"Plant-eaters"

Professor Peter O'DONOGHUE

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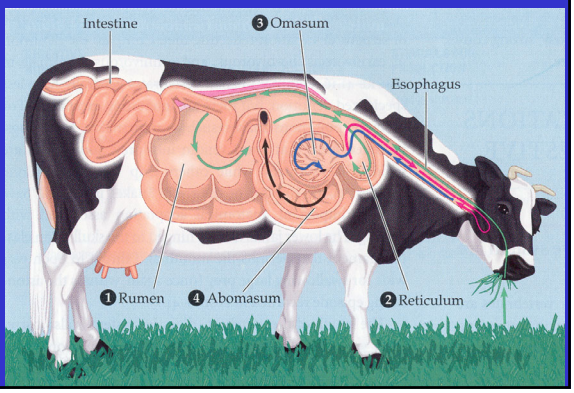
HERBIVORES



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The Paradox of Herbivory

- numerous animals ingest plant material
- but tough to digest (cellulosic cell walls)
- reliant on anaerobic fermentation
- mediated by endosymbiotic micro-organisms
  - bacteria, protozoa, fungi produce cellulases
  - generate volatile fatty acids
  - recycle microbial protein

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Metabolism

glycolysis:

$C_6H_{12}O_6$ → $C_3H_3O_3$ → further oxidised in presence of oxygen

glucose pyruvate (aerobic respiration)

reduced in absence of oxygen

(anaerobic fermenation)

→ $C_3H_6O_3$ lactic acid (homolactic/heterolactic)

→ C_2H_5OH ethanol (alcoholic)

alcohol break down to acetate and hydrogen:

$2C_2H_5OH + 2H_2O \rightarrow 2C_2H_3O_2 + 4H_2$ (excess hydrogen bad!)

in aerobic systems, excess hydrogen bound to oxygen and removed as water

in anaerobic systems, hydrogen bound to carbon dioxide and removed as methane

$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$ (methanogenesis)

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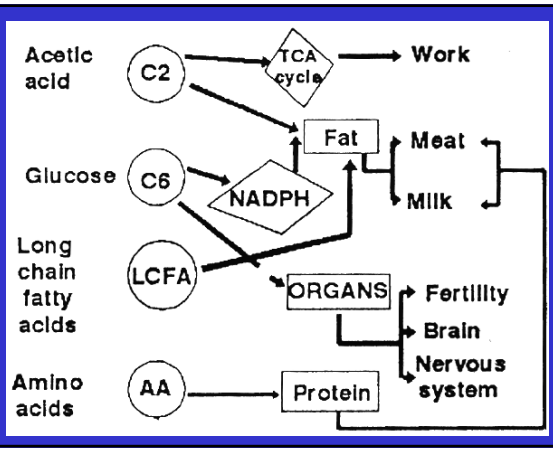

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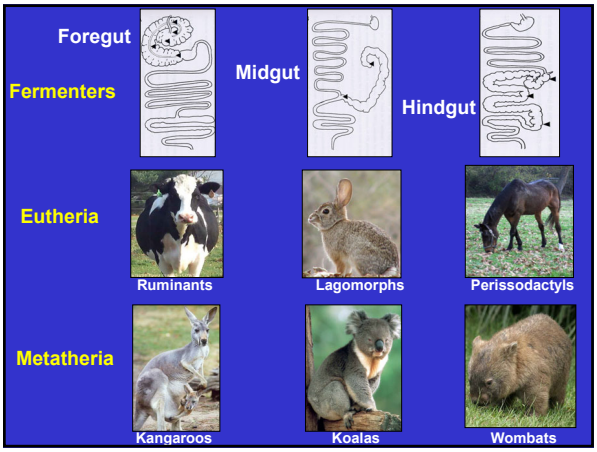

