From molecules to men: Effects of low-dose radiation at Chernobyl and Fukushima

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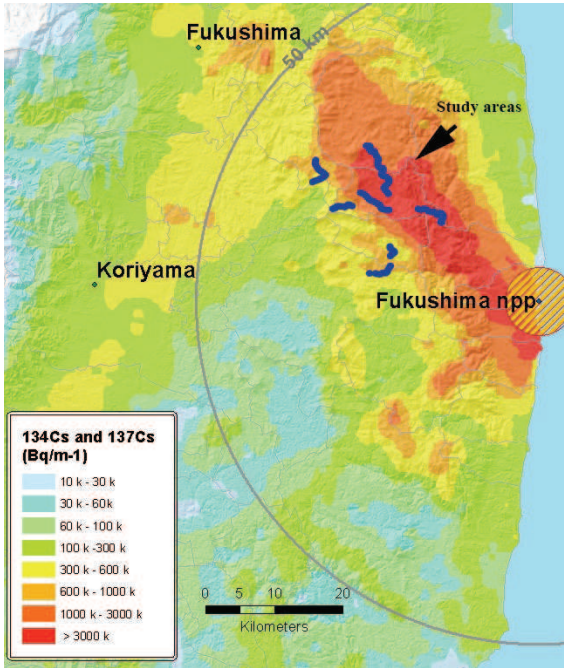
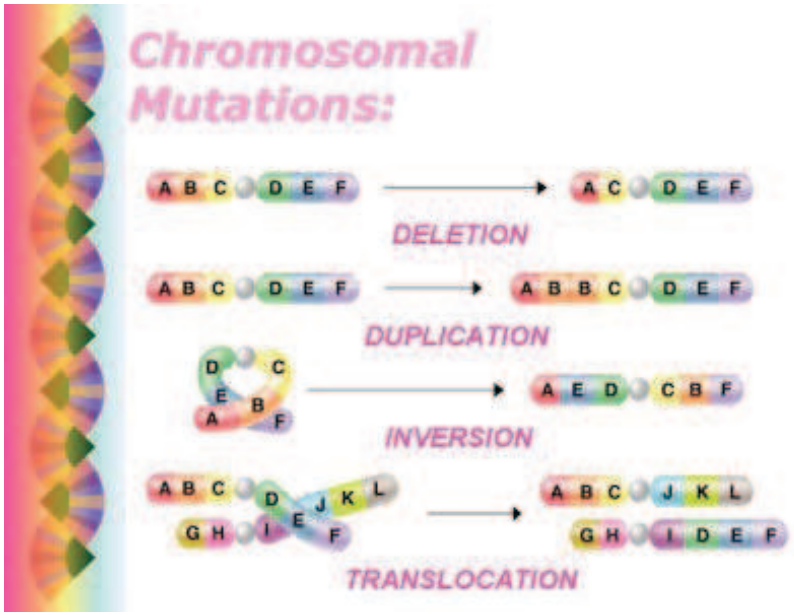
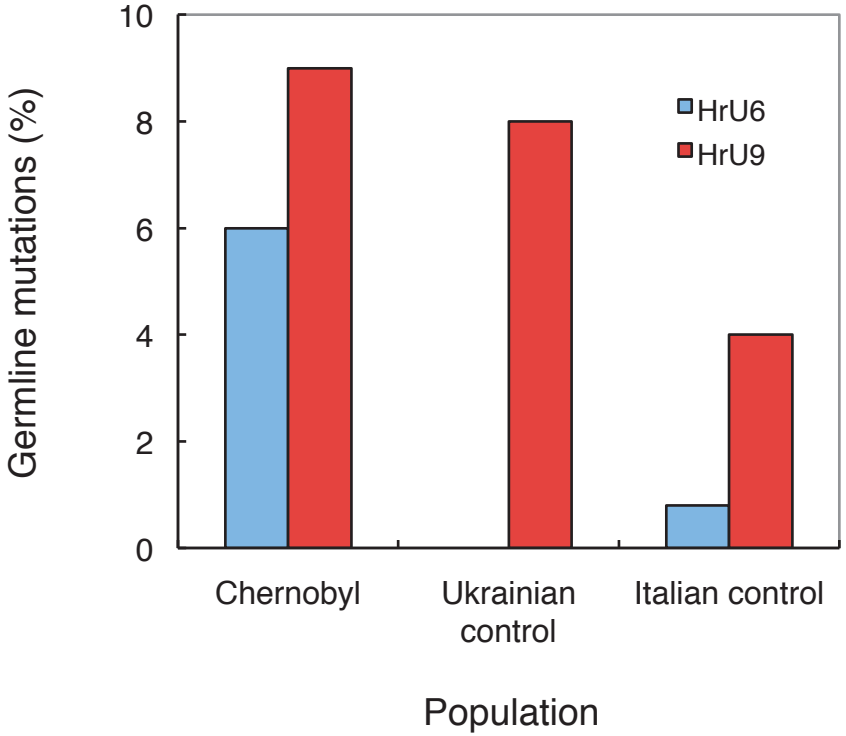


Mutations and DNA sequences



Microsatellite mutations in barn swallows



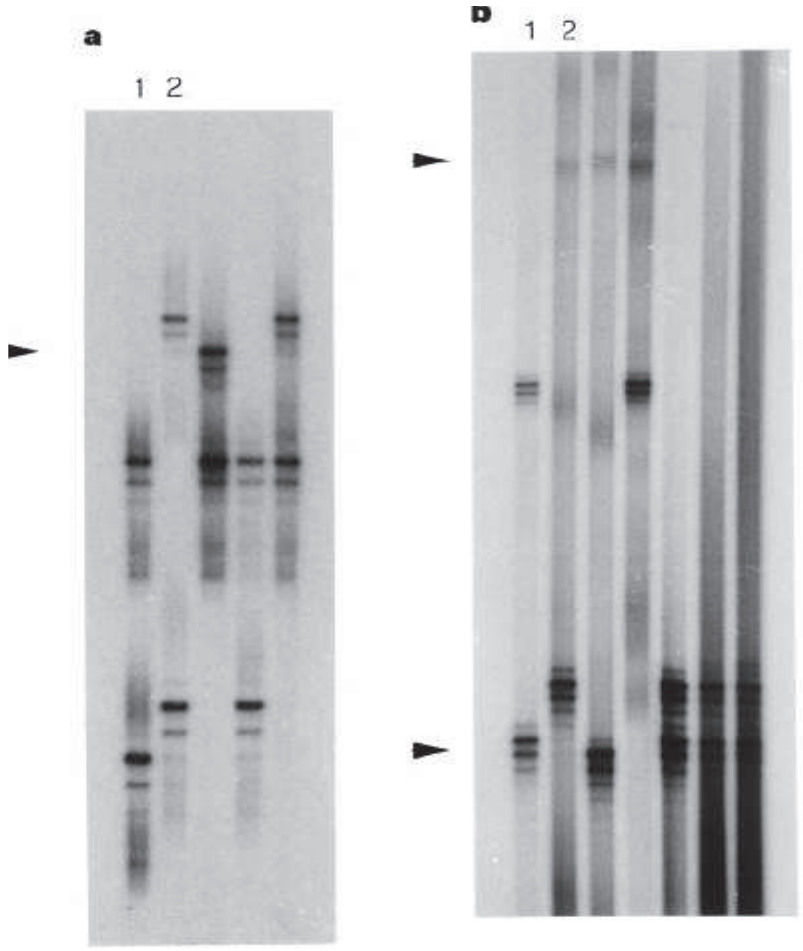
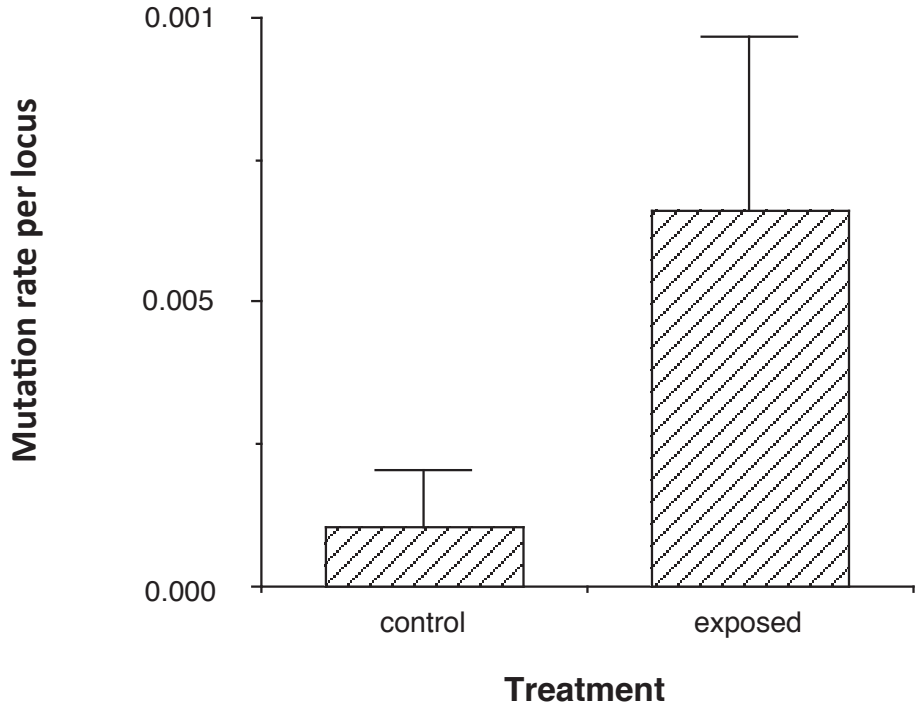


