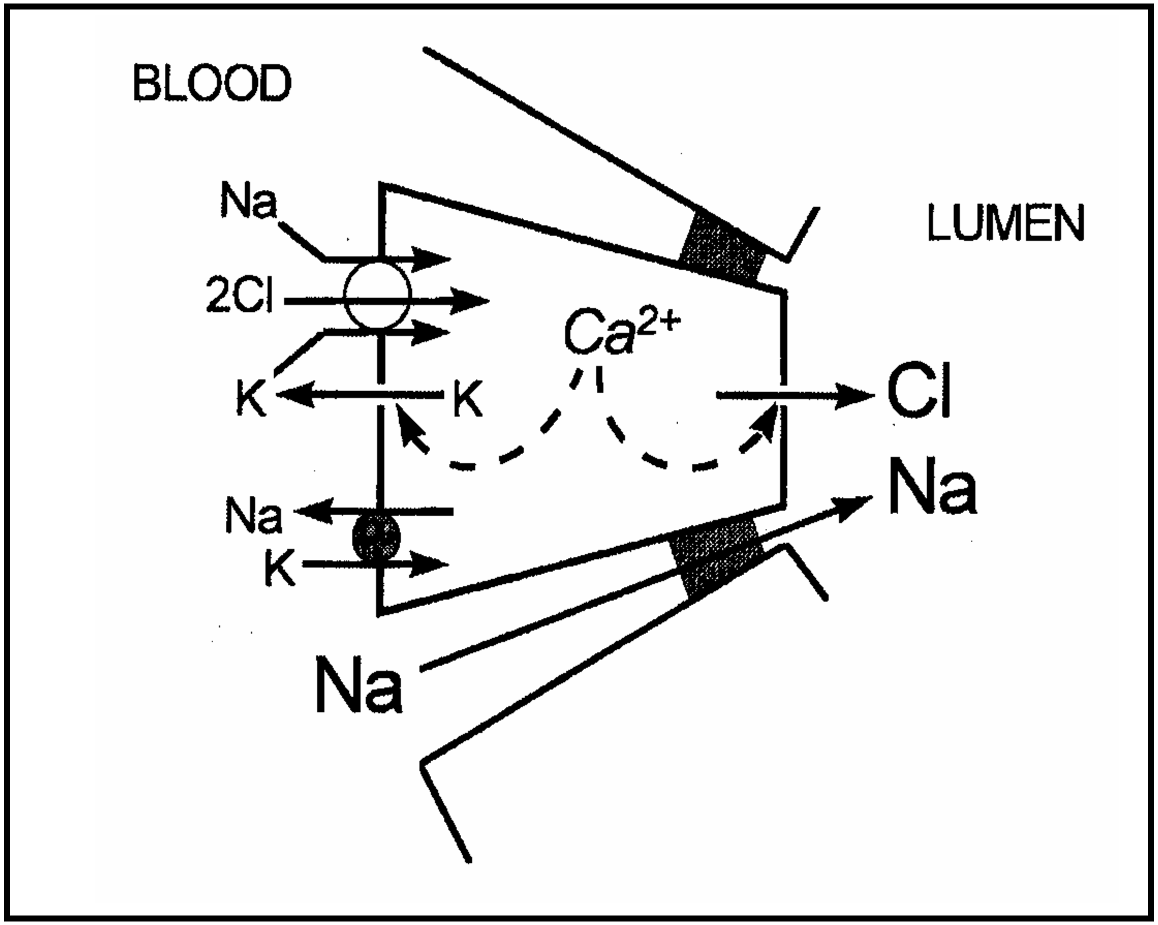
Lower gastrointestinal tract

Kidneys

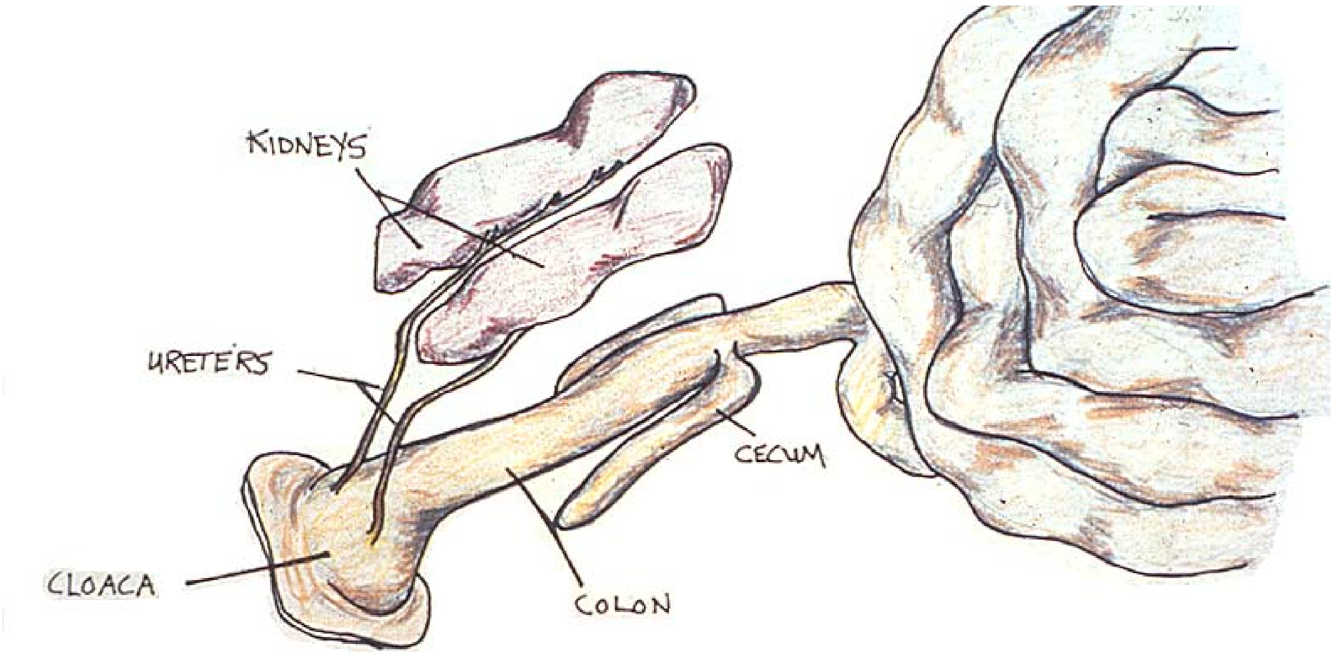
Avian salt gland



Secretion by avian salt glands: ion movements

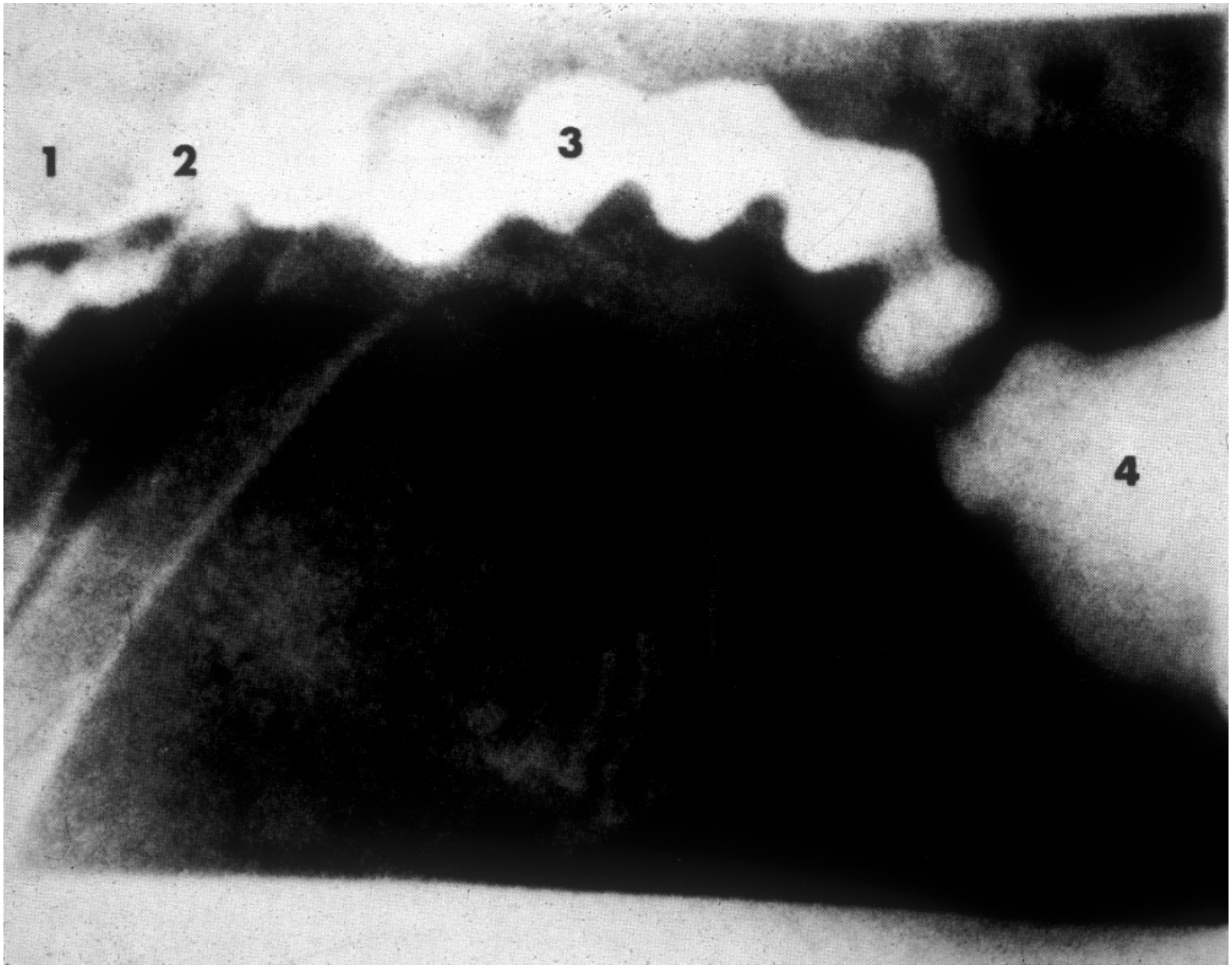


Renal and Gastrointestinal Anatomy of Birds



As birds do not have a urinary bladder, the ureteral urine is refluxed from the cloaca into the colon

Reverse Peristalsis of Avian lower GI Tract



The avian renal and gastrointestinal systems must function in concert in the regulation of ion and fluid balance

Evolutionary rationale for urine to enter lower gastrointestinal tract and lack of urinary bladder

- Excess mass of a urinary bladder
  - ❖GFRs of birds and mammals do not differ

Glomerular Filtration Rates of Birds And Mammals: Allometric Analysis

	GFR (ml/h)	Body Mass (g)	SNGFR (nl/min)
Mammals	1.24	17 - 500 x 10^3 *	~ 30
Birds	1.24	38 – 30 x 10^3 *	7 - 14

*Yokota, Benyajati, & Dantzler, 1985

Evolutionary rationale for urine to enter lower gastrointestinal tract and lack of urinary bladder

Excess mass of a urinary bladder

- ❖GFRs of birds and mammals do not differ
- ❖Fraction of filtered water reabsorbed by kidney
  - ▪Less by avian kidney
  - ▪Urine is in a constant state of flux
