Canadian Nuclear Safety Commission | Commission canadienne de sûreté nucléaire

Lessons Learned from the Small Mammal Field Irradiator Studies in Canada

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WORKSHOP ON UNCERTAINTIES IN FIELD STUDIES ON CHRONIC LOW LEVEL EFFECTS DUE TO RADIATION

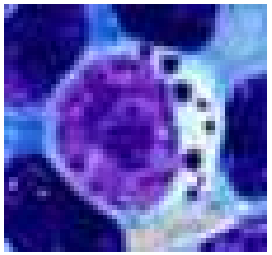
Lancaster, UK
February 4, 2013

CNSC CCSN

nuclearsafety.gc.ca

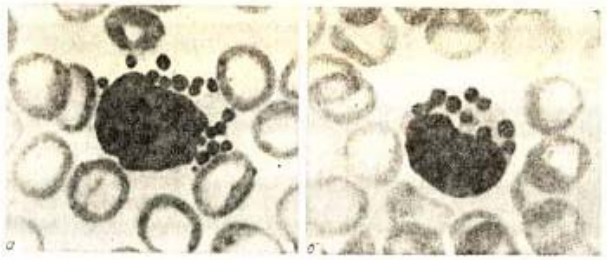
Beginnings – Bison / Voles

Bill Fuller 1975 – Ft. Providence



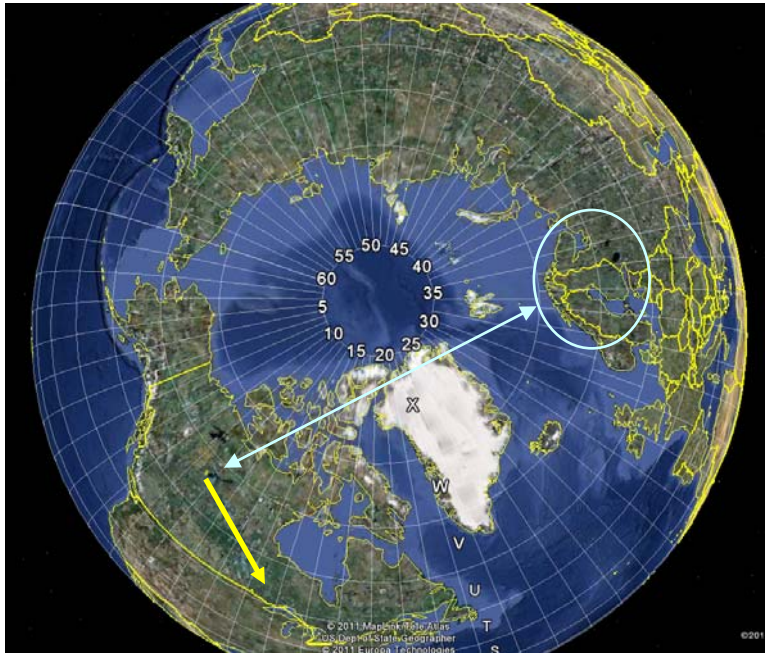
1991 Canada

1978 Russia



New Horizons - AECL / WNRE

1980



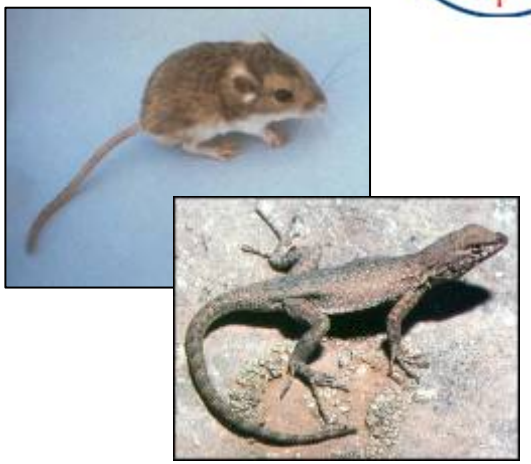
2001

Radioecology – The Early Years

Brookhaven oak-pine forest

1960's **HIGH dose rates**

Alteration of plant community structure next to Cs-137 irradiator

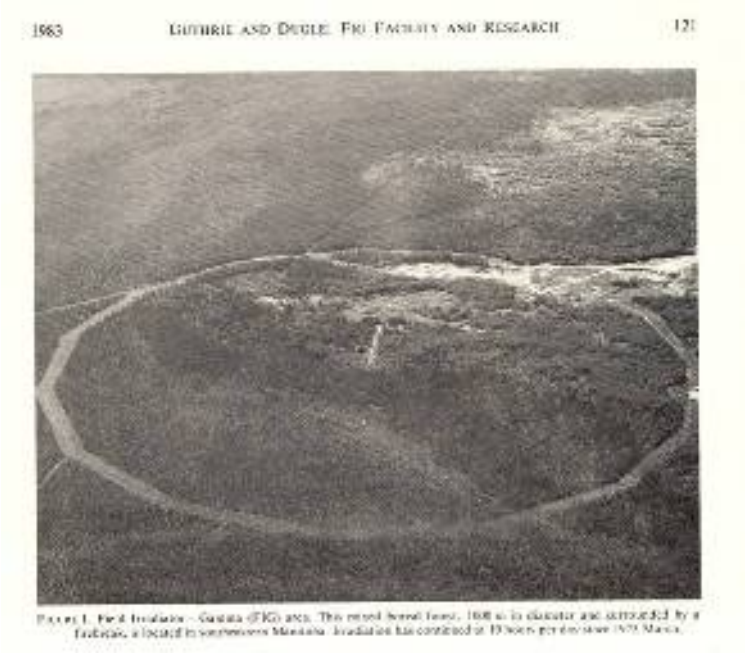


Nevada desert

Chronic exposure of fenced areas

Sterility in lizards starts at ~ 5 – 12+ Gy

Canada - The FIG Project (plants)



1 km radius natural boreal forest

Cs-137 Irradiator
1973 start irradiation

FIG – Animals

Myodes gapperi

- **Red-backed voles living in an artificial gradient of gamma radiation (1969-82)**
  Ann. Zool. Fennici (1985) 22: 257-271

- No effects on population dynamics or small mammal community structure
  Mean rate of 20 mGy/d or 875 µGy/h