Figure 1 Examples of microsatellite germline mutations for barn swallow loci in the Chernobyl population. **a**, *HrU6*; **b**, *HrU9*. Lane 1, the father; lane 2, the mother; other lanes show offspring. Mutant alleles are arrowed. Note that the offspring to the left in **b** is mutant for both its father's and mother's allele.

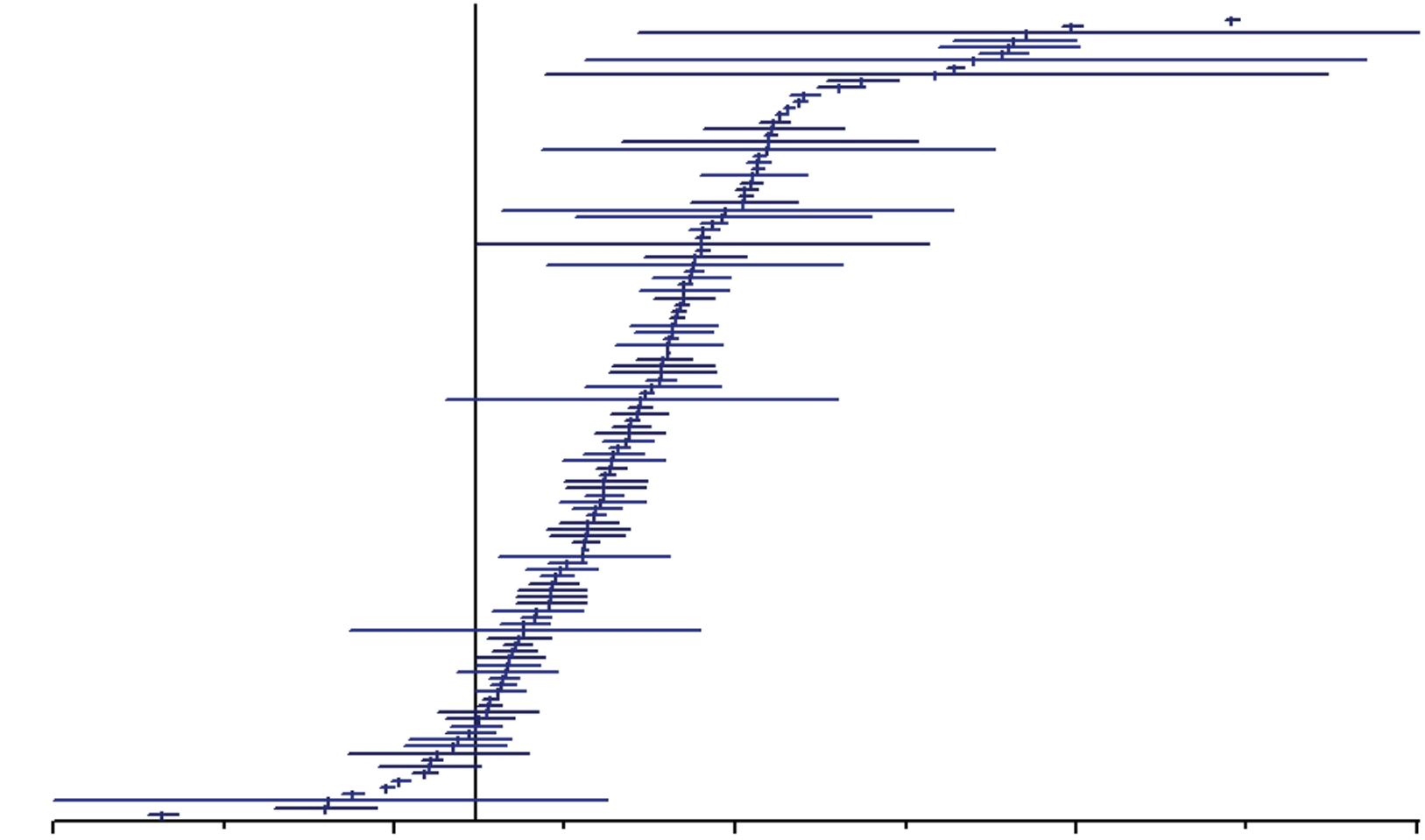
(Ellegren et al., Nature 389:593-596, 1997)

Mutation rate in wheat



O. Kovalchuk, Y. E. Dubrova, A. Arkhipov, B. Hohn and I. Kovalchuk,
Nature 407:583-584, 2000

Meta-analysis of radiation and mutation



(Randic, Mousseau & Møller unpubl.)

Meta-analysis results

Mean effect size	P value	N	95% CI	Bootstrap CI	Bias CI
0.81	< 0.0001	117	0.66 - 0.96	0.66 - 0.96	0.67 - 0.97