- ❖Argument does not “hold water”

Urine - to - Plasma Osmolar Ratios

Urine - to - Plasma Osmolar Ratios: an indicator of how well the kidney can conserve water by excreting solutes in water

Or simply the U/P_{osm}

Values for mammals range from less than 1 to 25

What do these values mean?

Value for humans?

Urine-to-Plasma Osmolar Ratios for Birds

Ring-necked Pheasant	1.5
Senegal Dove	1.7
Savannah Sparrow	1.7*
King Quail	1.8
White-crowned Sparrow	1.8
Domestic Fowl	2.0
Budgerigar	2.3
House Finch	2.4
Singing Honeyeater	2.4
Stubble Quail	2.6
Mean	2.05

Comparison of U/P_{osm} between birds and mammals

- ❖Not a valid comparison to make
  - ❖Urine in lower GI tract
    - ❖Effects of concentrated fluid in lower GI tract
  - ❖End product of nitrogen metabolism
    - ❖Uric acid vs. urea
      - ❖Urea ca. 50% of solute in mammal urine
      - ❖Uric acid not in solution in avian urine

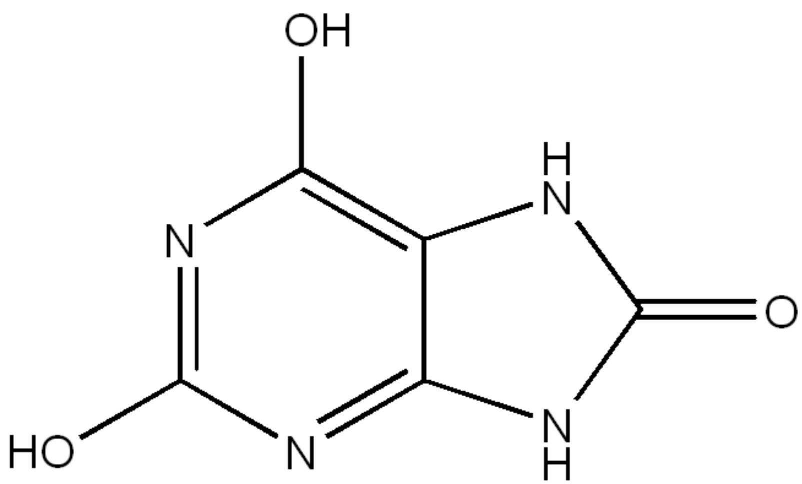
The chemical form in which excess nitrogen is excreted is important in water balance

Solubility of Nitrogen-Containing Compounds

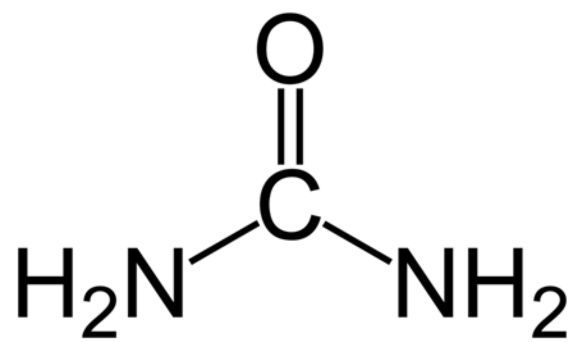
Compound	Solubility (mmol/L)
Uric Acid	0.381
Ammonium Urate	3.21
Sodium Urate	8.32
Potassium Urate	14.75
Urea	16,650
Ammonia	∞