House wren

- **No effects on breeding success**
  House wrens and tree swallows monitored in nest boxes at dose rates of up to 5 mGy/d [Zach et al. 1982 & 1993]

ZEUS – Small Mammals

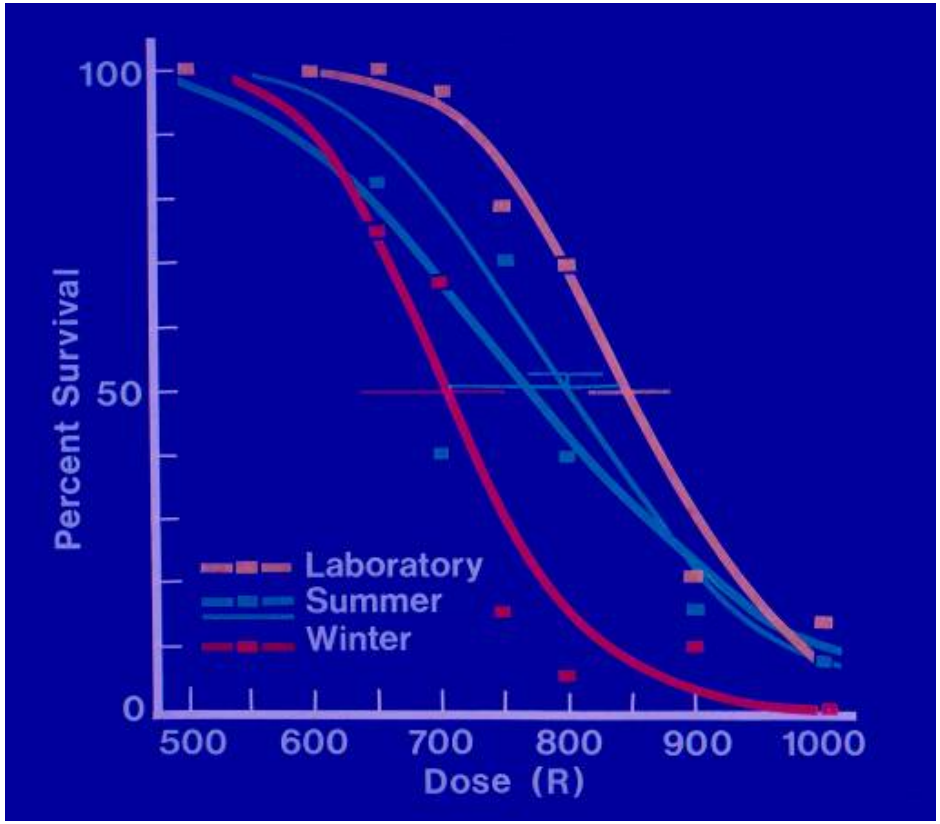
Cs-137 Gamma Irradiator - Aug 1979

"Portable" Irradiator

- **A live-trapping study of wild small mammals living on six 1-ha meadows**
- **Designed for ecological studies at adjustable dose rates (1978-86)**

J. Env. Rad. (2004) 75: 233-266

A New Rodent Model – The Vole



Acute X-rays
Meadow vole
LD_{50} @ 30 days
7 – 9 Gy
Annual gamma background ~ 1 mGy

A New Ecological Framework

Island Meadows

No "fence" effect

A major problem in experimental enclosures

- **The Meadow Vole**

  - Good disperser, colonized the area naturally (1974-1978)
  - Nests above ground, does not hibernate
  - Small home range, good site fidelity, well-researched biology
  - Reaches high densities, efficiently live-trapped in all seasons
  - Dominant in meadows with minimal interspecific competition

A Comprehensive Baseline

Old Field 1978

ZEUS Meadows

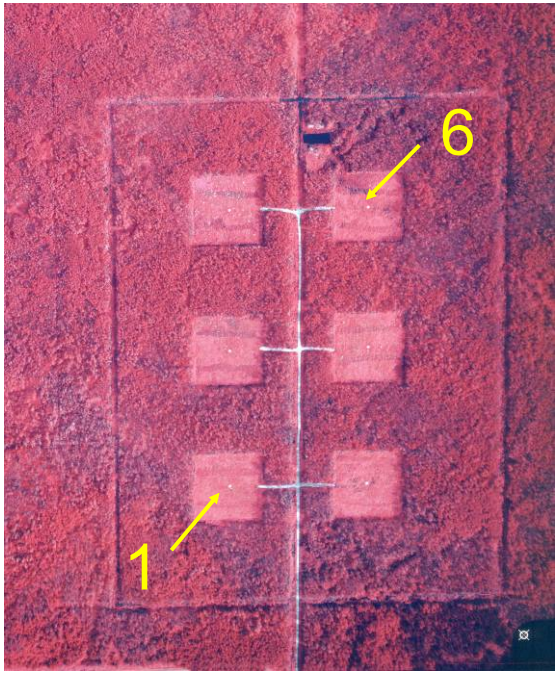
- **<u>Ecological Research</u>: 1967 +**
  Long-term population dynamics
  Ecol. Monog. (1985) 55: 399-420

