ICTP-SAIFR. Jan 2015

'The Wonderful World of Macroparasites'

Andy Dobson

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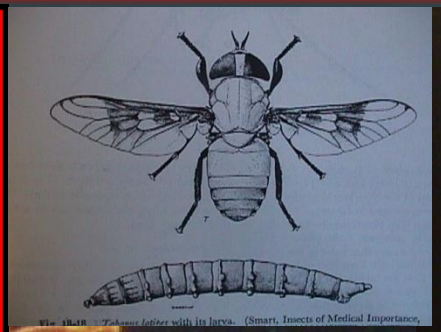
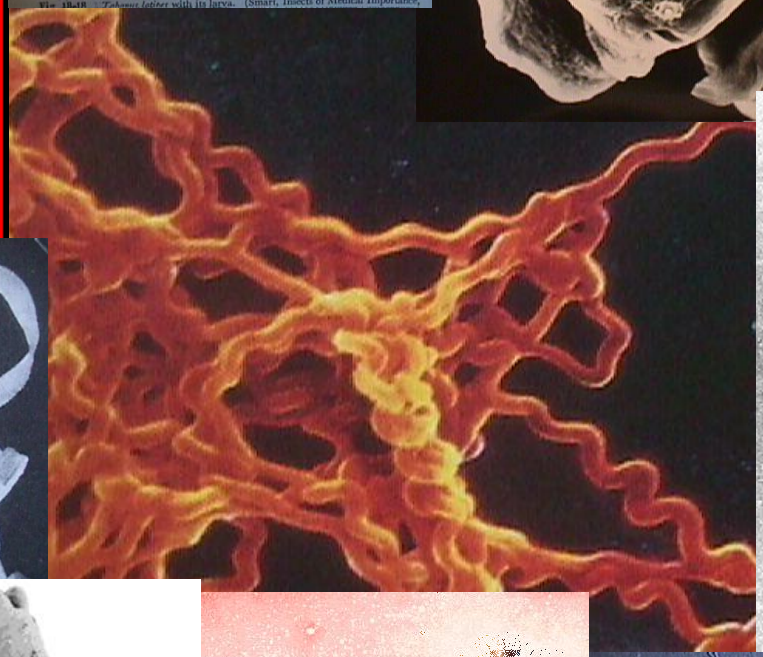
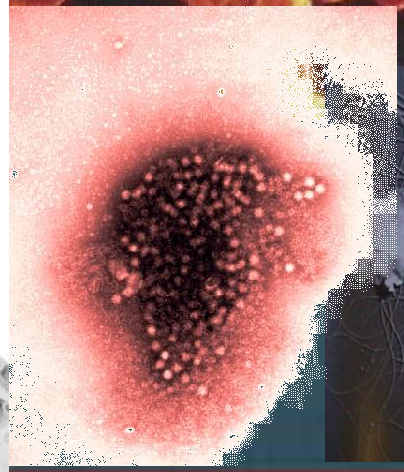
Cymothoa exigua
in
rose spotted snapper

There are some really,
really cool
parasites
out
there

Pathogens







Happy Birthday…Chuck!!

Outline

- How many species are there?
- How many parasitic species are there?
- The population dynamics of one very special macroparasitic worm….
- Is there any good news?

CAROLI LINNÆI
Naturæ Curioſorum *Dieſcoridis Secundi*

SYSTEMA NATURÆ

IN QUO
NATURÆ REGNA TRIA,
SECUNDUM
CLASSES, ORDINES, GENERA, SPECIES,
SYSTEMATICE PROPONUNTUR.

Editio Secunda, Auctior.

STOCKHOLMIÆ
Apud GOTTFR. KIESEWETTER.
1740.

CAROLI LINNÆI REGNUM ANIMALE.

I. QUADRUPEDIA.

II. AVES.

III. AMPHIBIA.

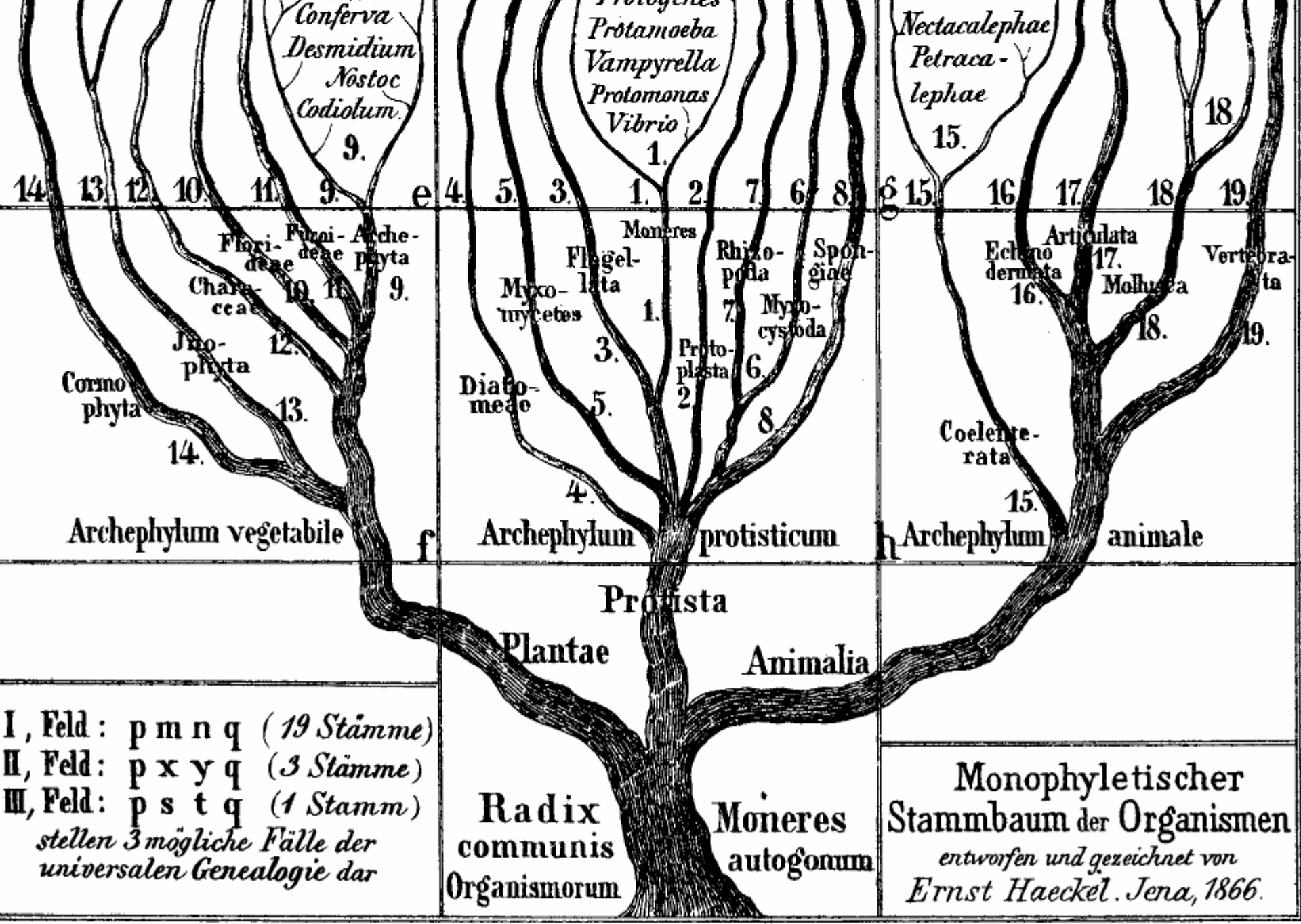
IV. PISCES.

V. INSECTA.

VI. VERMES.

PARADOXA

Ordines. Genera. Characteres Generici. Species.


Conferva
Desmidium
Nostoc
Codiolum
9.
Protogenes
Protamoeba
Vampyrella
Protomonas
Vibrio
1.
Nectacalephae
Petraca-
lephae
15.
18.
14 13 12 10 11 9. e 4. 5. 3. 1. 2. 7. 6. 8. g 15. 16. 17. 18. 19.
Flori-
deae
Fungi-
deae
Arche-
phyta
9.
Chara-
ceae
10. 11.
Moneres
Flagel-
lata
Myxo-
mycetes
1.
Rhizo-
poda
7.
Spon-
giae
Myxo-
cystoda
Articulata
Echino-
derma-
ta
16.
17.
Molluska
Vertebra-
ta
18.
19.
Jugo-
phyta
12.
3.
Proto-
plasta
2.
6.
Cormo-
phyta
13.
Diato-
meae
5.
8.
Coelente-
rata
14.
4.
15.
Archephylum vegetabile f
Archephylum protisticum
h Archephylum animale
Protista
Plantae
Animalia
I, Feld: p m n q (19 Stämme)
II, Feld: p x y q (3 Stämme)
III, Feld: p s t q (1 Stamm)
stellen 3 mögliche Fälle der universalen Genealogie dar
Radix
communis
Organismorum
Moneres
autogonum
Monophyletischer
Stammbaum der Organismen
entworfen und gezeichnet von
Ernst Haeckel. Jena, 1866.
b
d

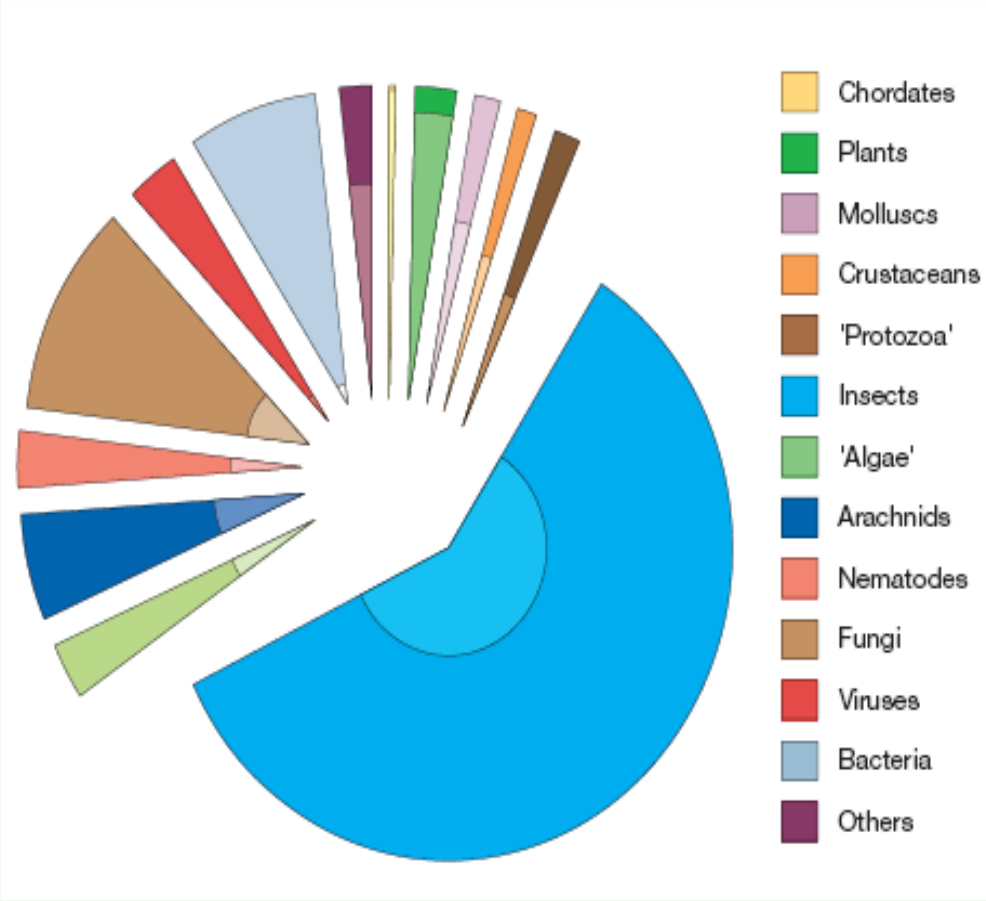
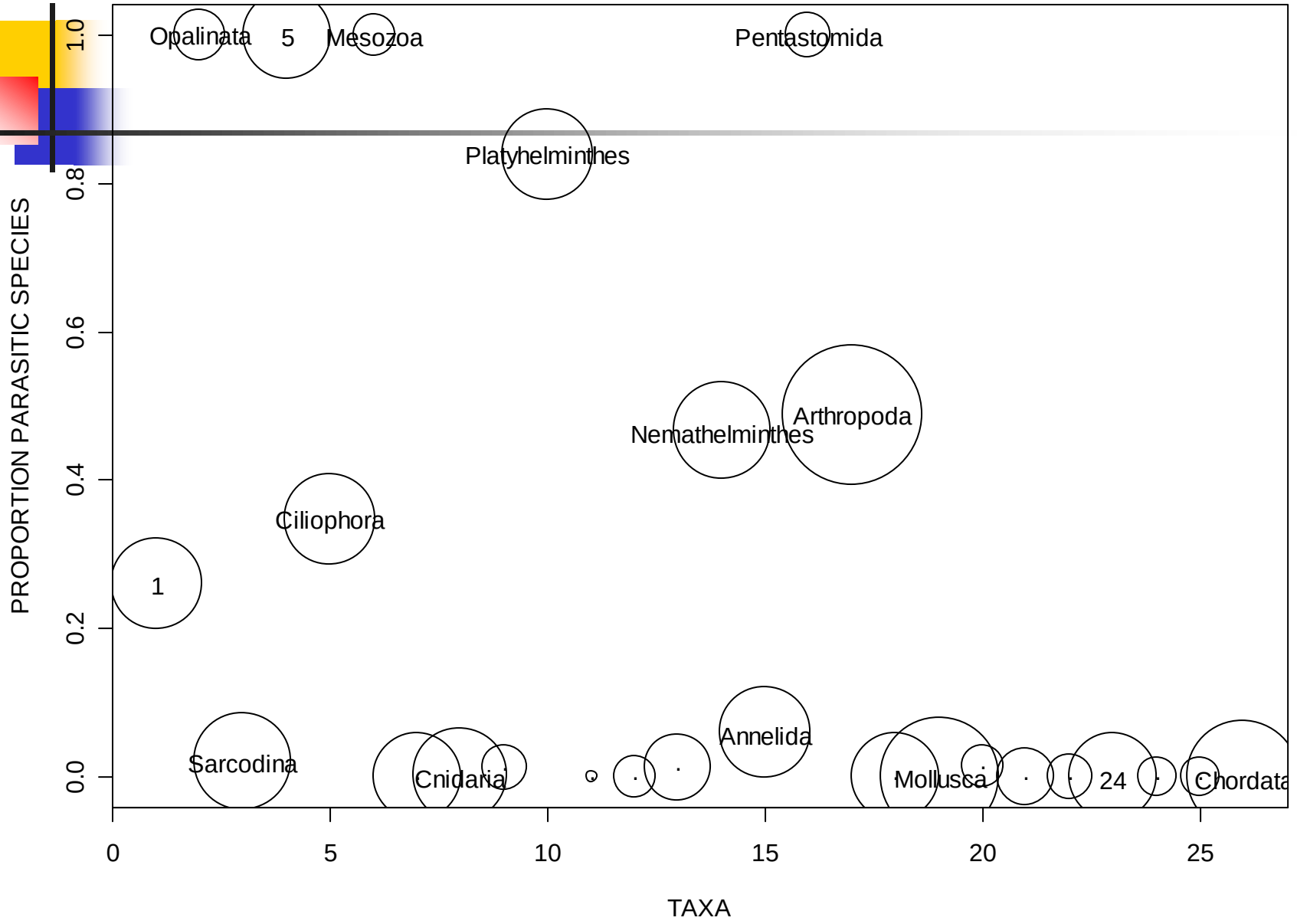


Figure 4 Species richness in major groups of organisms. The main 'pie' shows the species estimated to exist in each group; the hatched area within each slice shows the proportion that have been formally described. Data from ref. 7.

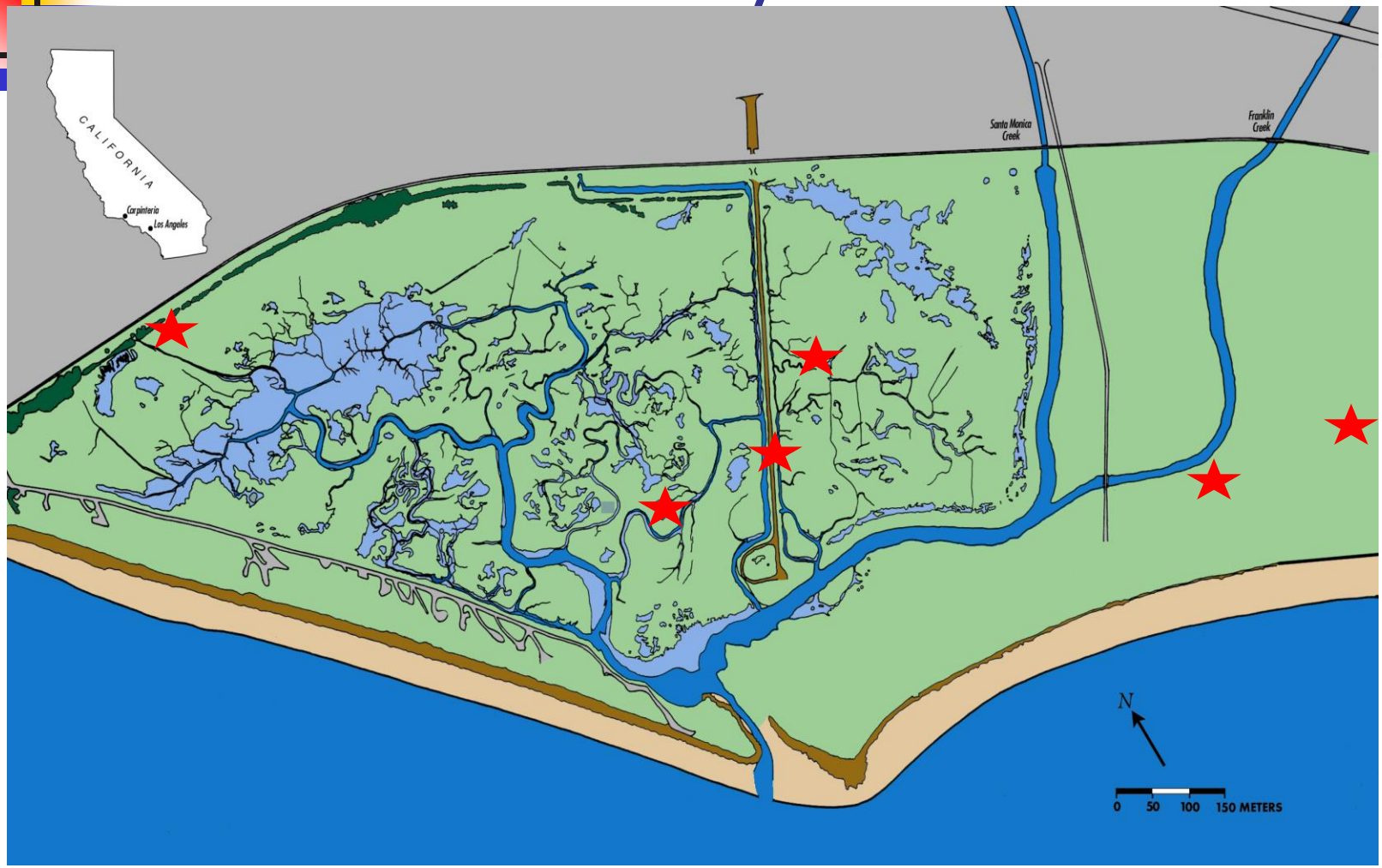
Getting the measure of Biodiversity
Andy Purvis and Andy Hector,
Nature 405, May 2000.

Phylogenetic distribution of parasitism



How much biodiversity is there in a tidal marsh??

Carpinteria Salt Marsh
Santa Barbara County CA USA



(Work with Kevin Lafferty, Armand Kuris, and UCSB/NIH/NSF Saltmarsh Parasite Project

USGS

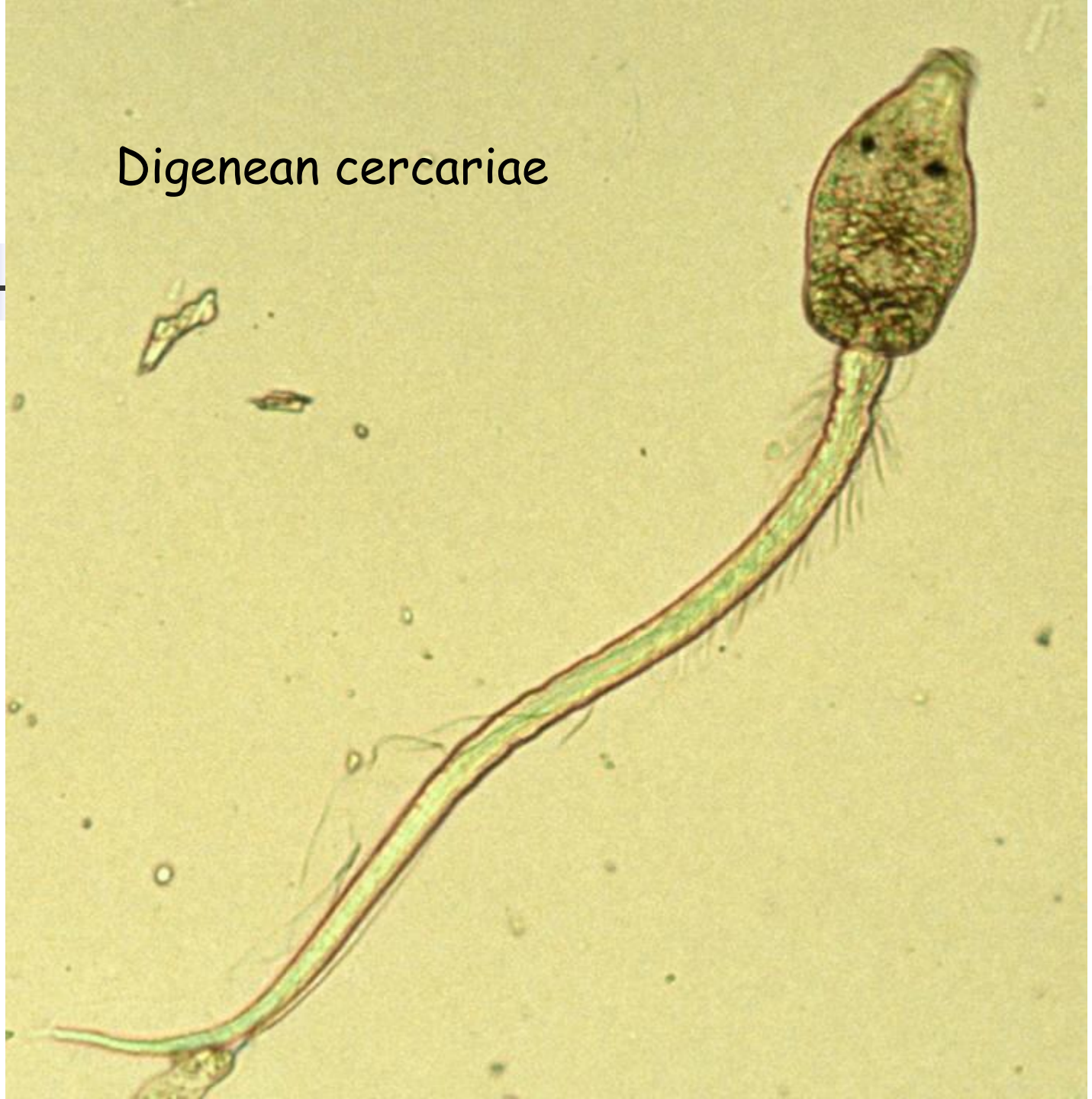
UCSB
Salt marsh
Parasite food-web
Team in action.


VAUGHAN
FINE TOOLS SINCE 1869
SuperSteel
MADE IN U.S.A.
USGS

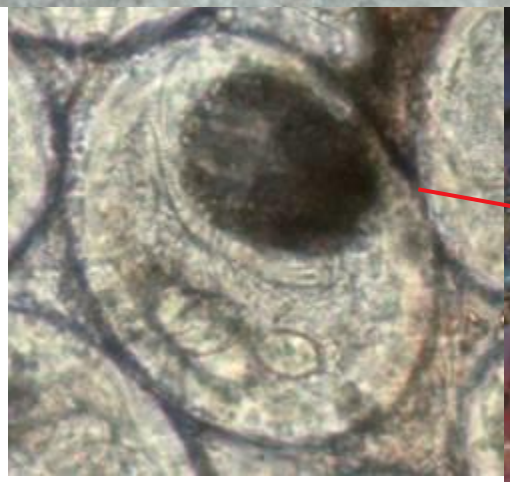
All trematodes identified to species

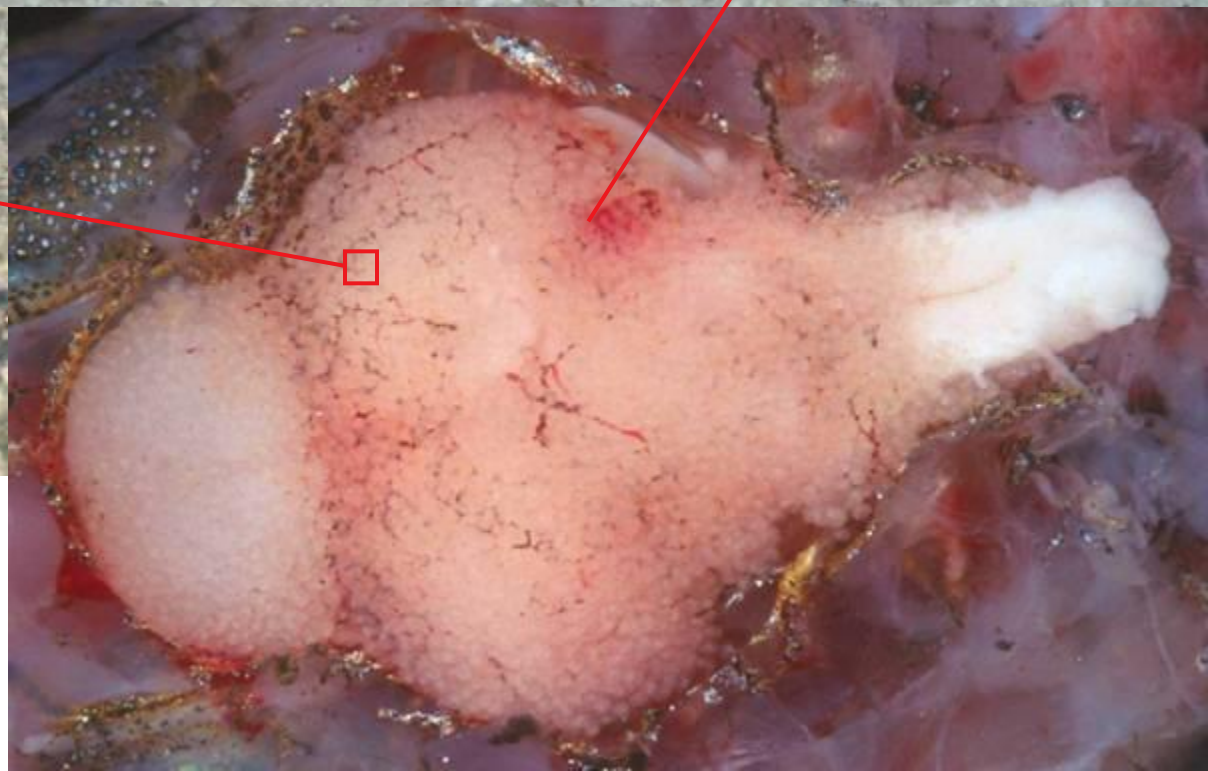
USGS

Digenean cercariae



Euhaplorchis californiensis metacercariae coat the killifish's brain





Lafferty and Morris 1996,
***Ecology* 77:1390-1397**

What do food webs look like?

Tertiary consumers

Primary/secondary consumers

Primary producers

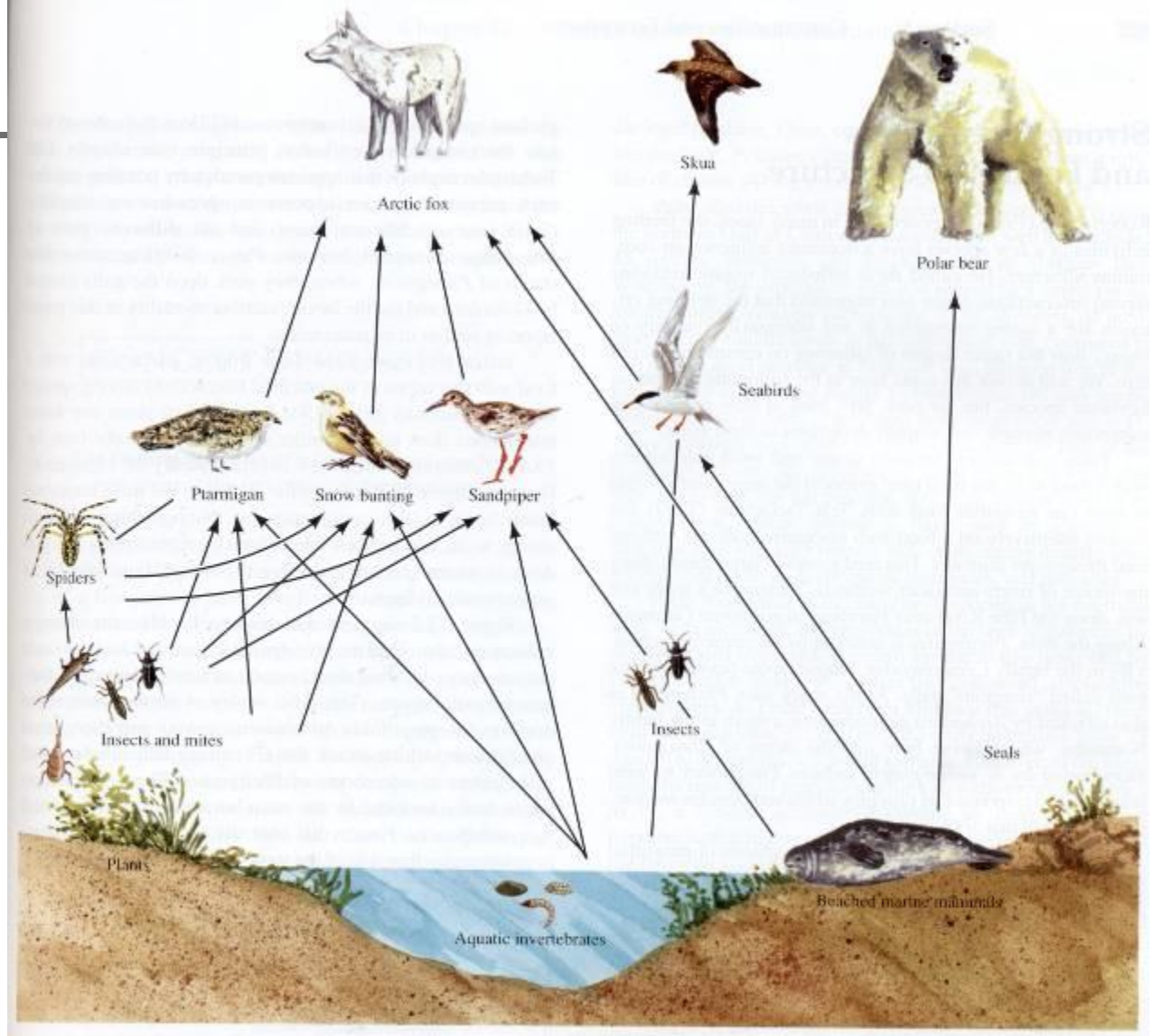


Figure 17.3 Simple food web of an Arctic island.