End products of nitrogen metabolism in birds and mammals

Structure of nitrogen containing compounds

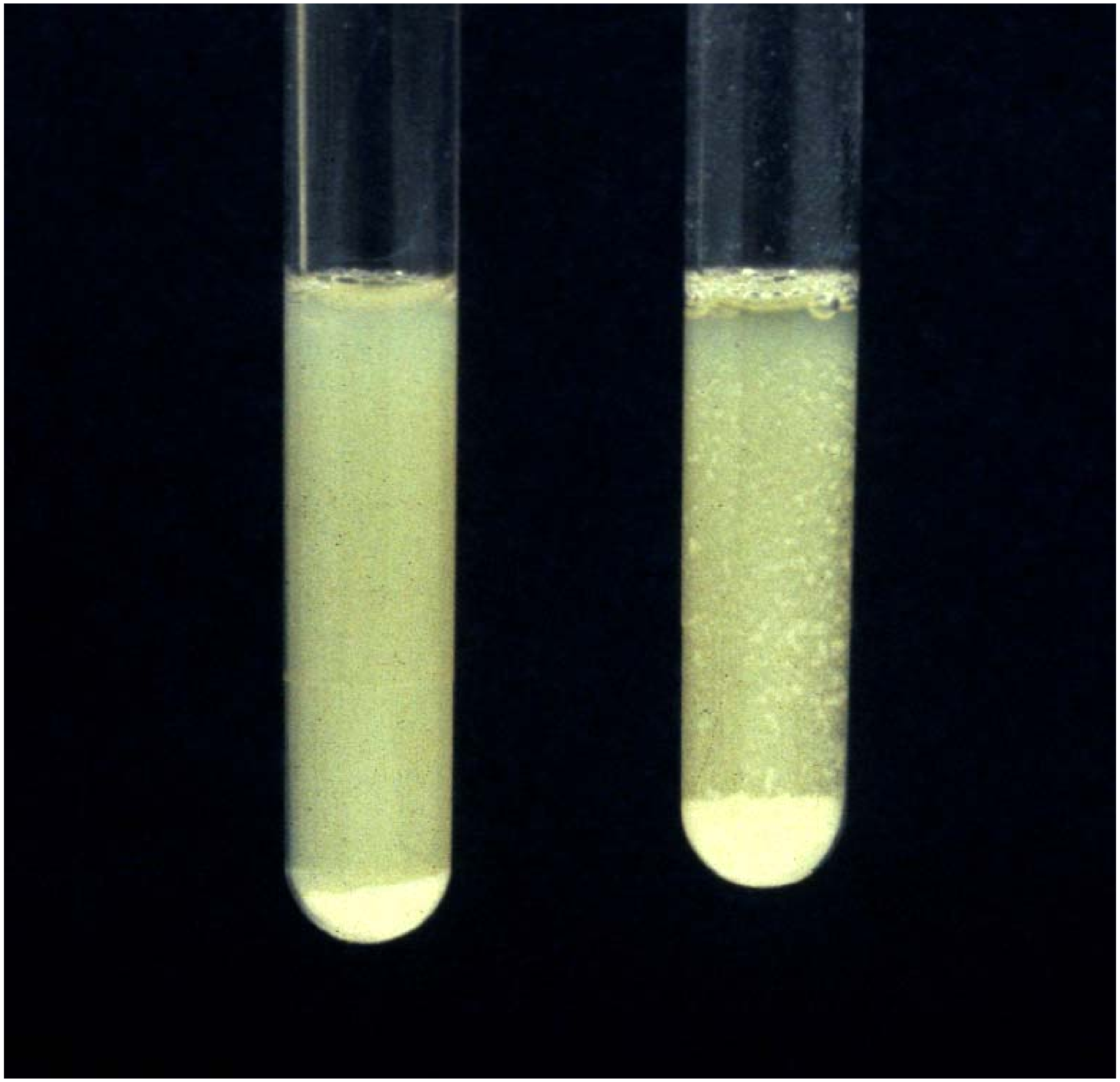


Uric Acid



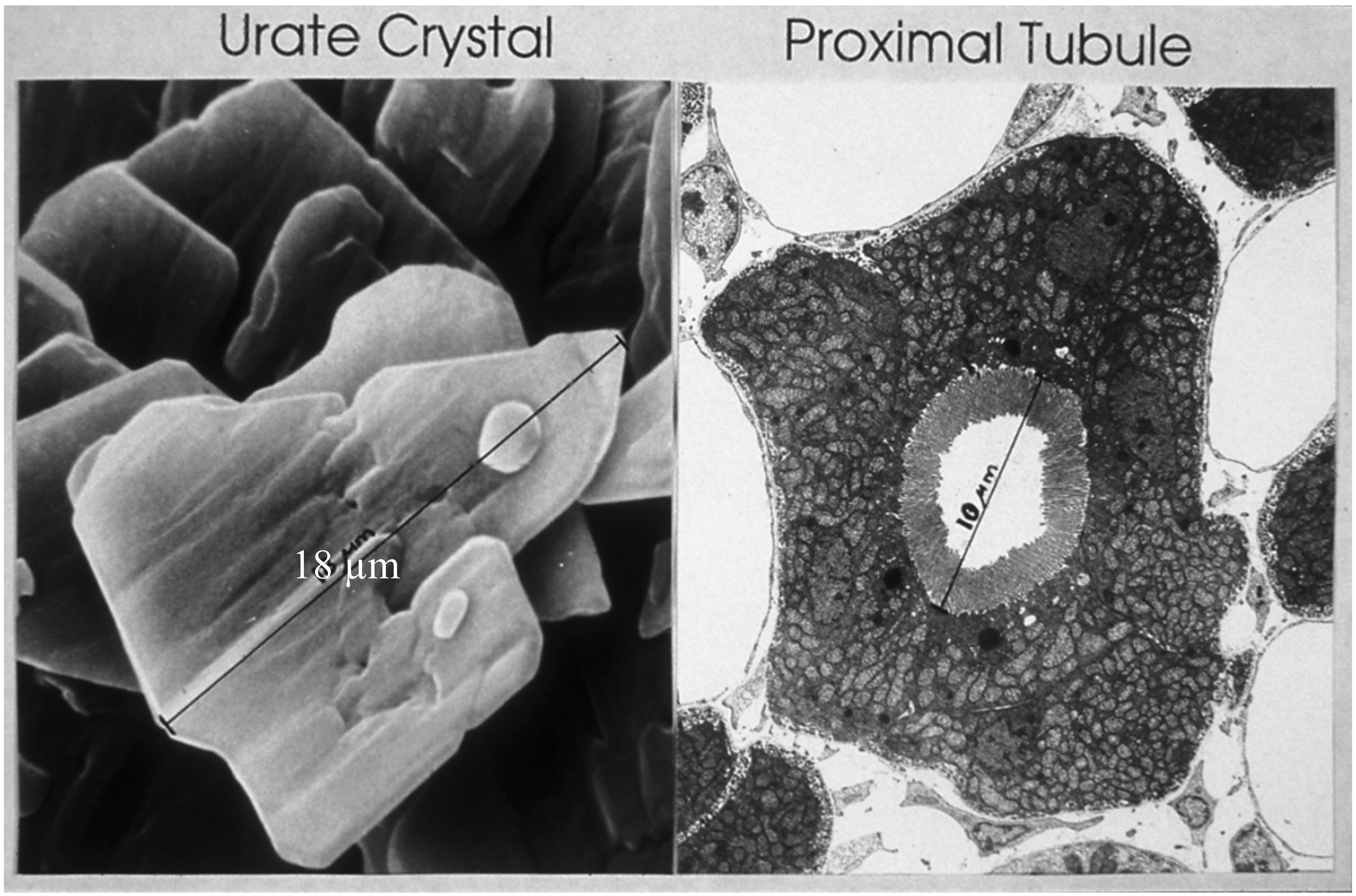
Urea

Avian Ureteral Urine Samples

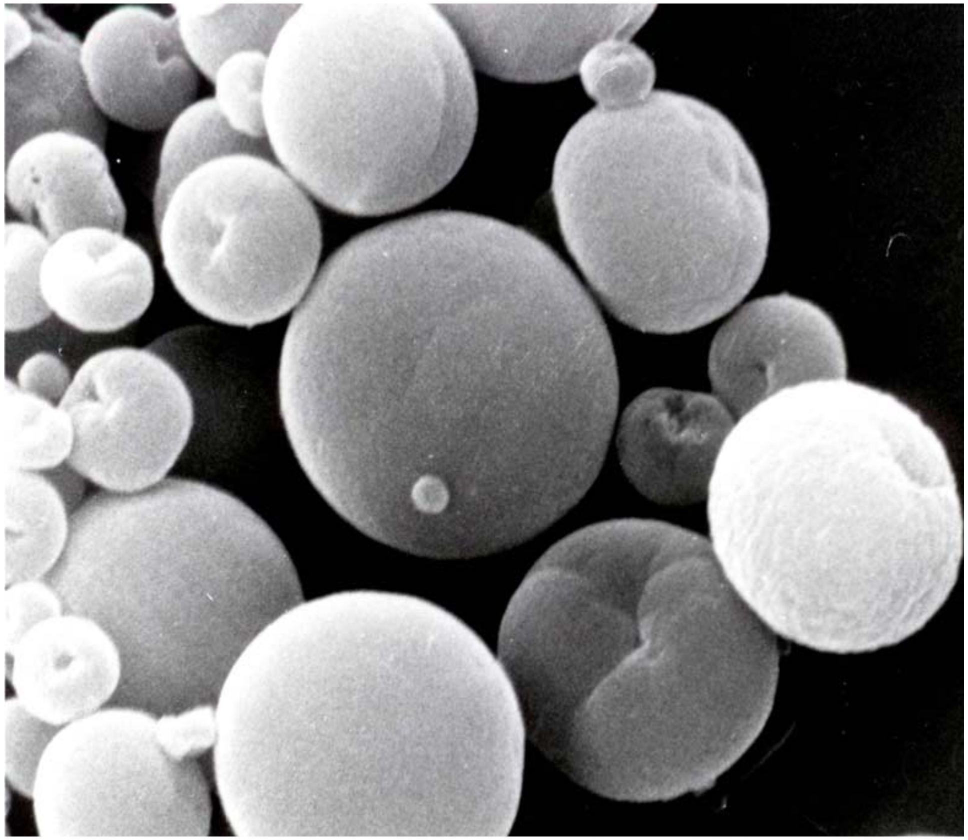