Brian Turner & Longworth Trap

Year-round Live-trapping

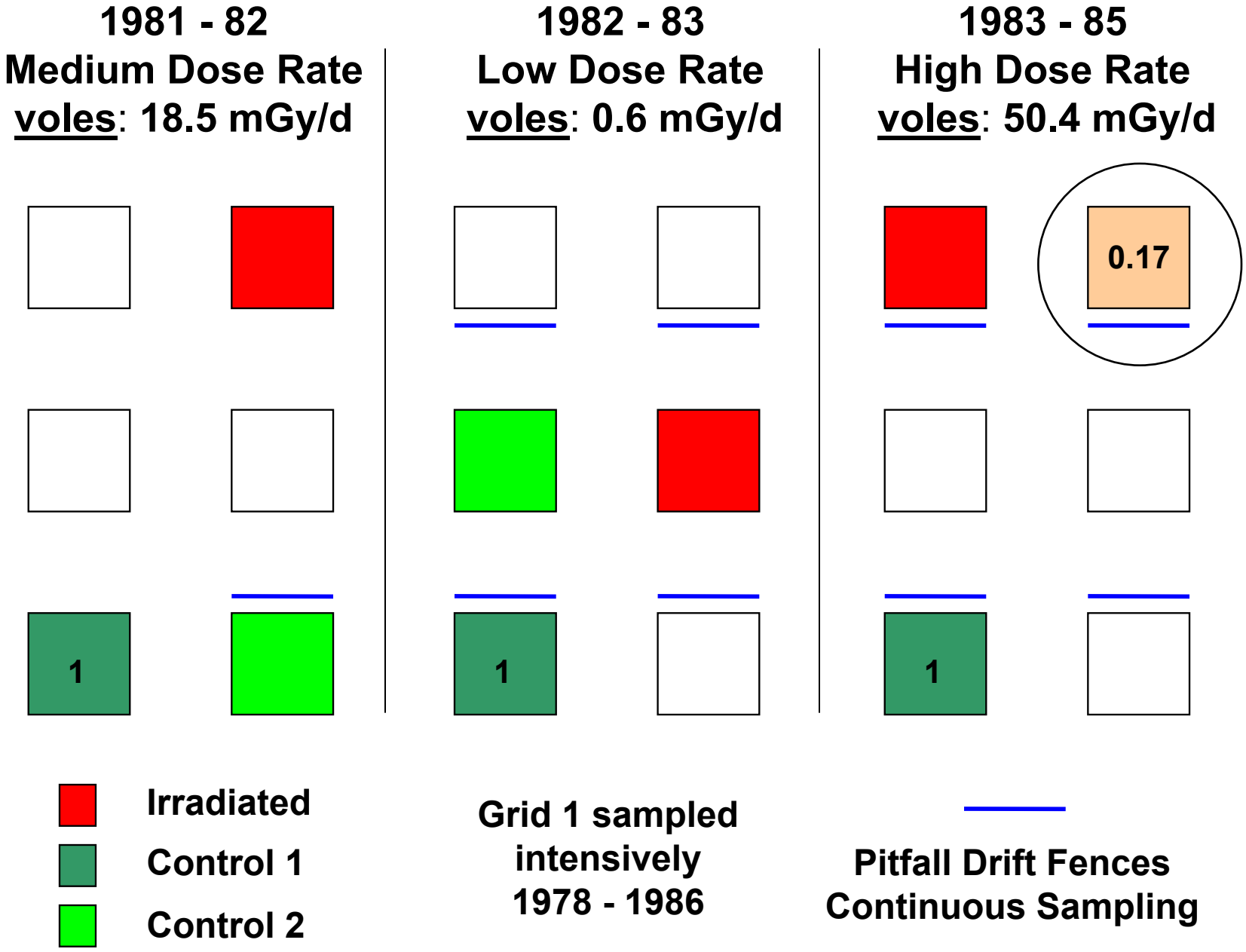
A Flexible Experimental Design

Three experiments at different dose rates



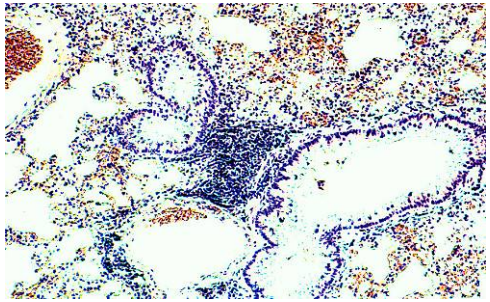
- **Target was ~ 1 – 100 mGy/d**
- 1 to 1.5 years each, start with a young cohort of non-breeding voles in autumn
- Fixed irradiated meadow and two meadow controls trapped every two weeks
- Six old field controls and four other ZEUS meadows trapped in spring / fall to capture annual low / peak; sometimes more often

Population / Community Ecology & Health

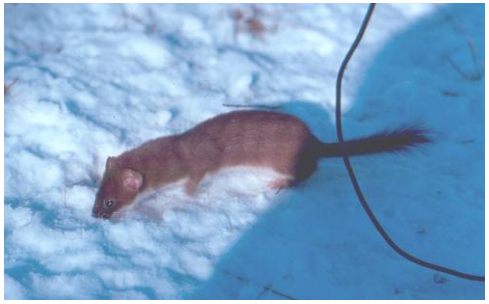

1981 - 82
Medium Dose Rate
voles: 18.5 mGy/d
1982 - 83
Low Dose Rate
voles: 0.6 mGy/d
1983 - 85
High Dose Rate
voles: 50.4 mGy/d
0.17
1
1
1
Irradiated
Control 1
Control 2
Grid 1 sampled
intensively
1978 - 1986
Pitfall Drift Fences
Continuous Sampling

Asking a Relevant Question

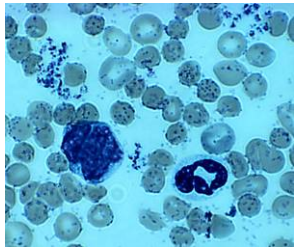
Radiation + "*The Cost of Living in the Real World*"

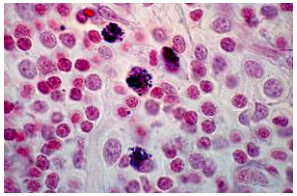


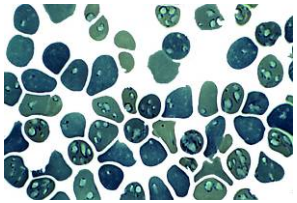
Immunosuppression
Parasites, Disease,
Predators
"<u>Stress</u>"

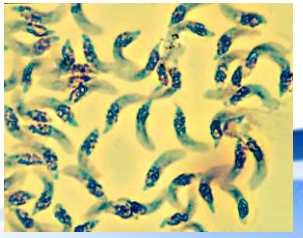


- **Health Studies were started in the 1980's**
  Haematology, Histology, Parasitology, Viral Serology, Endocrinology



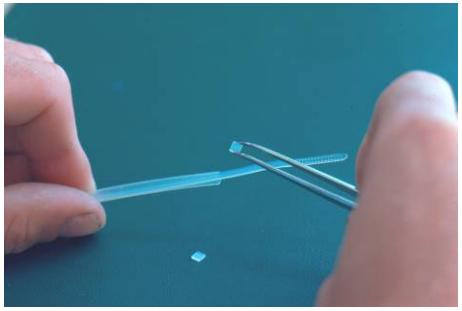






Ensuring Accurate Dosimetry

Uniform exposures (77 - 88% irradiation time)