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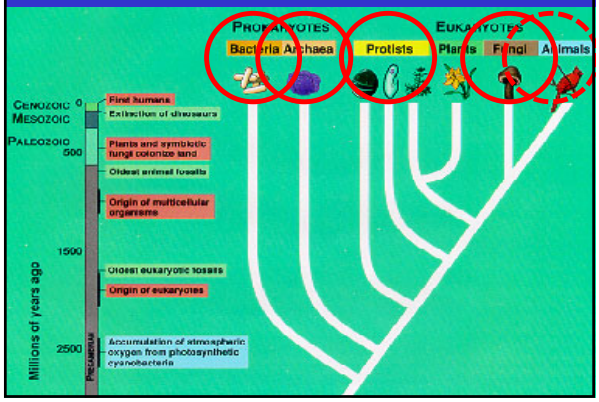
Endosymbiotic Micro-organisms



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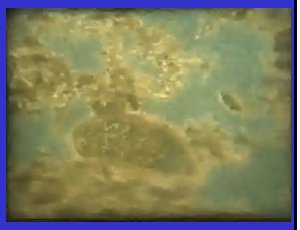
Rumen Ciliates



ruminants
- domestic (cattle, sheep, goats)
- feral (deer, buffalo)

ciliates
- trichostomes
- entodiniomorphids

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SURVEY

		Number examined	Percentage prevalence	Concentration #/ml
SEX	Male	50	92%	2.8×10^5
	Female	20	95%	3.2×10^5
BREED	British breeds	35	91%	2.8×10^5
	Brahman cross	35	94%	3.2×10^5
LOCATION	SE-QLD	50	92%	2.8×10^5
	Central QLD	20	95%	3.2×10^5
DIET	Feed-lot	17	88%	2.8×10^5
	Free-range	53	94%	3.2×10^5
TOTAL		70	93%	3.1×10^5

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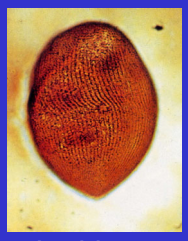
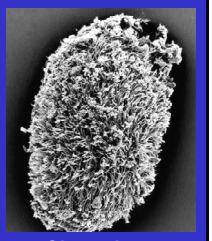
Trichostomes





Isotricha *Dasytricha* *Charonina*

3 genera, 4 species

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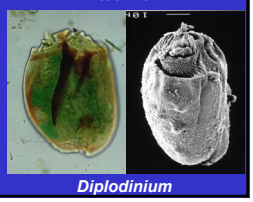
Entodiniomorphid ciliates

Genus	No. species
Entodinium	18
Diplodinium	9
Eudiplodinium	1
Eremoplastron	1
Ostracodinium	2
Metadinium	1
Polyplastron	1
Epidinium	2

8 genera, 35 species

Entodinium



Diplodinium

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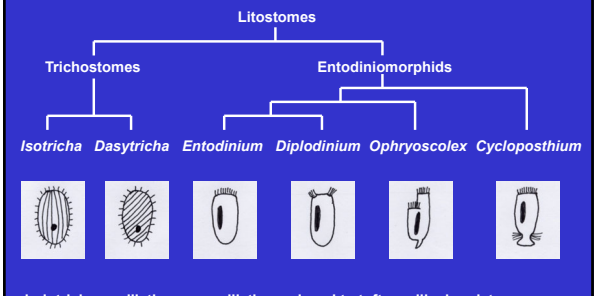
Major Endosymbiotic Ciliates



holotrichous ciliation

ciliation reduced to tufts, pellicular plates

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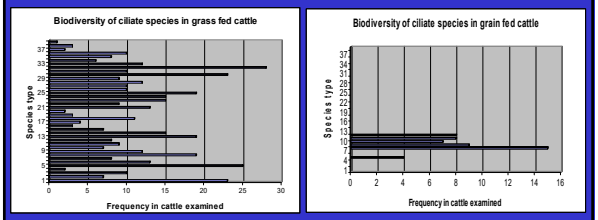
Ciliate community structures