Peter LaTourrette

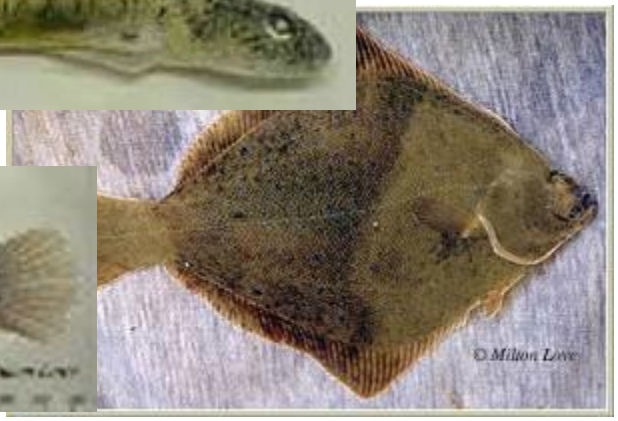






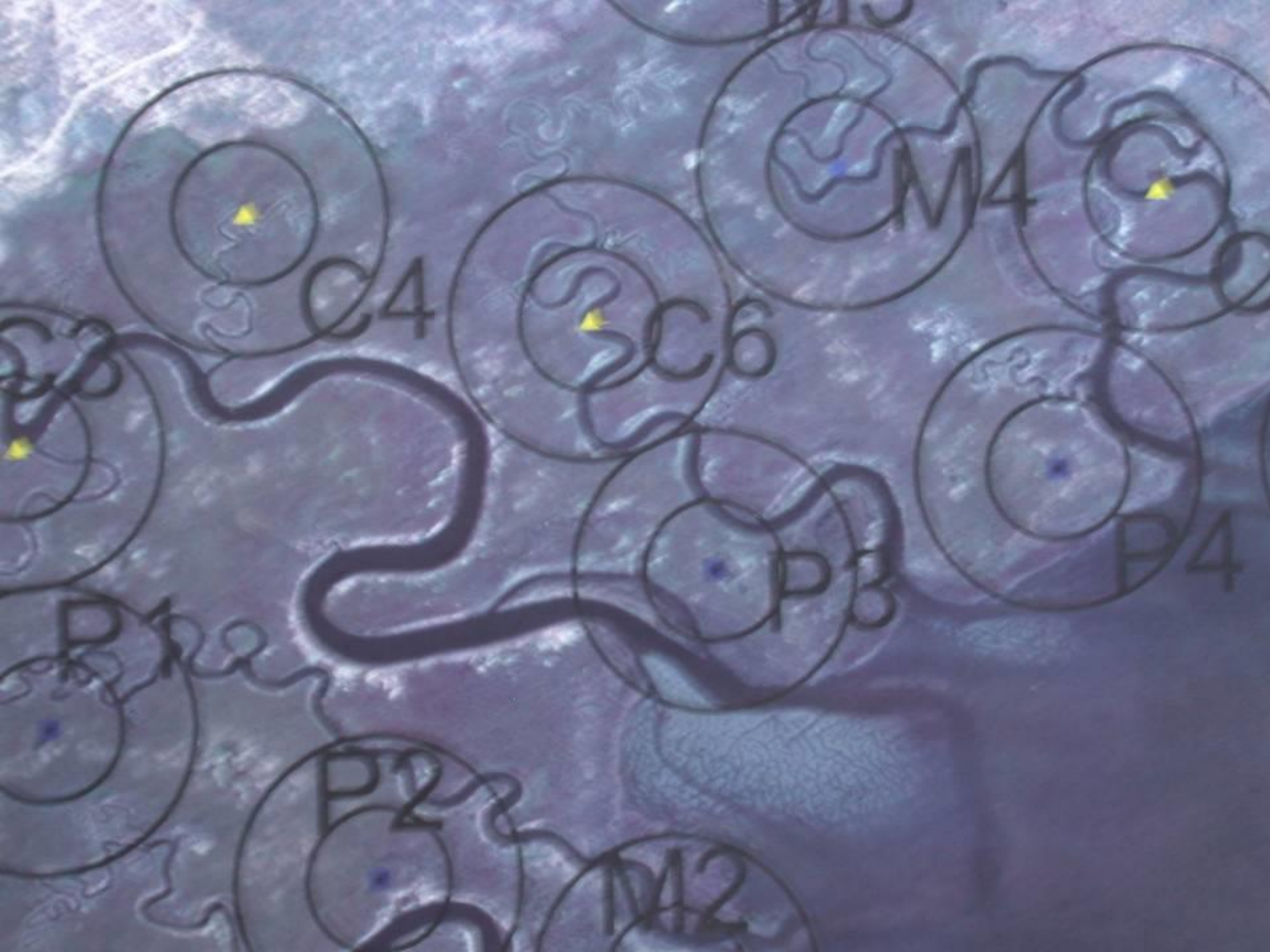
Milton Love





©Milton Love


1 mm
1 cm

3 Coastal Wetlands


M3
M4
C4
C6
P1
P2
P3
P4
M2

Snail sampling at each site:

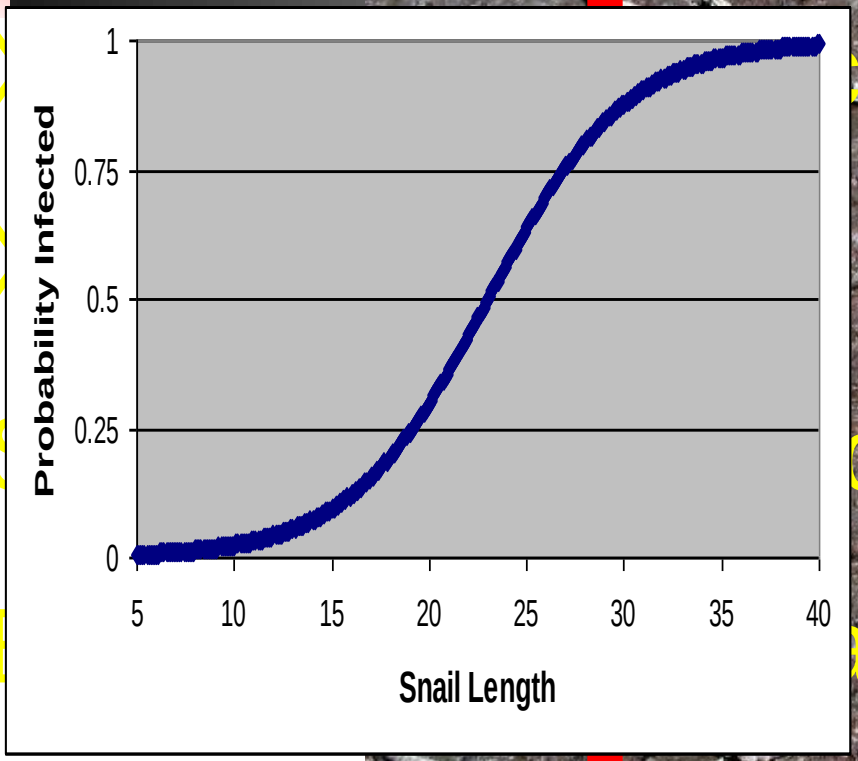
- **20 random quads**
- **Measure and count every snail**

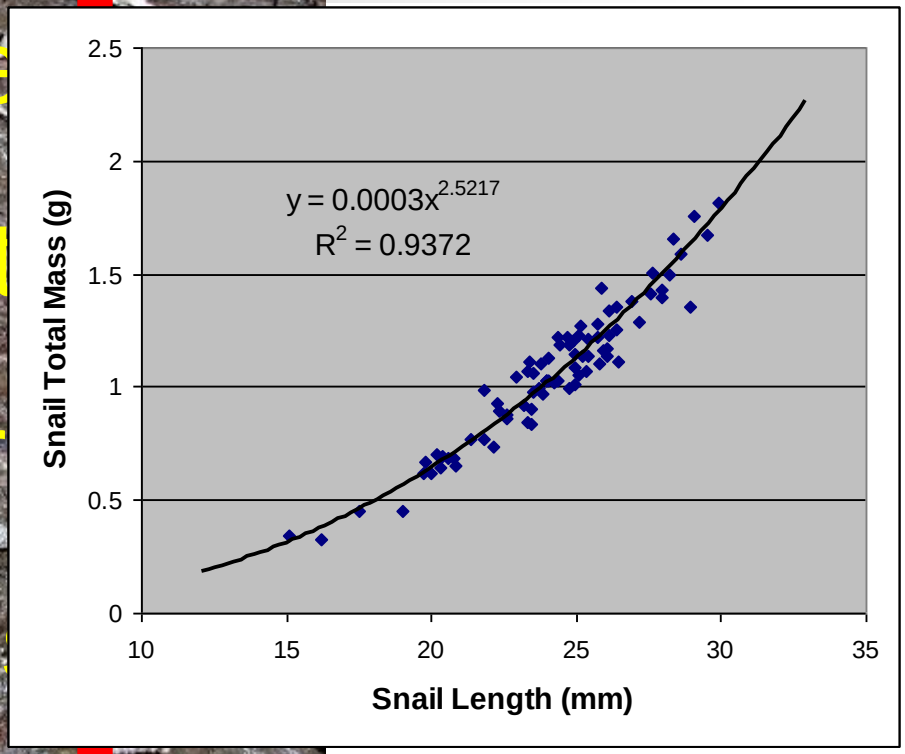
→ Density and Size-frequency distributions

UCSB
Salt marsh
Parasite food-web
Team in action.

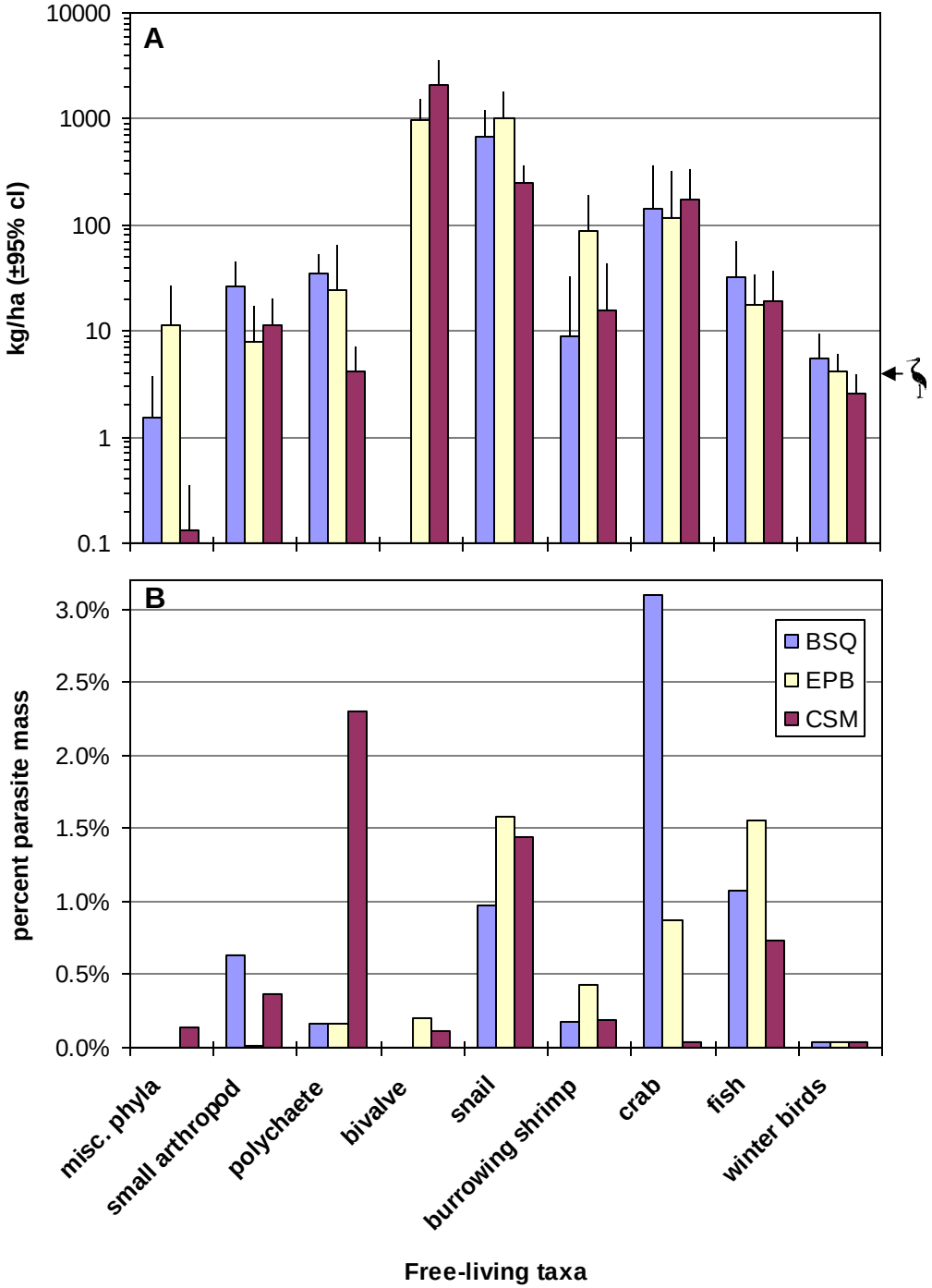
How to calculate biomass?

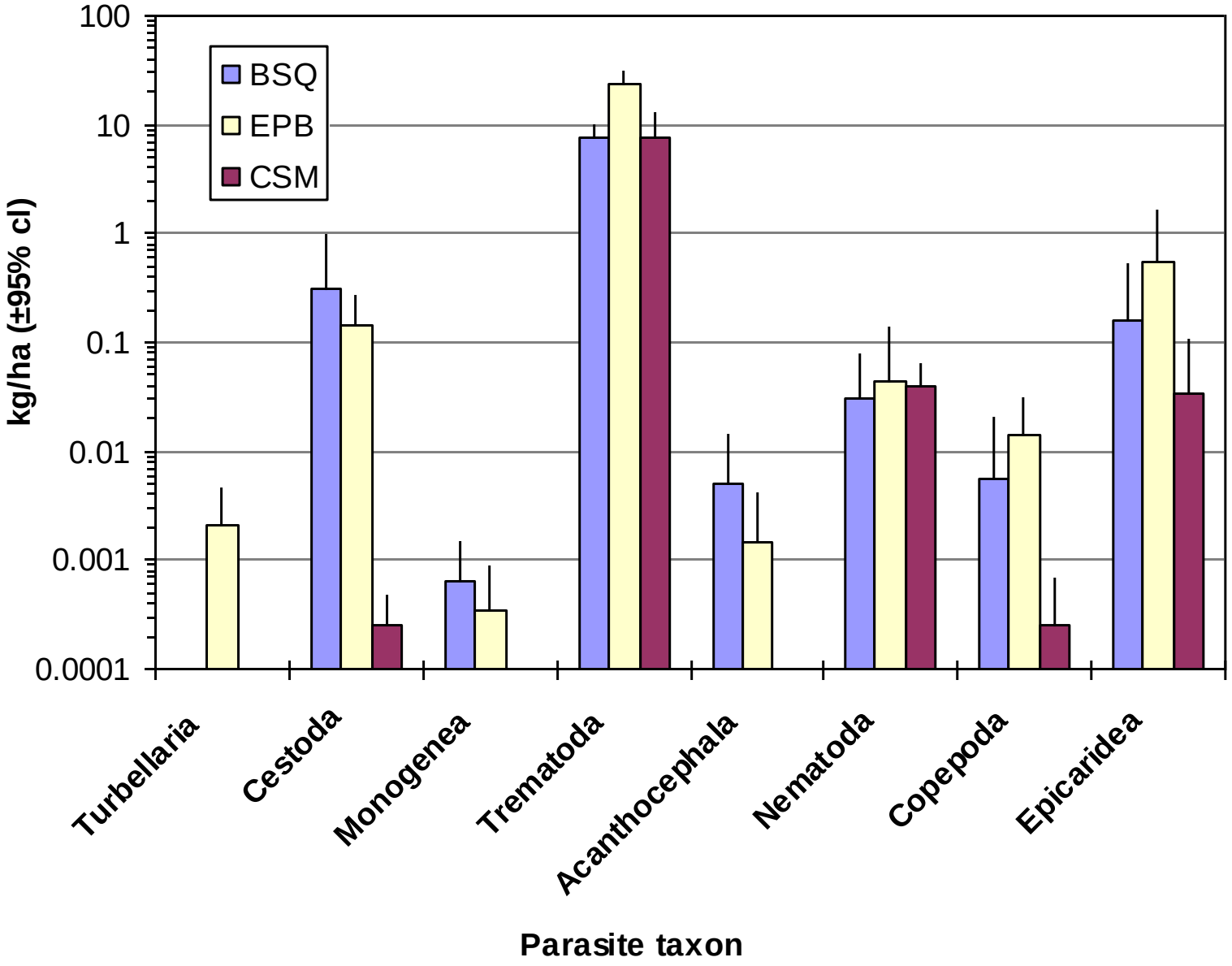
(individual snail length)



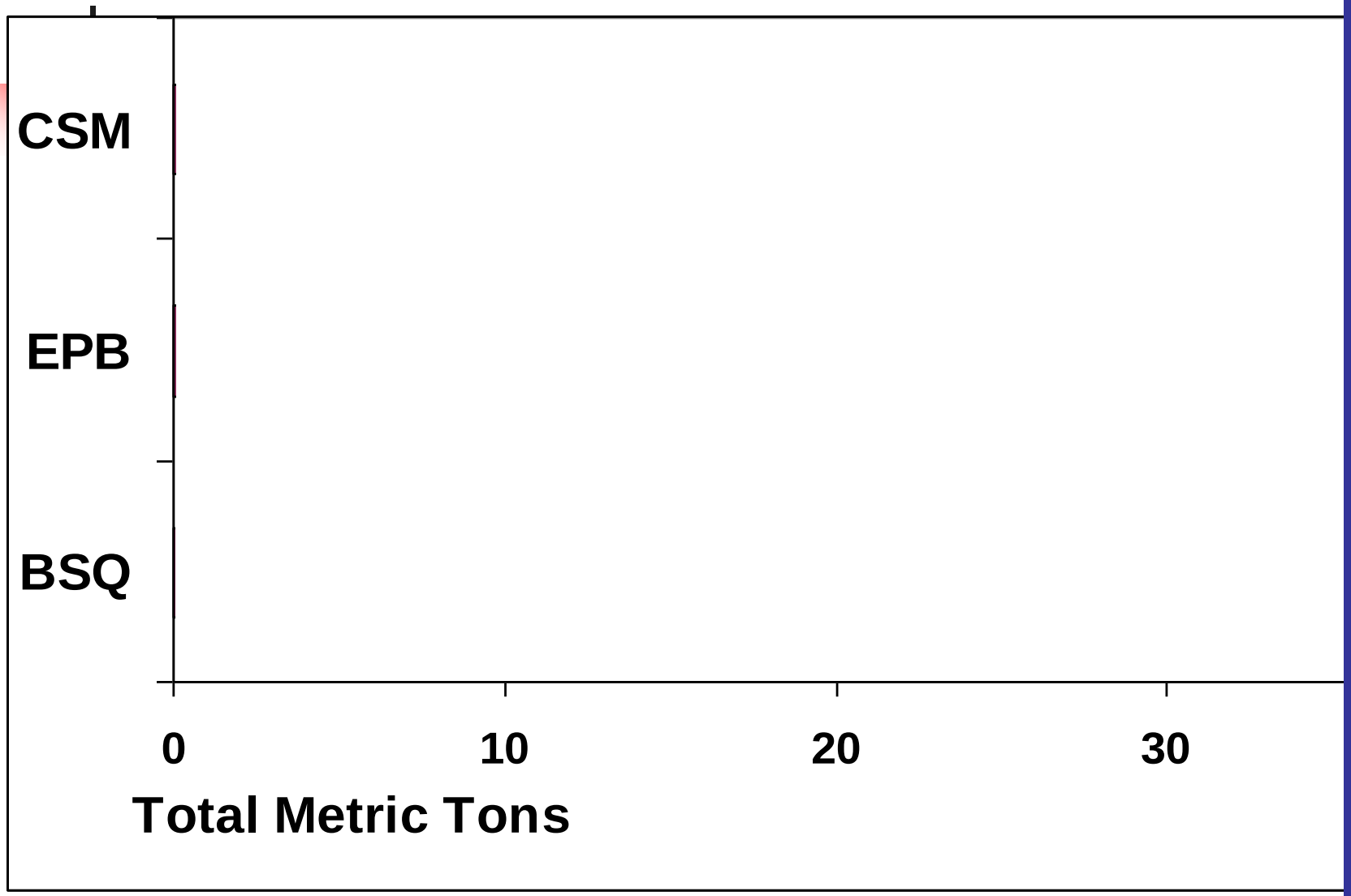


Determine mass density for each habitat type by averaging across sites

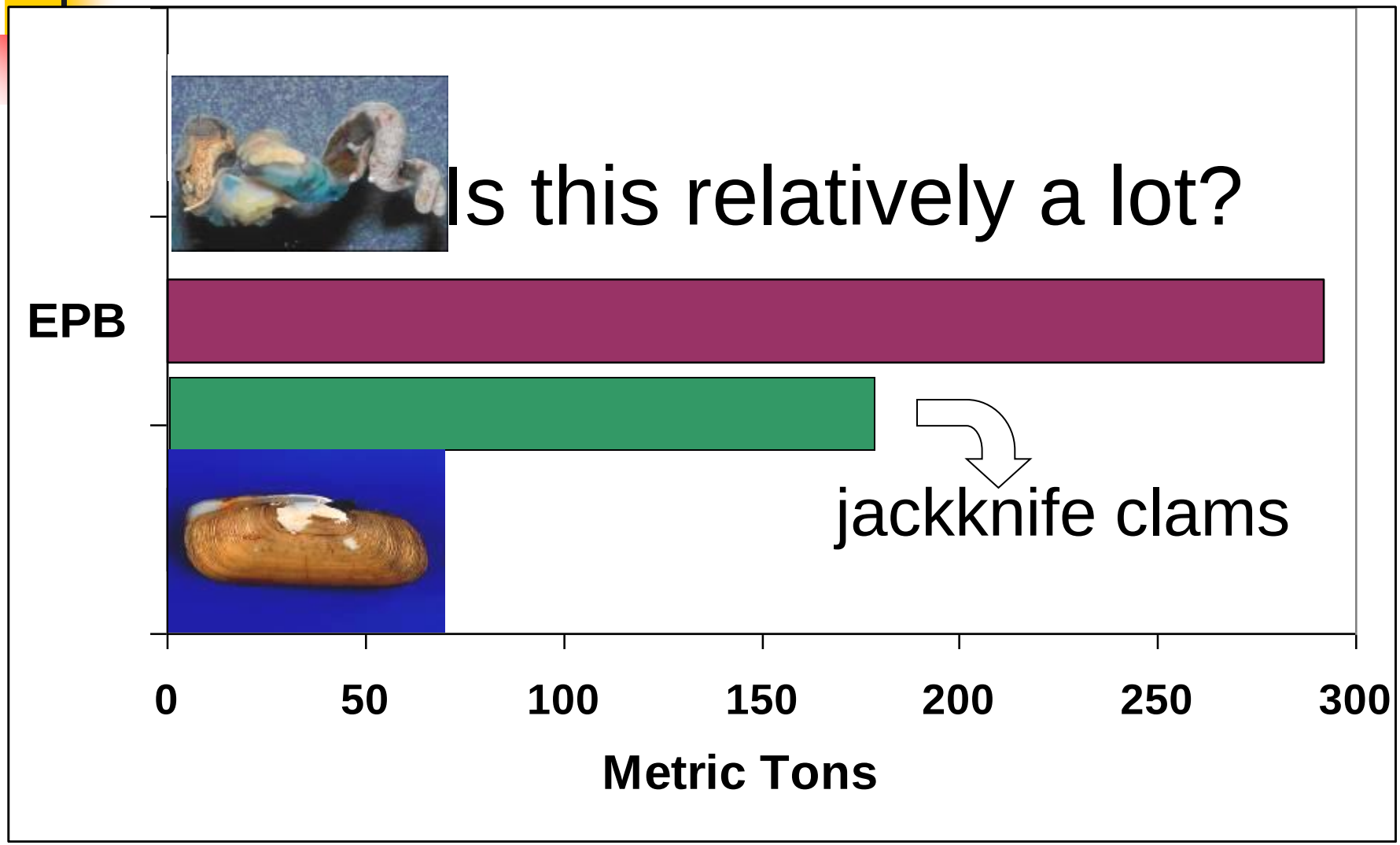

A
10000
1000
100
10
1
0.1
kg/ha (±95% cl)
B
3.0%
2.5%
2.0%
1.5%
1.0%
0.5%
0.0%
percent parasite mass
BSQ
EPB
CSM
misc. phyla
small arthropod
polychaete
bivalve
snail
burrowing shrimp
crab
fish
winter birds
Free-living taxa


100
10
1
0.1
0.01
0.001
0.0001
kg/ha (±95% cl)
BSQ
EPB
CSM
Turbellaria
Cestoda
Monogenea
Trematoda
Acanthocephala
Nematoda
Copepoda
Epicaridea
Parasite taxon

Total Parasite Snail Biomass



Total Parasite Snail Biomass



But, is that biomass a lot?

What's a metric ton?