- **Repeated Measures ANOVAs all NS**
  530 of 875 *Microtus* collars recovered
- Medium & low dose rate exposures matched ambient gamma fields
- High dose rate exposures were lower than expected (50.4 mGy/d vs 92.2 mGy/d)

Monitoring Lifetime Exposures

Estimated using nestlings, and individual life histories

- **3 weeks <u>in utero</u> exposure**
- **6-7 weeks to enter live traps from birth**
- **10-15 weeks typical "adult" lifespan**
- 538 individuals recaptured, <u>very many single captures</u>, typical of vole studies

<u>Lifetime Exposures</u>

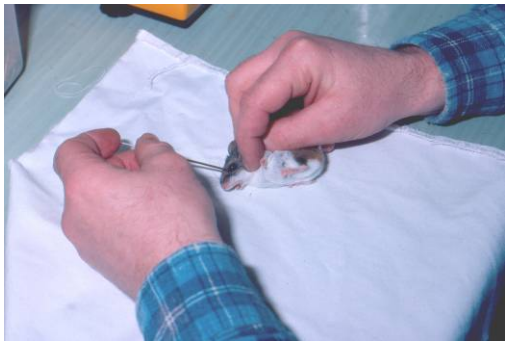
- **Low: 0.05 Gy**
- **Medium: 1.1 Gy**
- **High: 4.1 Gy**
- **High secondary control – 0.02 Gy**

Overwintered, breeding voles in spring 1984 exposed to ~10 Gy

LD_{50} for acute X-rays over 30 days is 7-8 Gy

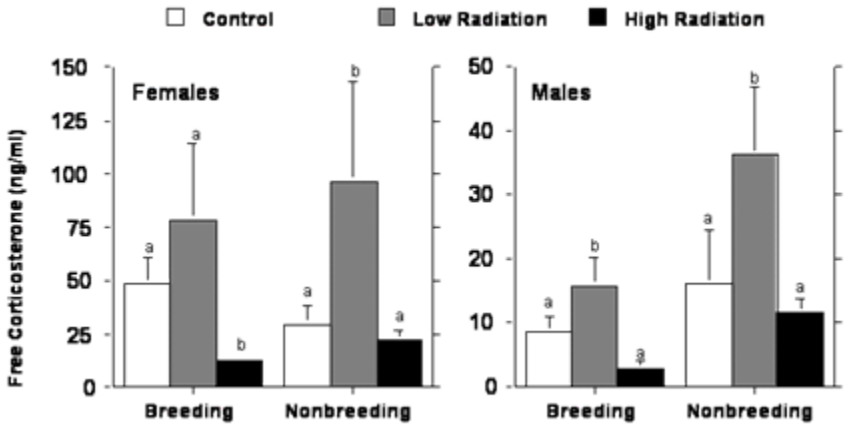
Measuring Meaningful Parameters

HAEMATOLOGY, Viral Serology, Genetics …



- Biweekly, numbered slides, 4 microscopists
- Bone marrow and histopathology
- Laboratory colony for baseline studies in immunology, haematology and parasitology

N=7,365: *Microtus*, *Myodes*, *Peromyscus*, *Zapus*, *Synaptomys*, a few shrews



PILOT STUDY

N=254: Evidence for chronic stress / hormesis (*Mp*)

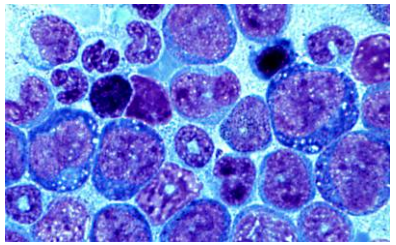
Environm. Toxicol. Chem. (2005) 24: 334-343

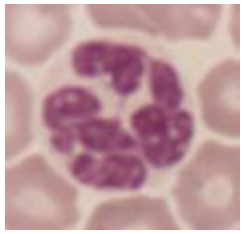
What Did We Learn – Ecology vs. Health?

Ecology: No trace of effects on survival, reproduction, dispersal, growth, etc. – **Animals "APPEAR" to be healthy but…**

Pilot Study: small, heterogeneous sample **(N=254)**, missing medium dose comparison due to genetics studies with serum

- ✓ HPA axis stimulated at LOW dose only (**Hormesis),** NS decrease at high dose
- ➢ Liver function affected, elevated MCBC in response to higher corticosteroid production by the adrenals, but with complex trends
- ➢ **Classic stress with elevated neutrophils at LOW dose (but only N=105, total diffs)**
- ➢ Bone marrow perturbations, e.g. juvenile neutrophils, **(normoblasts, lower PCV)**



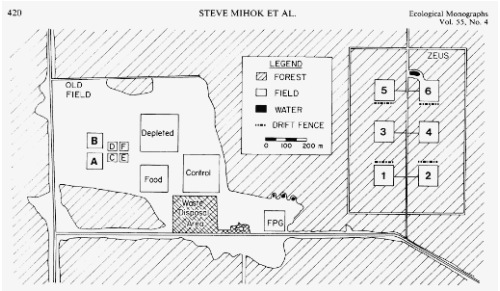


+ 54%

Do Health Results Hold Up?
Mining The Data

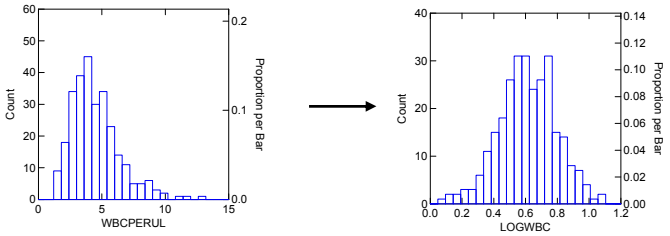
<u>CAUTION</u> is required when analyzing blood data due to many confounding factors, biological and statistical