Analysis of pellet indicates it is about 65% uric acid

Size of urate crystals and diameter of renal tubules



Physical Form of Uric Acid in Avian Urine

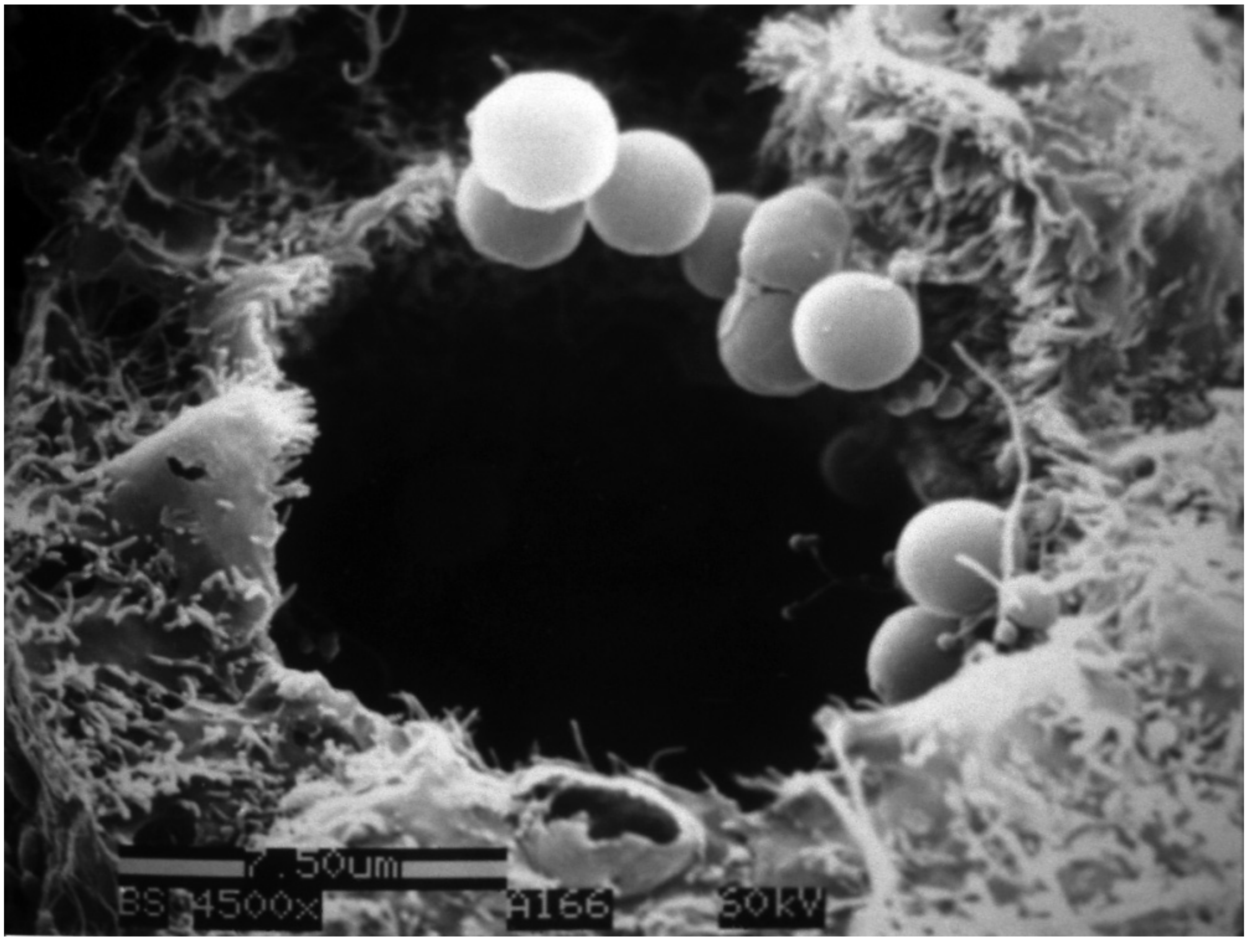


Small spherical structures (1 - 14µm in diameter)