Express in units we can all identify with

→ Convert biomass to numbers of people

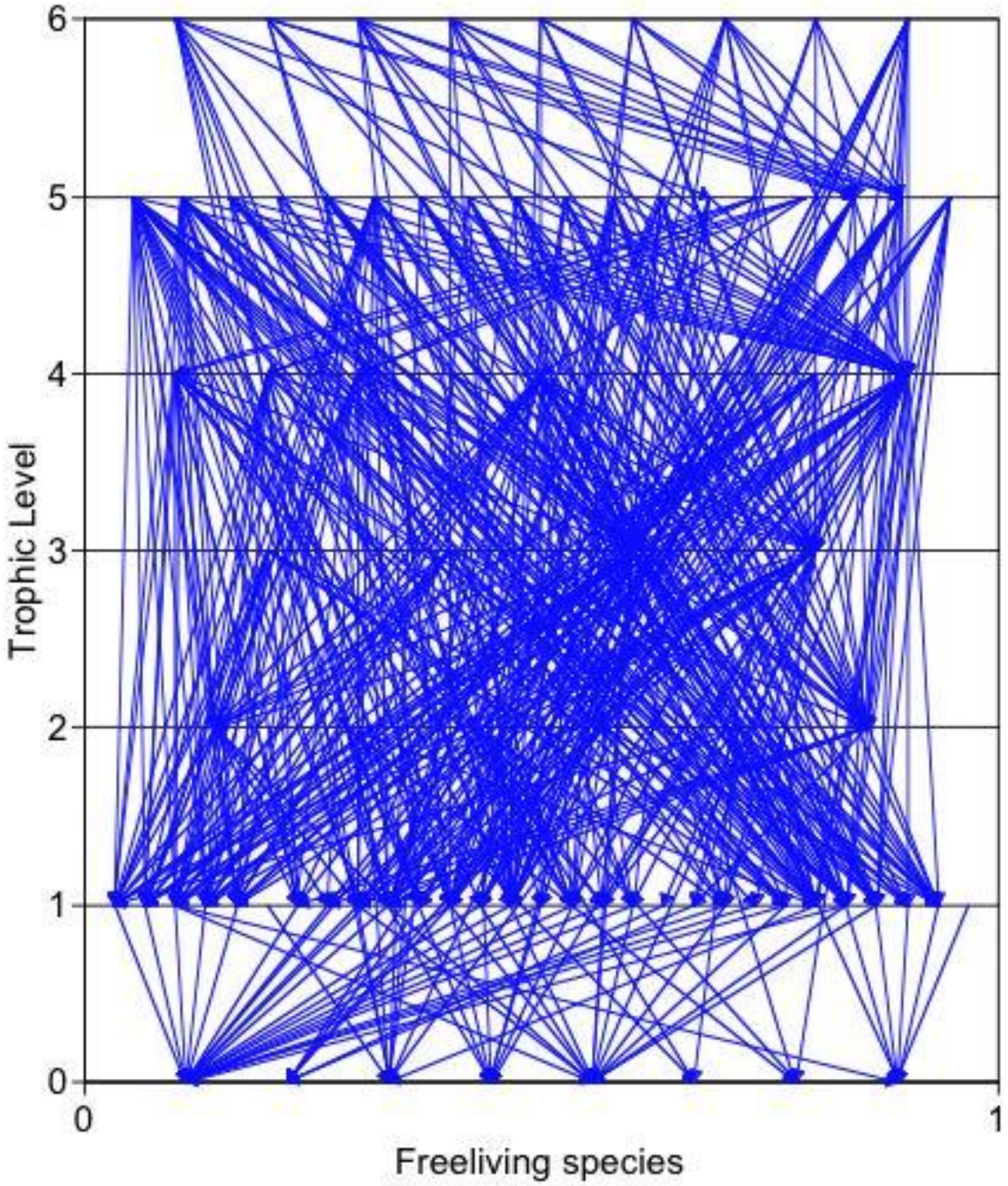
The Armand Kuris

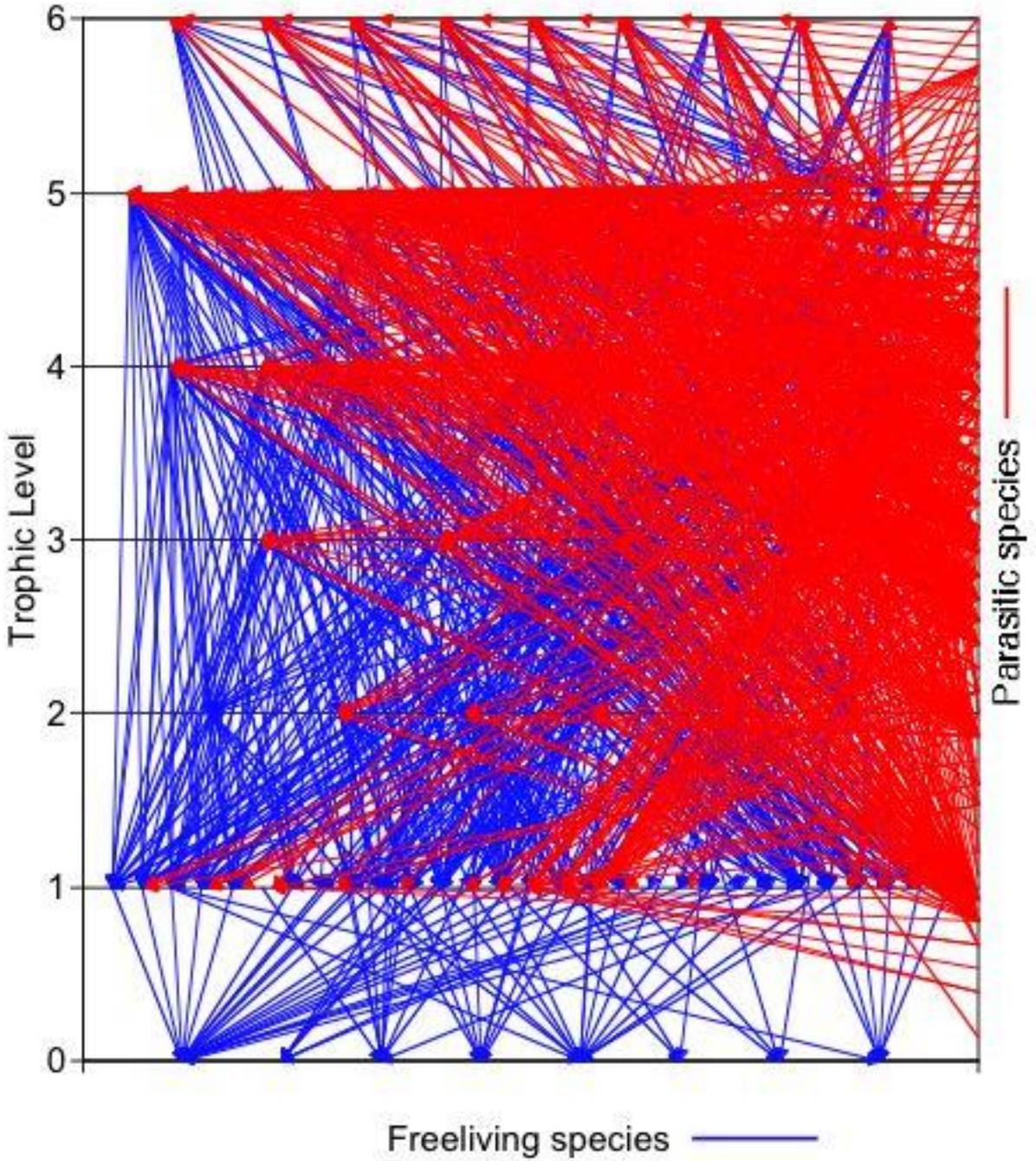
~75 kg

CSM 97 x

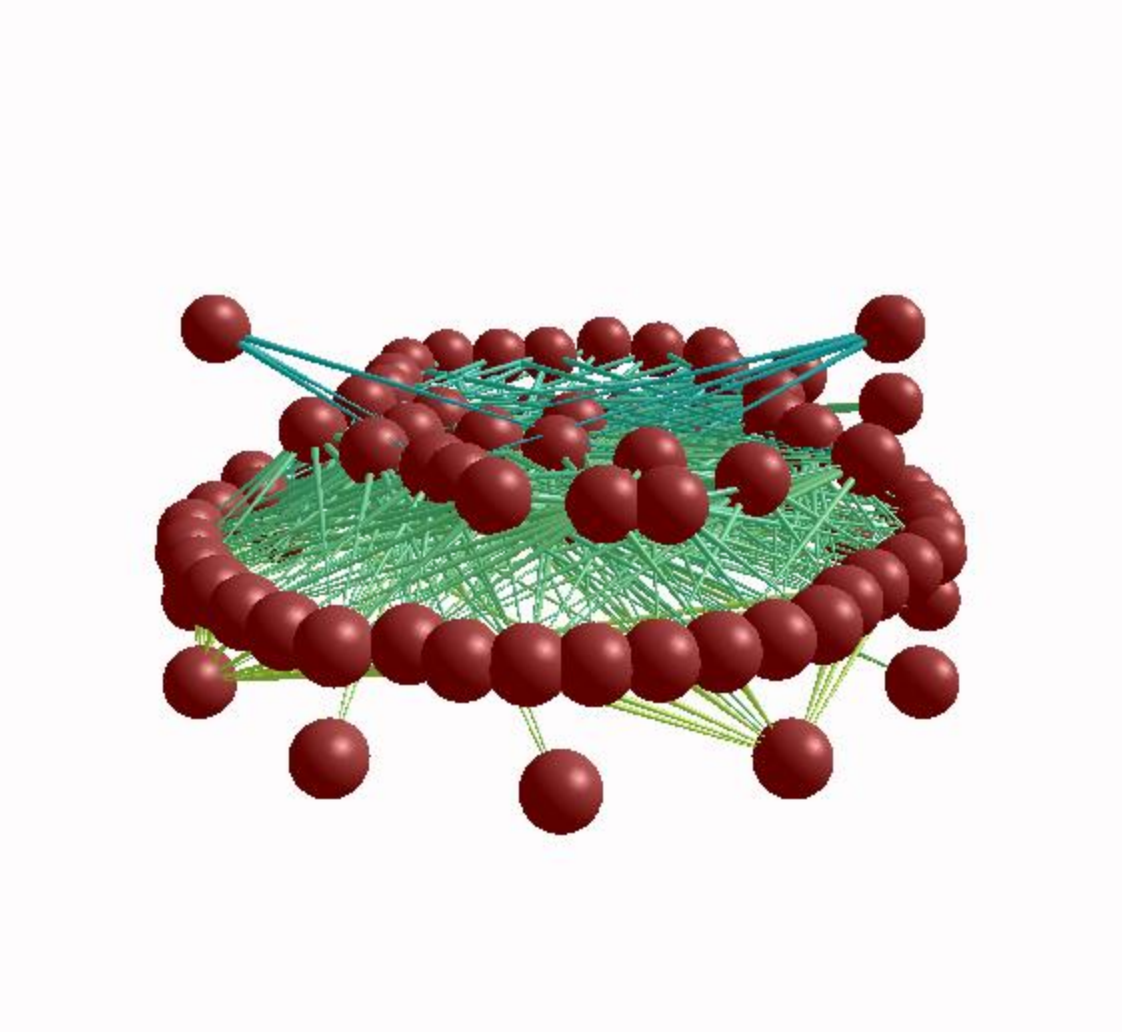
EPB 3,891 x

BSQ 373 x

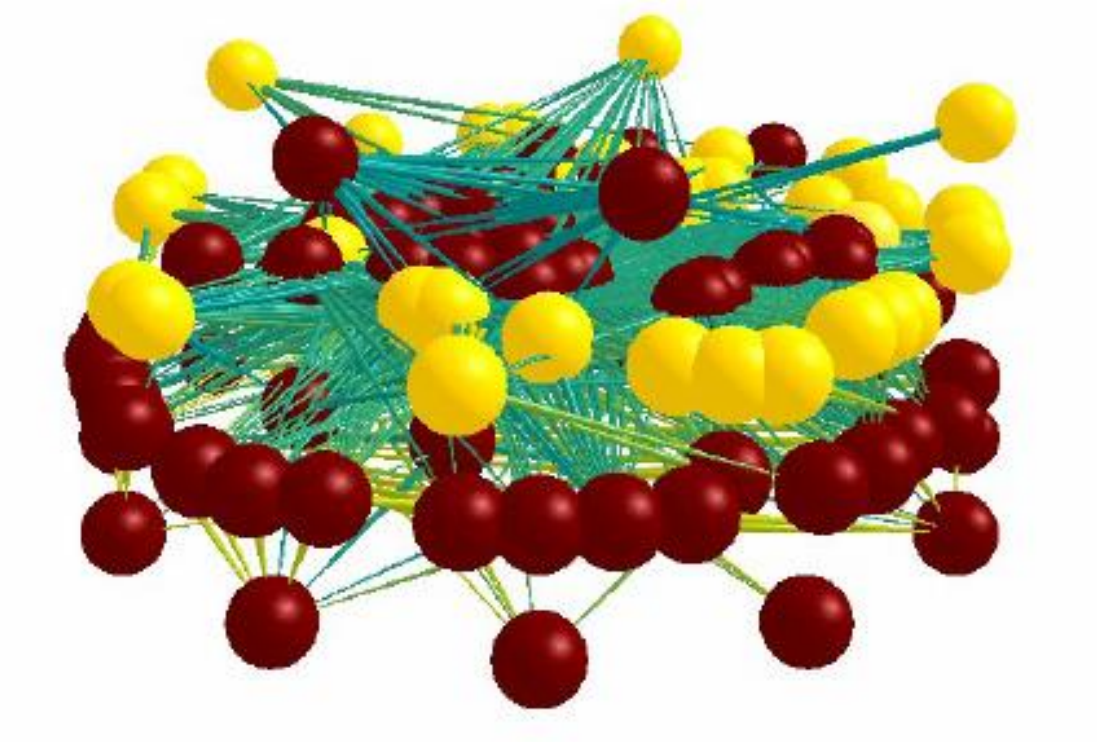

6
5
4
3
2
1
0
Trophic Level
0
1
Freeliving species


6
5
4
3
2
1
0
Trophic Level
Parasitic species
Freeliving species

Carpinteria free-living species web

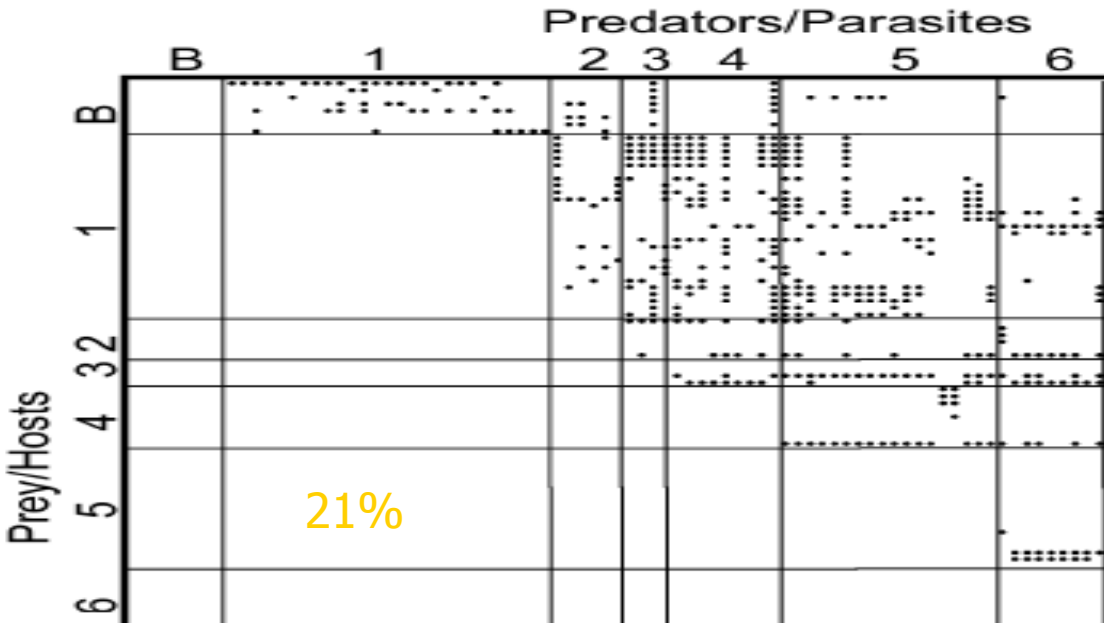


Carpinteria complete species web

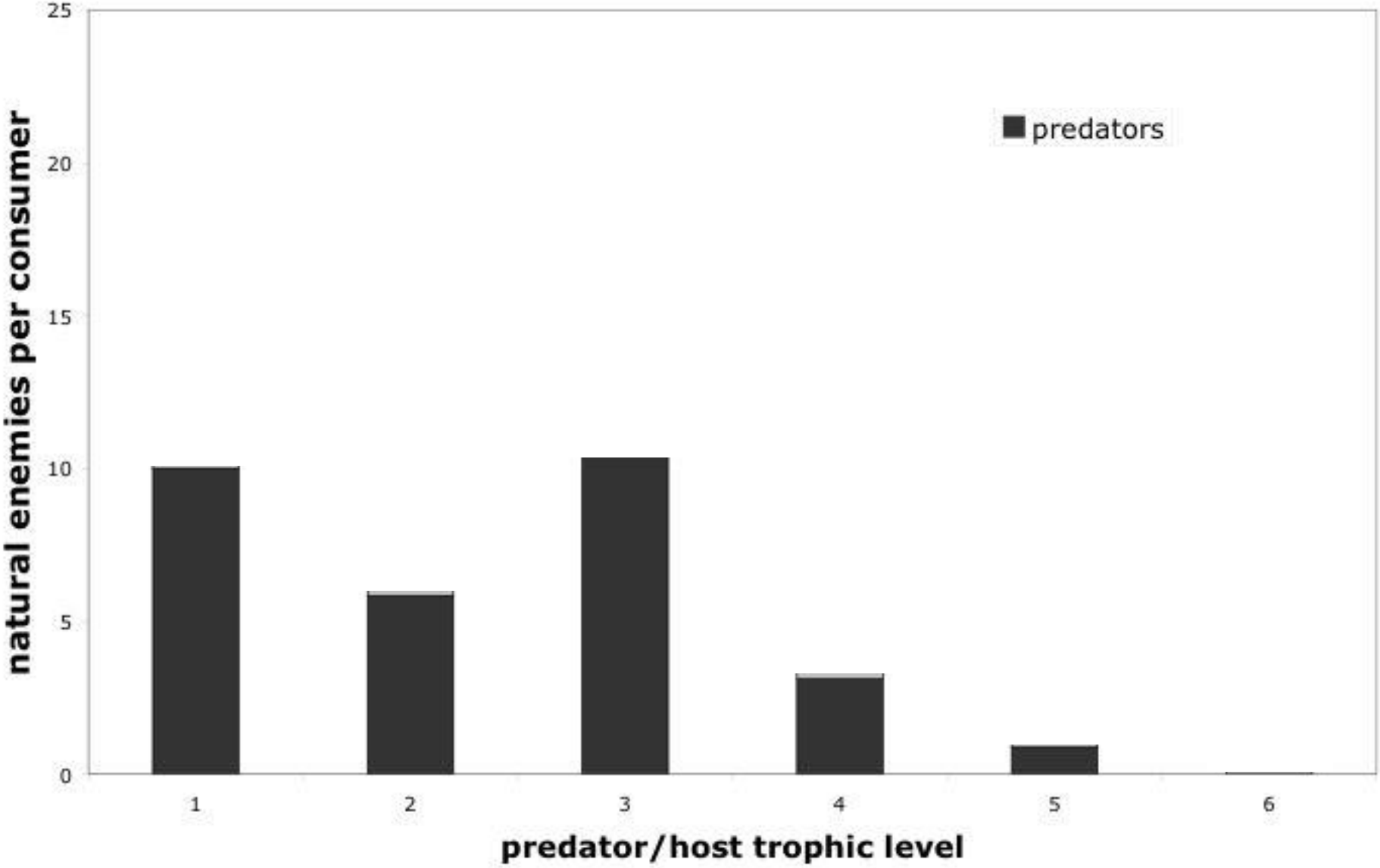


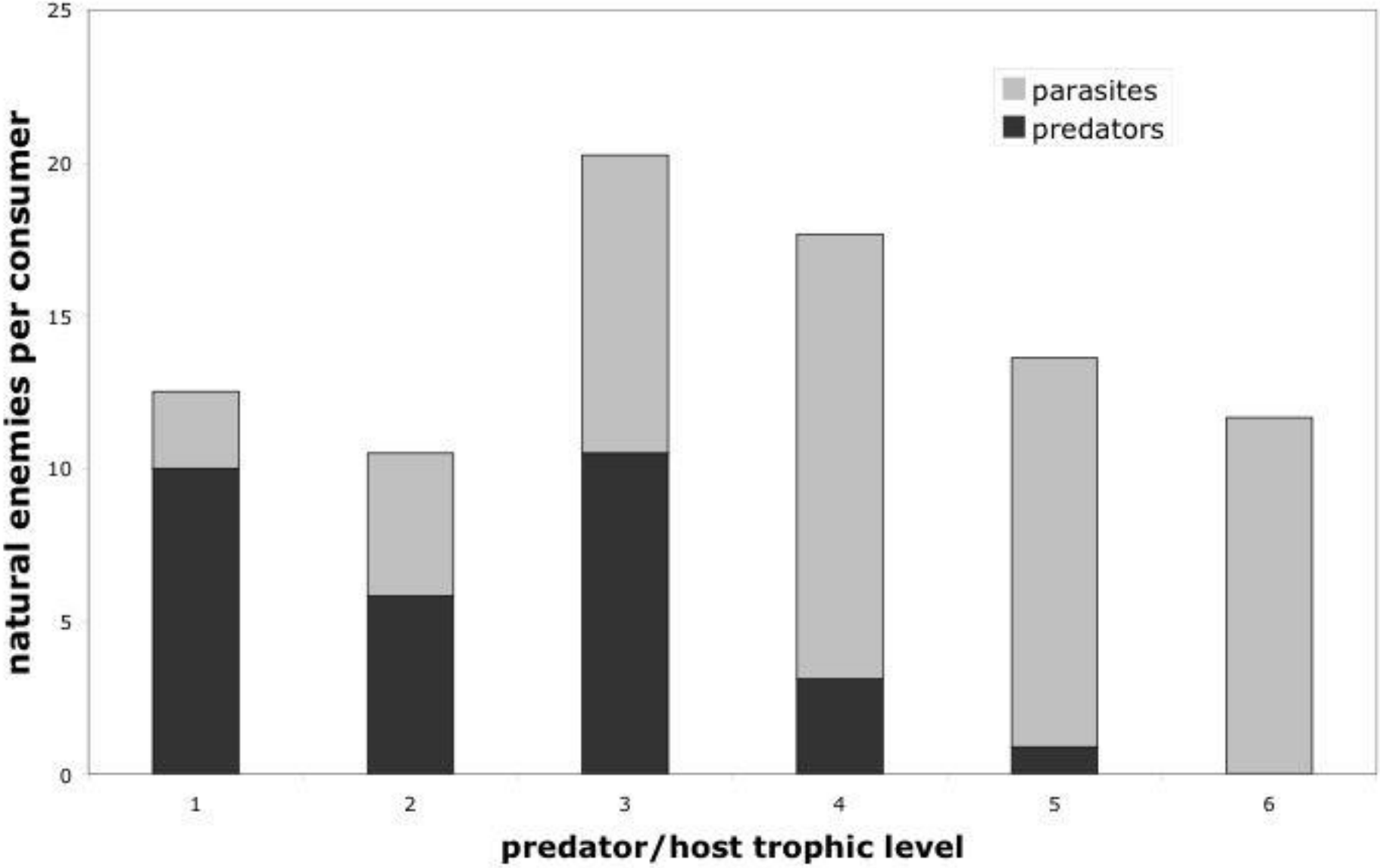
Yellow balls are parasitic species

Carpinteria Salt marsh food web



Species along the top consume those arranged along the left edge


natural enemies per consumer
25
20
15
10
5
0
predators
1
2
3
4
5
6
predator/host trophic level


parasites
predators
natural enemies per consumer
0
5
10
15
20
25
1
2
3
4
5
6
predator/host trophic level

Genomic analyses of sediment in almost the same salt marsh

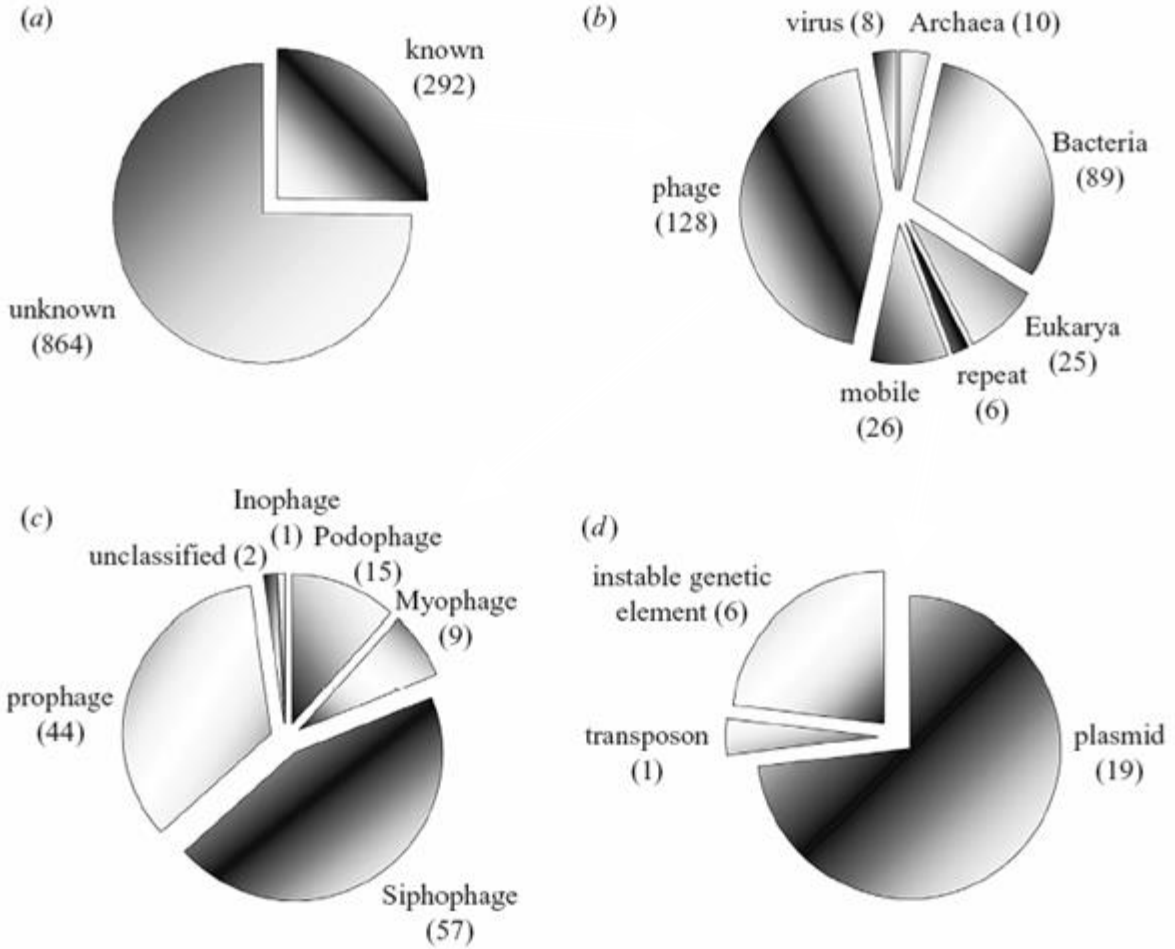


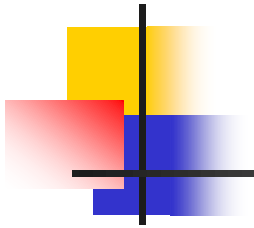
Figure 1. Genomic overview of the uncultured sediment viral community from Mission Bay, CA, USA, based on sequence similarities. (*a*) Number of sequences with a significant hit (*E*-value < 0.001) to GenBank. (*b*) Distribution of significant hits among the major classes of biological entity. (*c*) Families of phage represented in the sediment library. (*d*) Types of mobile element identified in the library.

Diversity and population structure of a near-shore marine-sediment viral community

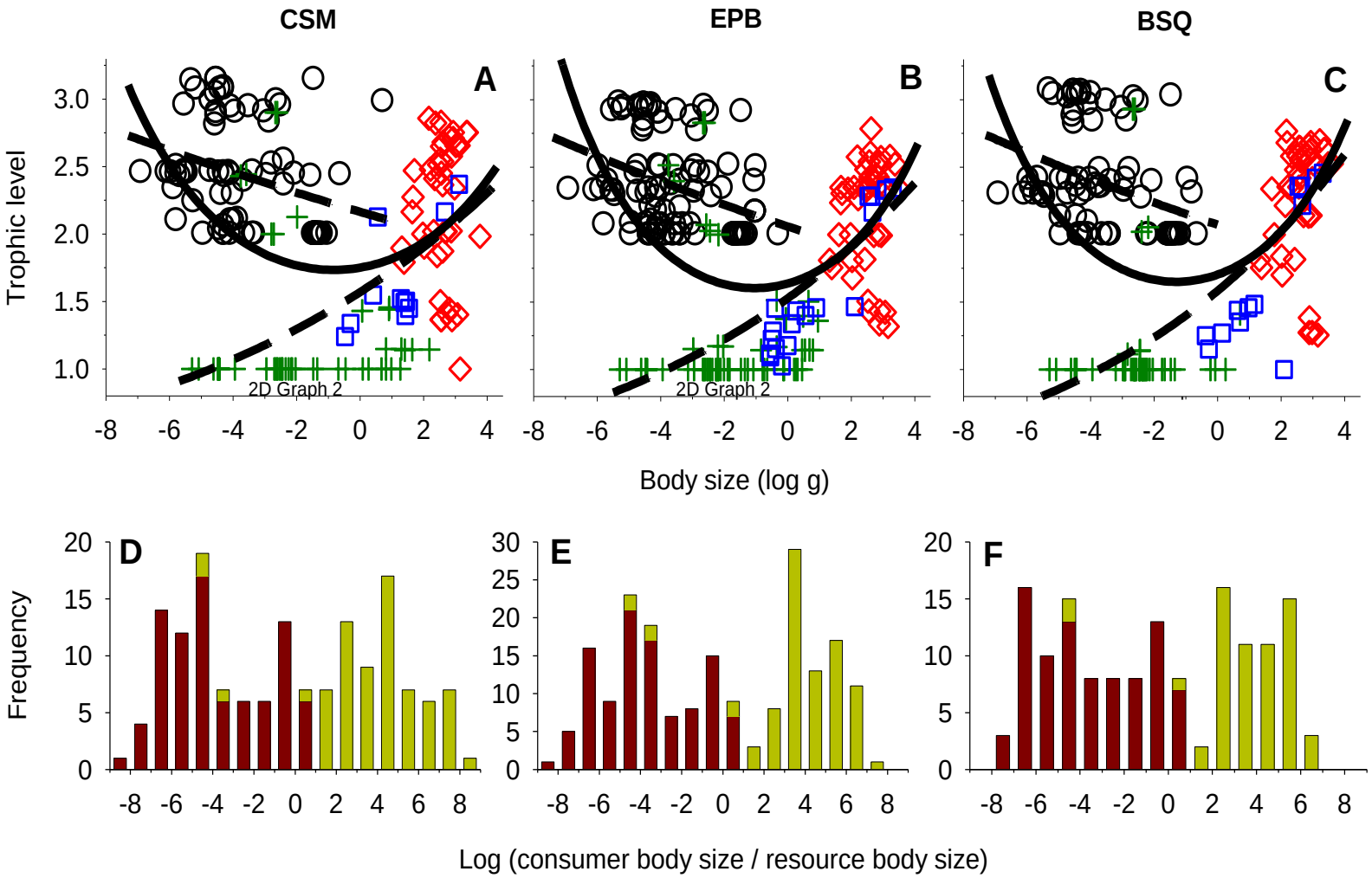
Proc. R. Soc. Lond. B (2004)

Mya Breitbart[1], Ben Felts[2], Scott Kelley[1], Joseph M. Mahaffy[2], James Nulton[2], Peter Salamon[2] and Forest Rohwer[1,3*]

Creates a interesting set of huge questions



- How many species / taxa in marsh in total?
- What determines pattern of abundance?
- How do they all coexist?
- Questions that go back to MacArthur, May, and constant discussion in EEB & ESA to this day….



- **Fig. 2. Variation in trophic level with body size and in consumer-resource body-size ratios for parasitic and free-living species in three estuarine food webs.**

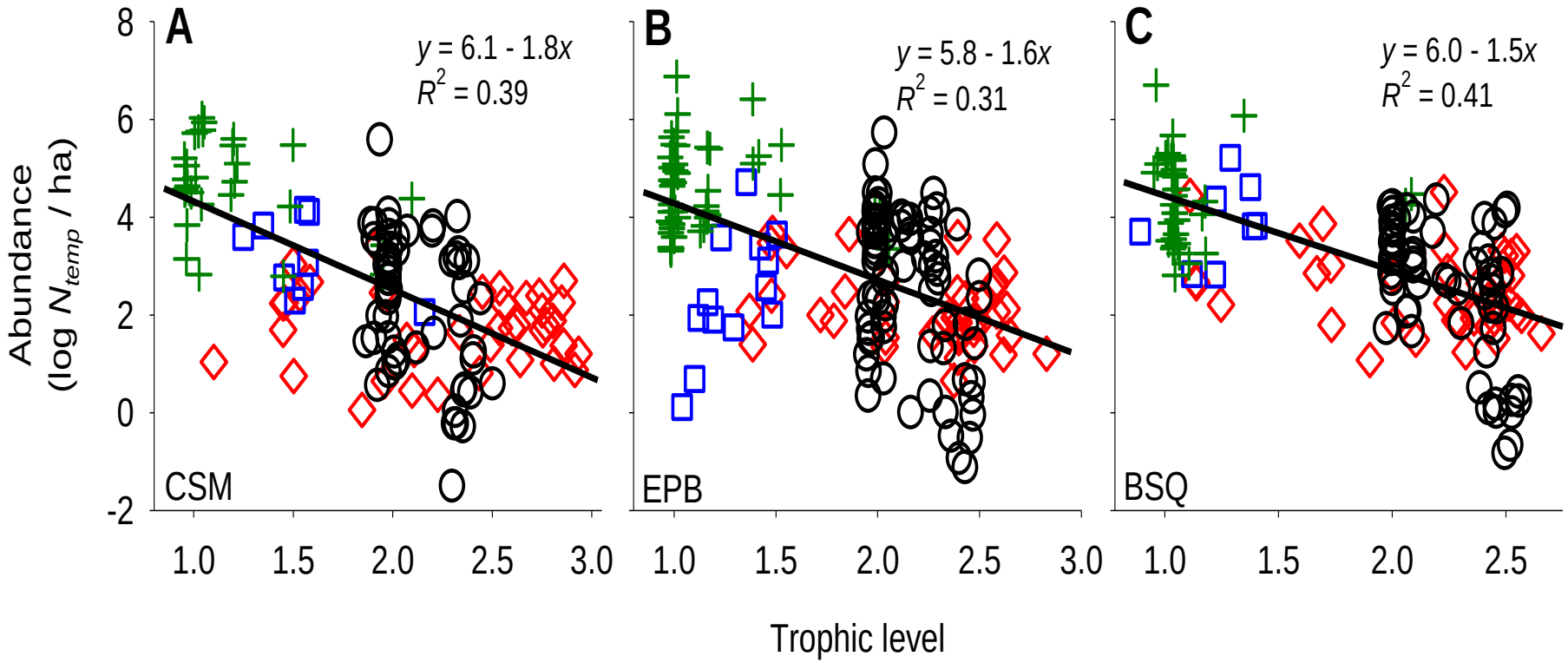


Fig 3. Abundance as a function of trophic-level for parasites and free-living species in three estuaries. (A-C)

Log_{10} temperature-corrected abundance decreases with trophic level using a GLM (Tables S3, S4) to control for body size (holding constant the mean log_{10} body size in each estuary, CSM: -0.83, EPB: -1.13, BSQ: -1.23). The anti-log of the slope provides an estimate of λ, the overall trophic transfer efficiency (TTE) in each ecosystem. Symbol key: parasite (○**),** invertebrate (+), fish (□), bird (◇).