Free-range (grass-fed) cattle

- broad range of species
- 39 ciliate species *in toto*

Feed-lot (grain-fed) cattle

- narrow range of species
- 6 *Entodinium* spp. only

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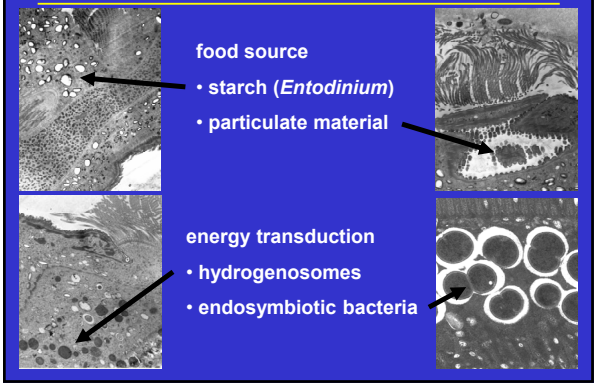
Ultrastructure



food source

- starch (*Entodinium*)
- particulate material

energy transduction

- hydrogenosomes
- endosymbiotic bacteria

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compare sheep and goats

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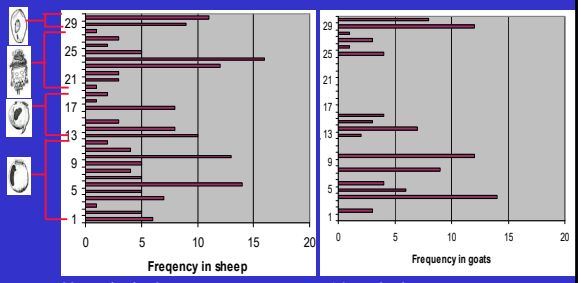
Host specificity



29 species in sheep
Broad range

16 species in goats
Restricted- mostly *Entodinium*

15 species shared

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Comparison

Greater biodiversity (species + abundance) in sheep than in goats

- may be related to **DIET**
- Sheep are grazers: cellulose-rich grasses
- Goats are browsers: starch-rich forbs, leaves, stems, some grass

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Rumen ciliates of deer in Australia

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	DIVERSITY
Host Species	• Red deer - 20 spp. • Rusa deer - 18 spp. • Fallow deer – 11 spp.
Host Gender	•Male deer (25 spp.) •Female deer (22 spp.)
Host Age	•↑ in mature deer (17-21 spp.) •1-4 years old (11- 12 spp.) • 8 and 12 years old (NEGATIVE)
Farmed Vs Wild	•↑ in wild deer (29 spp.) •↓ in farmed deer (17 spp.)
Geographic location	• Some variation in species richness (10-16 spp.)

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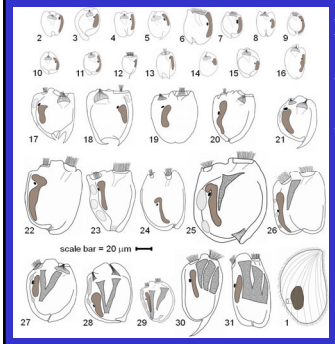
Ciliate Diversity



Differ in size

- smaller species (abundant)
- feeding strategies:
  - starch
  - particulate material
  - bacteria

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Comparison

- 31 ciliate species identified in 3 deer species
- ↑ ciliate concentrations in rusa deer
- ↑ species richness in red deer
- smaller ciliate species were in abundance
- no ciliates possessed mitochondria
- hydrogenosomes and coccoid bacteria present

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Macropodid Ciliates

marsupials
- **macropodids (kangaroos, wallabies)**

ciliates
- **trichostomes?**
- **entodiniomorphids?**

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Macropod Survey

Host species	N° exam.	% prev.
Potoridae (rat kangaroos) *Hypsiprymnodon, Aepyprymnus*	4	0
Peramelidae (bandicoots) *Isoodon, Perameles*	2	0
Dasyuridae (dasyurids) *Dasyurus*	1	0
Phalangeridae (possums) *Trichosurus*, Pseudocheirus	14	0
Vombatidae (wombats) *Lasiorhinus, Vombatus*	29	62%
Macropodidae (kangaroos and wallabies)		
Dendrolagus (tree kangaroos)	8	0
Lagorchestes (mala)	1	0
Macropus (kangaroos)	91	70%
Macropus (wallaroos)	36	86%
Macropus (wallabies)	104	55%
Onychogalea (nailtail wallabies)	3	0
Petrogale (rock wallabies)	19	84%
Setonix (quokkas)	5	80%
Thylogale (pademelons)	43	58%
Wallabia (swamp wallabies)	11	100%
TOTAL	371	61%