Spheres ca. 65% uric acid

Uric acid bound to a matrix protein

Urate Spheres Within Renal Tubules



Prevention of Uric Acid Precipitation

Protein in Avian Urine

Avian urine contains 5 mg/ml protein

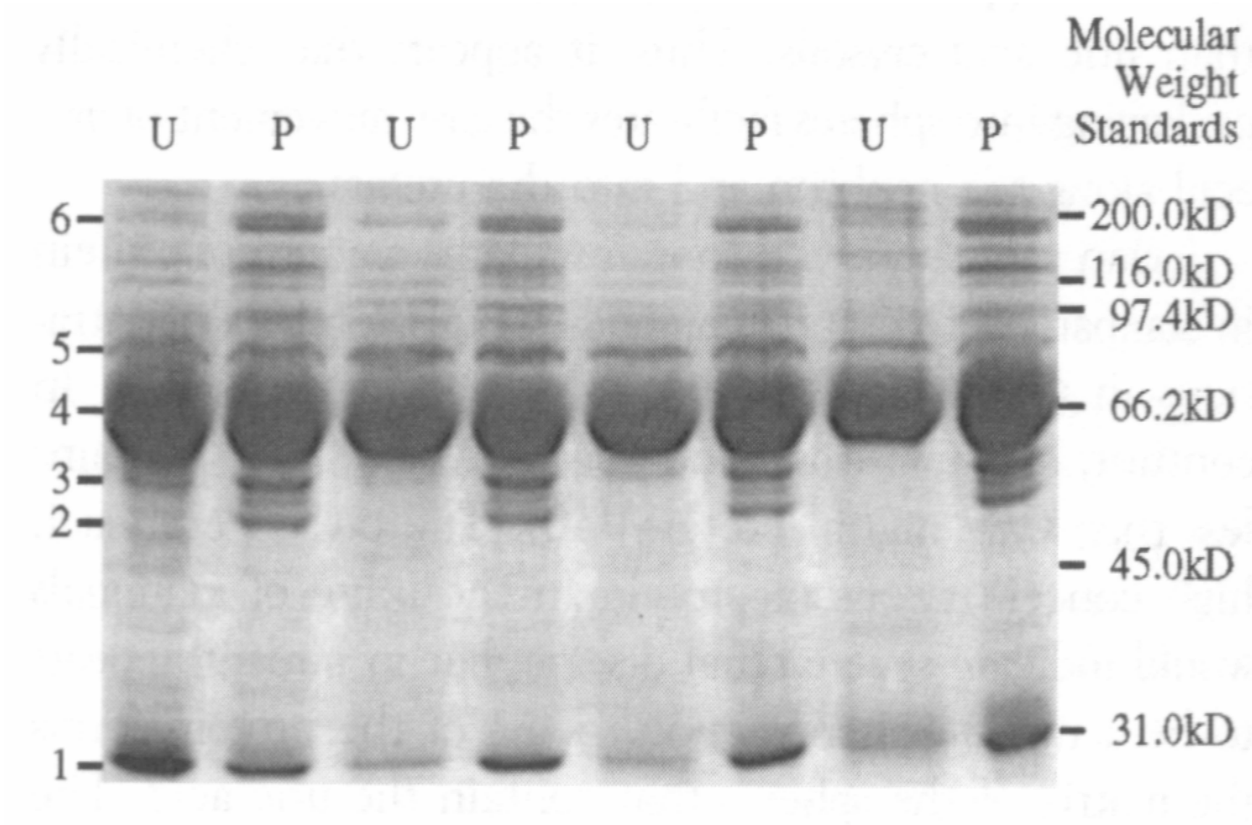
Protein conc. in human urine ca. 0.05 mg/ml

Energy in Avian Ureteral Urine

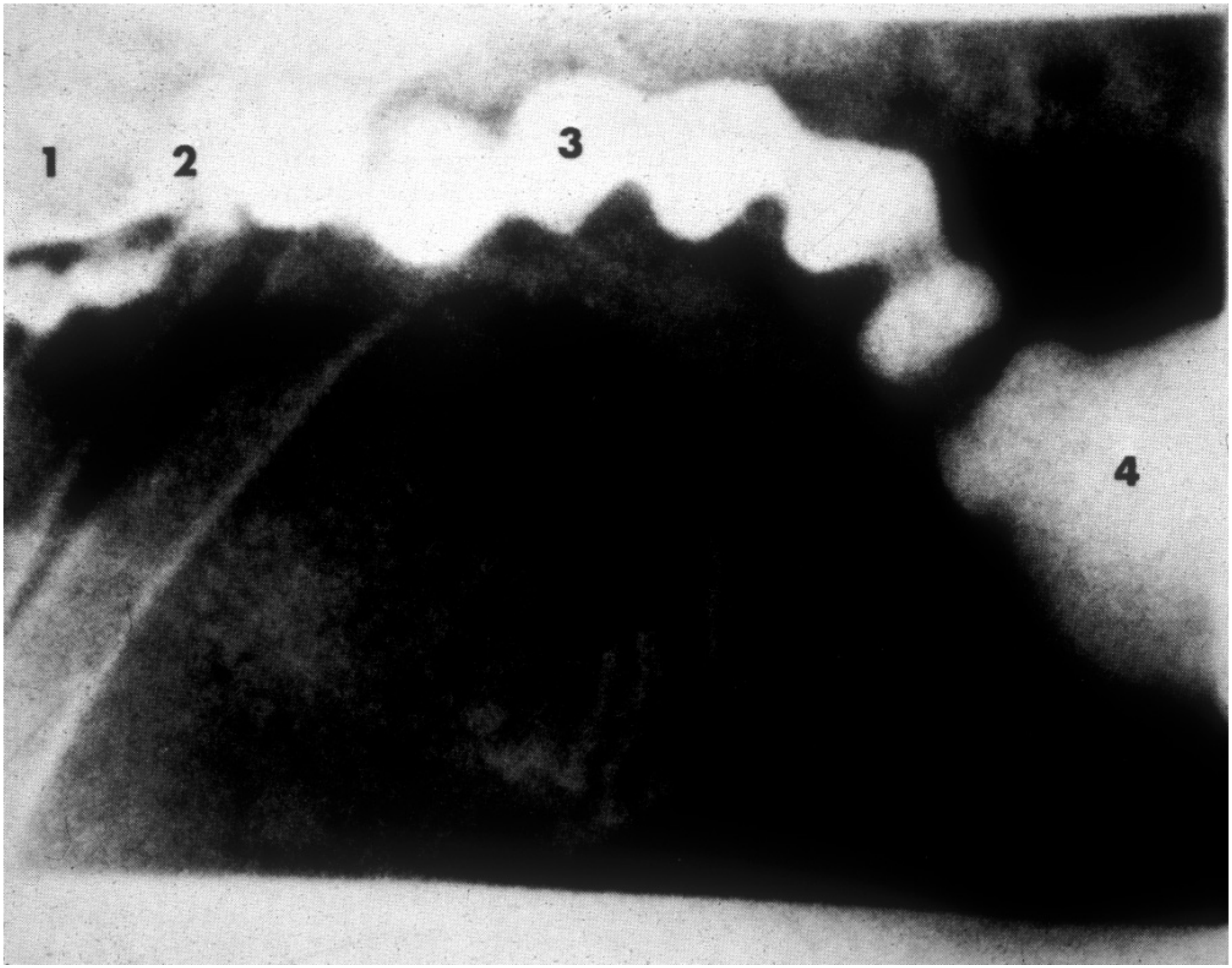
	Male	Female
Kcal/Day	5.3	12.4
% BMR	5.4	11.3