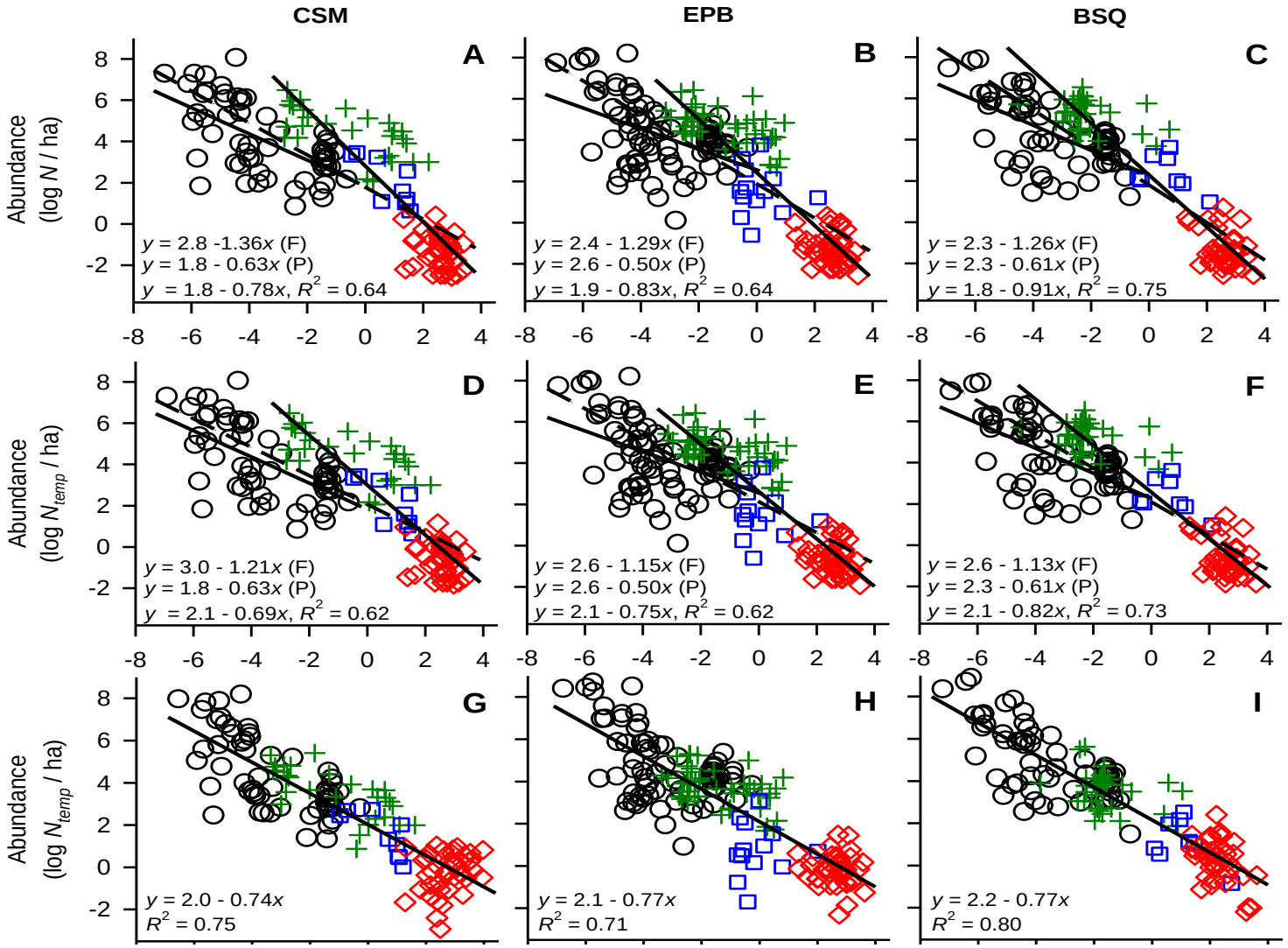
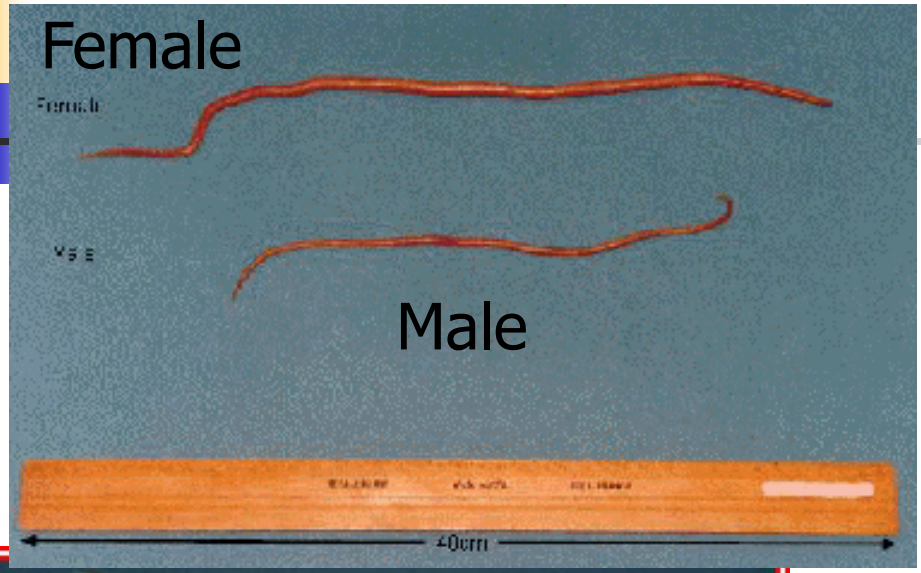


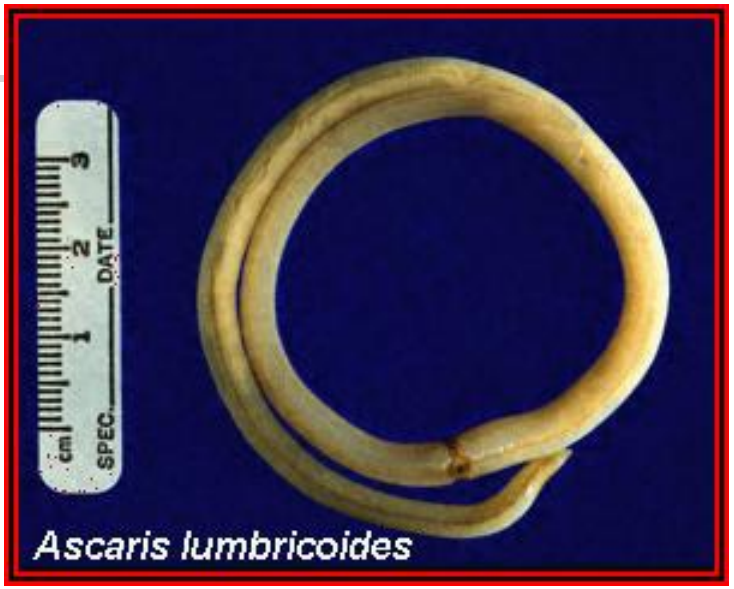
Fig 1. Abundance as a function of body-size, plotted on logarithmic axes, for parasites and free-living species in three estuaries.

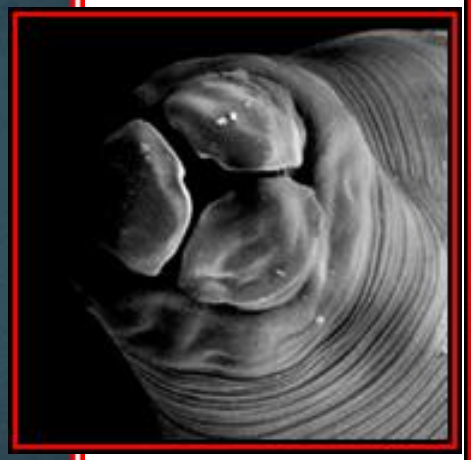
Hookworms sink their teeth into the intestinal walls of more than a billion people every day to drink their fill of blood (500x magnification).

Do Parasites Rule the World?

Ascaris lumbricoides



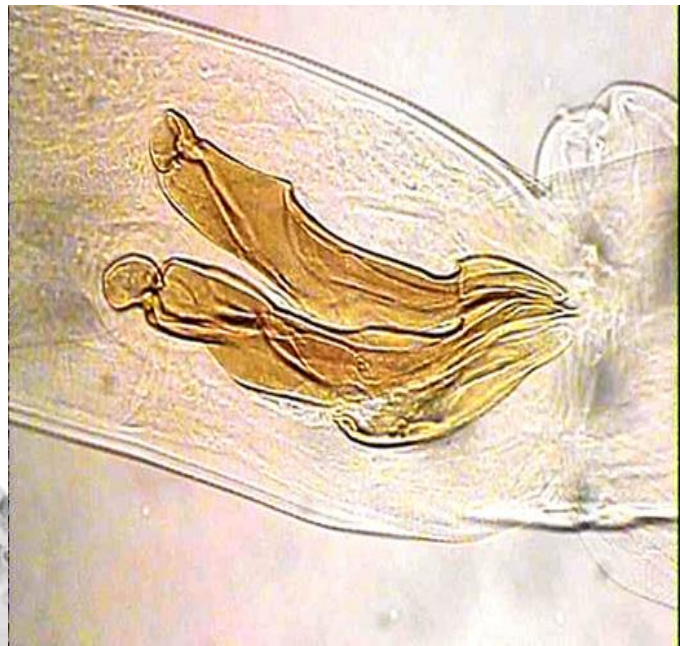




Immunity is more subtle and transient….

Complex body structures that produce by-products.
Inhabit a variety of tissues and organs, internal and external

! Charismatic at all scales !



Parasitic helminths

- Nematodes – simple and complex life cycles
- Cestodes – always complex, sequential vertebrate & invertebrate hosts
- Trematodes – always complex, always a snail for asexual, then vertebrate, sometimes a second invertebrate
- Acanthocephalans – always complex, arthropod and vertebrate

Global Burden of Intestinal Nematode Infections

- How many people are infected globally?
- What impact does this have on them?
- How much has the situation changed in last 50 years?

M.-S. Chan (1997) Parasitology Today, 13, 438-443

This Wormy World…. Stoll, 1947 & Chan 1997

- **1947**
- Humans – 2.2 x10^9
- 29% urban
- *Ascaris* 30%
- 644 million cases
- *T.trichura* 16%
- 355 million
- Hookworm 21%
- 457 million

- **1997**
- 5.6 x 10^9
- 45% urban
- 24%
- 1273 million cases
- 17%
- 902 million cases
- 24%
- 1277 million cases

Chan 1997, Global Burden of Intestinal Nematodes, Parasitology Today, 13, 438-443

The Worm gets the Bird. *Trichostrongylus tenuis* and red grouse

Andy Dobson and Peter Hudson

Parasite Ecology meets Downton Abbey….!

Dobson (Jnr) and Hudson (Snr)

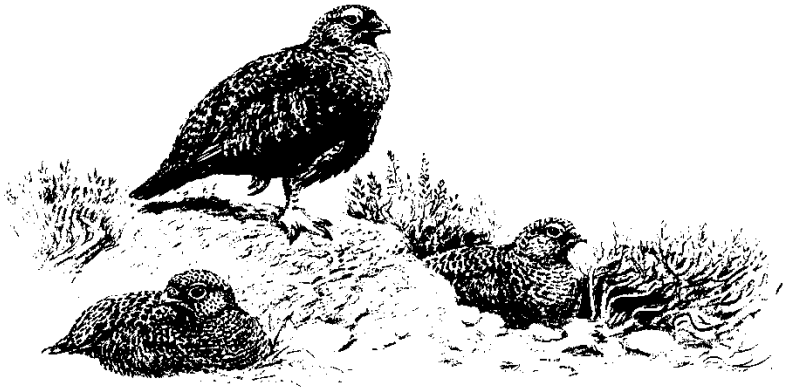
Grouse Parasite Interactions

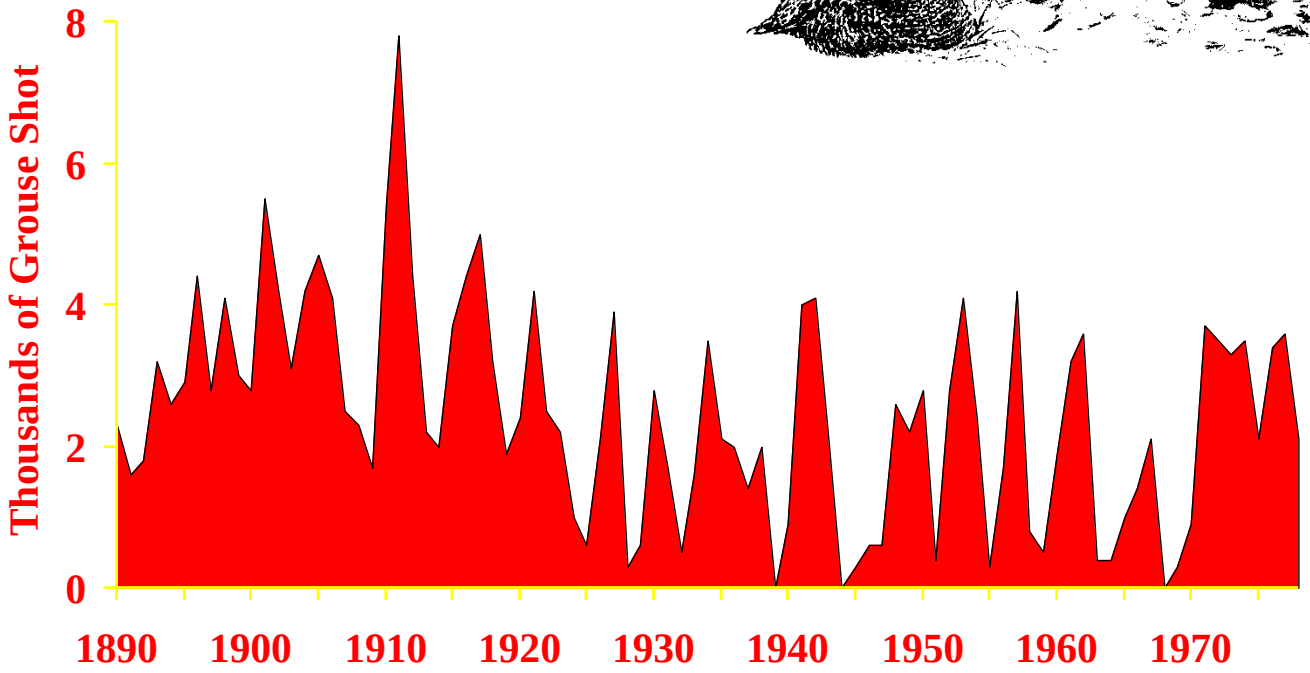
What are the consequences for population & community?

1. Individual level productivity
2. Population level dynamics
3. Community level interactions

Understanding ~ Monitoring Experiments & models

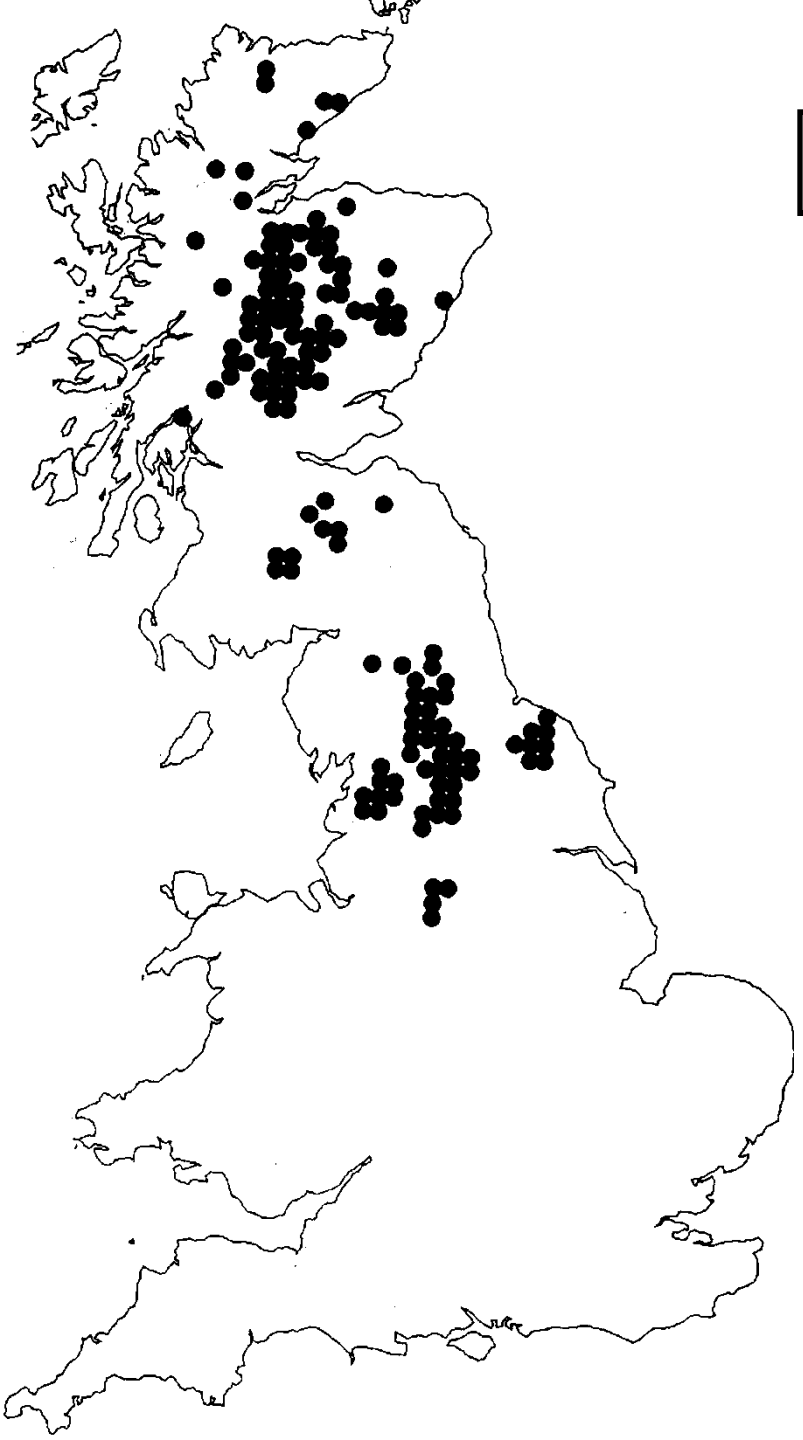
2. Grouse Demography



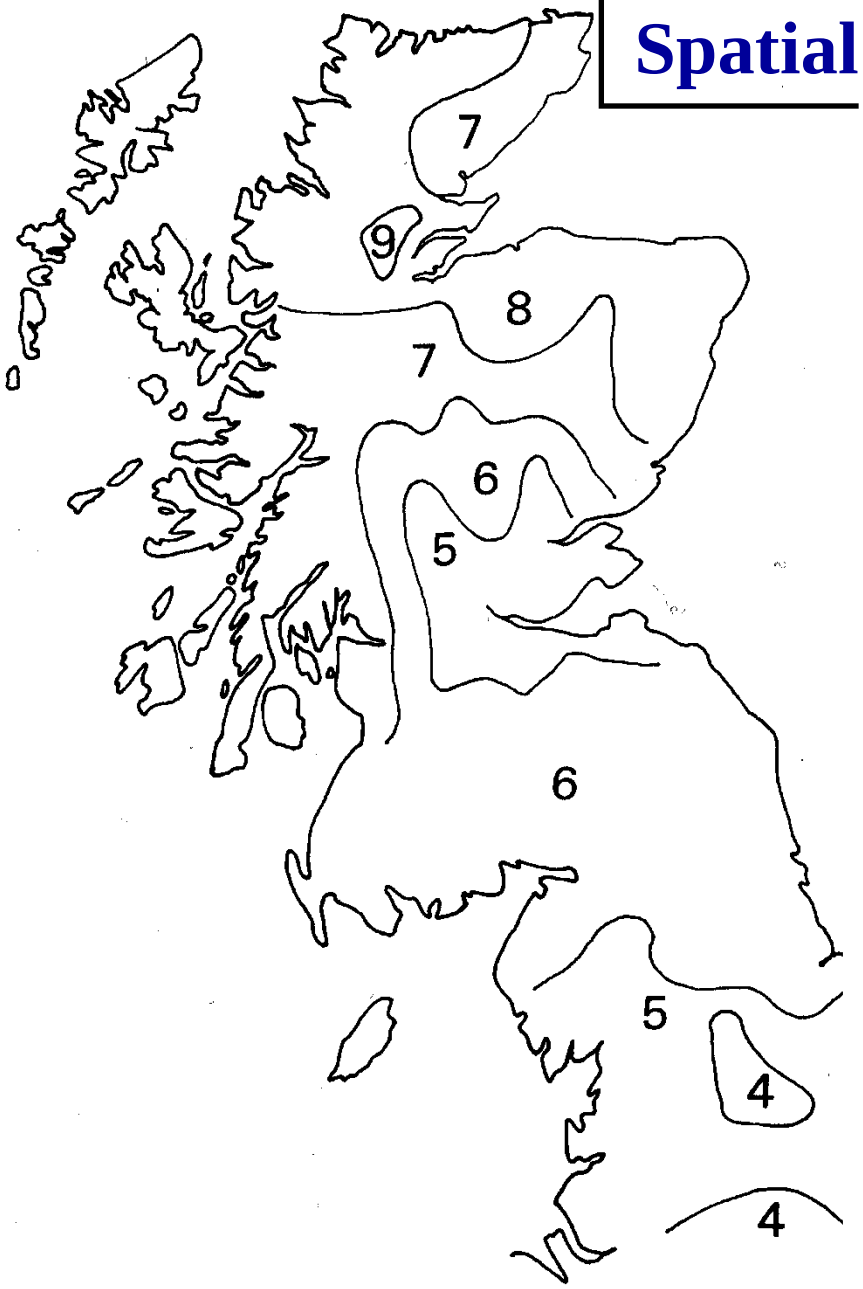


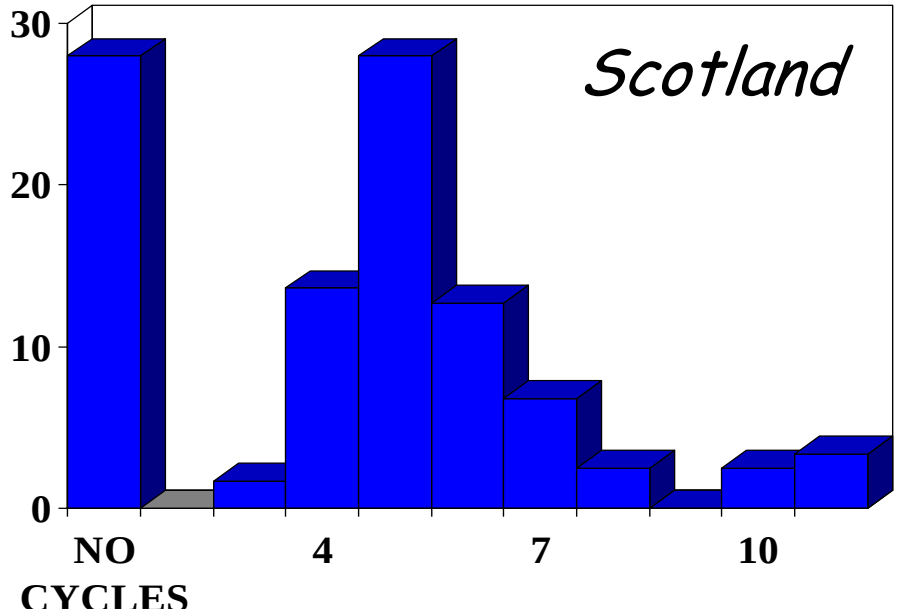
Earlier grouse workers….