4 sets of controls



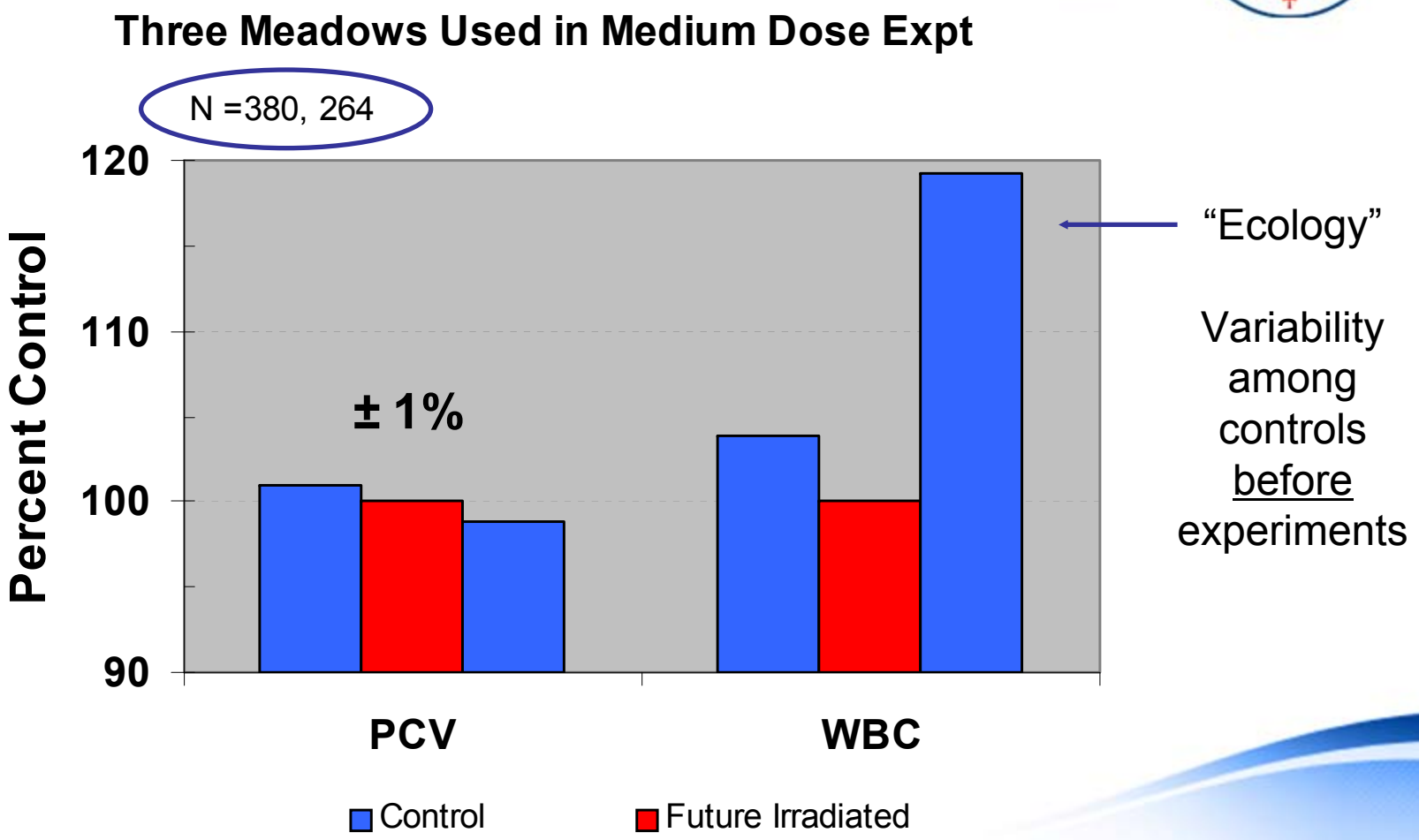
- ✓ Matching controls CRITICAL (same dates, same ecological setting, life history stage, etc.)
  - – Significant differences can be generated by pooling controls

- ✓ **Data transformation REQUIRED**
  - – Otherwise, lose statistical power, violate assumptions of ANOVA



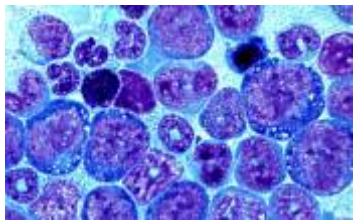
Logs - leukocytes
Box-Cox - PCV
Non-parametric - *rare cells*