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Bandia gen. nov.

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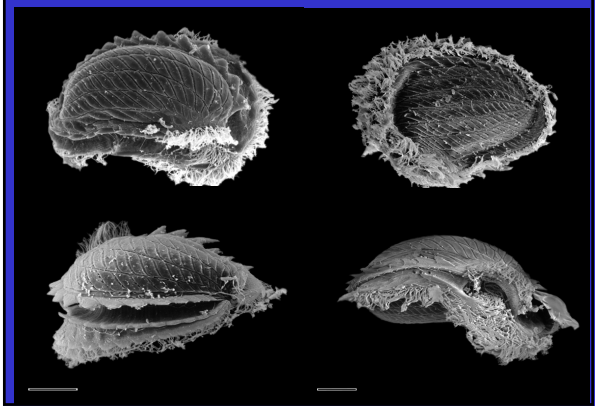
Macropodinium Dehority, 1996



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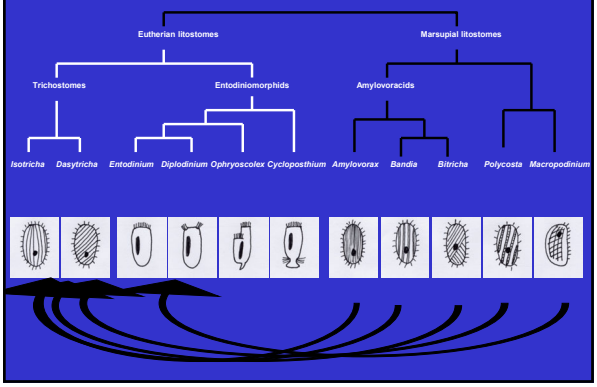
PRESUMPTIVE RELATIONSHIPS



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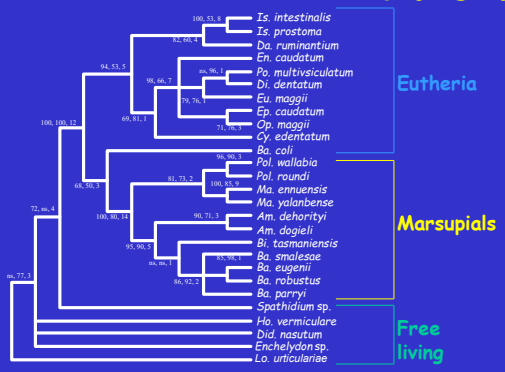
small subunit ribosomal RNA phylogeny



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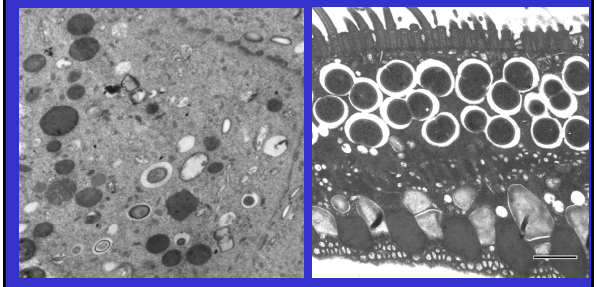
Organelles of energy transduction (no mitochondria)

some with hydrogenosomes | **some with symbiotic bacteria**



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Protozoan symbionts in hindgut-fermenting mammals HORSES

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Ciliate biodiversity in horses