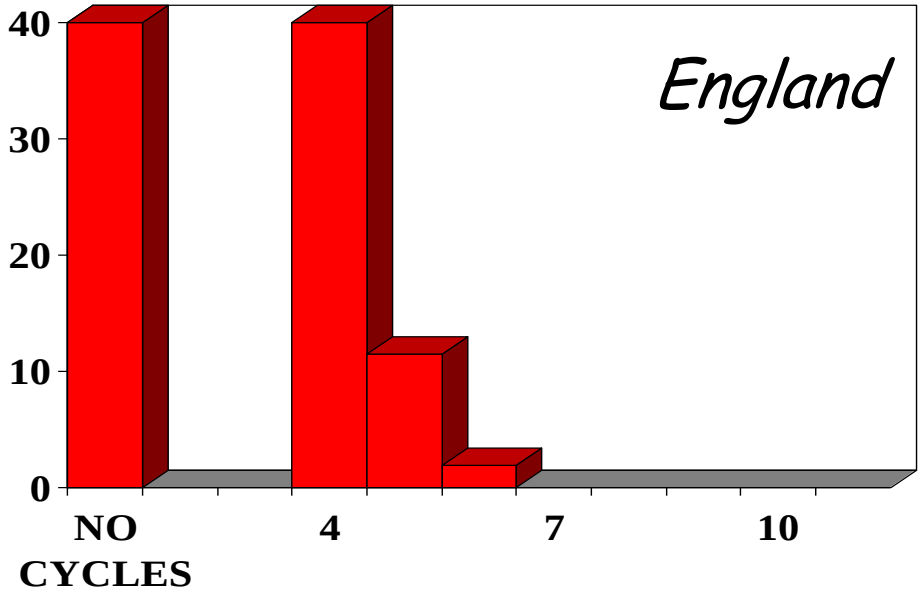
Hunting Records - England & Scotland



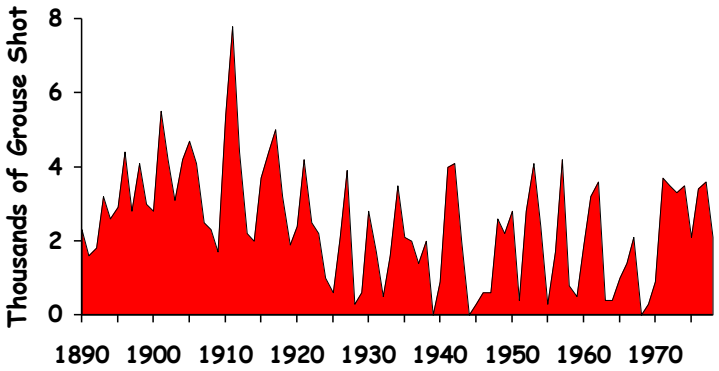
Spatial Variation in Cycle Period

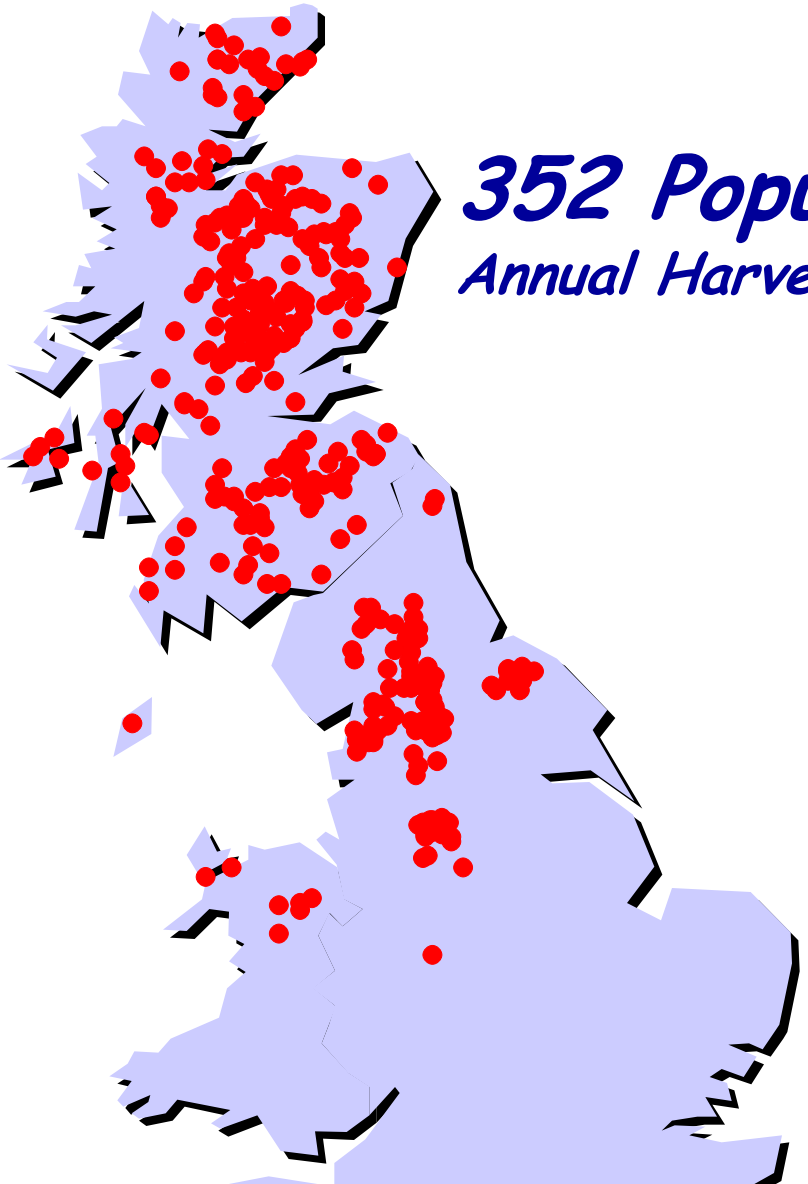






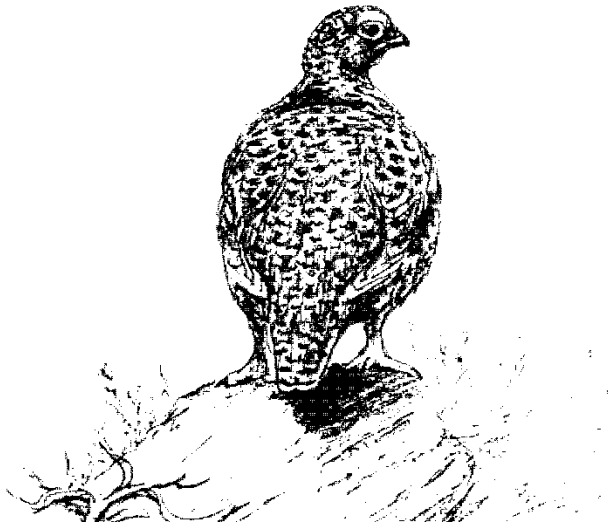
Harvested Red Grouse Populations



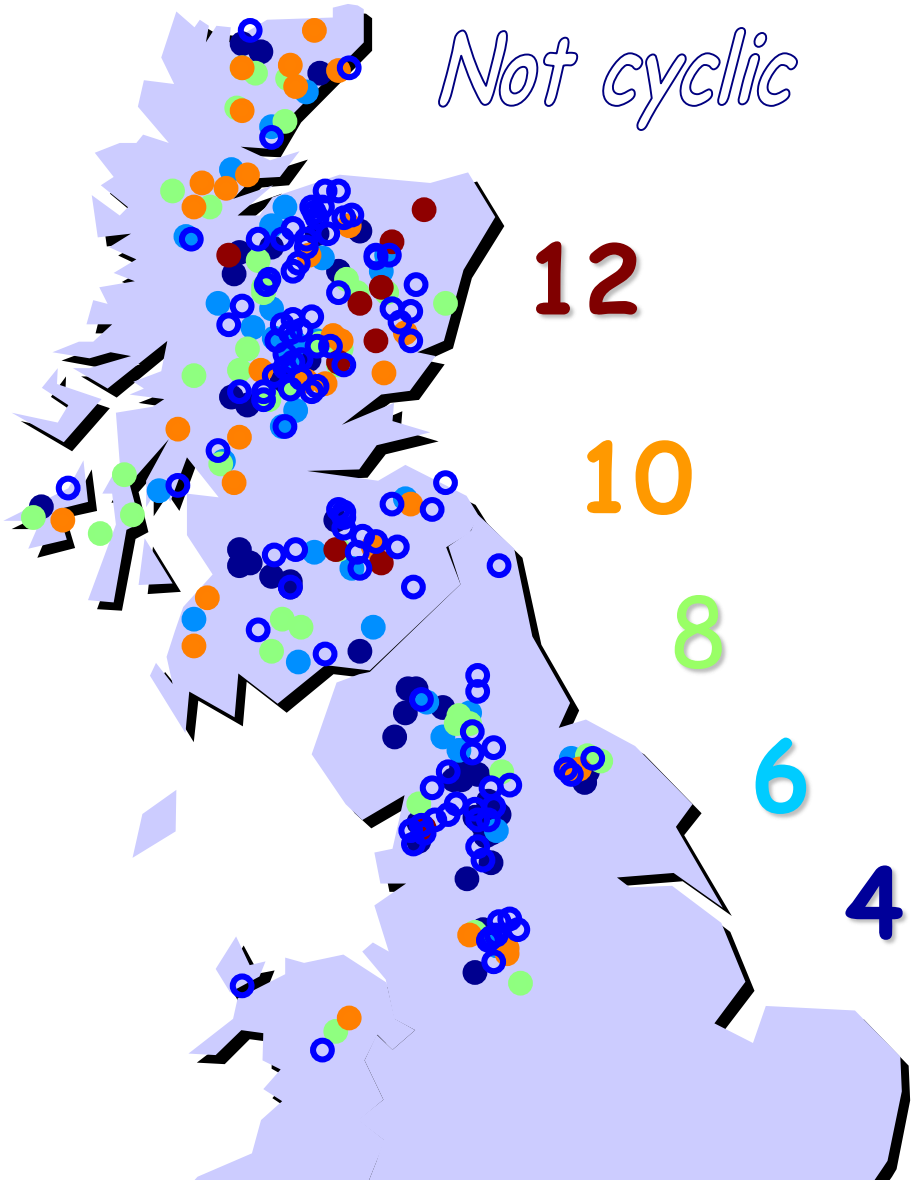


352 Populations

Annual Harvesting Data



Harvested Red Grouse Populations

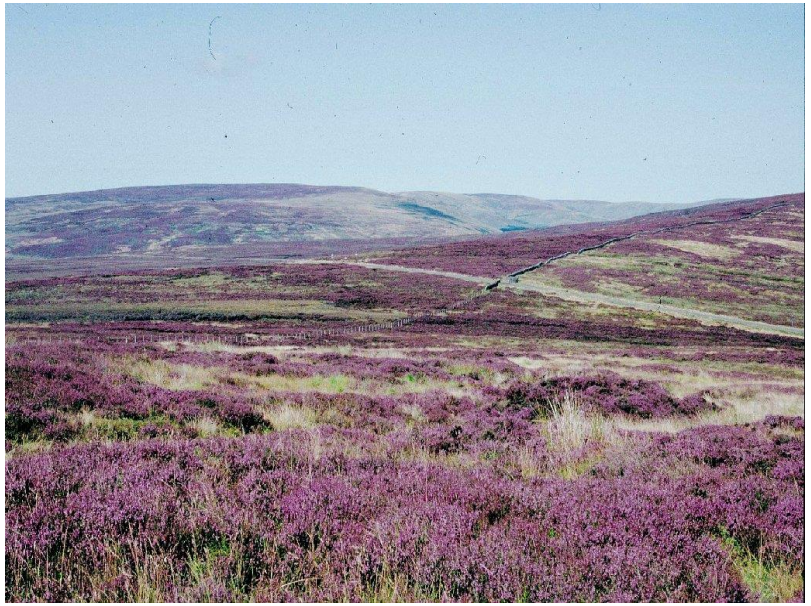


57% cyclic
21% weakly cyclic
22% not cyclic

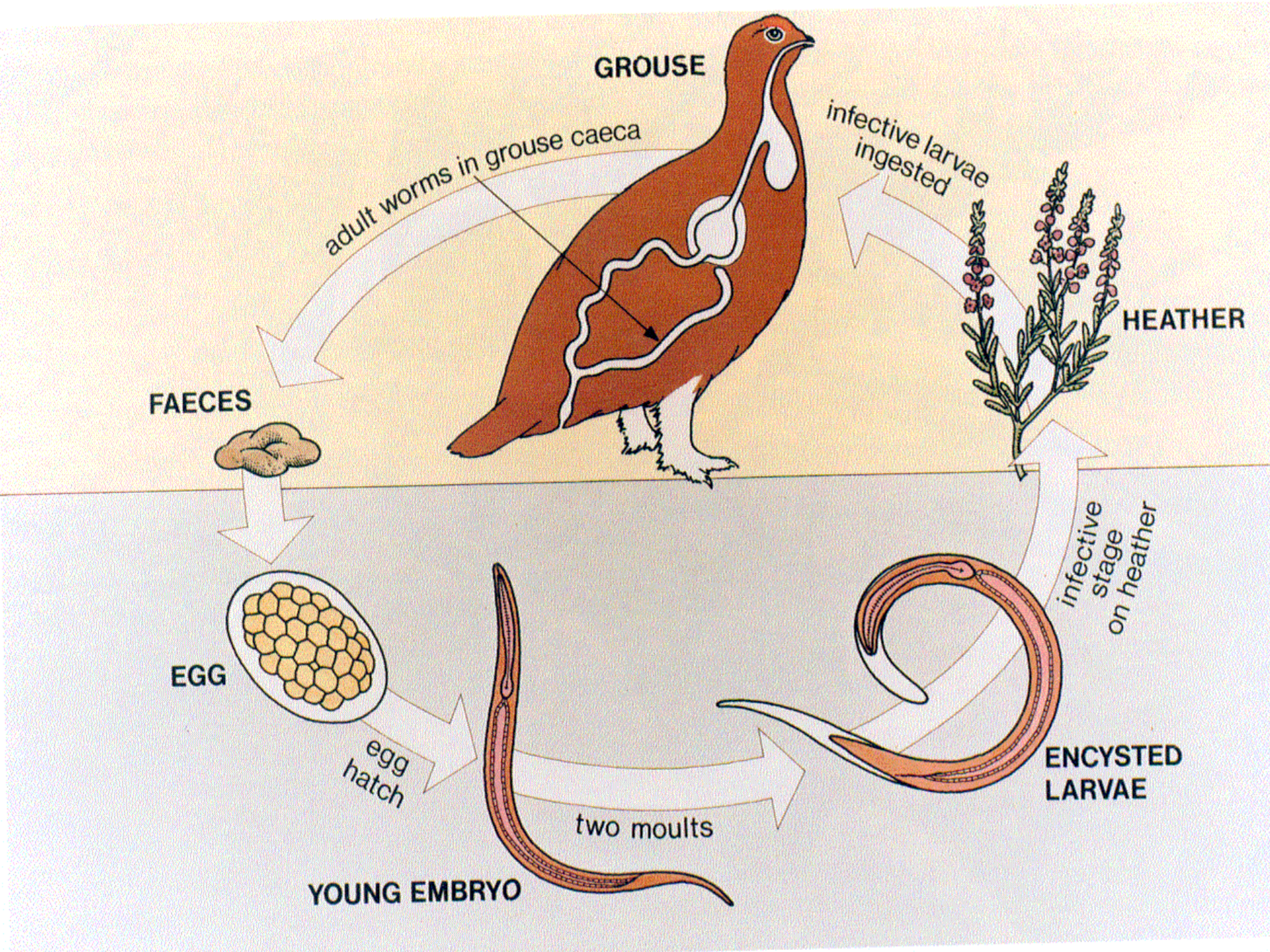
Do Parasites influence Host Dynamics?

Red grouse and *Trichostrongylus tenuis*

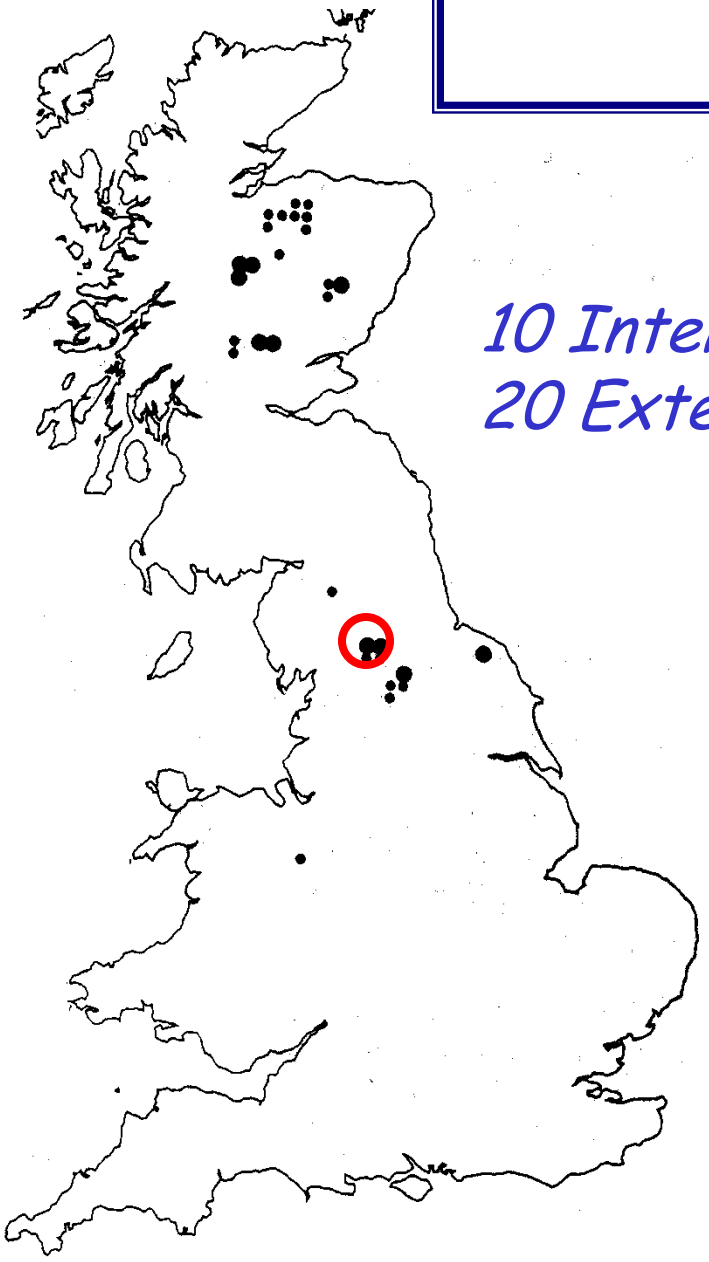
Red Grouse



Trichostrongylus tenuis


GROUSE
adult worms in grouse caeca
infective larvae ingested
HEATHER
FAECES
EGG
egg hatch
YOUNG EMBRYO
two moults
infective stage on heather
ENCYSTED LARVAE

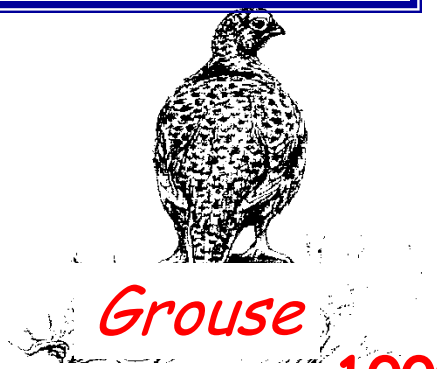
Demography ~ 20 years

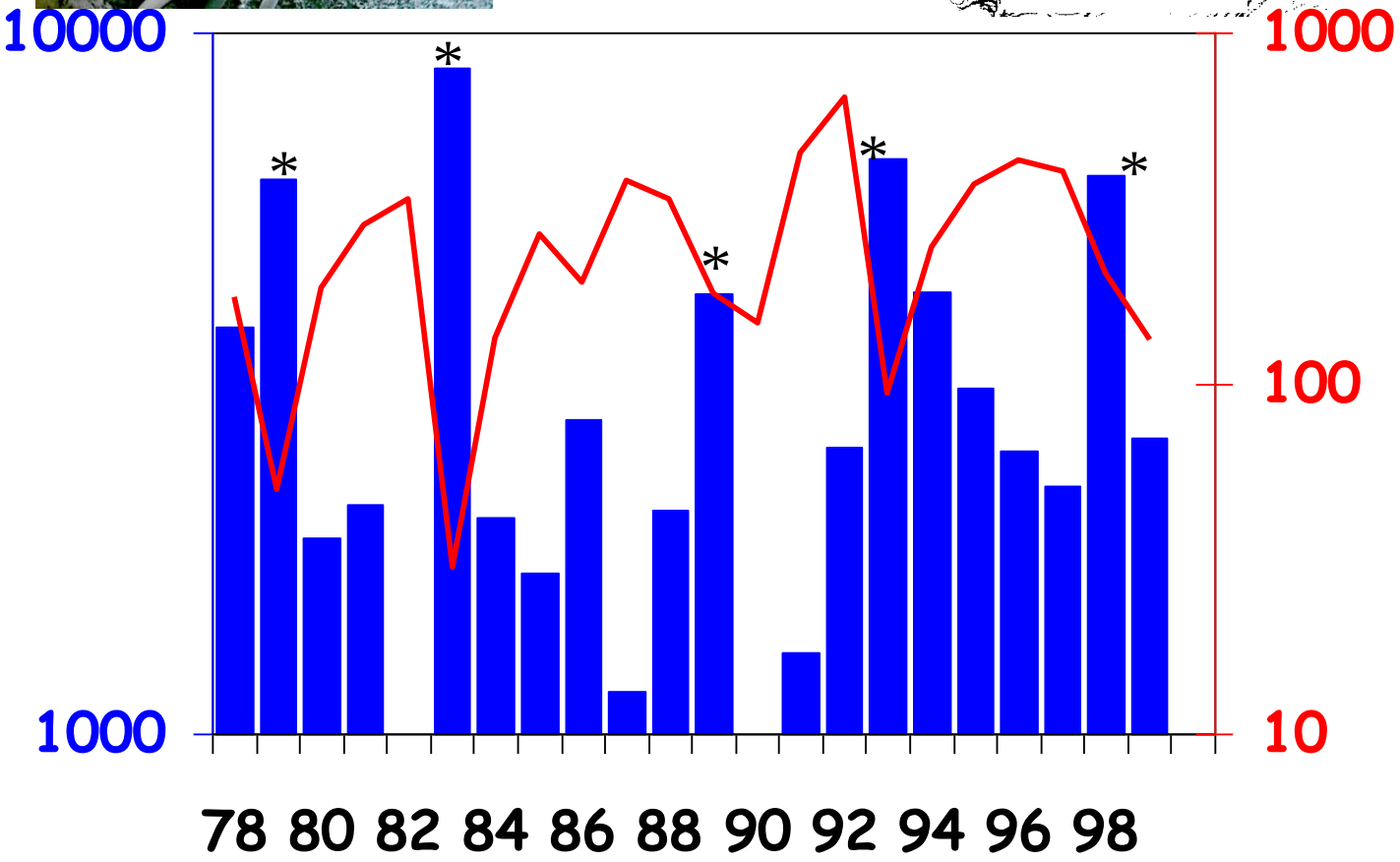


10 Intensive
20 Extensive

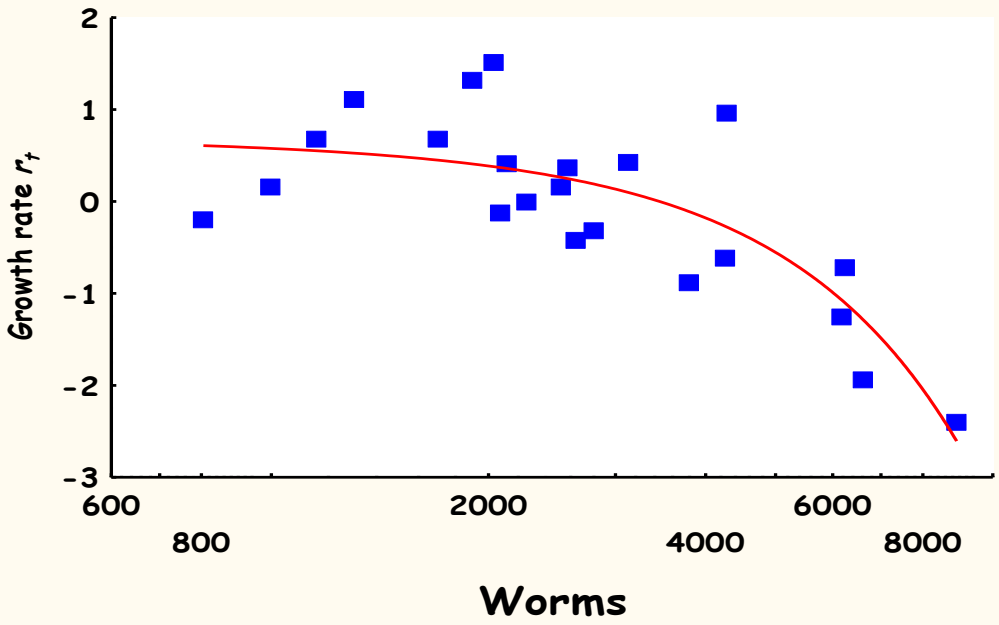
Spring: Breeding density
Clutch size
Hatching success
Chick survival
July: Breeding Production
August: Numbers shot
Winter: Corpses

Intensive Study Area

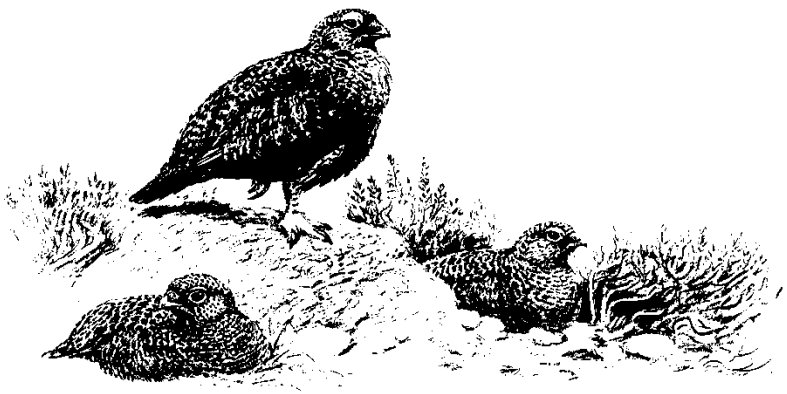


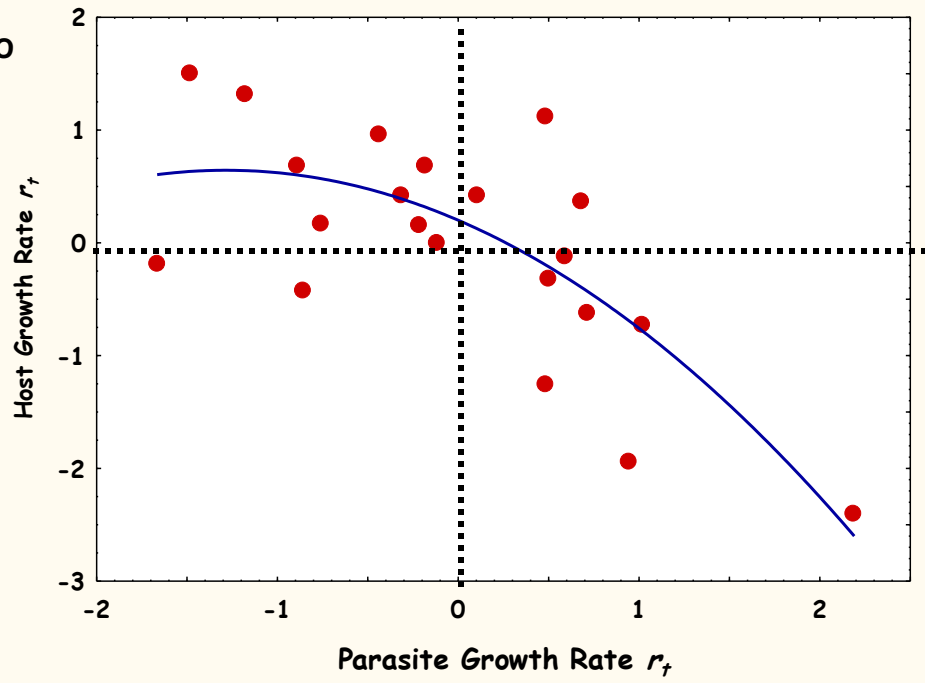


Grouse & Worms: Demographic Data

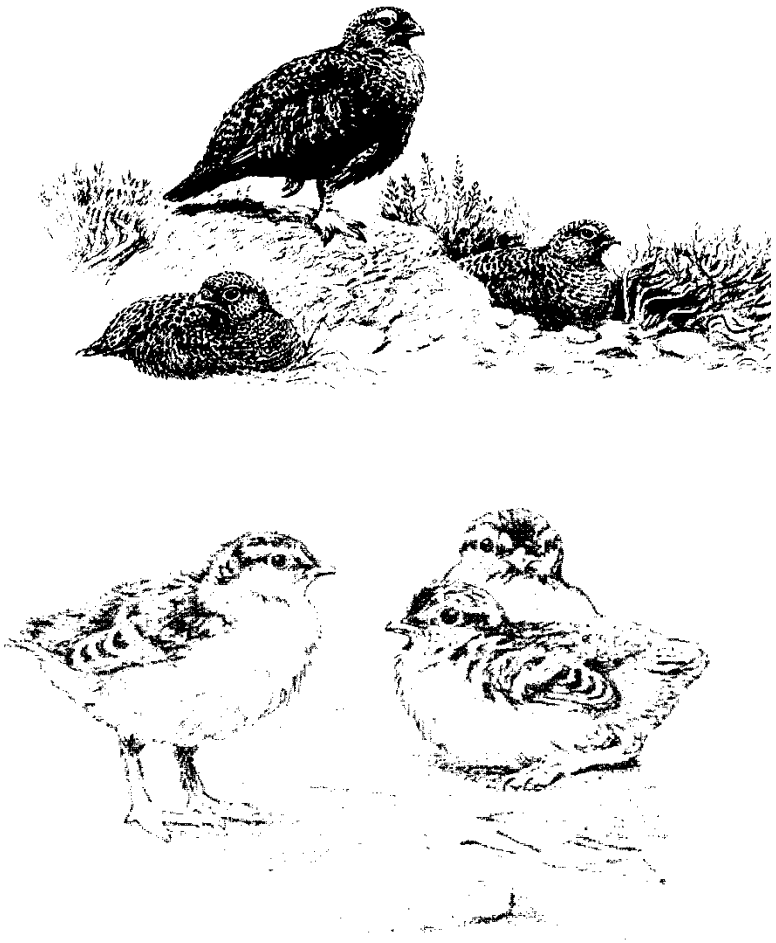


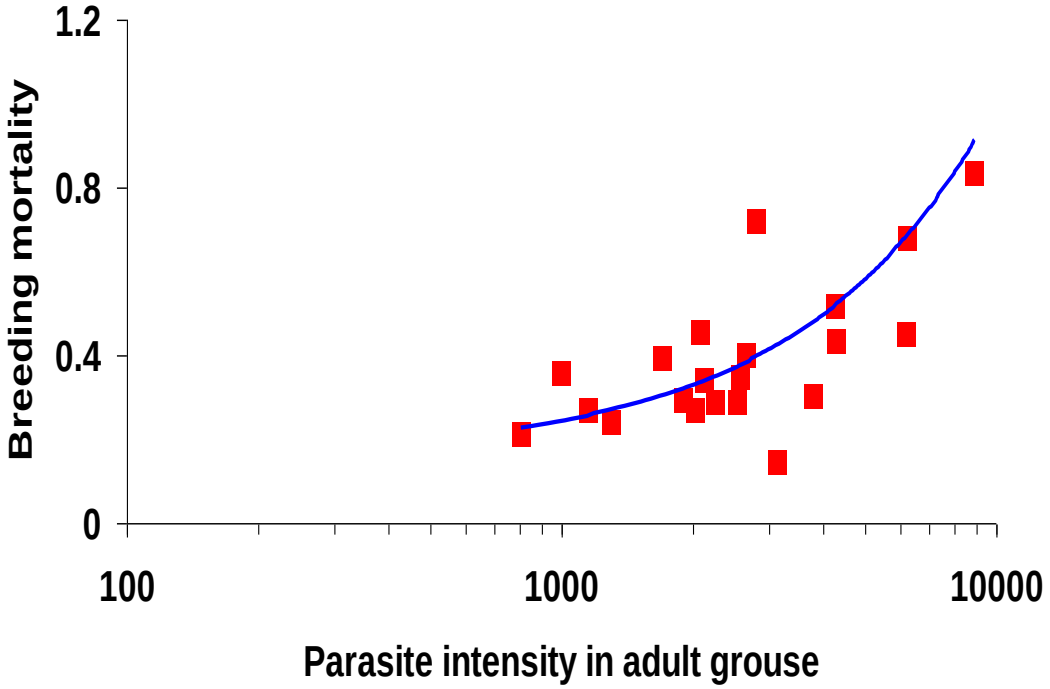
Parasite Associated Reduction in Growth Rate





Grouse & Worms: Demographic Data

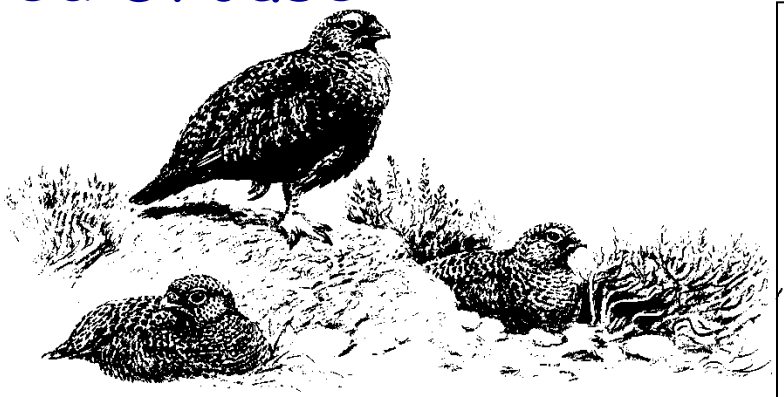




Do Parasites influence Host Dynamics?

Destabilising Features at individual level

Red Grouse



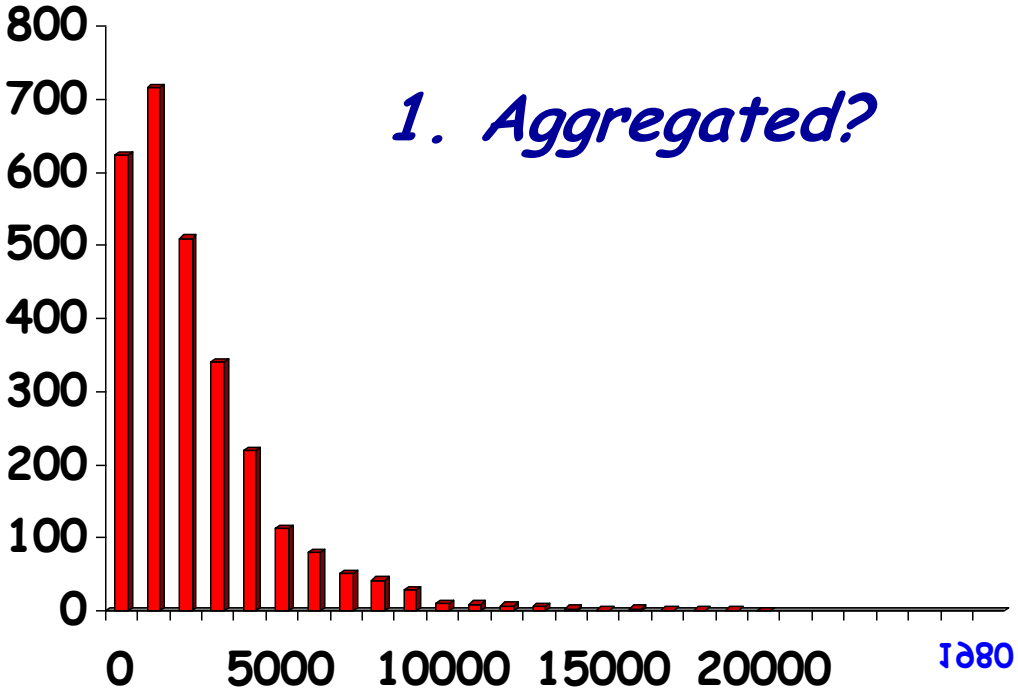
Trichostrongylus tenuis

Destabilizing Features:

1. Regular distribution $\kappa \to \infty$
2. Parasite induced reduction in host fecundity $\delta < \alpha$
3. Time delays in life cycle

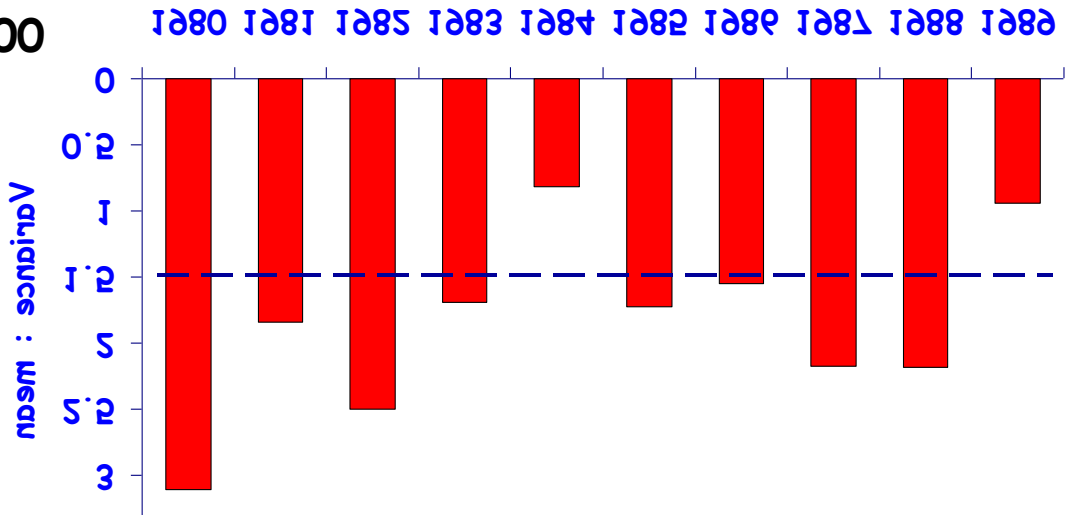
1. Individual Level Productivity

Grouse parasite frequency distributions

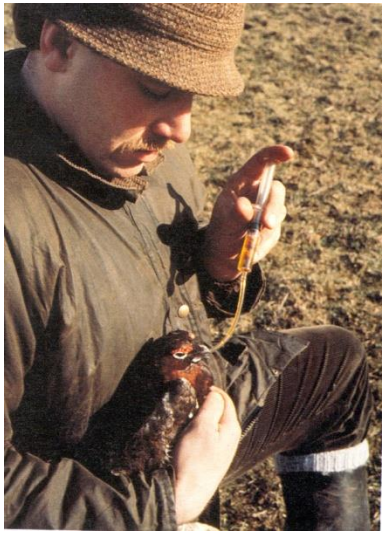


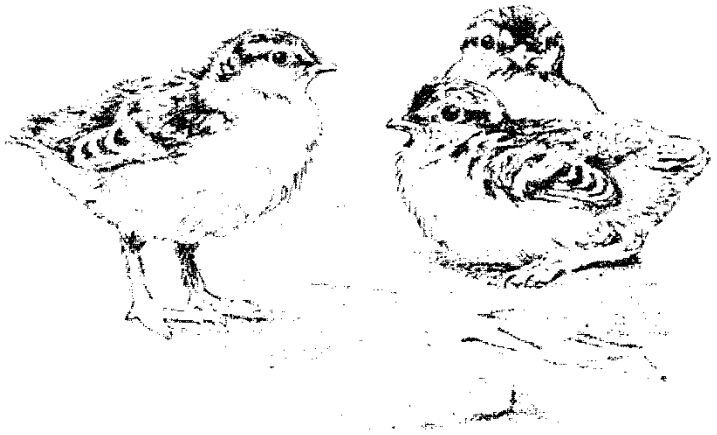
1. Aggregated?