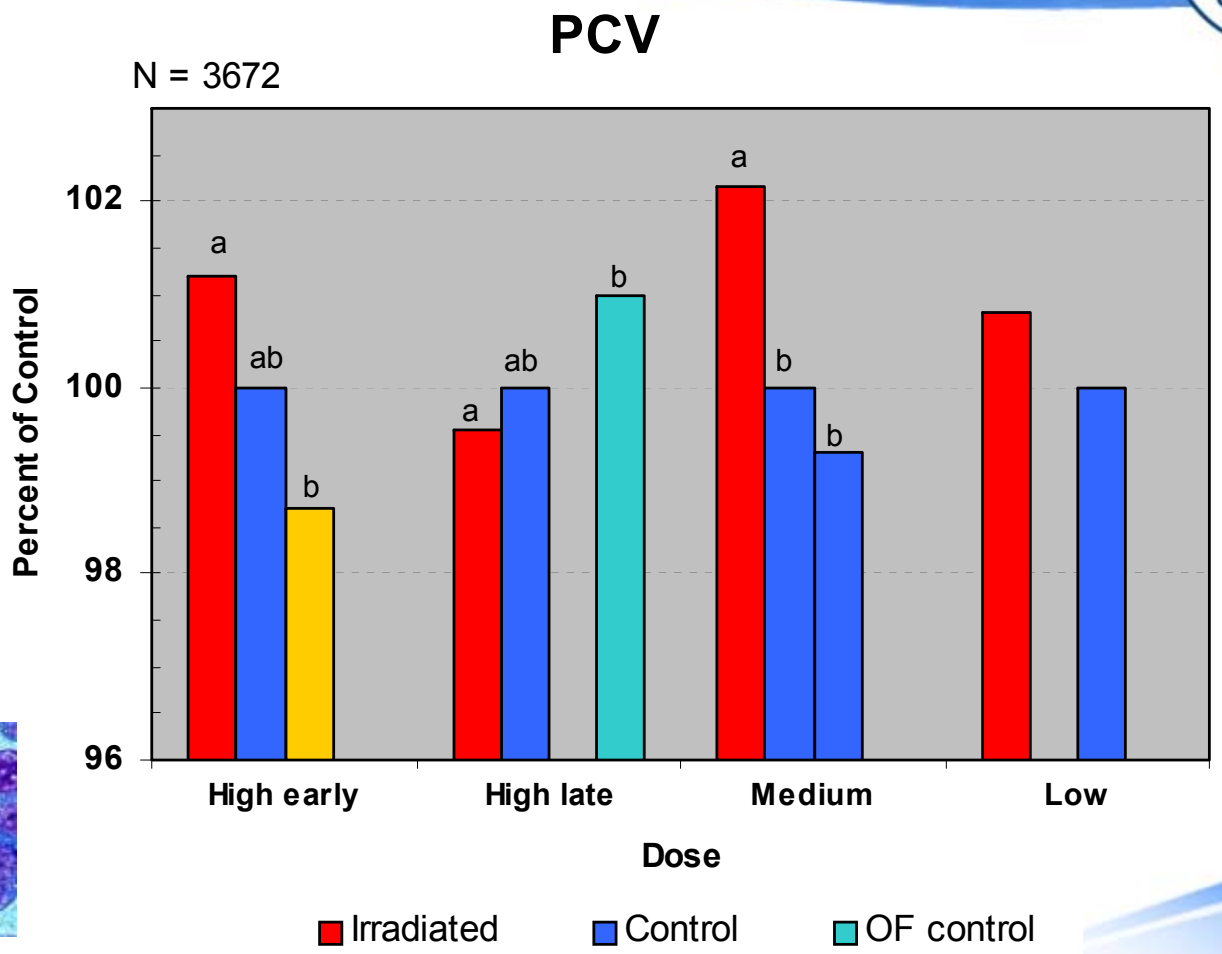
Confidence: Baseline Data, Multiple Controls



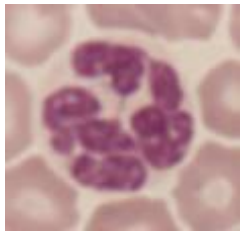
Gross Physiological Effects are Subtle

± 2% ONLY

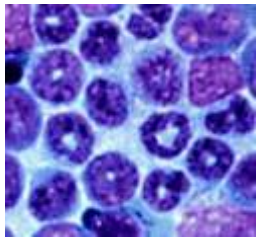




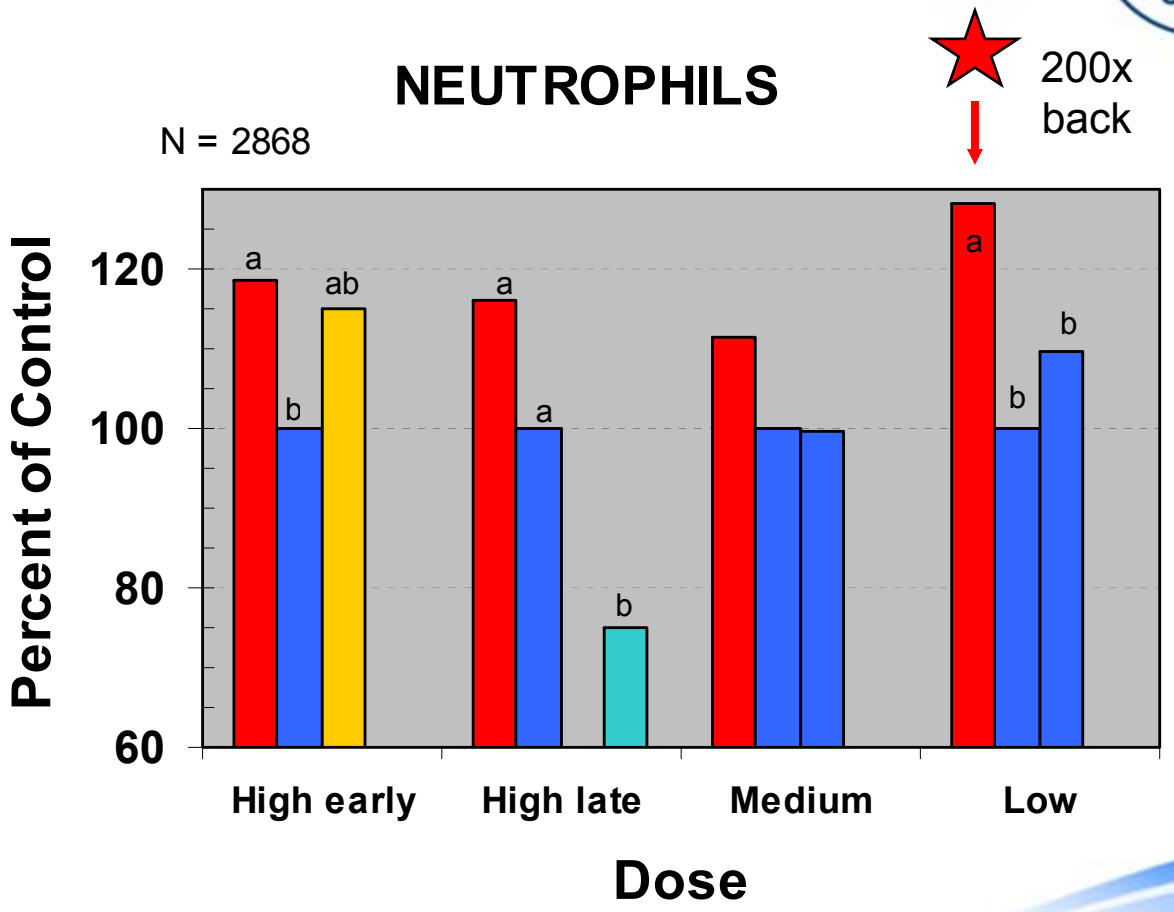
Stress Response Occurs at Very Low Doses



± 25%



Juvenile Cells also in Blood

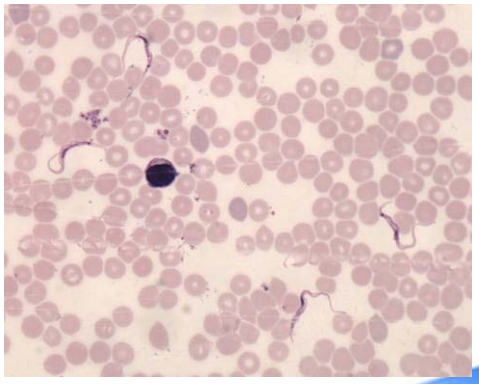


Are Results Consistent for Microtines?