Species Richness

HORSES	Number of ciliate species			
	Entodiniomorphids	Trichostomes	Suctoria	TOTAL
QLD	34	10	2	46
VIC	29	5	1	35

Relative Abundance

HORSES	Ciliate concentration (number per ml)			
	Entodiniomorphids	Trichostomes	Suctoria	TOTAL
QLD	1.9 million	0.1 million	0.003 million	2.1 million
VIC	0.2 million	0.01 million	0.001 million	0.2 million

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53 Ciliate Species identified

Entodinomorphida
- 8 species of cycloposthiids
- 5 species of spirodiniids
- 9 species of ditoxids

Trichostomatida
- 5 species of paraisotrichids
- 8 species of blepharocorythids
- 16 species of buetschlids

Suctoria
- 2 species of acinetids

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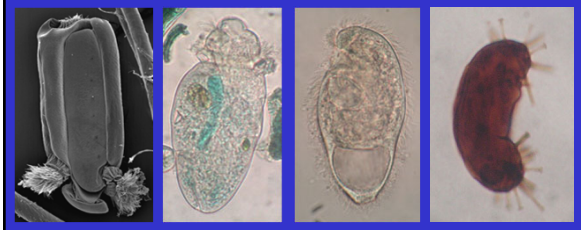
Exemplars

Cycloposthiids | **Spirodiniids** | **Paraisotrichids** | **Acinetids**



Cycloposthium scutigerum | *Spirodinium confusum* | *Paraisotricha colpoidea* | *Allantosoma intestinalis*

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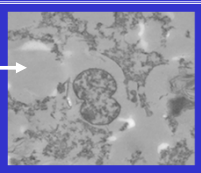
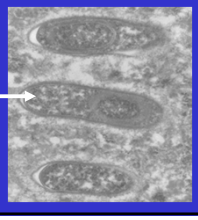
Organelles of Energy Transduction

Paraisotricha colpoidea
- **starch granules**
- **no mitochondria, no hydrogenosomes no endosymbiotic bacteria**



Cycloposthium bipalmatum
- **endosymbiotic bacteria?**
- **no mitochondria no hydrogenosomes**



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Wombat species

Common Wombat | Southern hairy-nosed wombat | Northern hairy-nosed wombat

Vombatus ursinus | *Lasiorhinus latifrons* | *Lasiorhinus krefftii*

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Ciliate biodiversity in wombats

Species Richness

WOMBATS	Number of ciliate species			
	Entodiniomorphids	Trichostomes	Suctoria	TOTAL
22 common	0	6	0	6
5 hairy-nosed	0	3	0	3

Relative Abundance

WOMBATS	Ciliate concentration (number per ml)			
	Entodiniomorphids	Trichostomes	Suctoria	TOTAL
22 common	0	10,000	0	10,000
5 hairy-nosed	0	400	0	400

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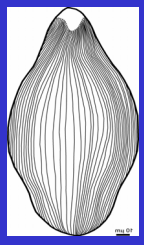
6 Ciliate Species identified

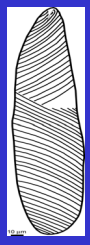
Amylovaracids

5 *Amylovorax* spp.



longitudinal kineties

1 *Bitricha* sp.



2 transverse fields

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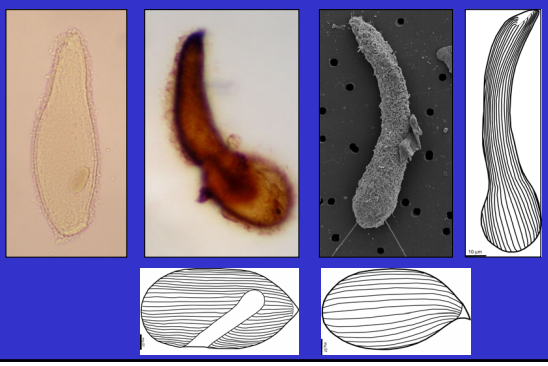
Amylovorax morphotypes