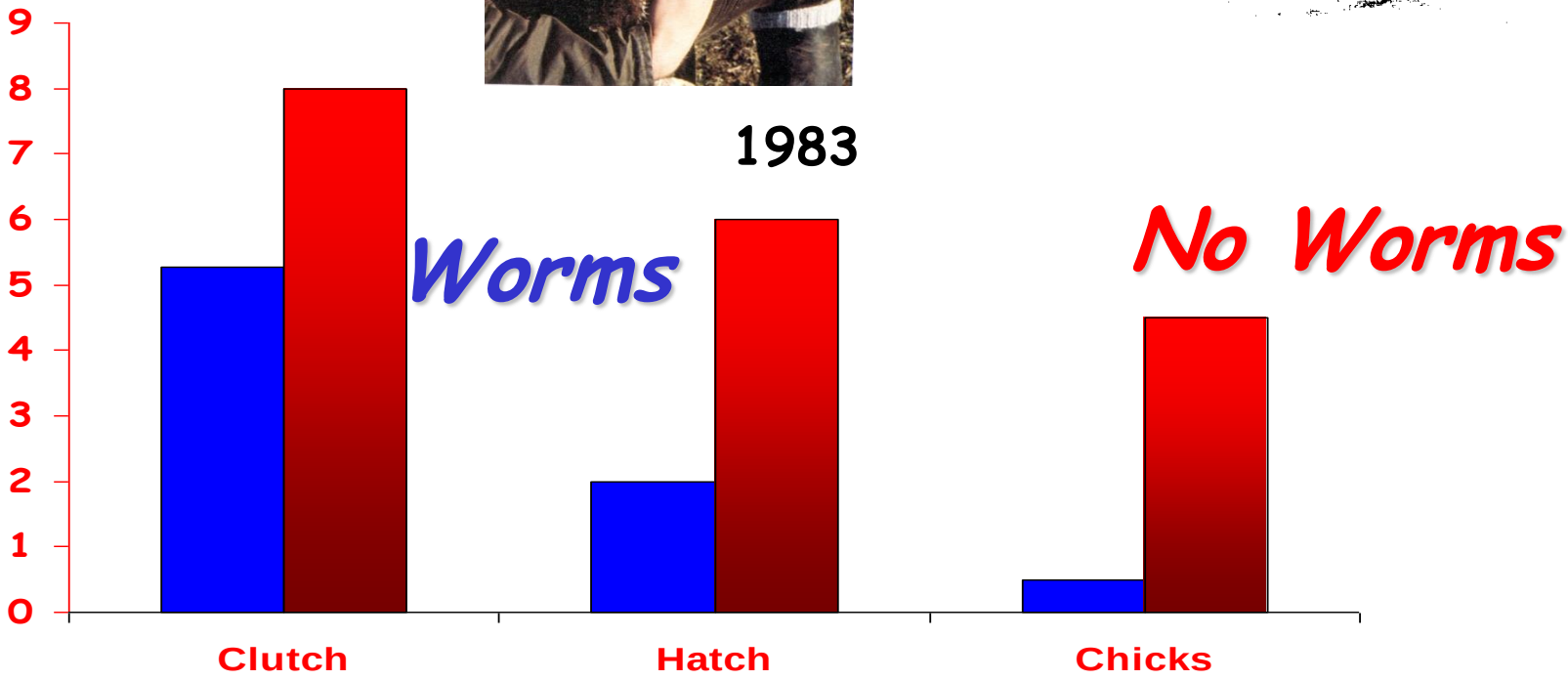
2. No…Close to Random



2b. Parasite induced reduction in host fecundity

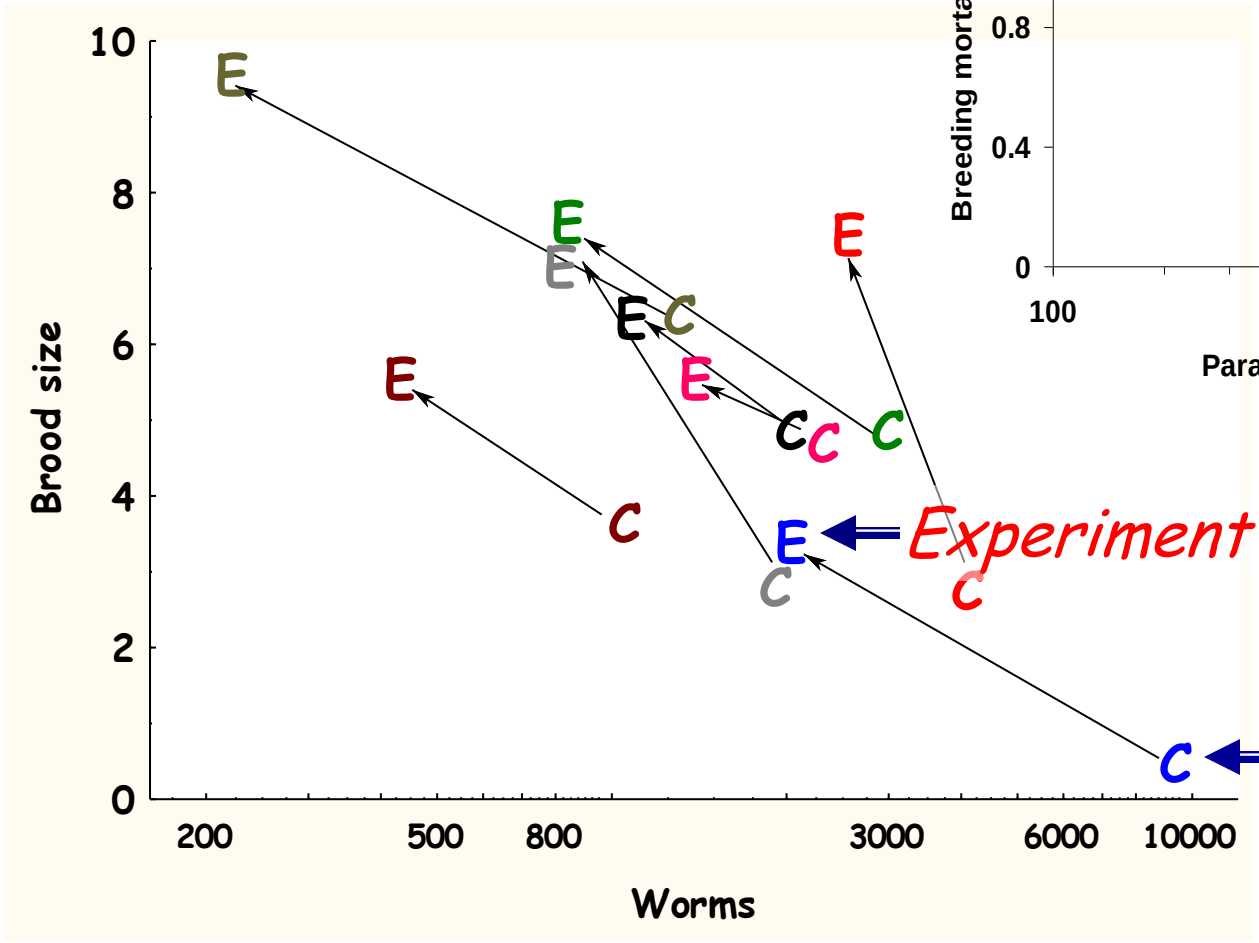


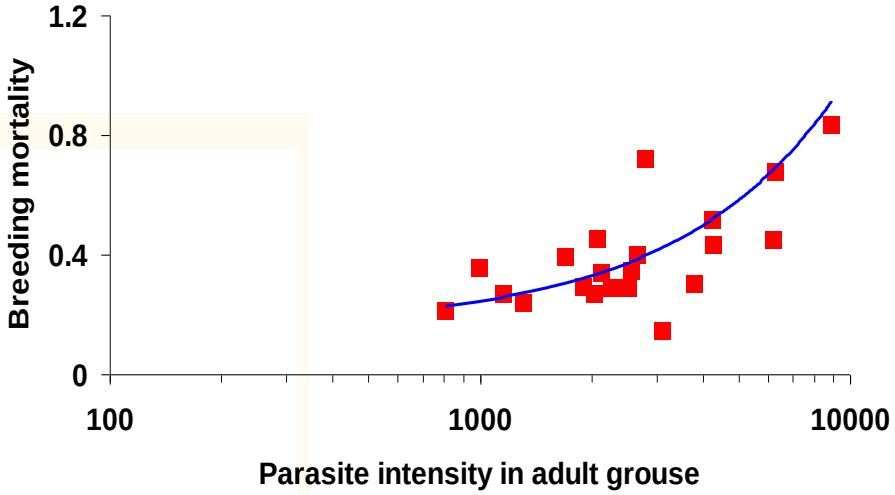




1983

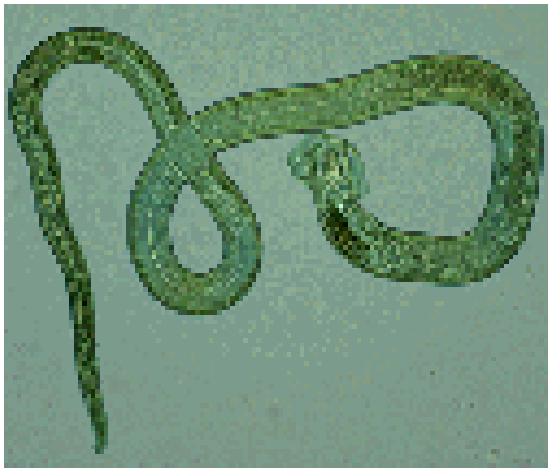
2b. Parasite induced reduction in host fecundity

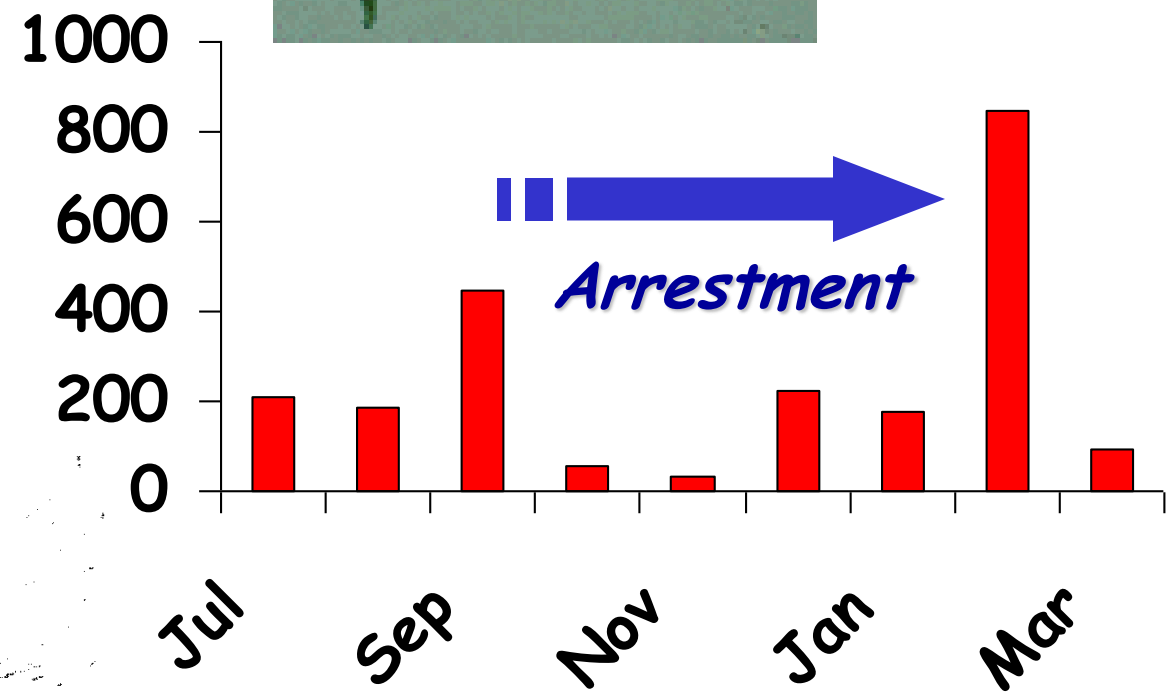




2c. Time delays in parasite life cycle

Time of Parasite Recruitment

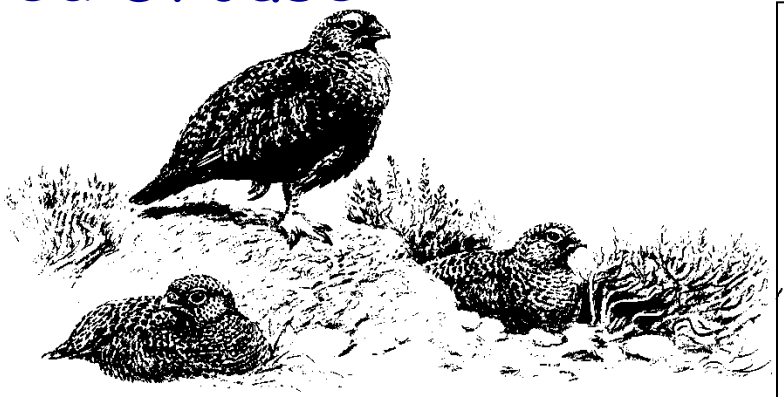




Do Parasites influence Host Dynamics?

2. Destabilising Features at individual level

Red Grouse



Trichostrongylus tenuis

Destabilizing Features:

1. Regular distribution $\kappa \rightarrow \infty$
   MMMmm a a bit
2. Parasite induced reduction in host fecundity $\delta < \alpha$
   Yep
3. Time delays in life cycle
   Yep

Trophic Interactions

What are the consequences for population & community?

1. Individual level productivity

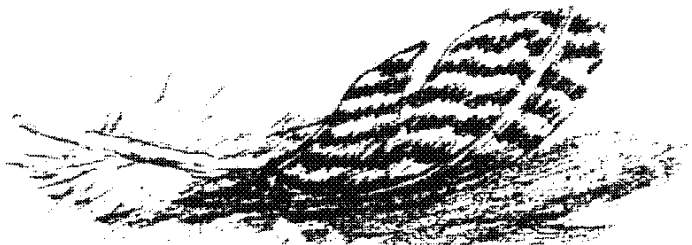
   Frequency Dist. Fecundity Reduction

   & Time delay

2. Population level dynamics

3. Community level interactions

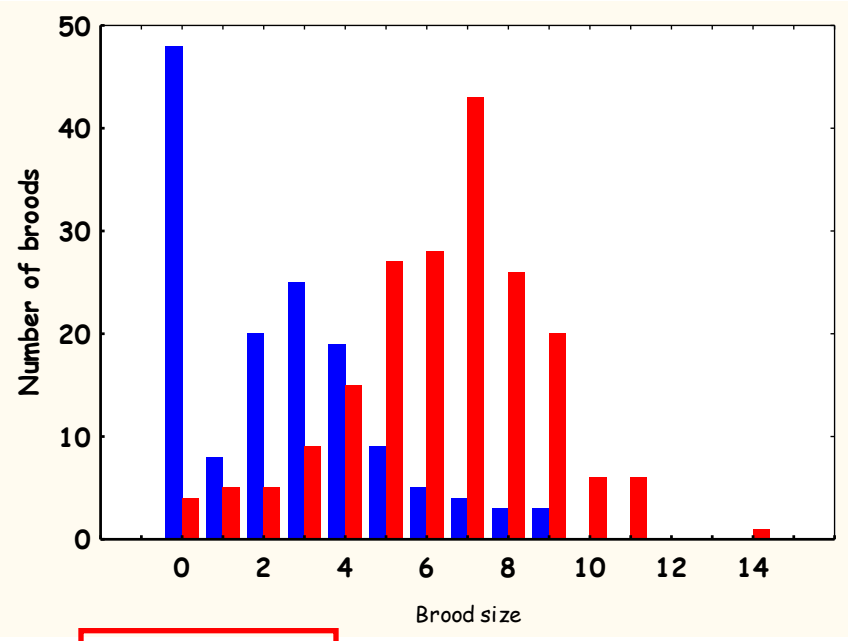
Understanding ~ Monitoring Experiments & models



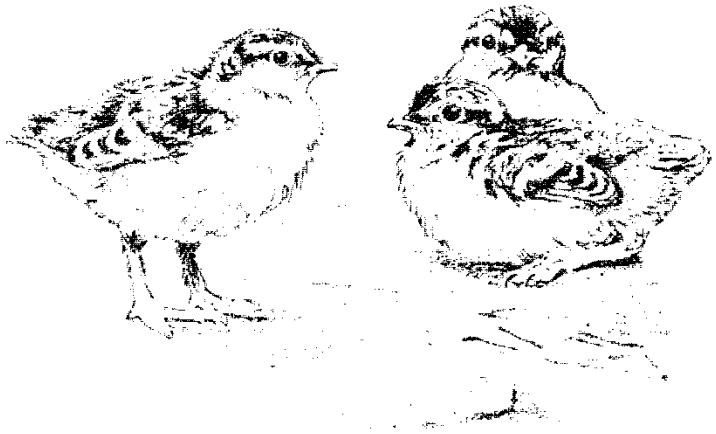
1. Individual Level Productivity

Grouse brood frequency distributions

High & Low Worms



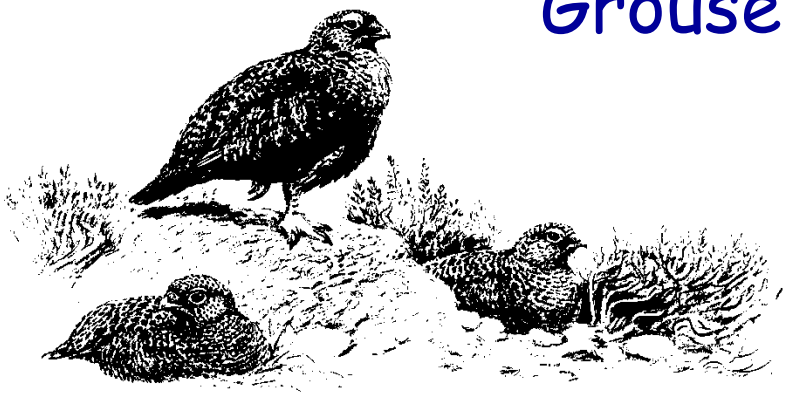
Worms → Female Condition → Chick survival

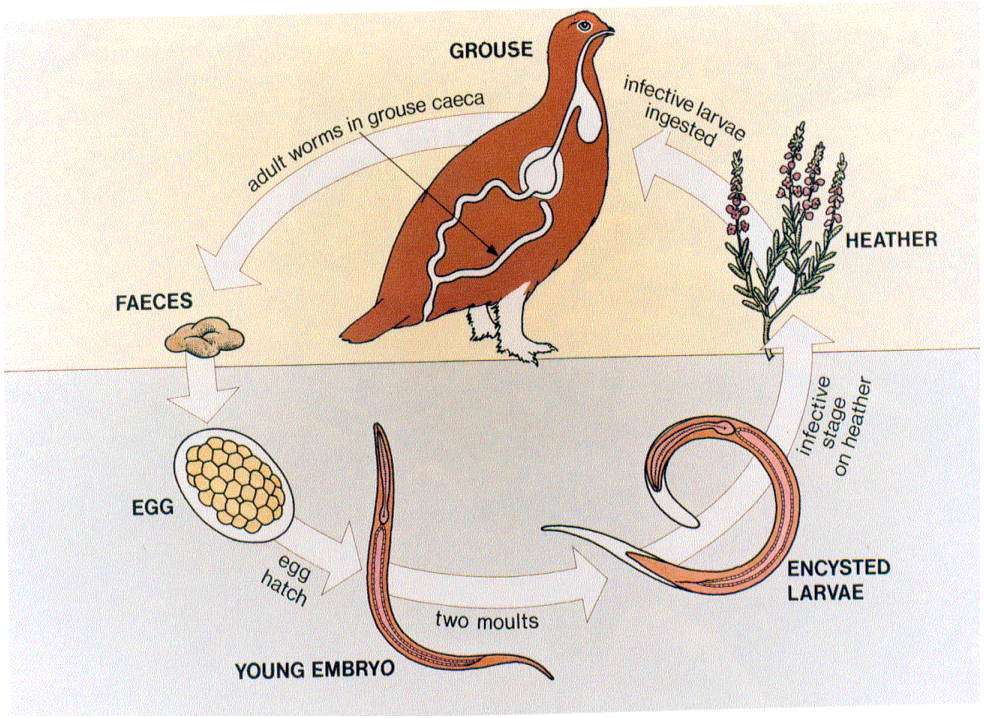


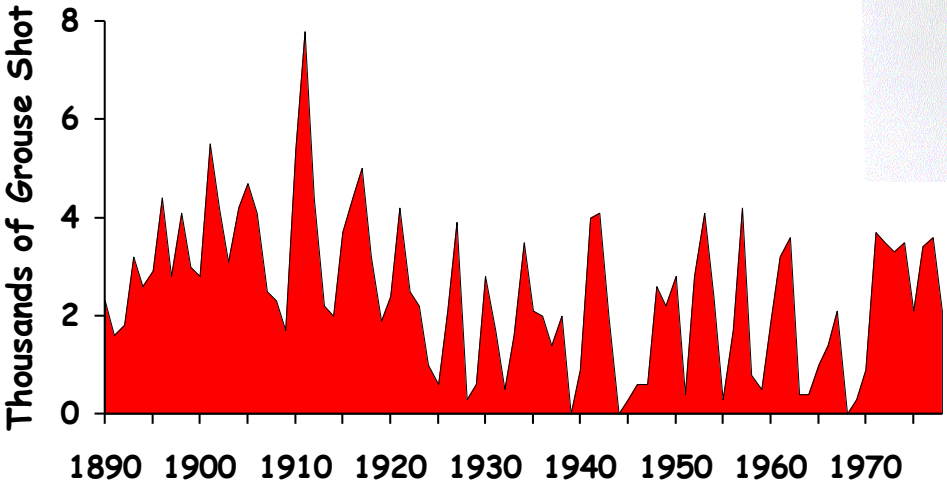
2. Population Level Dynamics

Dobson & Hudson Macroparasite model

Grouse

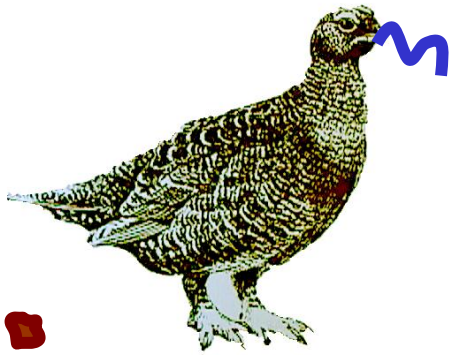


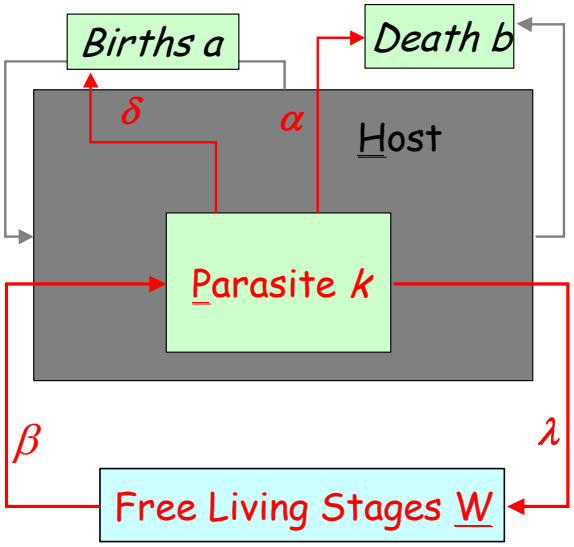


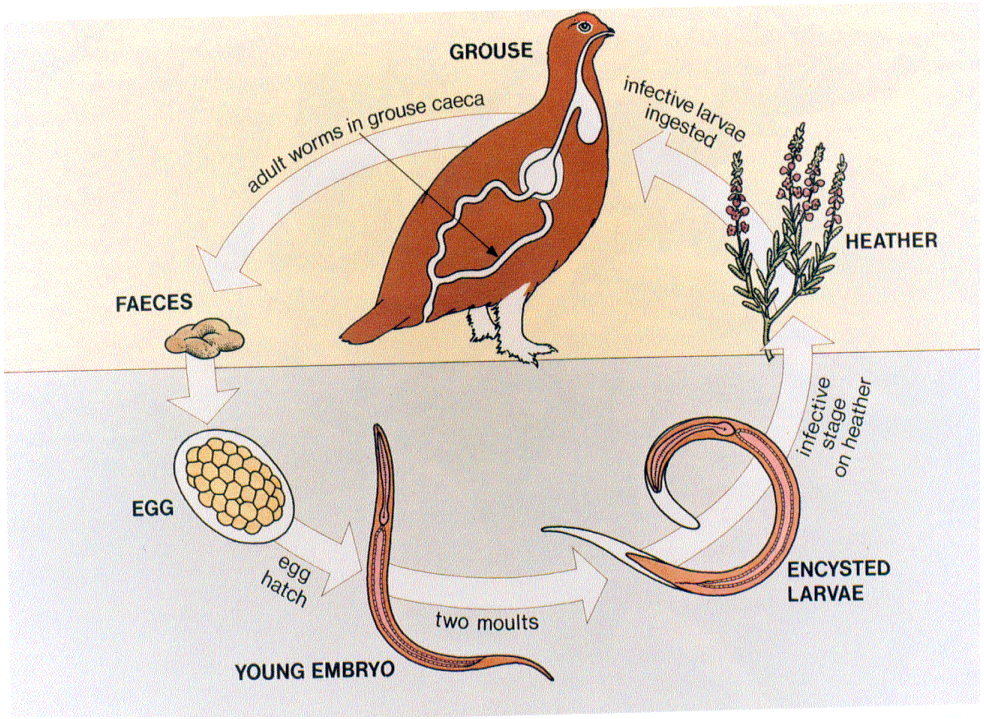


2. Population Level Dynamics

Dobson & Hudson Macroparasite model

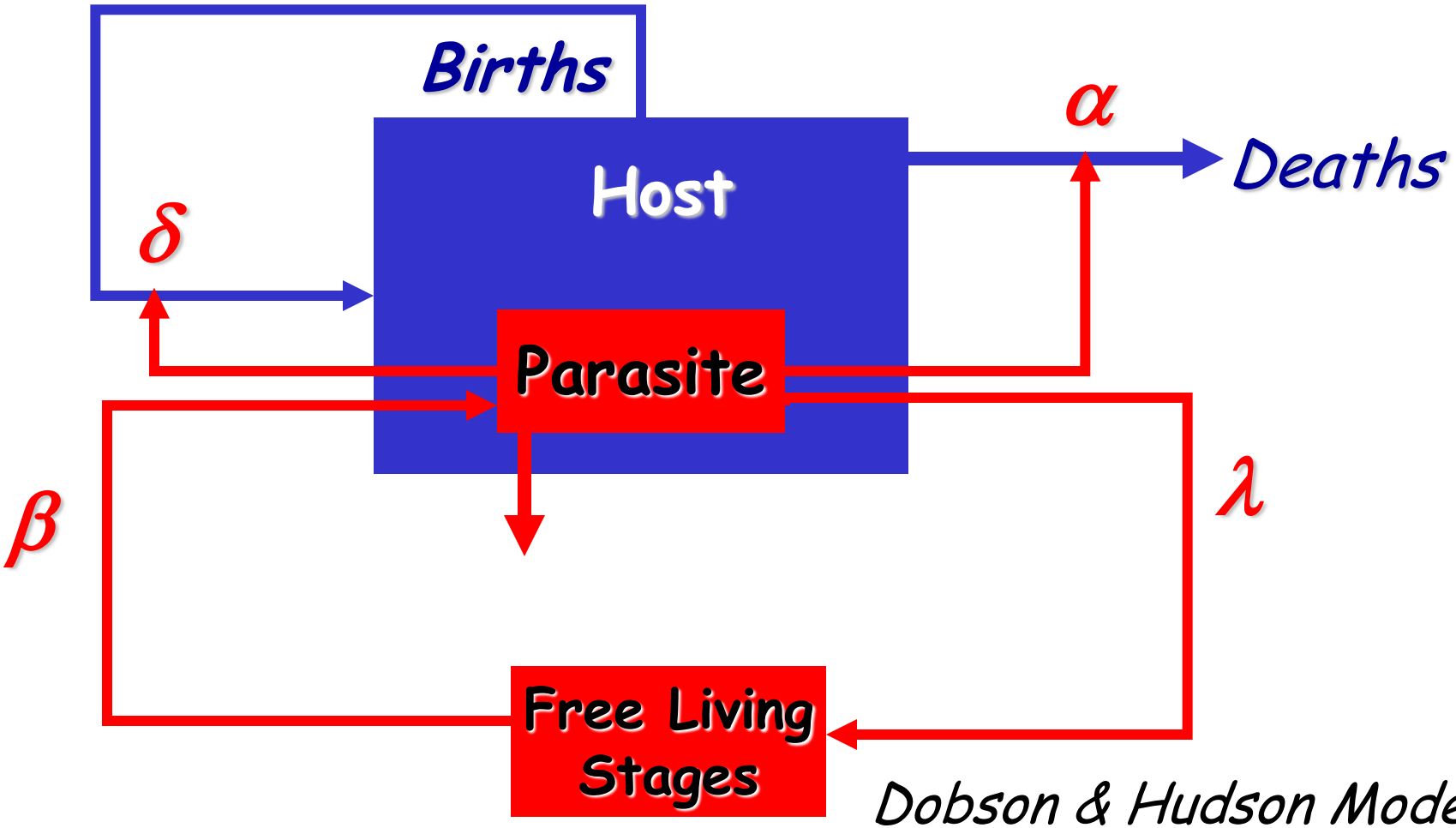






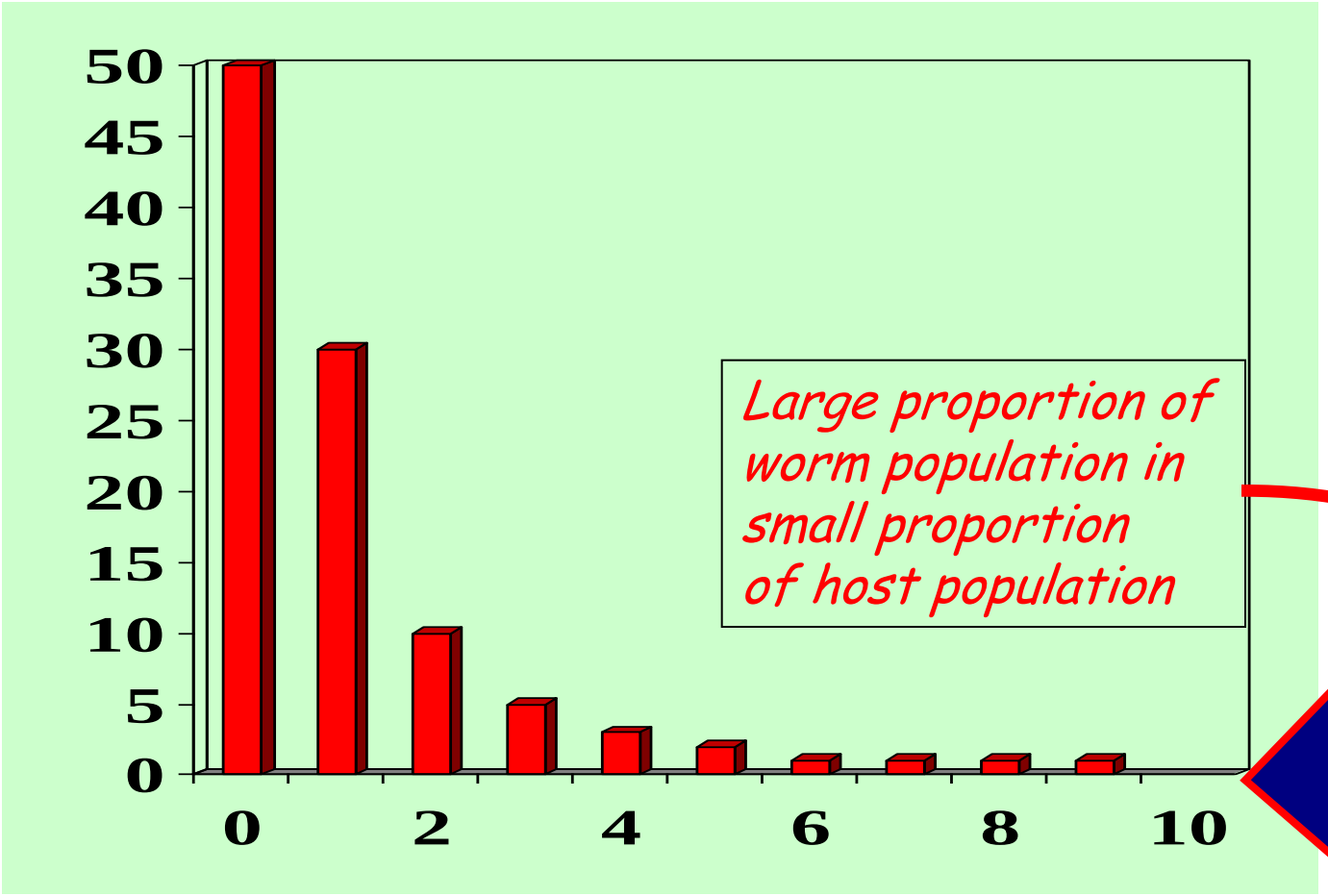
Do Parasites influence Host Dynamics?