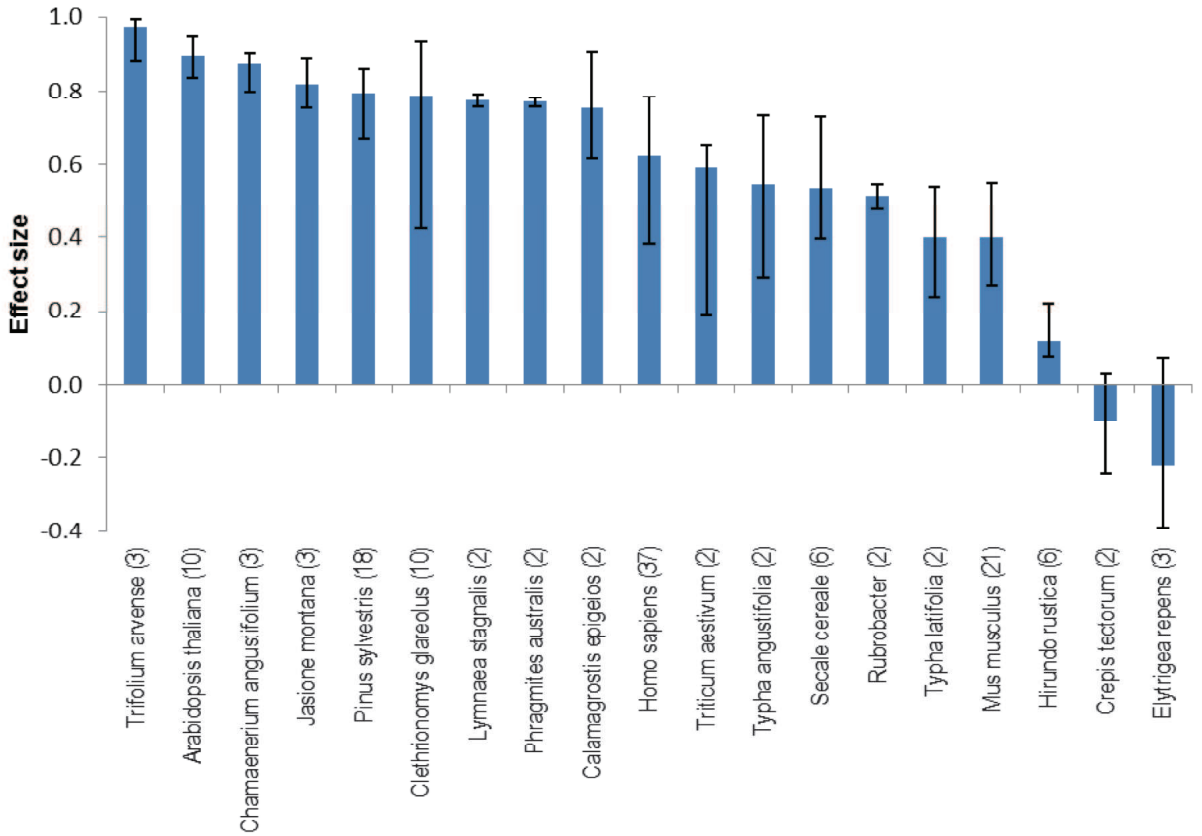
Sqrt Pooled Variance = 0.80

Mean Study Variance = 0.05 Ratio = 15.32

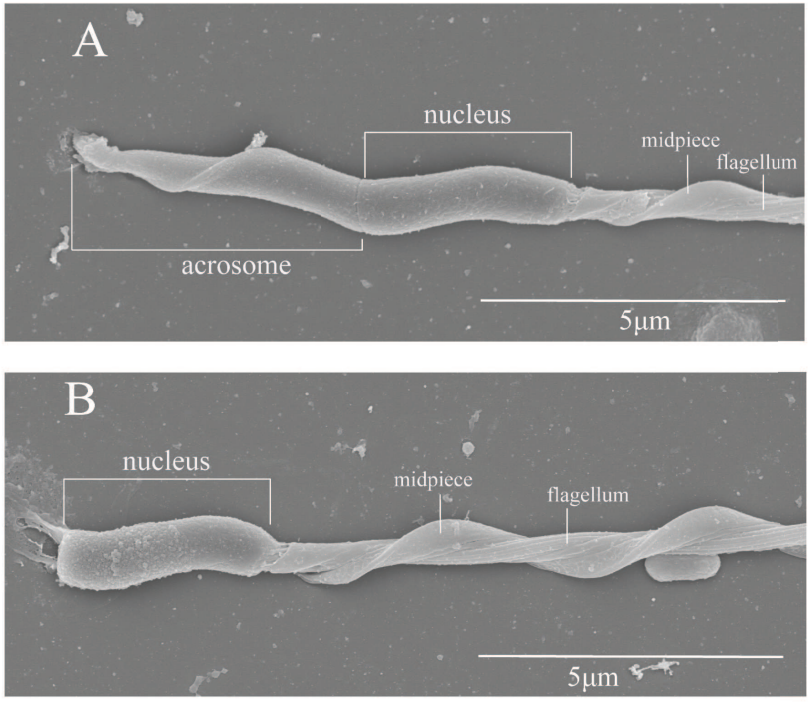
FAIL-SAFE NUMBER

Rosenthal's method: 4920

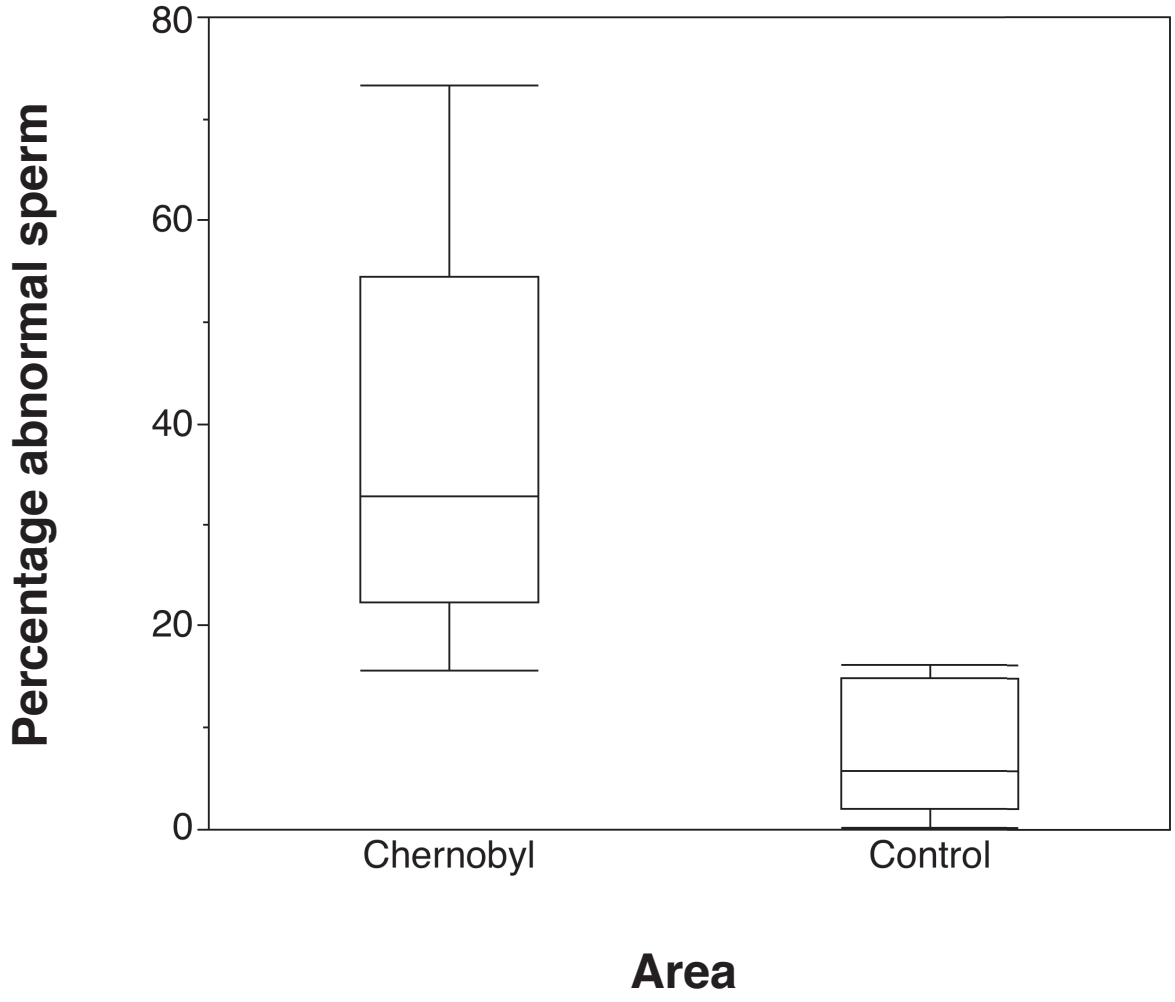
Interspecific differences in mutation rates