Synaptomys cooperi

Extremely rare, hardly seen in 20 years of work; modest resident population on high dose meadow in 1984, pitfall captures ++

Odd result – very high rates of infection with *Trypanosoma microti*, also high parasitaemia (transmitted by fleas)



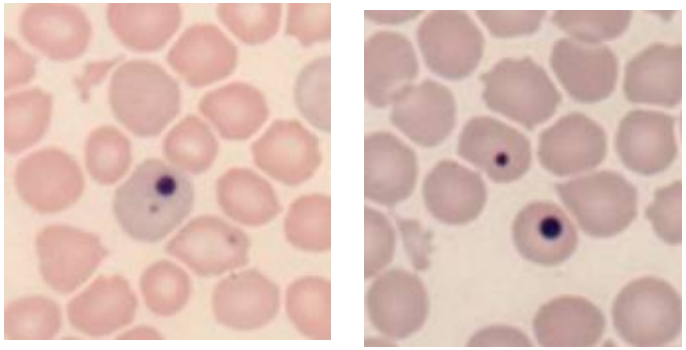
- **BUT** - lemmings survived, reproduced, etc. and appear to be "healthy", just like voles
- **Parasite is rare and is not pathogenic in *Microtus;* does not reach high parasitaemia**
- **No studies for comparison on *Synaptomys* haematology, ecology hardly documented**

Should We Study Other Species?

Long-lived hibernator, poorly-studied
Low trappability, Also highly mobile

Unexpected results – “abundant” micronuclei found in RBCs during high dose experiment (many animals)

- **Normoblasts, poor reticulocyte response, large drops in PCV**
- **BUT** - mice survive, reproduce, etc. and appear to be “healthy”
- **More radiation sensitive?**
  Lived much longer?
  Non-filtering spleen type?
  Hibernation physiology?

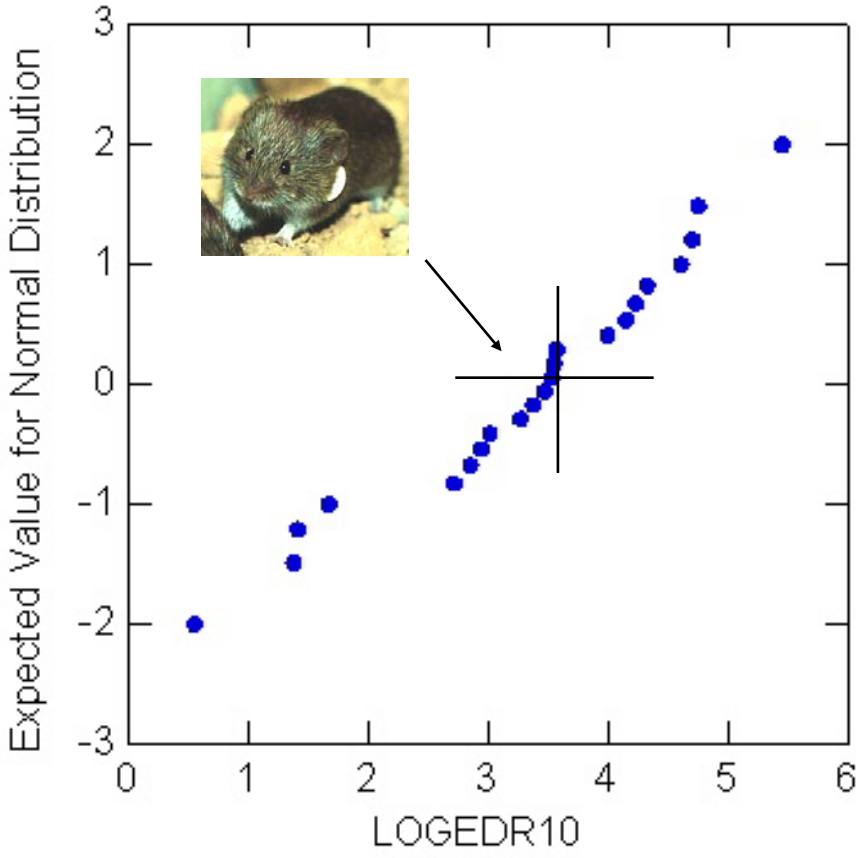


PCE on left, RBCs on right

What Did the ZEUS Experiment Tell Us?

- Short-lived, prolific small mammals are nominally "healthy" at up to ~ 50 mGy/d of "nearly continuous" gamma exposure
- They survive, reproduce and maintain viable populations over several generations, even with in utero exposure
- Sensitive species exist, e.g. the long-lived meadow jumping mouse, perhaps because it is a hibernator?
- Animals are stressed at very low doses; this can be measured with the right tools and is biologically meaningful
- Animals appear to adapt to radiation damage through basic compensatory mechanisms (the HPA stress axis)
- Long-term implications remain an open question, especially for long-lived animals

Where do Canadian Data Fit?



Add data for...
Microtus **1,847 µGy/h**
Myodes **875 µGy/h**

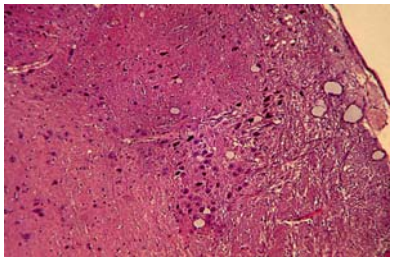
No change in HDR_5
in a log-normal model
as vole data are close
to distribution mean

Lessons Still to be Learned

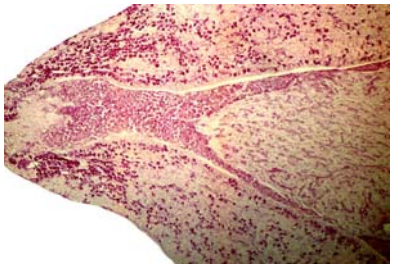
- Are existing chronic gamma exposure studies (with ~10% “recovery time”) relevant to realistic field conditions, especially where internal alpha emitters account for most of the dose?