3. Population level effects



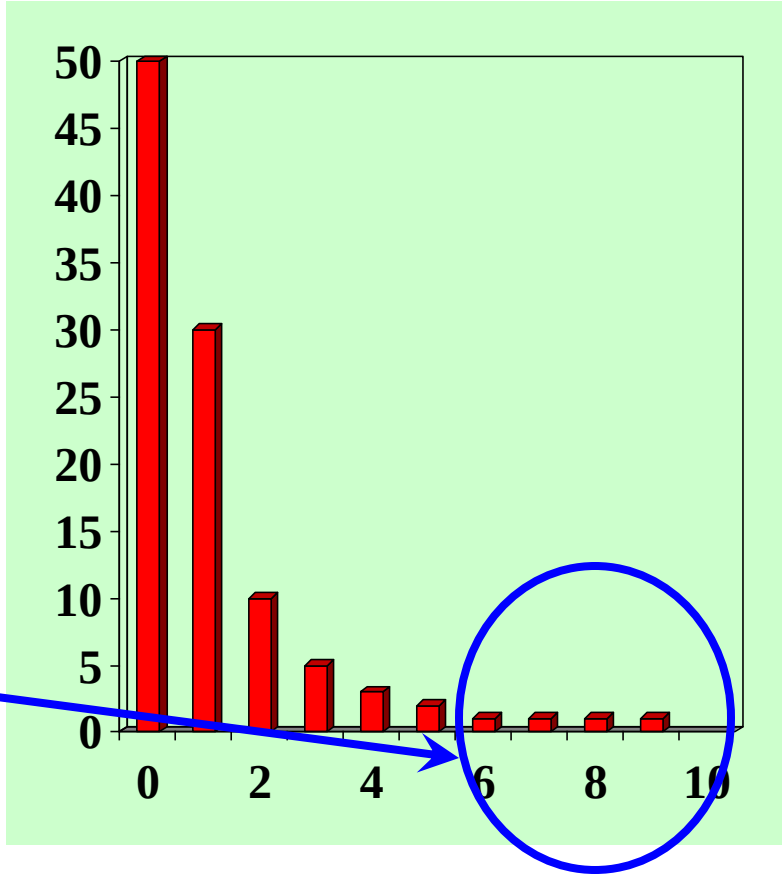
Dobson & Hudson Model

Macroparasites invariably have an aggregated distribution



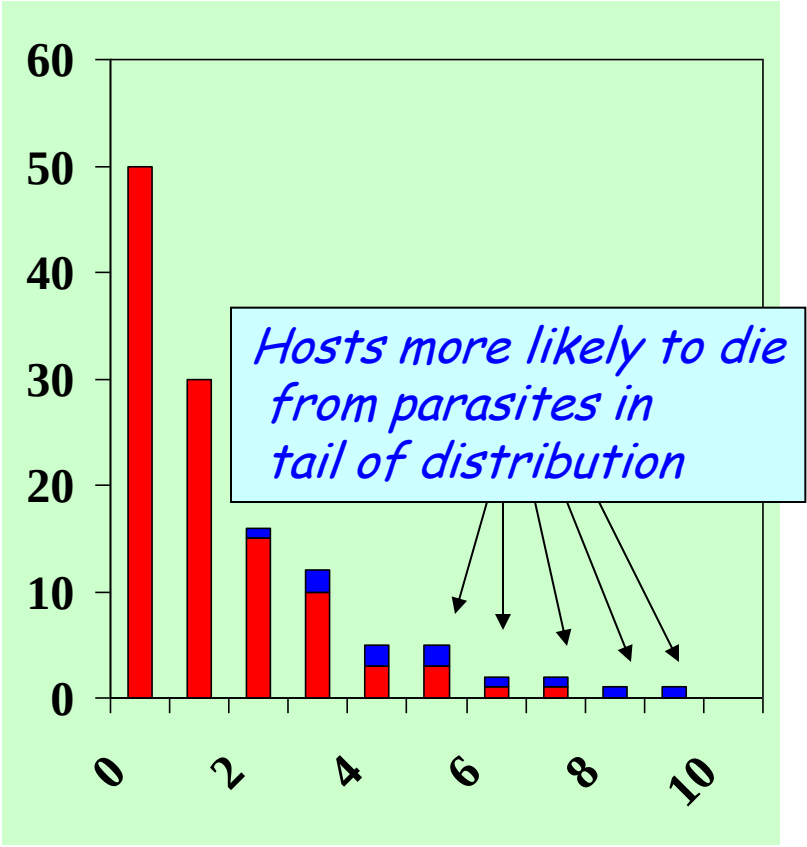
Aggregated distributions = Biological interest

- Overall parasites experience higher densities
- *Mortality and morbidity just in the tail*
- *So impact on host and selection pressure will be higher here*



Aggregated distributions = Biological interest

- *Highly virulent parasites have low means because they kill the hosts in the tail of the distribution*
- Some selection against this because of reduced mating opportunities in dioecious species
- *So selection towards moderate virulence*



2. Population level dynamics

Dobson & Hudson Macroparasite model

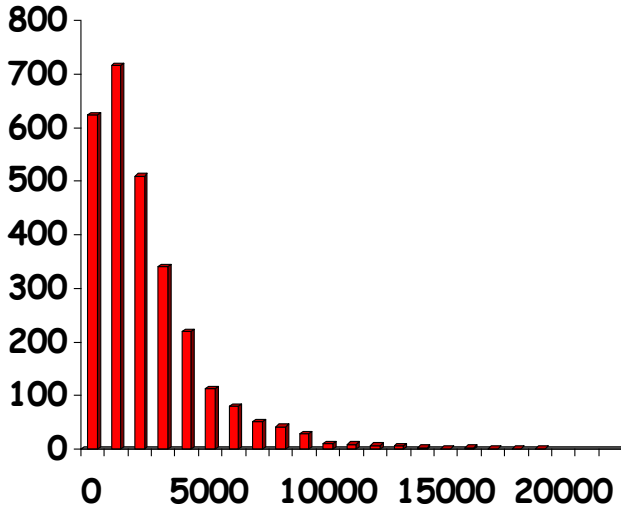
$$\frac{\delta H}{\delta t} = aH - bH - (\alpha+\delta)P$$

$$\frac{\delta W}{\delta t} = \lambda P - \gamma W - \beta WH$$

$$\frac{\delta P}{\delta t} = \beta WH - P(\mu+\beta+\alpha) - \alpha \frac{P^2}{H}\left(\frac{k+1}{k}\right)$$

2. Parasite impact on fecundity

3. Parasite impact on mortality-host and parasite!

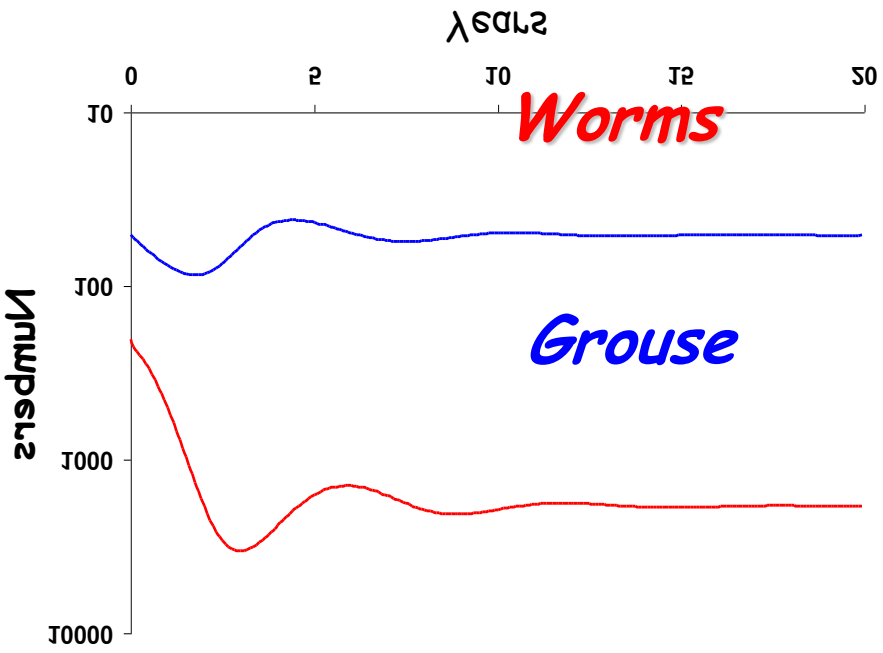


1. Individual risk of parasite induced impacts (-ve binomial)

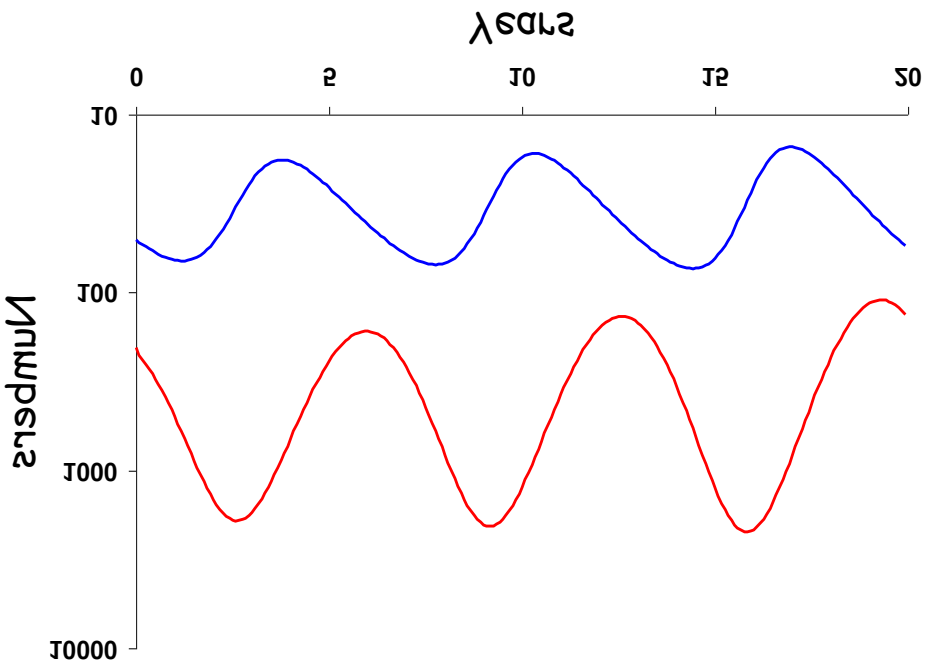
2. Population level dynamics

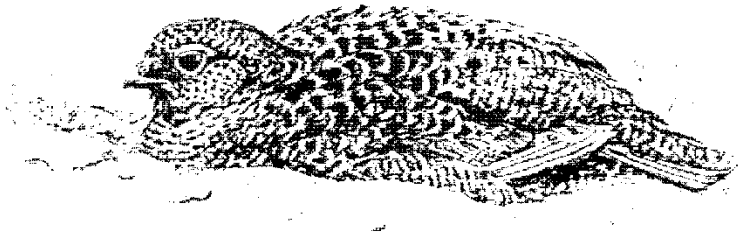
Dobson & Hudson Simulations

Low impact on fecundity



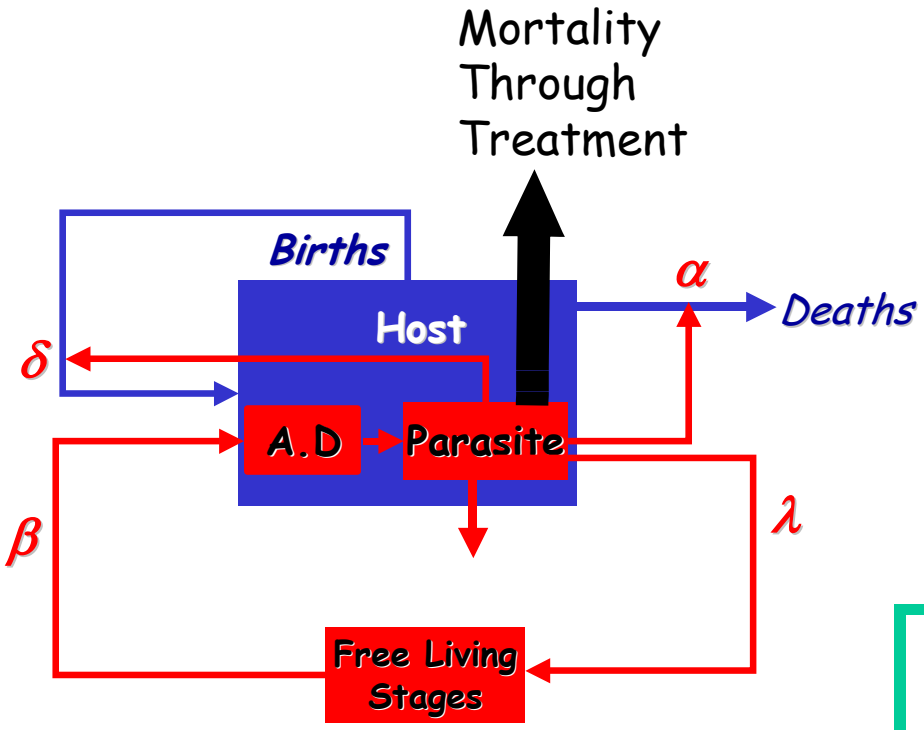
High impact on fecundity

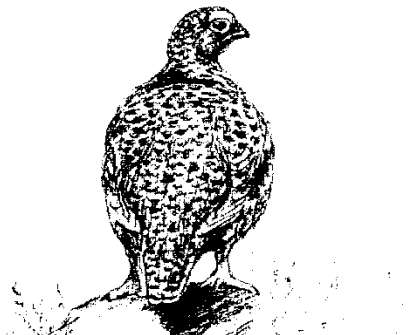


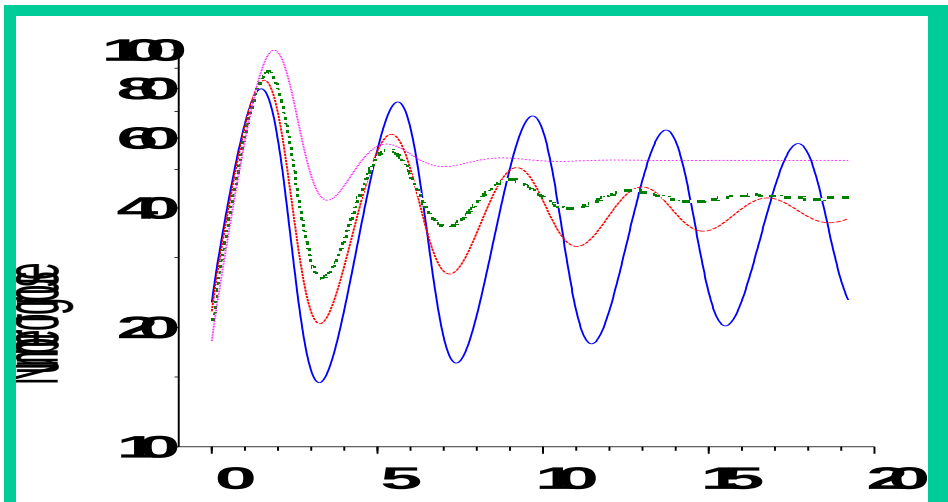


Do Parasites influence Host Dynamics?

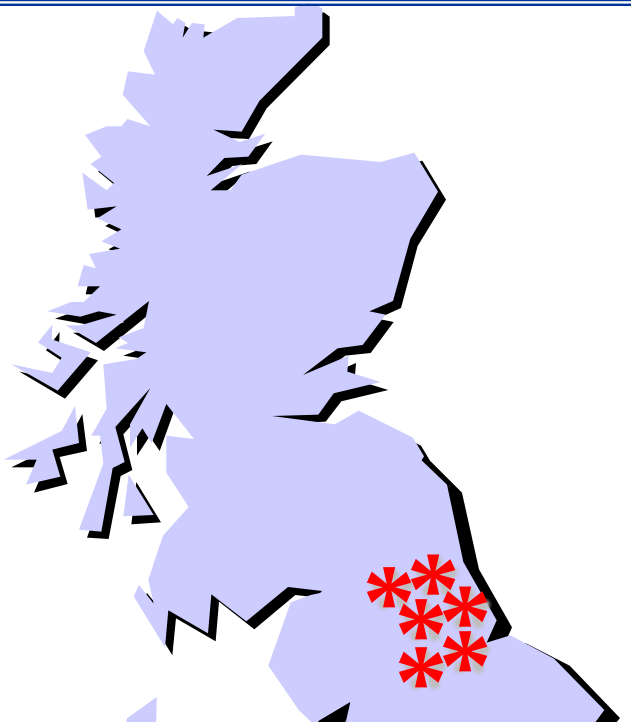
3. Population Level Consequences







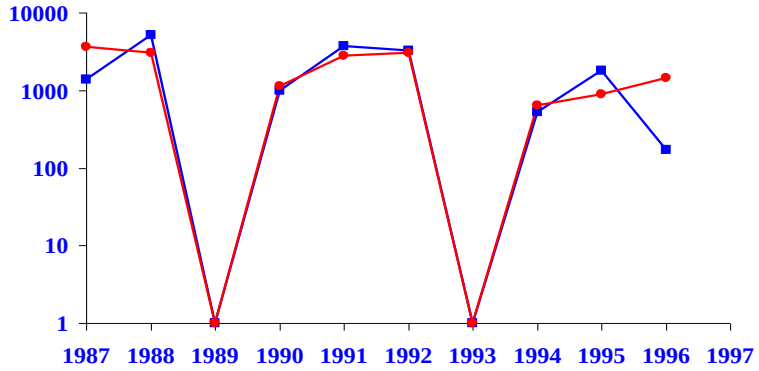
2. Population Level Experiments



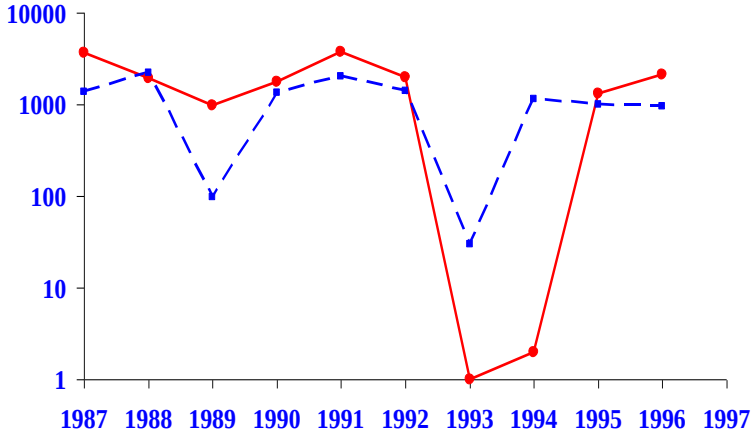
2. Population Level Experiments

Reducing Parasites Reduces Variance in Growth Rate

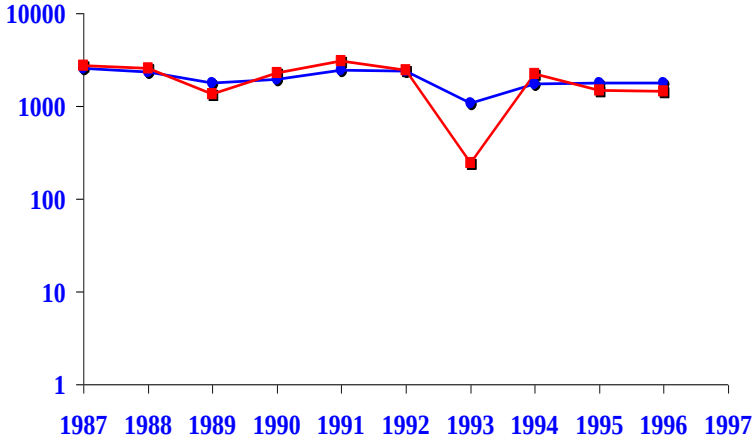
a. Control



b. One Treatment

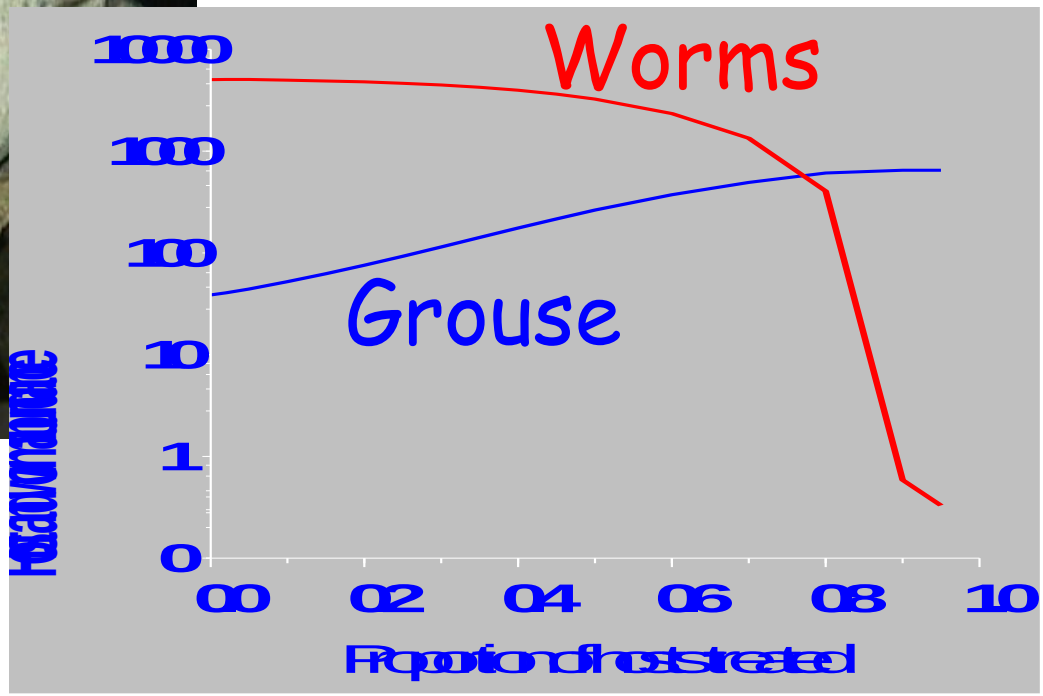


c. Two Treatments



Do Parasites influence Host Dynamics?

3. Controlling infection: Direct Treatment

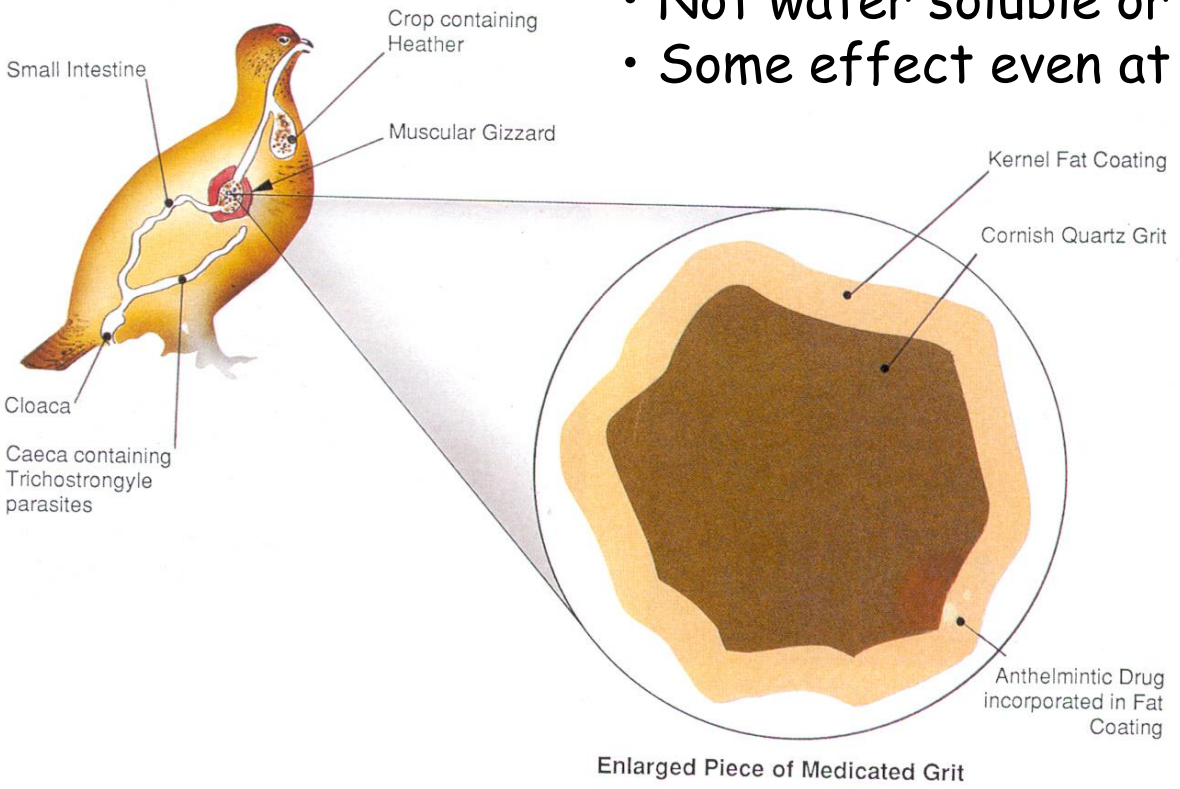


Do Parasites influence Host Dynamics?

3. Controlling infection: Medicated grit

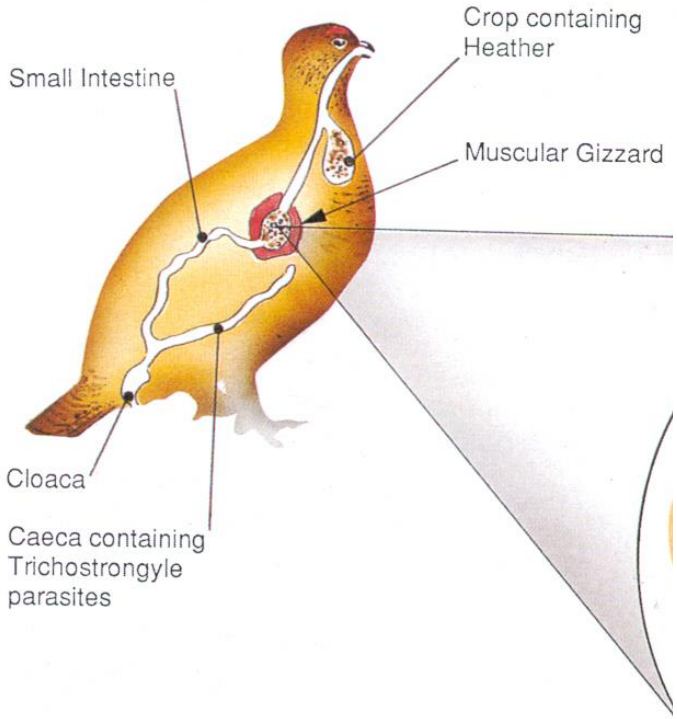
Fenbendazole effective:

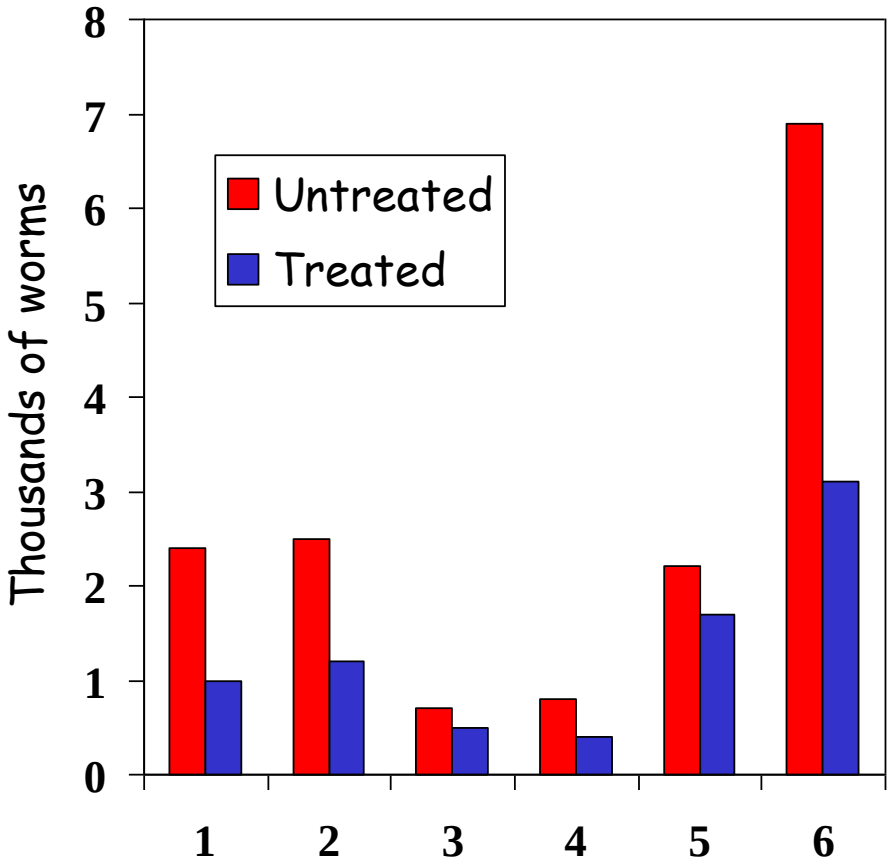
- Split dose treatment over 15 days
- Safe to wildlife
- Not water soluble or break down in light
- Some effect even at low doses



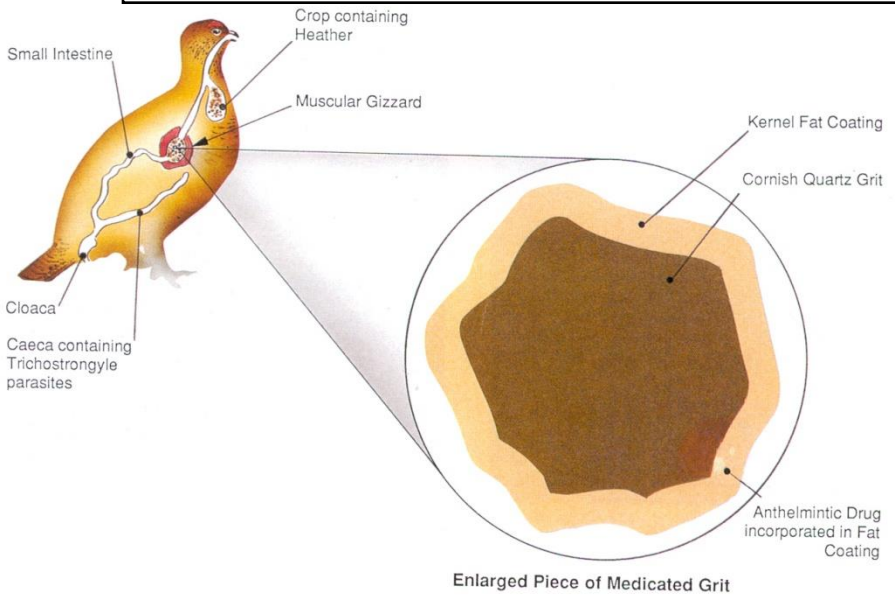
Do Parasites influence Host Dynamics?