Abnormal sperm

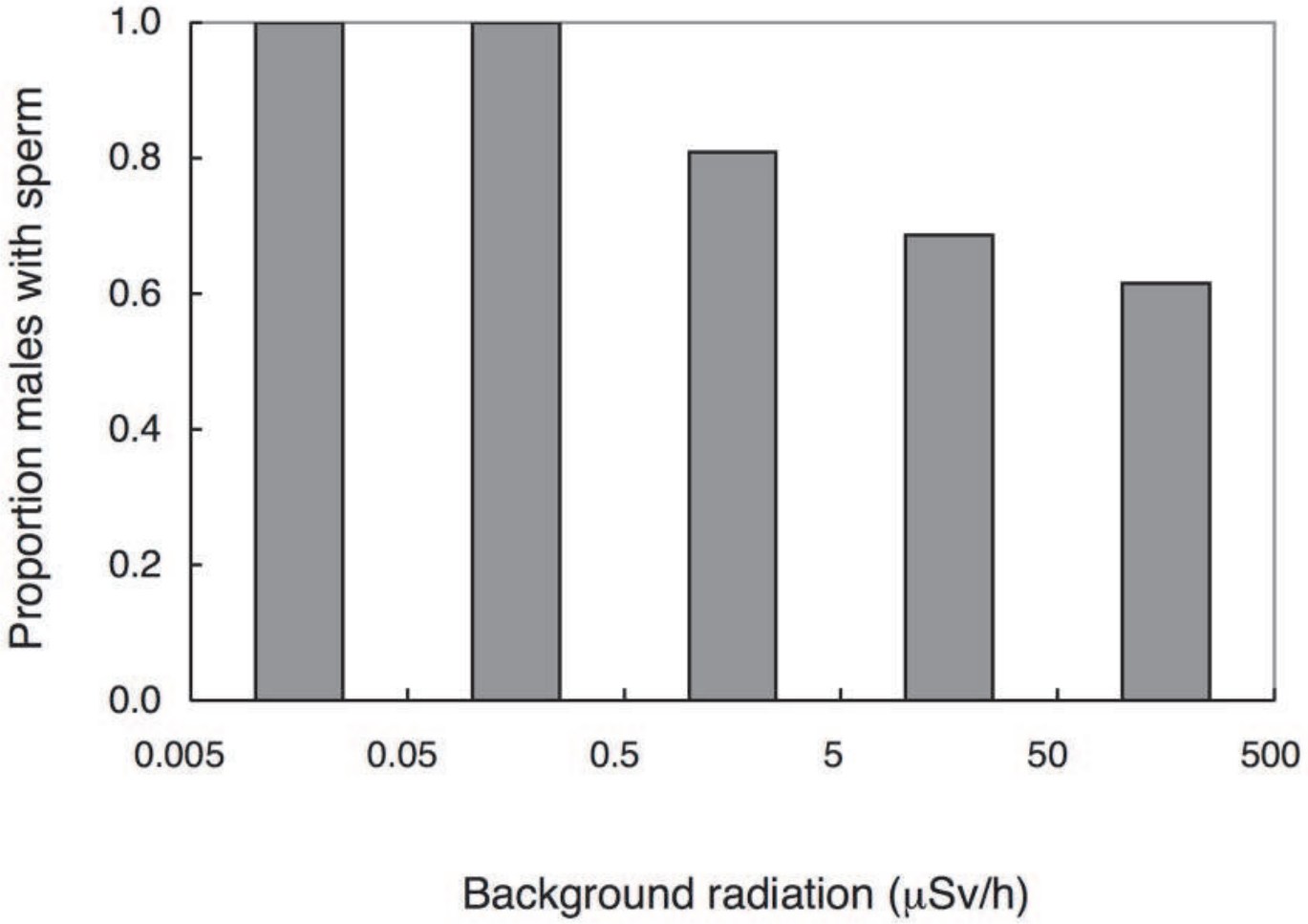


Abnormal sperm in birds

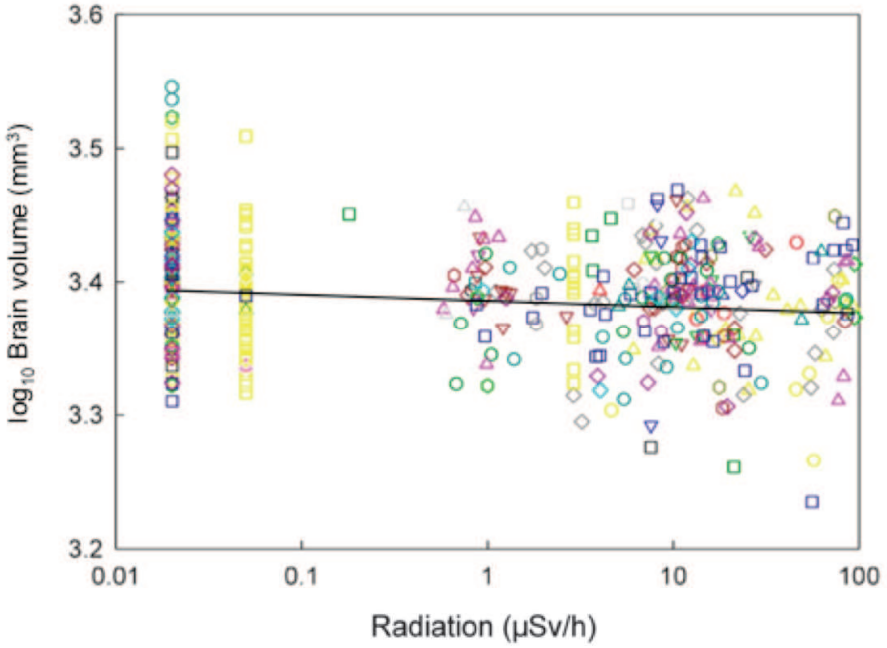


$F = 45.83$, $df = 1,9$,
$r^2 = 0.83$, $P < 0.0001$

287 males from 38 species – R^2 = 43%



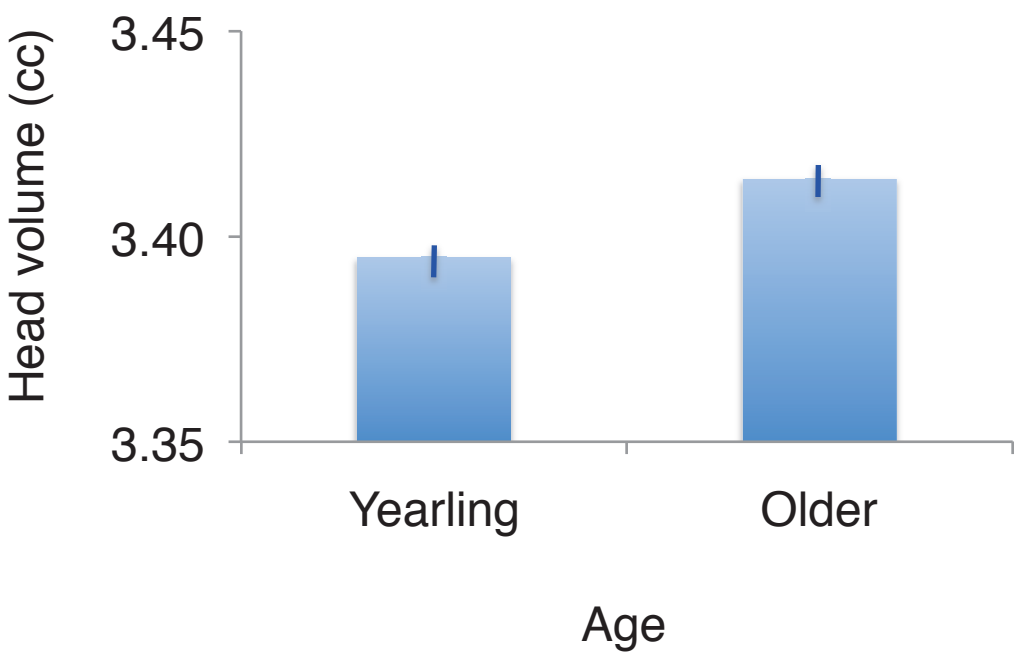
Brain size and radiation from Chernobyl



(Møller et al., PLoS One 6(2):e16862, 2011)