Nature of Protein in Urine of Birds

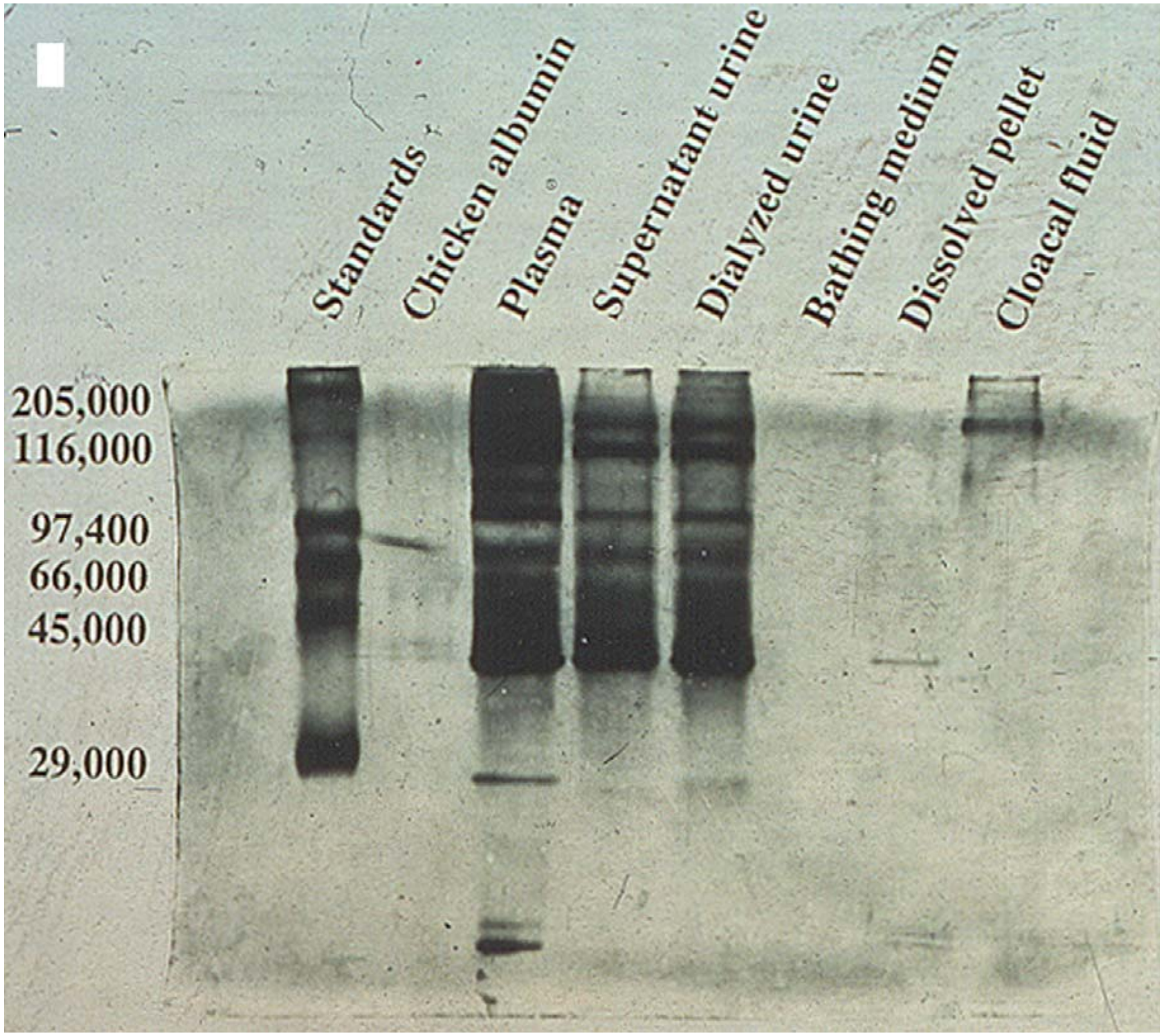
SDS-PAGE of avian urine and plasma



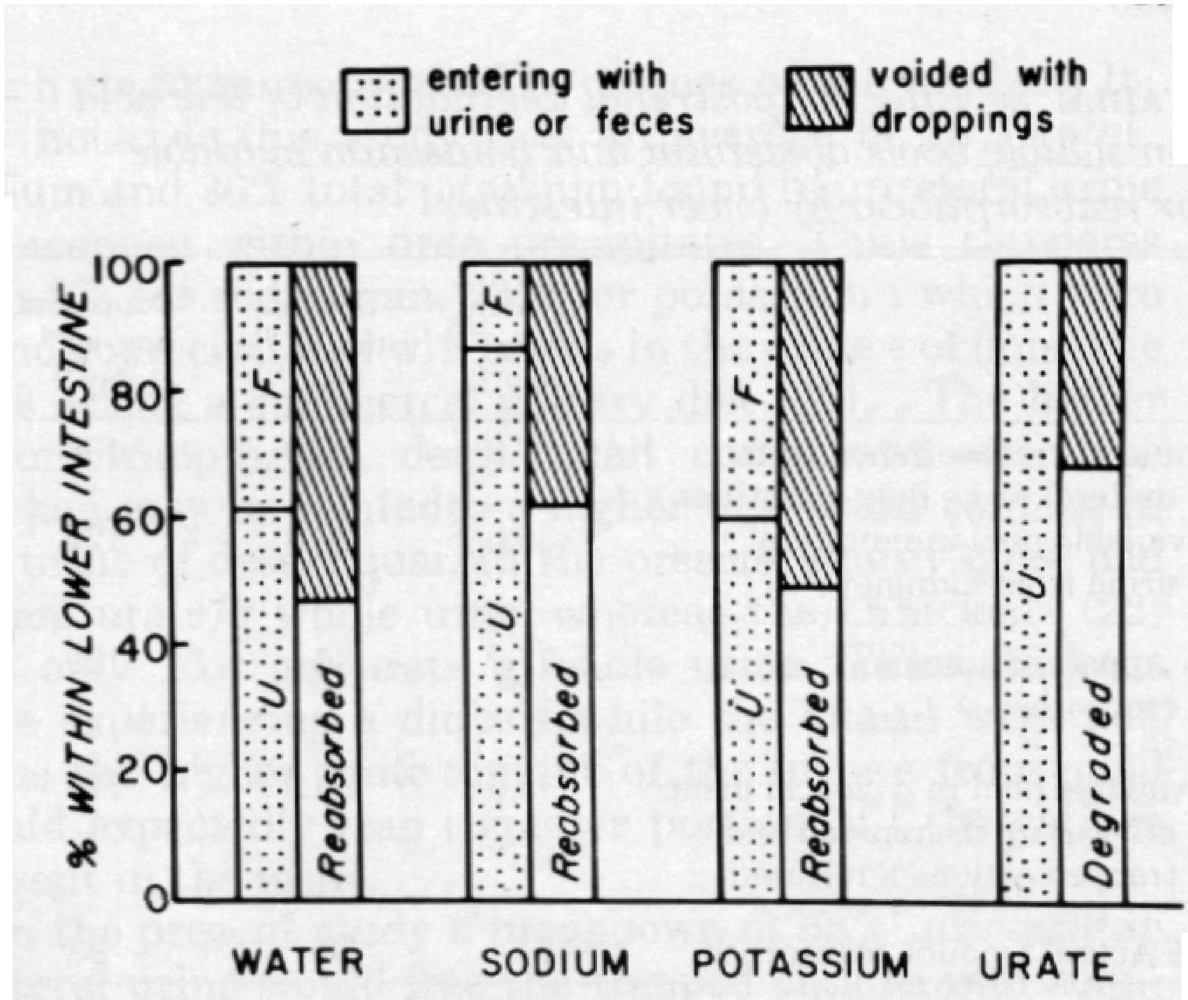
Reverse Peristalsis of Avian lower GI Tract