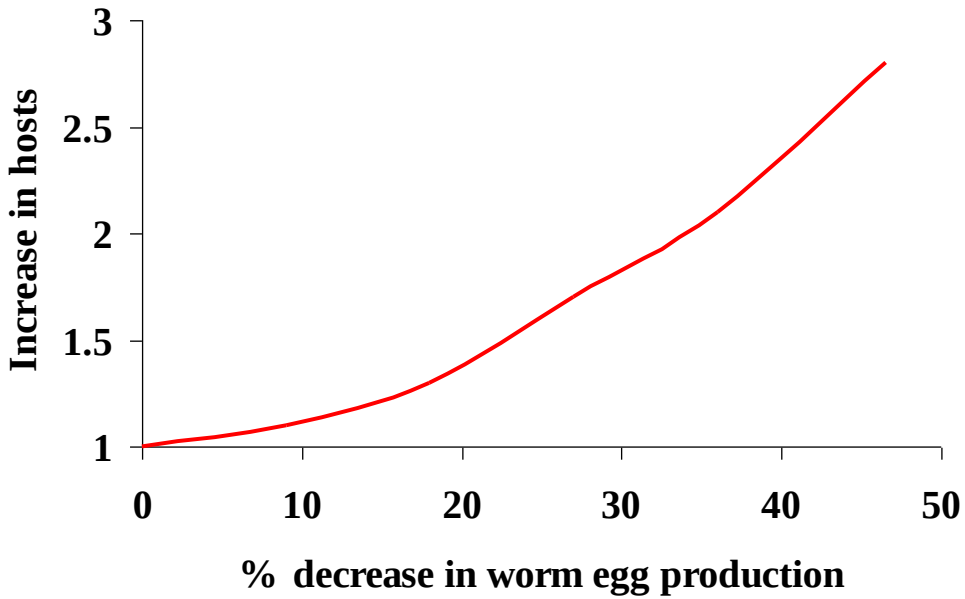
3. Controlling infection: Medicated grit





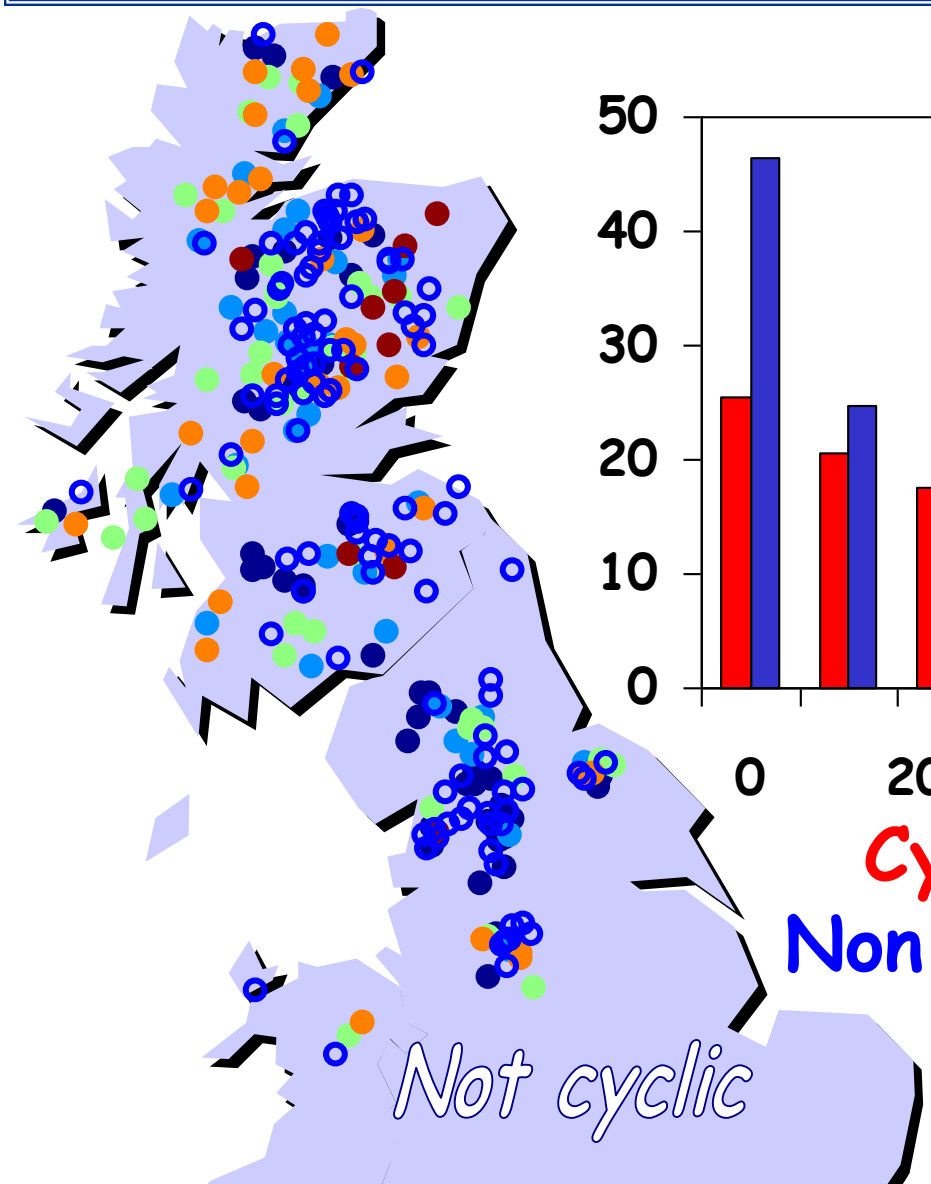
Medicated Grit & Reduced Worm Fecundity

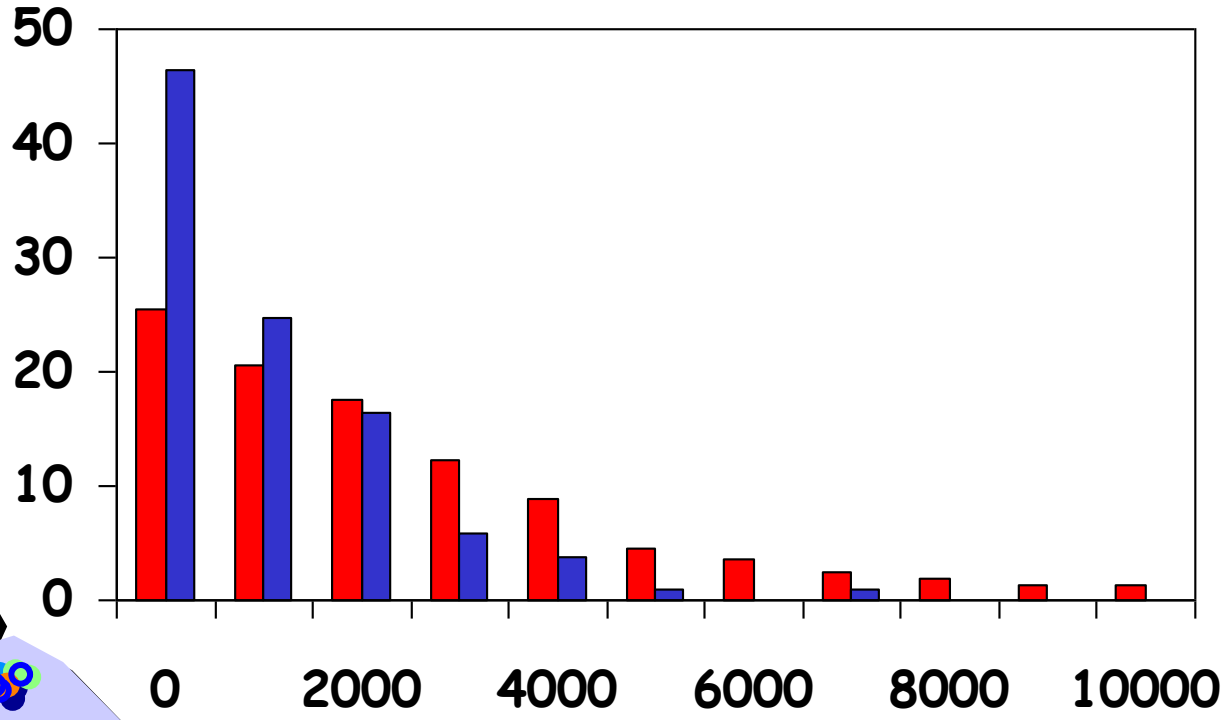




Do Parasites influence Host Dynamics?

3. Why are some populations not cyclic?





Cyclic: 24%>3000 worms

Non Cyclic: 6%>3000 worms

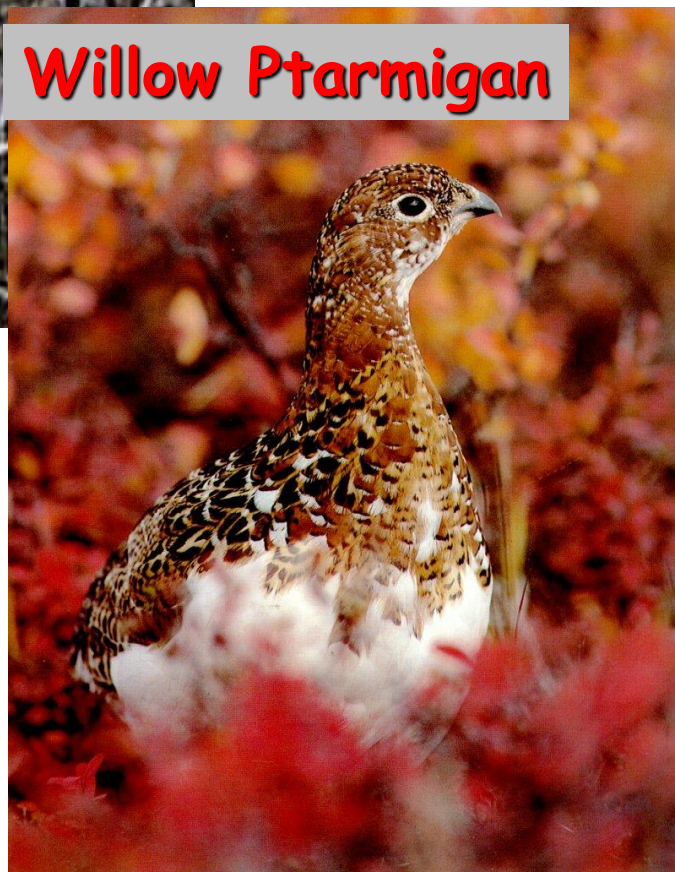
Do Parasites influence Host Dynamics?

Are grouse a special case?

Svaalbard Reindeer

Rock Partridge

Soay Sheep



Willow Ptarmigan

Trophic Interactions

What are the consequences for population & community?

1. Individual level productivity

   Frequency Dist. & Fecundity Reduction

2. Population level dynamics

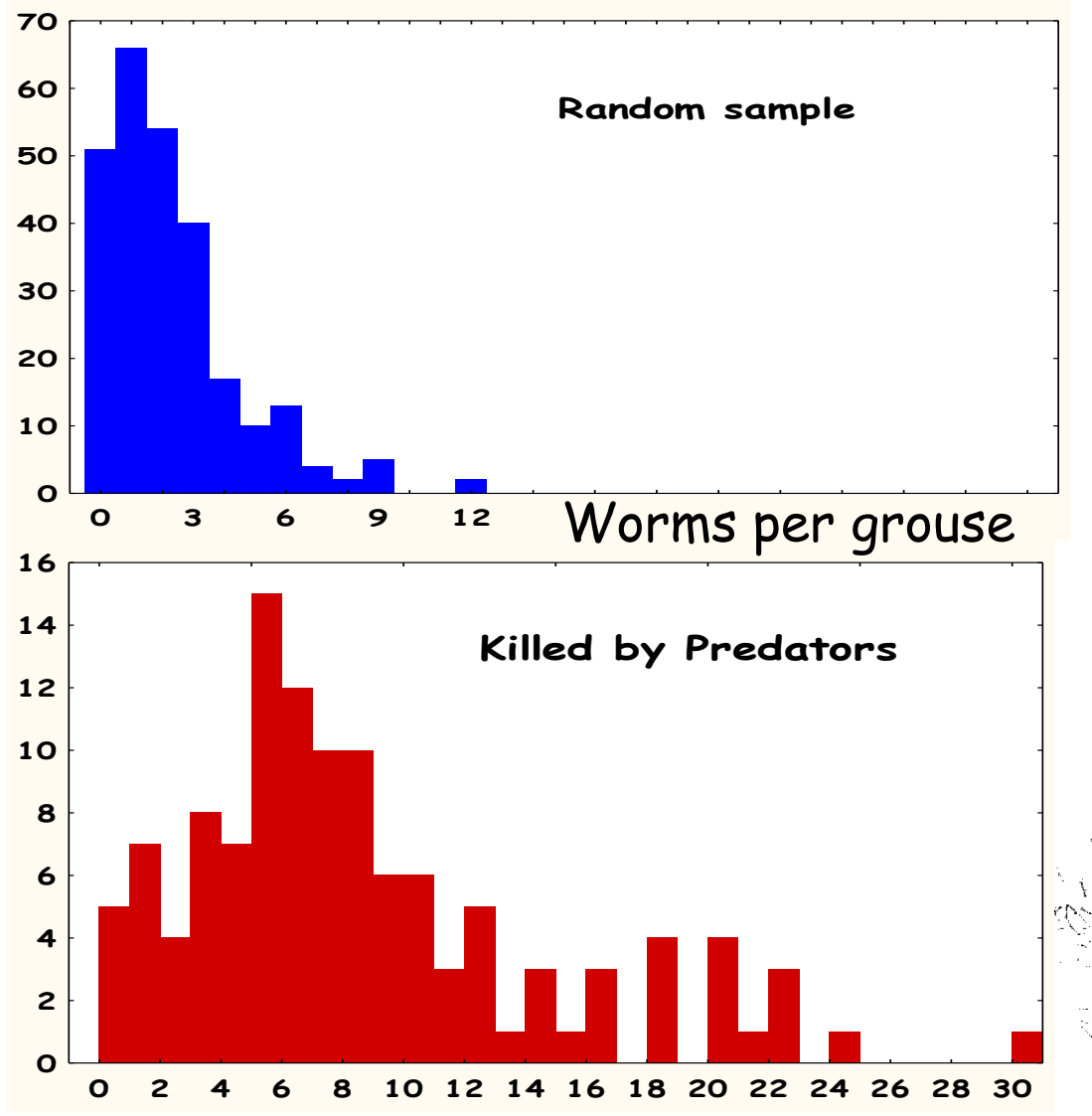
   Parasites play a major role & captured in model

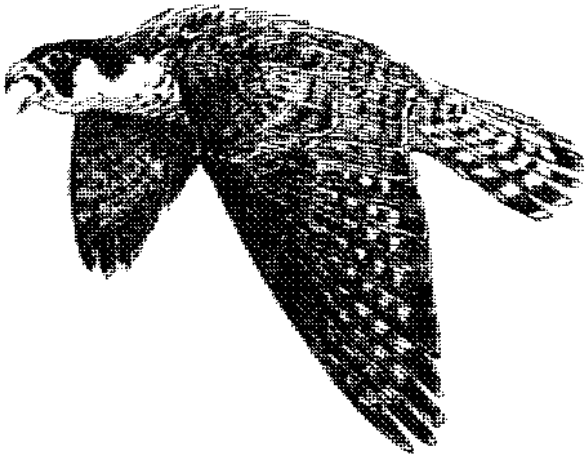
3. Community level interactions

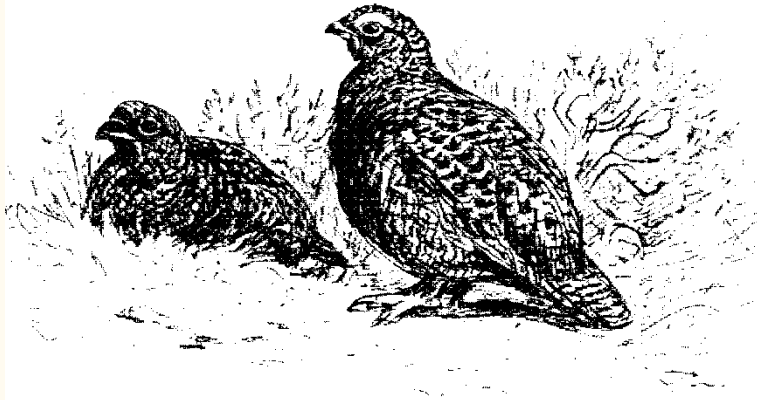
   Understanding ~ Monitoring Experiments & models

Interactions with Predators

Predators selectively kill heavily infected Hosts

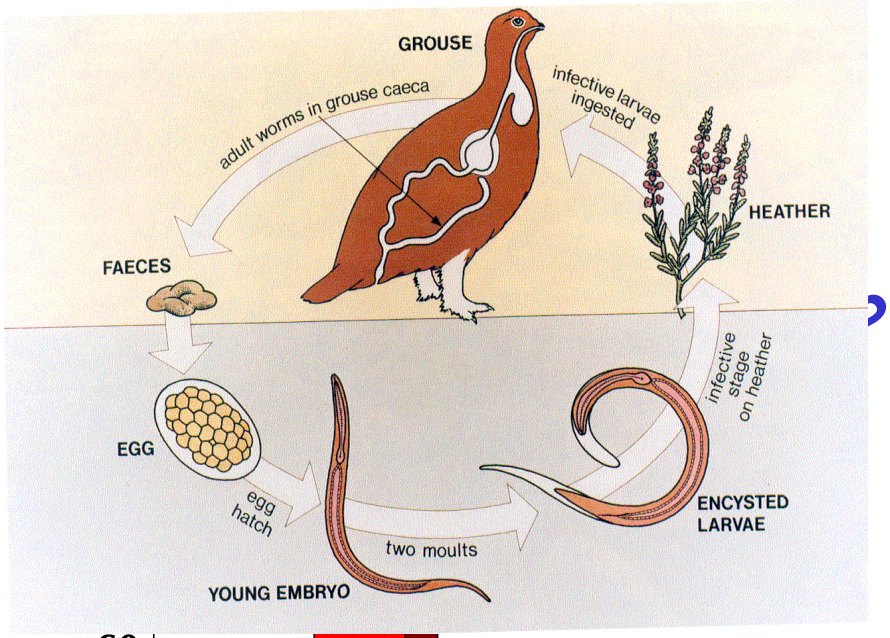


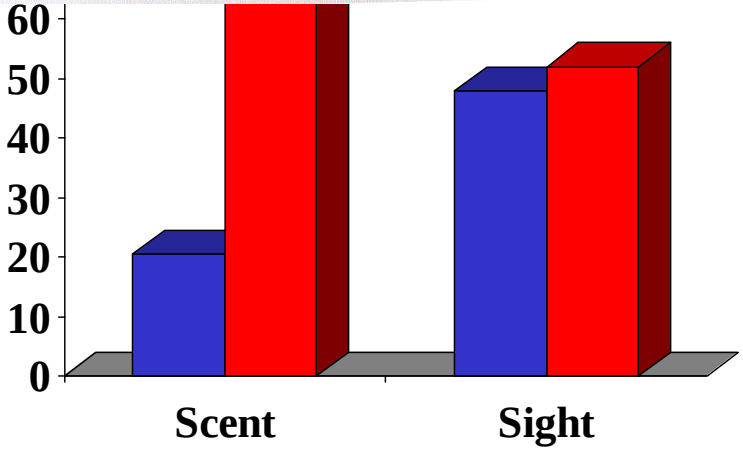




Interactions with Predators

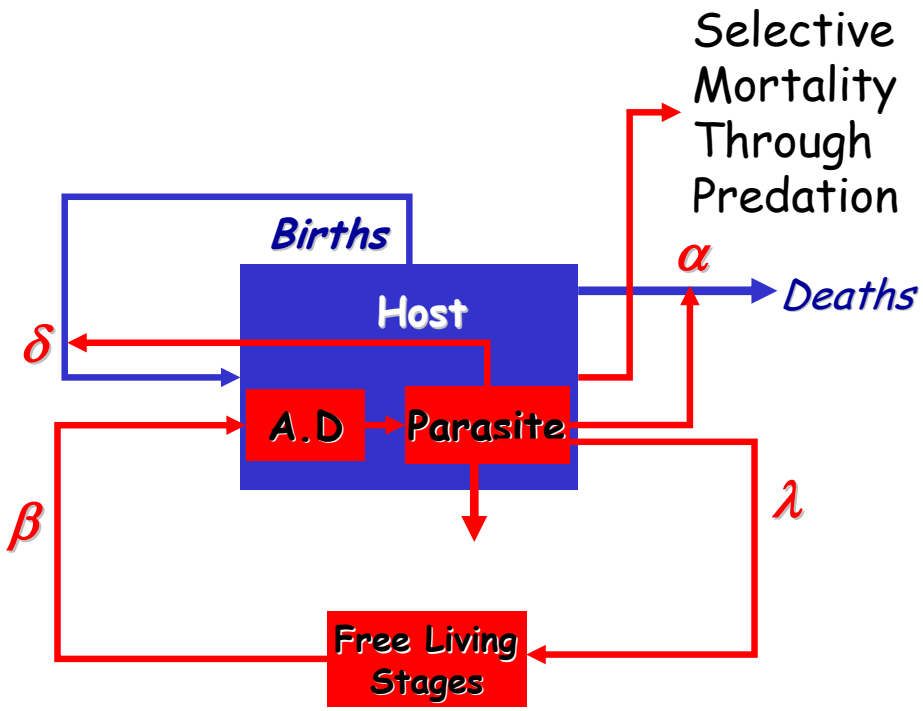
How Do Predators Identify Heavily Infected Grouse?

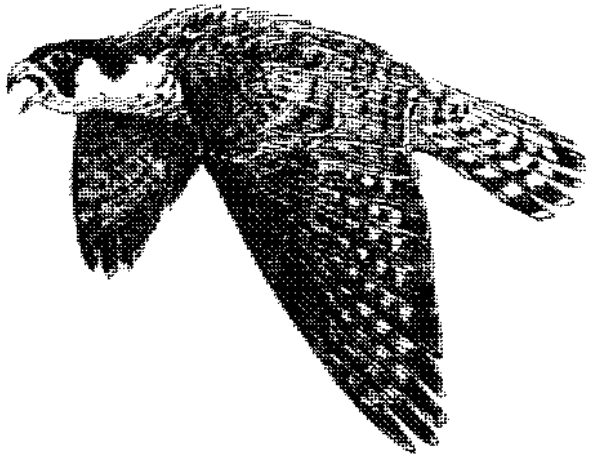


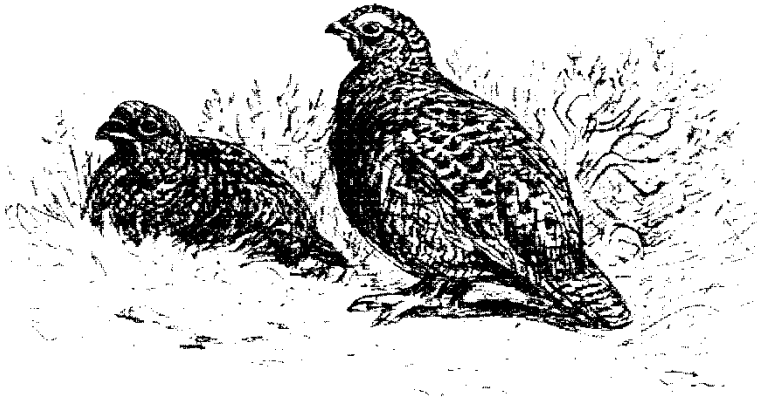


Do Parasites influence Host Dynamics?

3. Population Level Consequences







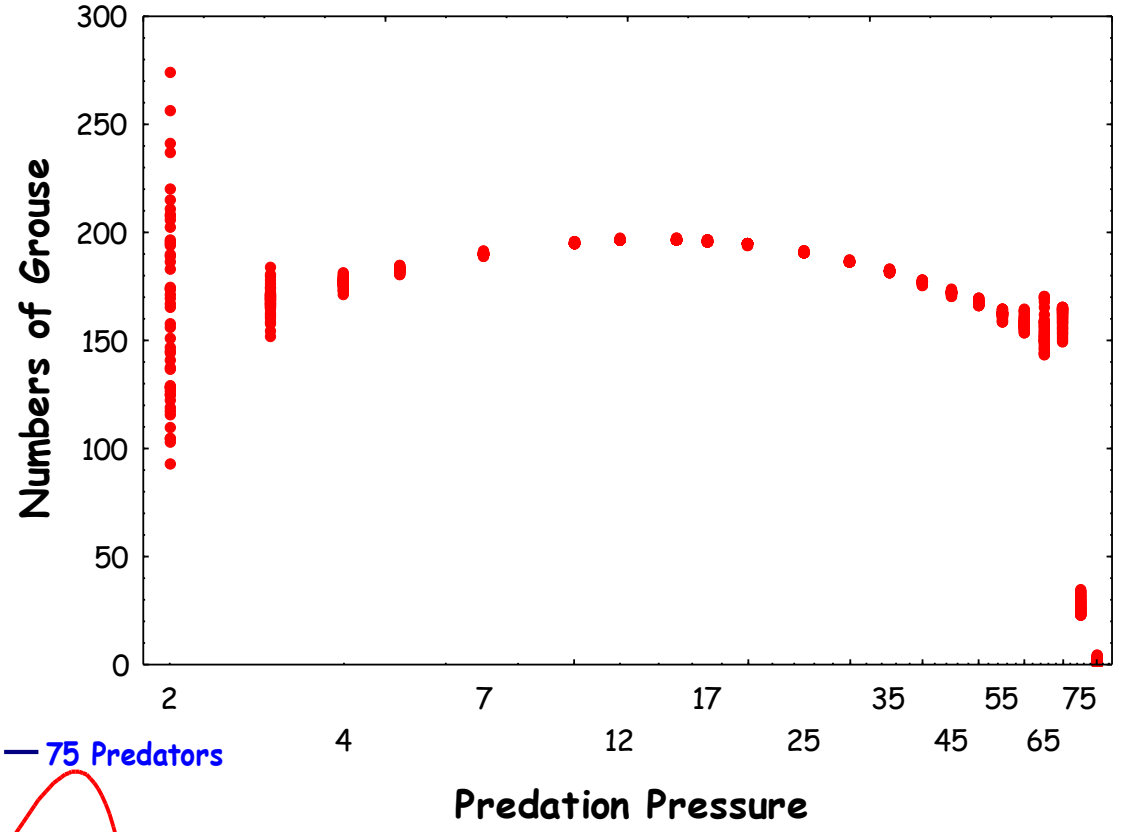
Interactions with Predators

Consequences of Selective Predation

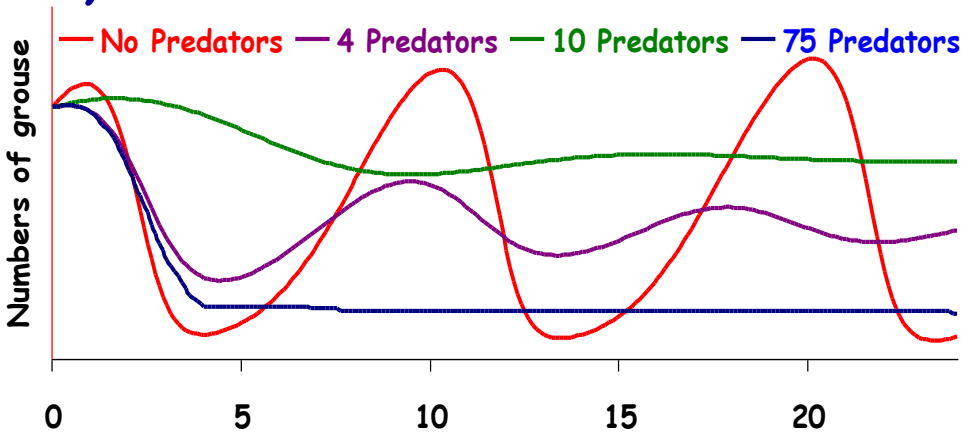
Selective predation

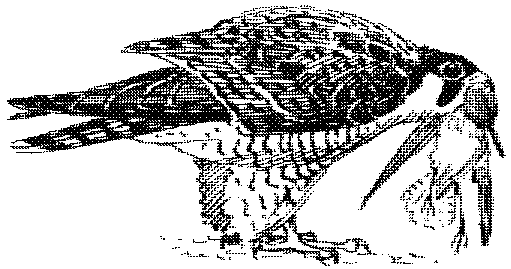
~ dampens cycles

~ increases equilibrium



Dynamics





Community Level

Population Level Patterns

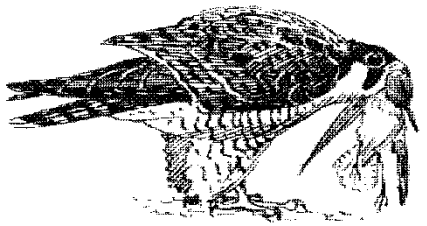
Individual level Processes

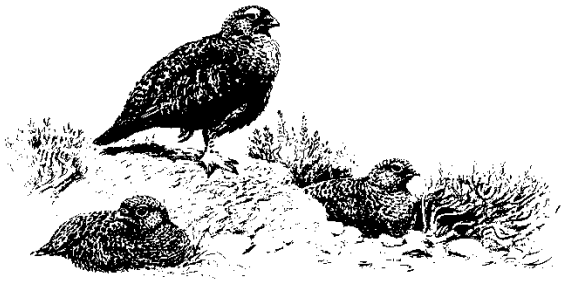
Models

Experiment

Models

Experiment





Global Burden of Intestinal Nematode Infections

- How many people are infected globally?
- What impact does this have on them?
- How much has the situation changed in last 50 years?

M.-S. Chan (1997) Parasitology Today, 13, 438-443

Summary

- Understanding the ecology and evolution of host-parasite relationships requires us to develop a quantitative understanding of their natural history.
- This requires us to study parasitic relationships at a range of spatial and temporal scales.
- Mathematics will be as powerful here as microscopes!
- Parasitism is arguably the commonest life-style on the planet – at least 40% of metazoan species are parasitic, maybe 90% of all species.
- Not all parasitism leads to disease.