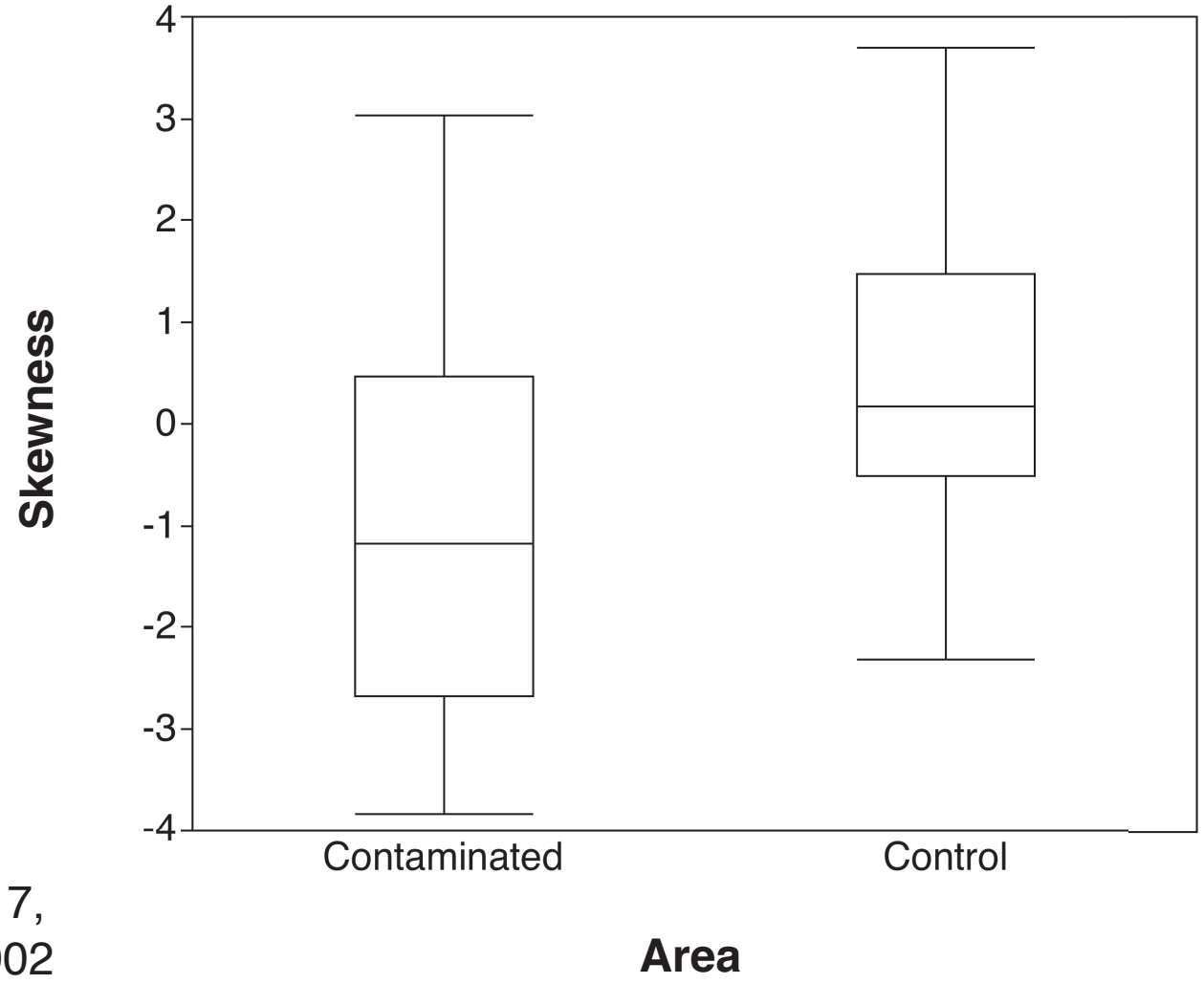
Selection against small heads

F = 9.92, df = 1,284, P = 0.0018



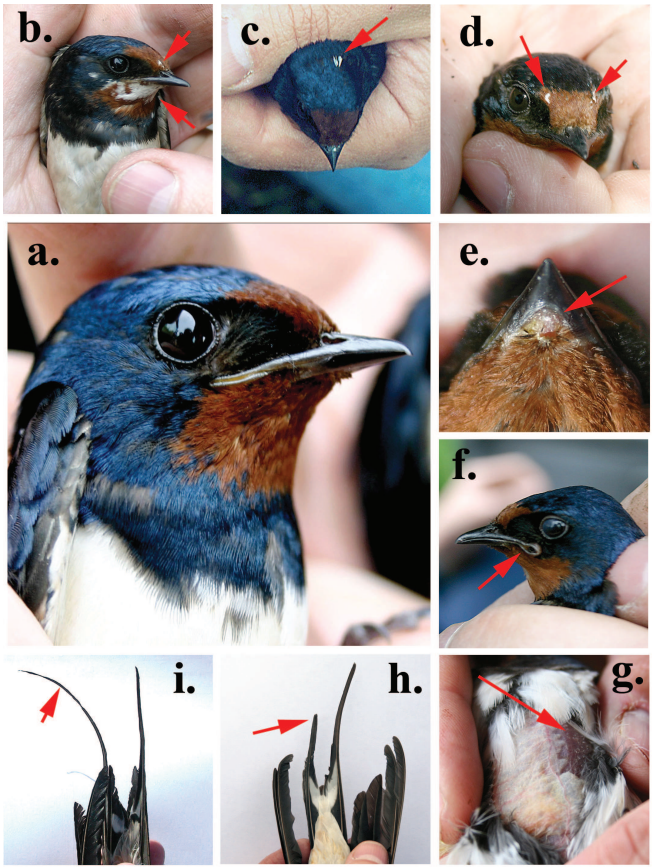
(Møller et al., PLoS One 6(2):e16862, 2011)

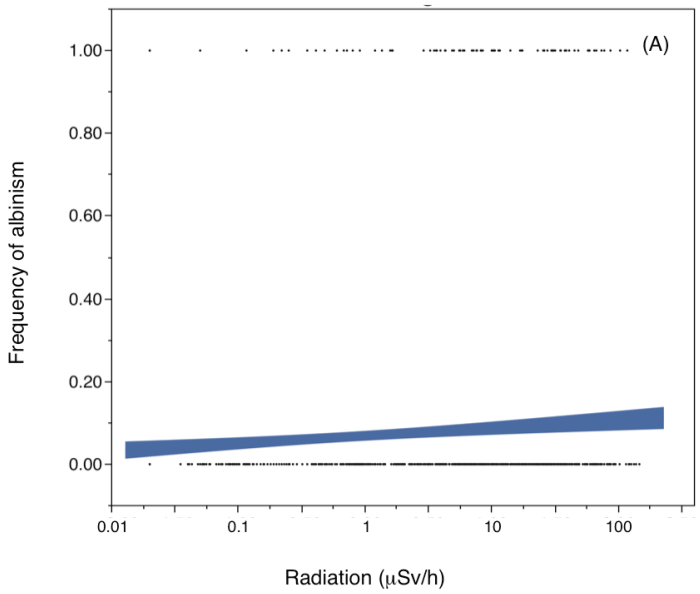
Left-skewed brain sizes

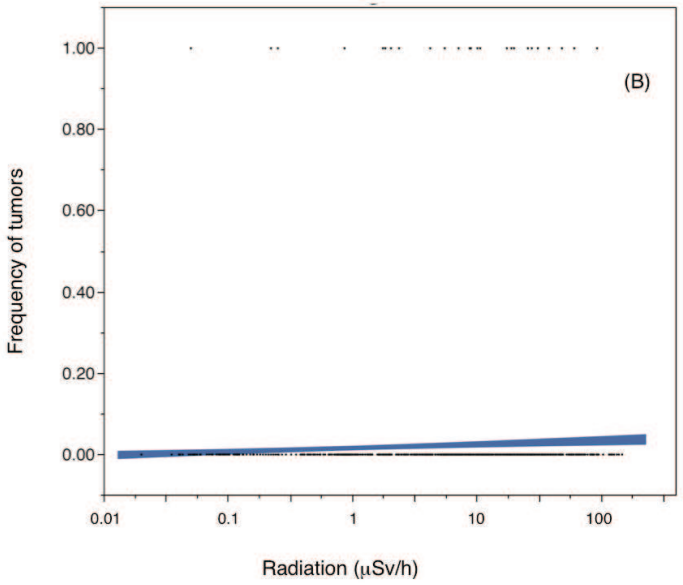


F = 22.66, df = 1,17,
r^2 = 0.57, P = 0.0002

Abnormalities

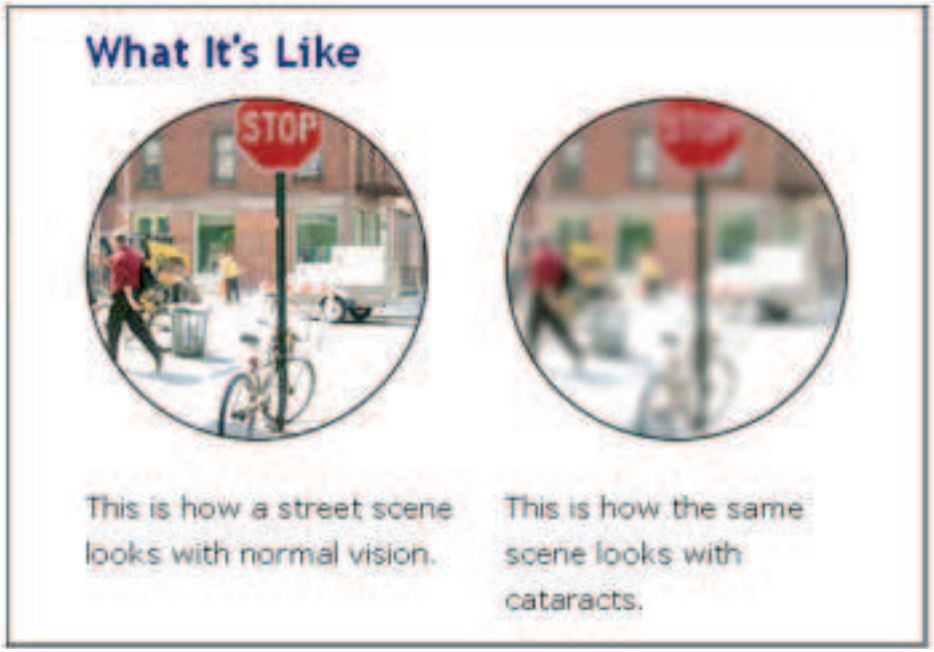


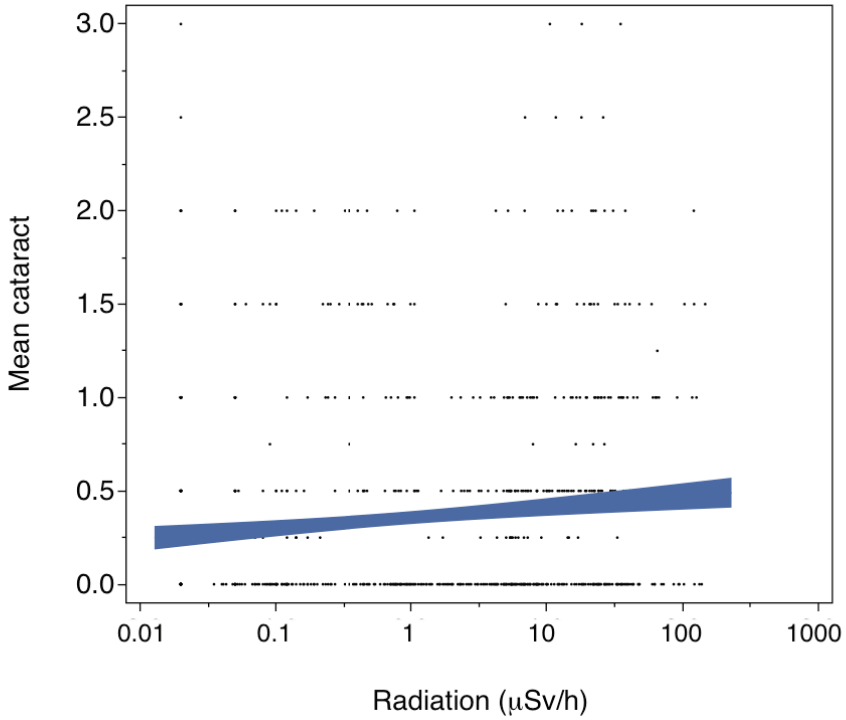

(A)
Frequency of albinism
1.00
0.80
0.60
0.40
0.20
0.00
0.01
0.1
1
10
100
Radiation (μSv/h)