"We Don't Know, What We Don't Know"

Brain: prions ?

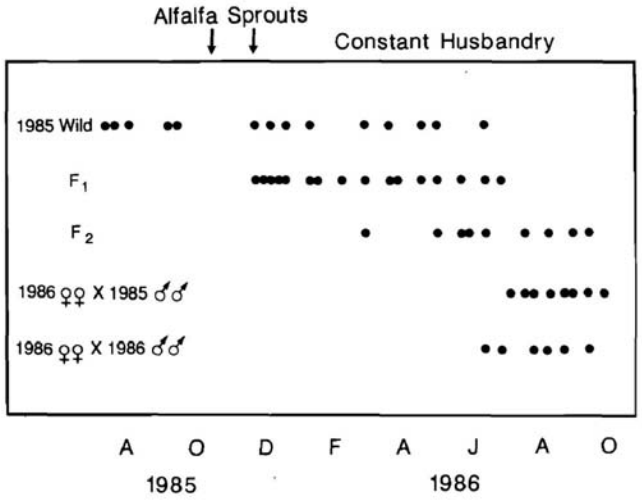


Demyelination

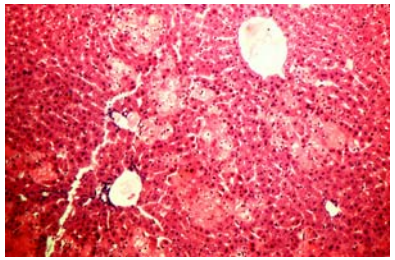


Pituitary Gonadotropes?

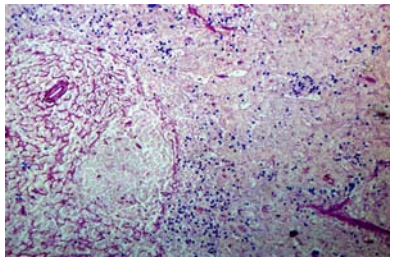
Mihok & Boonstra (1992)
Canadian Journal of Zoology



Stress and multi-generational reproductive failure



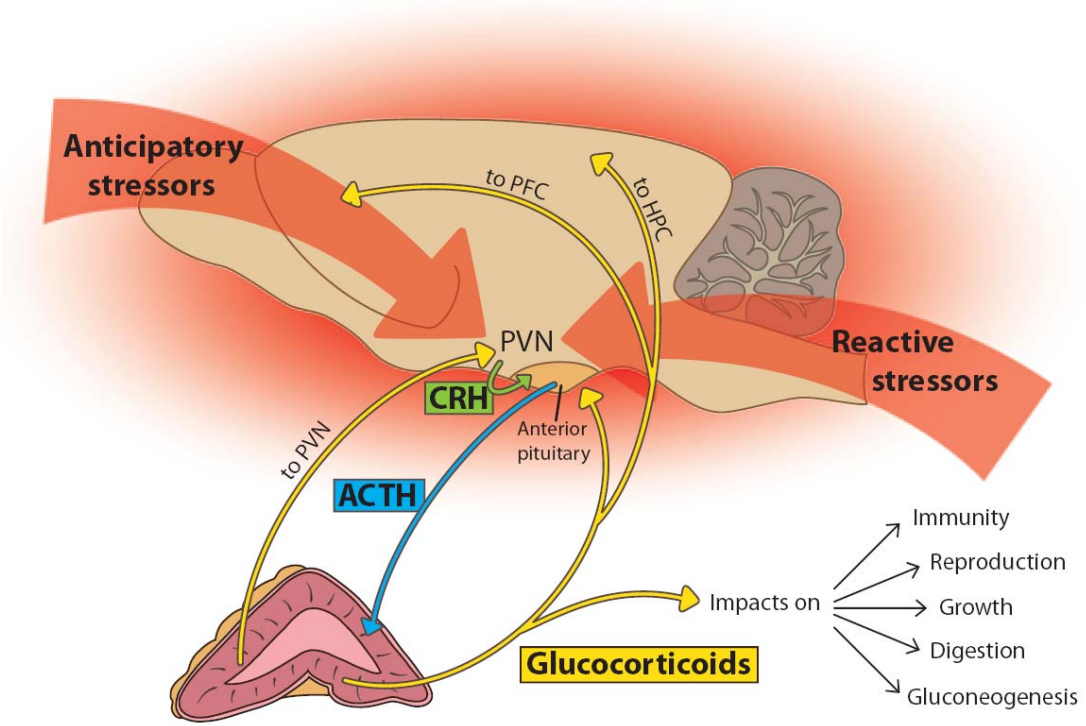
Liver necrosis

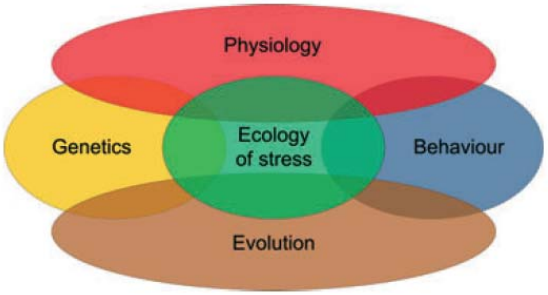


Spleen basophilia

New Directions - The Ecology of Stress

Rudy Boonstra: Reality as the leading cause of stress: rethinking the impact of chronic stress in nature. Functional Ecology





Special Issue, January
"Life is difficult"
(M.S. Peck, The Road Less Travelled, 1978)

Regulatory Perspective

- Human health is protected at the level of the individual, non-human biota are protected at the population level
- Endangered or protected species require special considerations
- While results of this work show that animals are “stressed” at low levels of exposure, they do survive and maintain viable populations
- The results of this work show that releases from Canadian nuclear facilities do not pose an unreasonable risk to non-human biota

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Commission canadienne de sûreté nucléaire

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Canada