SDS PAGE of Avian Excreted Fluid



Modification of Urine in Lower GI Tract of Birds



Degradation of Uric Acid in Lower GI Tract

- ❖ 68% of uric acid in ureteral urine
  - ❖ Bacterial action
    - ❖ Fate of liberated nitrogen
      - ❖ Glutamic acid
        - ❖ Renal tubules--Buffer H ions
        - ❖ Gluconeogensis
        - ❖ Citric acid cycle
      - ❖ Short chain volatile fatty acids

Products Formed From the Breakdown of Uric Acid in Avian Lower GI tract

77% of [^{15}N]uric acid introduced into ceca of cockerels disappeared in 60 min

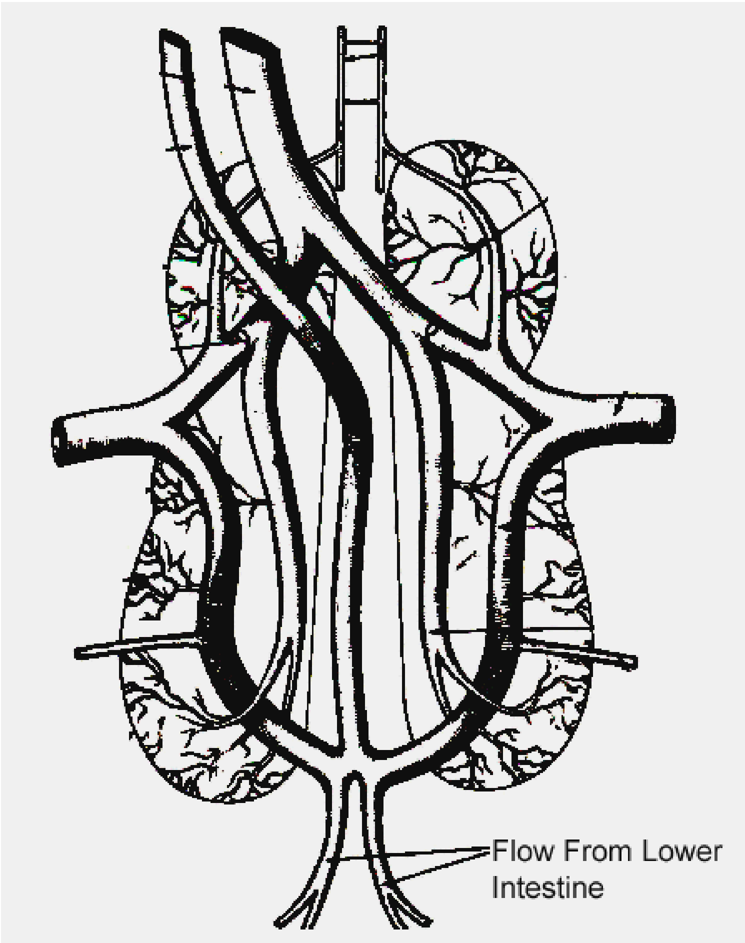
Labelled nitrogen appeared in plasma within glutamine

And nitrogen appeared as ammonia and rapidly absorbed

Where do these product go?

Karasawa, 1989

Vasculature Surrounding the Avian Kidney



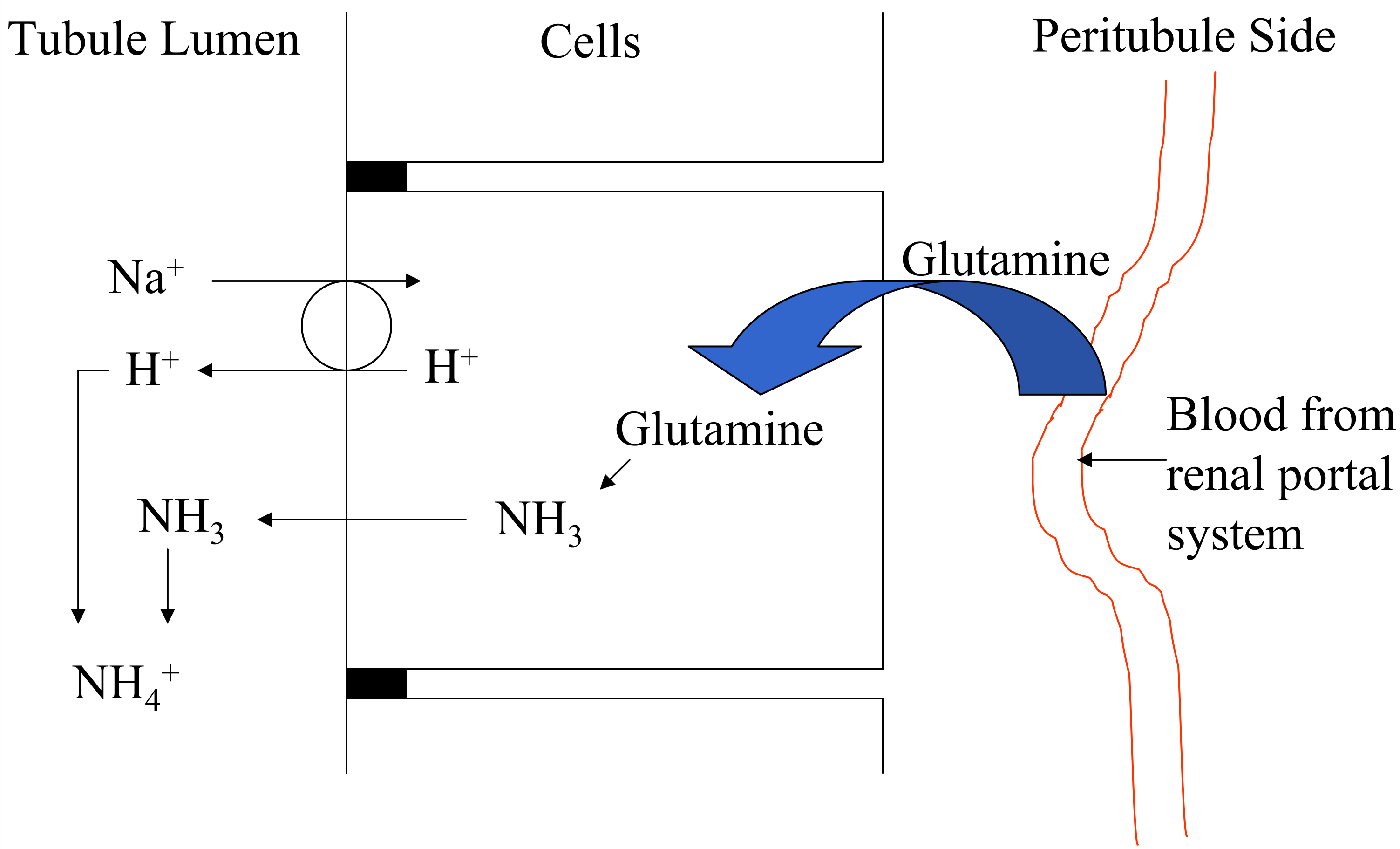
Birds have a functional renal portal system

Coccygomesenteric vein drains into renal portal system

Akester

Use of glutamine by renal tubules

(To buffer hydrogen ions)