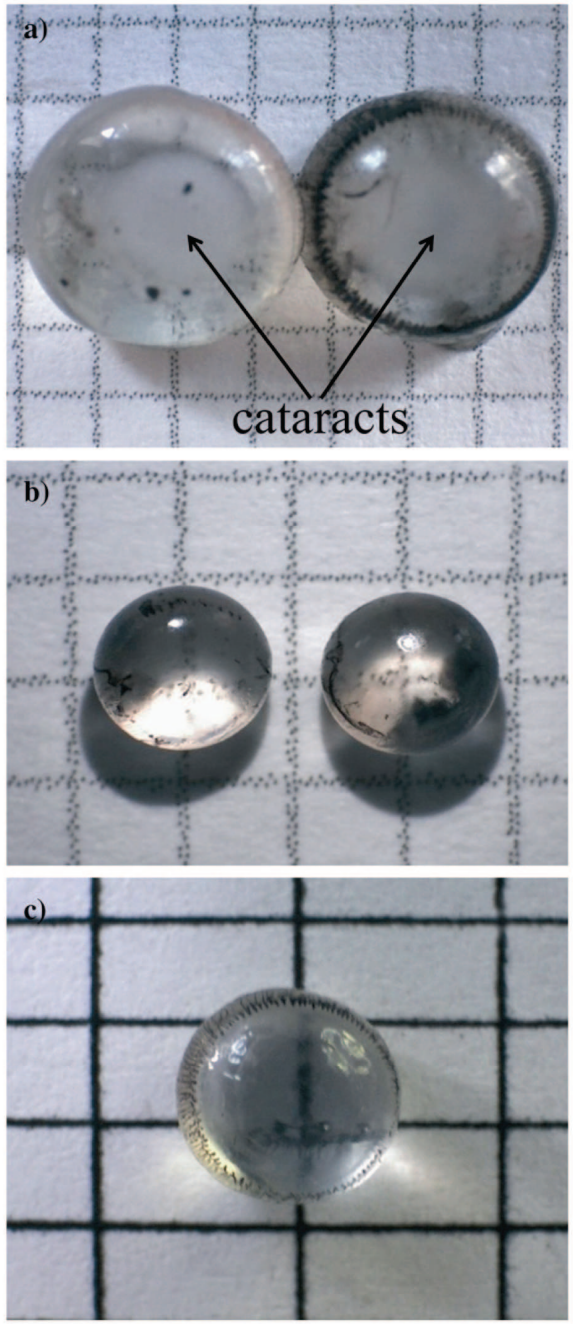

(B)
Frequency of tumors
1.00
0.80
0.60
0.40
0.20
0.00
0.01
0.1
1
10
100
Radiation (μSv/h)


a.
b.
c.
d.
e.
f.
g.
h.
i.
j.
k.
l.
m.
n.
o.
p.
q.
r.
s.
t.
u.
v.
w.
x.
Mousseau & Møller (c) 2012

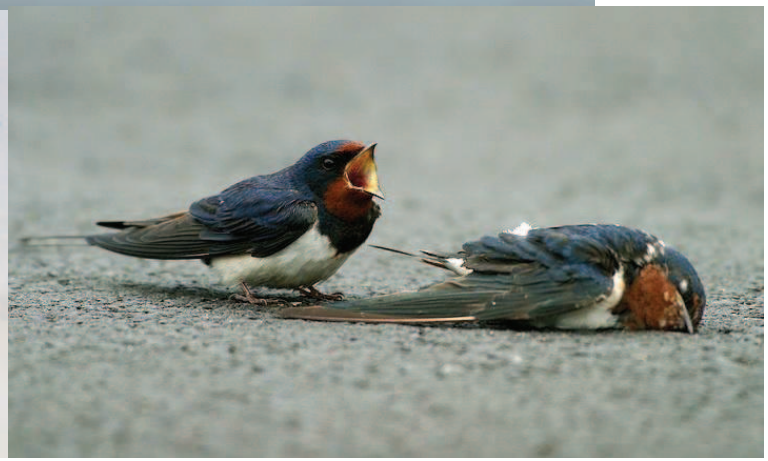
Lenses and cataracts



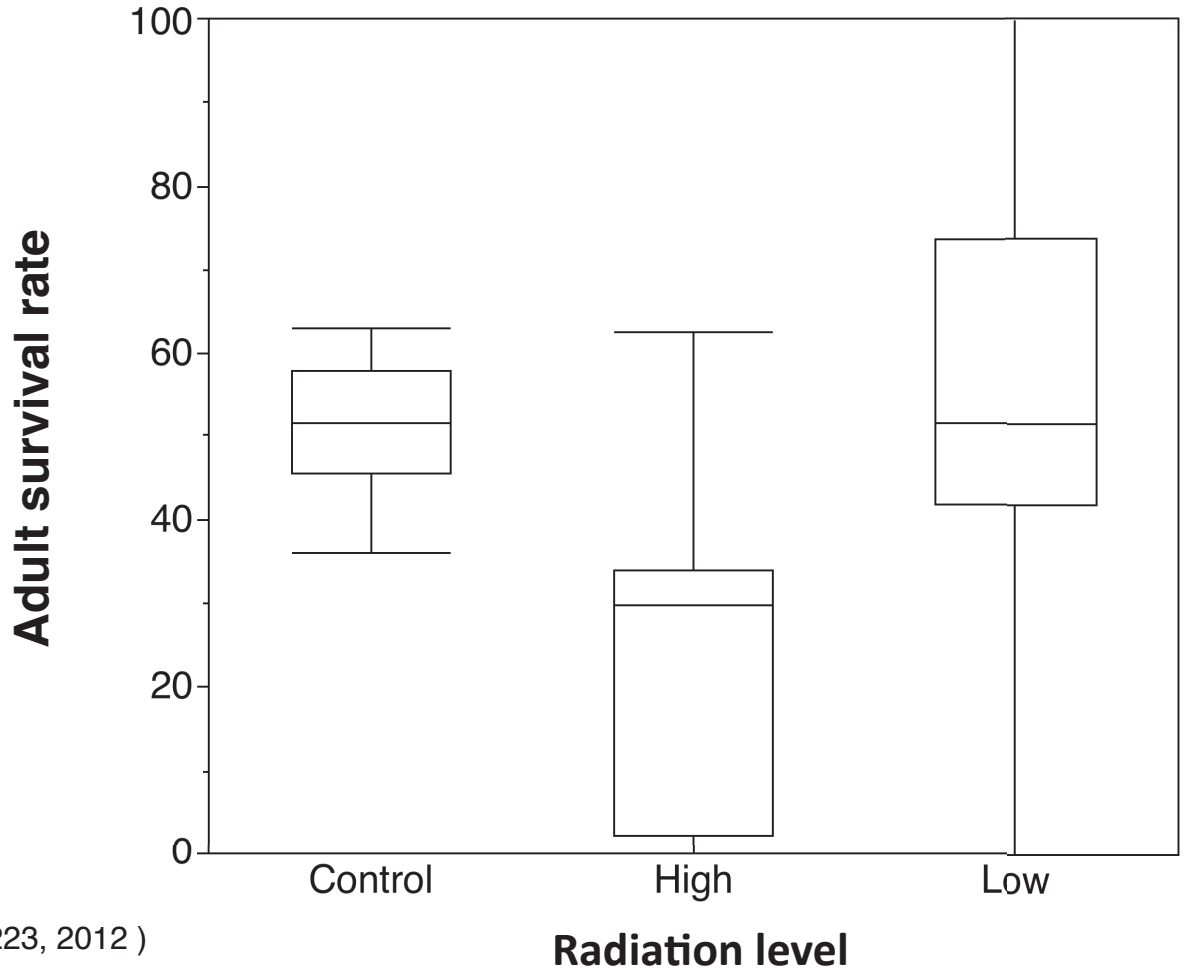

Mean cataract
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.01
0.1
1
10
100
1000
Radiation (μSv/h)


a)
cataracts
b)
c)