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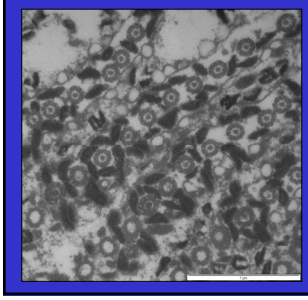
Organelles of Energy Transduction

Amitochondriate

Hydrogenosomes



Endosymbiotic Bacteria

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Termite flagellates

termites
- **social insects** (higher/lower)
- **nest type** (dampwood/drywood/subterranean)

flagellates
- **trichomonads**
- **hypermastigids**

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SE Queensland survey

Termite family	Habitat type	Castes	Number colonies
Lower			
Rhinotermitidae	Subterranean	workers, soldiers, alates	38
Kalotermitidae	Drywood	workers, soldiers, alates	2
Higher			
Termitidae	Subterranean	Workers, soldiers	20
			60

all lower termites had endosymbiotic flagellates

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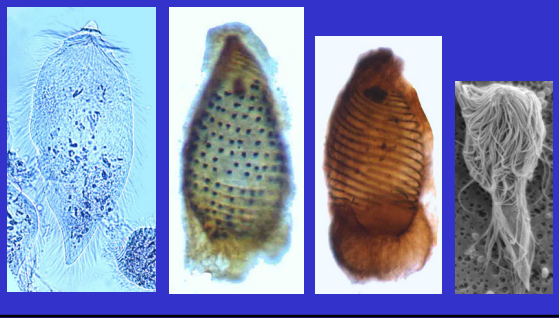
Hypermastigids abundant in rhinotermitids

Pseudotrichonympha Spirotrichonympha Holomastigotoides Microjoenia



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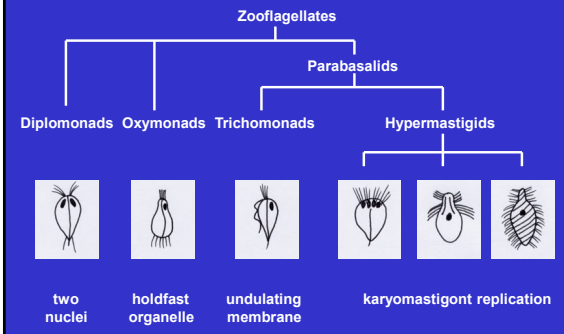
Major Endosymbiotic Flagellates



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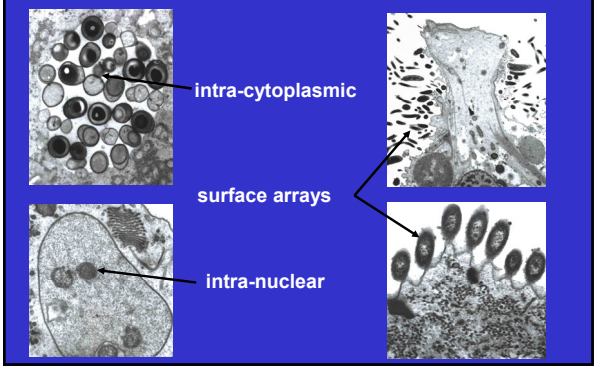
Endo-symbiotic bacteria

Ecto-symbiotic bacteria



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CONCLUSIONS

RUMINANT CILIATES (cattle, sheep, goats, deer)
- starch feeders with hydrogenosomes
- particulate feeders with endosymbiotic bacteria

MACROPODID MARSUPIAL CILIATES (kangaroos, wallabies)
- starch feeders with hydrogenosomes
- particulate feeders with endosymbiotic bacteria

HINDGUT FERMENTERS (horses, wombats)
- starch feeders with hydrogenosomes
- particulate feeders with endosymbiotic bacteria

TERMITE FLAGELLATES
- starch feeders with hydrogenosomes?
- particulate feeders with symbiotic bacteria?

SAME PROBLEM SOLVED THROUGH EVOLUTION
- divergent organismal evolution
- conserved organelle evolution? SET?

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