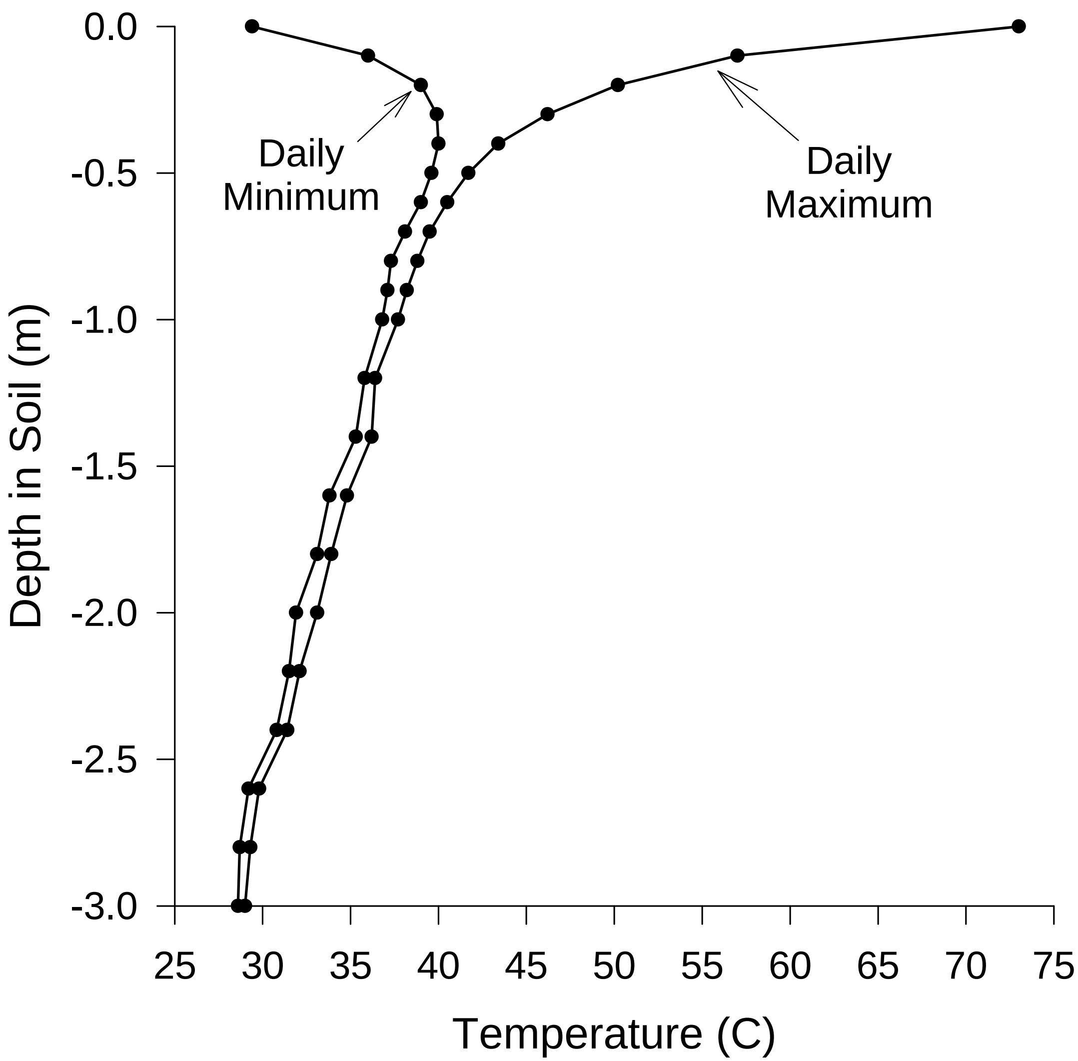
Comparison of Small Birds and Small Mammals in a Desert Environment

Small kangaroo rats made famous by Knut and Bodil Schmidt-Nielsen

Perognathus pencillatus

These animals live in burrows that can be a meter or more in depth

Soil Temperature vs. Depth in Soil



Walsburg, 2000

Black-tailed Gnatcatcher: small bird of Sonoran Desert

Black-tailed Gnatcatcher • Polioptila melanura

Verdin: small bird of Sonoran Desert

Verdin (juvenile) • Auriparus flaviceps

Saguaro Cactus

Skin of Dead Saguaro Cactus

Skin of Dead Saguaro Cactus

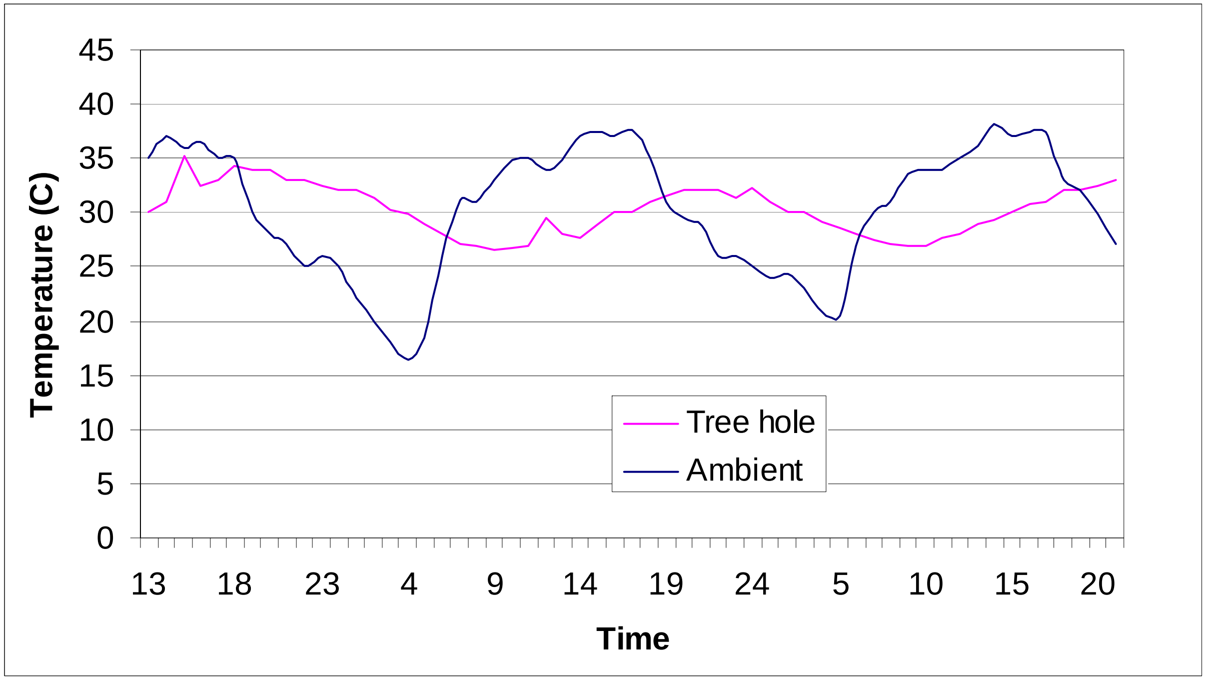
Gilded Flicker

Gila Woodpecker

Elf Owl with young in saguaro cavity

Photo courtesy of Thomas Wiewandt

Comparison of ambient and saguaro cavity temperatures



Data from Soule

Summary

The study of avian physiology has been very interesting and challenging

Birds inhabit a wide range of habitats

May be better able to cope with harsh environments than mammals