Survival and reproductive rates



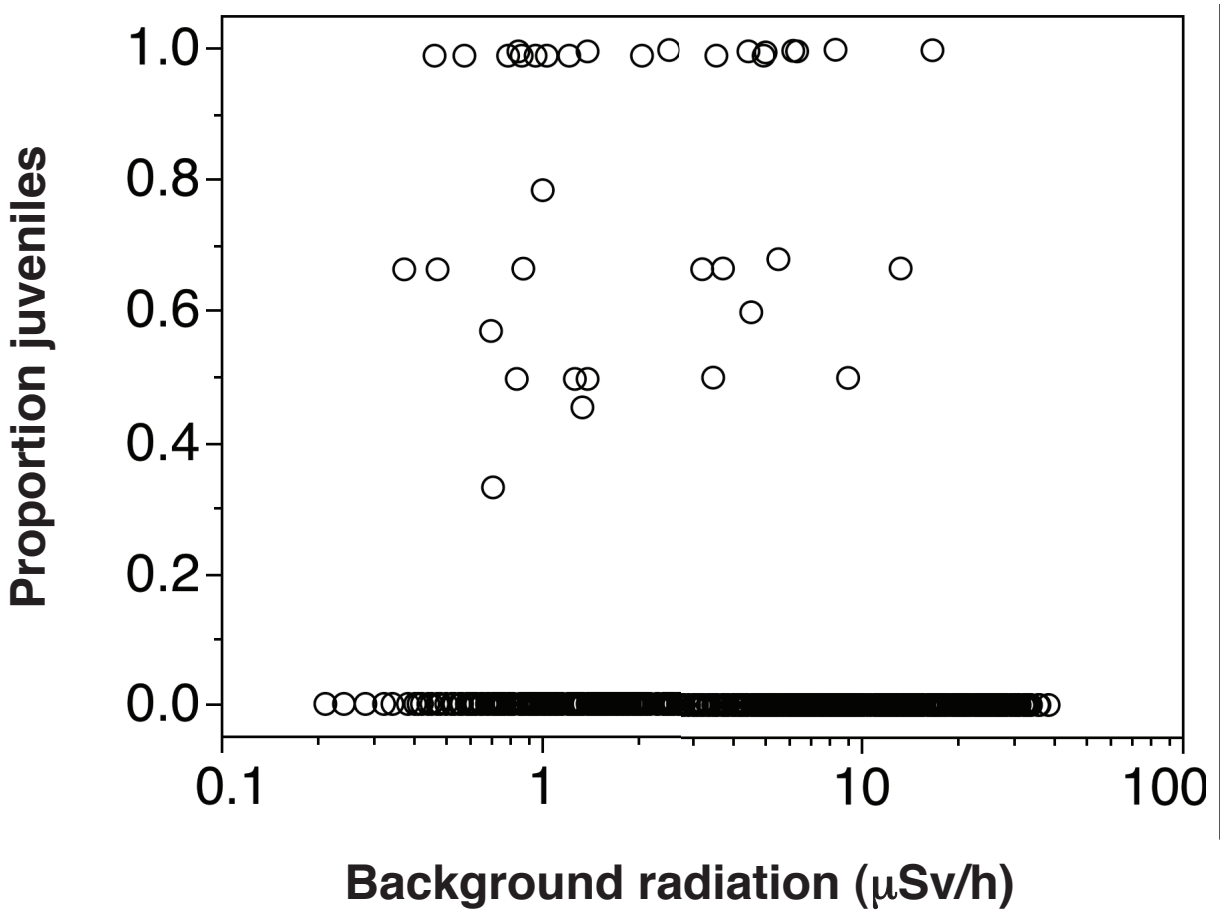
Adult survival rate of birds



$F = 8.02$, df = 2,45,
$r^2 = 0.26$, $P = 0.0011$

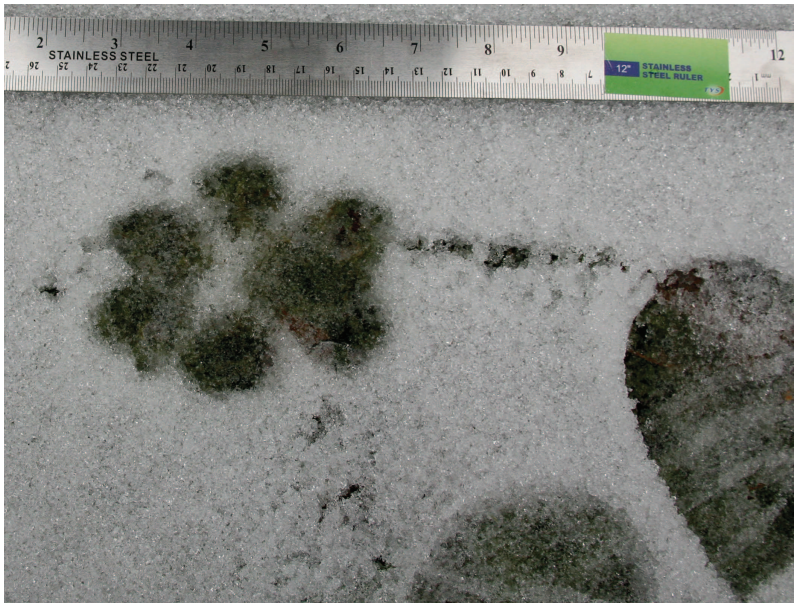
(Møller et al., PLoS One 7(4):e35223, 2012)

Juvenile swallows in Fukushima

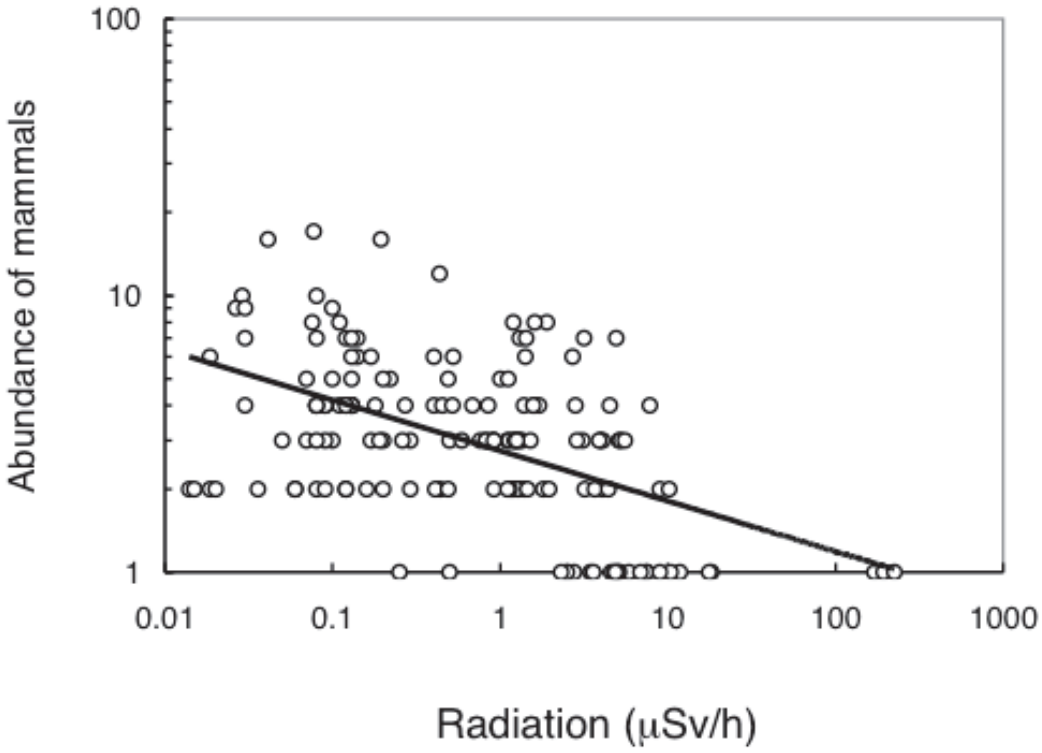


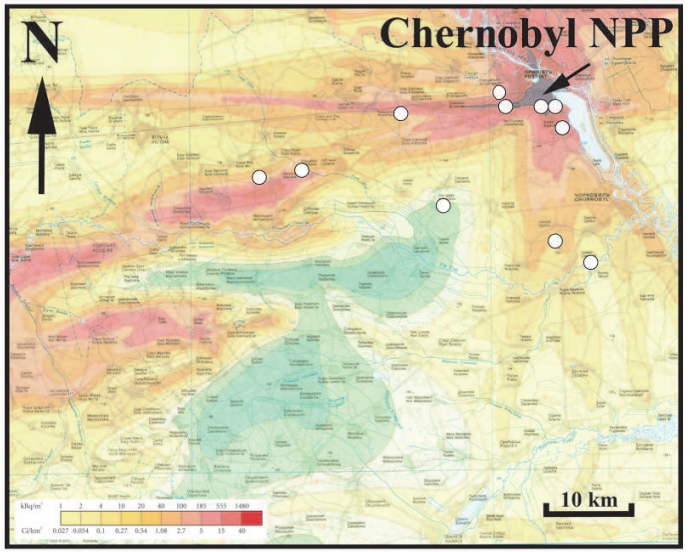
$F = 15.62$, $df = 1,696$,
$r^2 = 0.03$, $P < 0.0001$

Interspecific interactions



Mammals and radiation

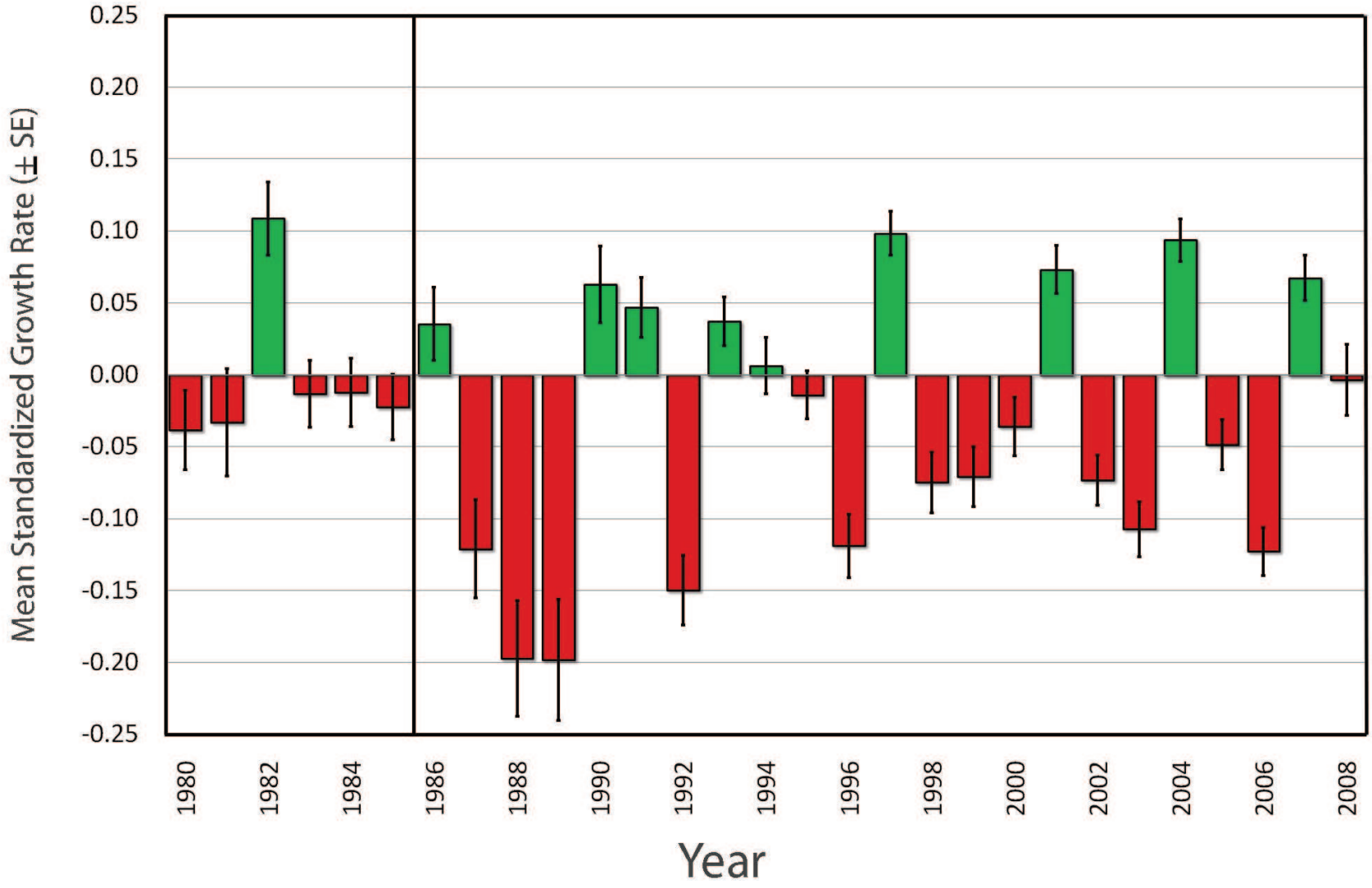




(Møller & Mousseau, Ecol. Indicat. 26:112-116, 2013)

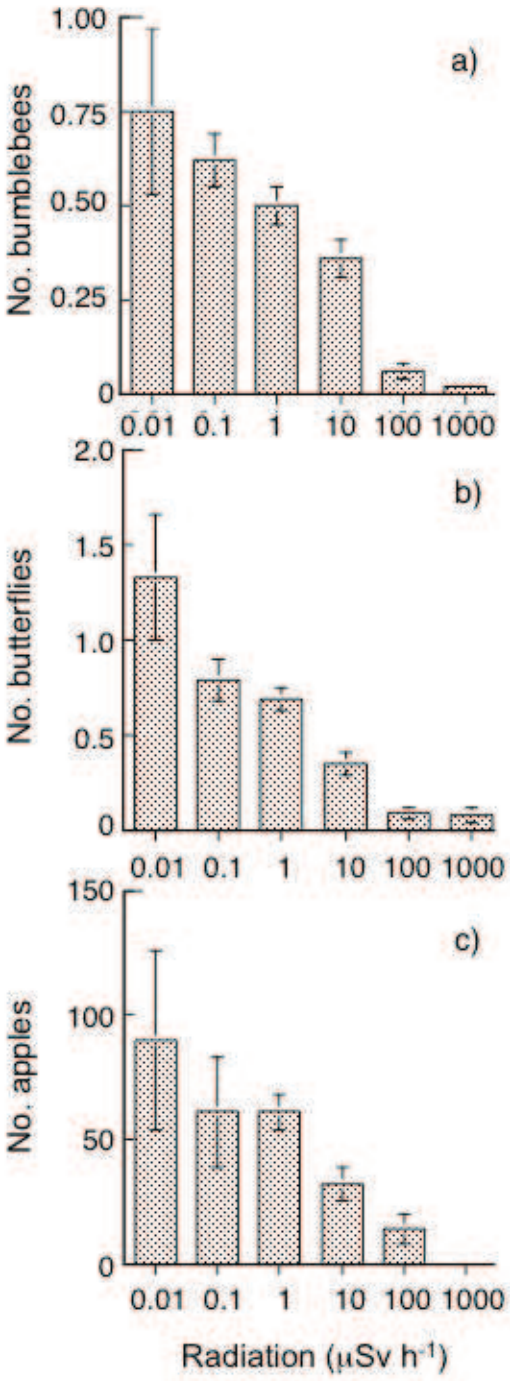
Radiation and tree rings

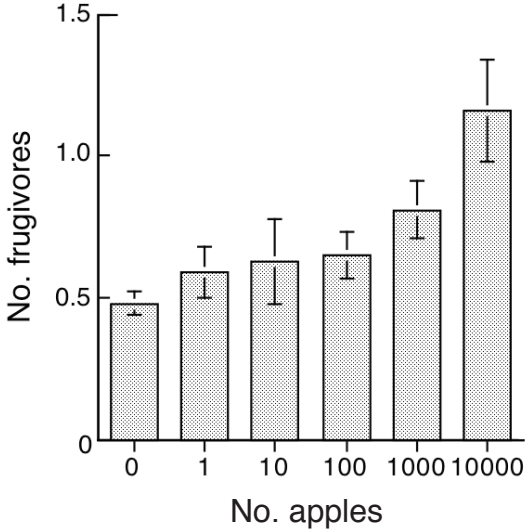
Standardized tree growth rate

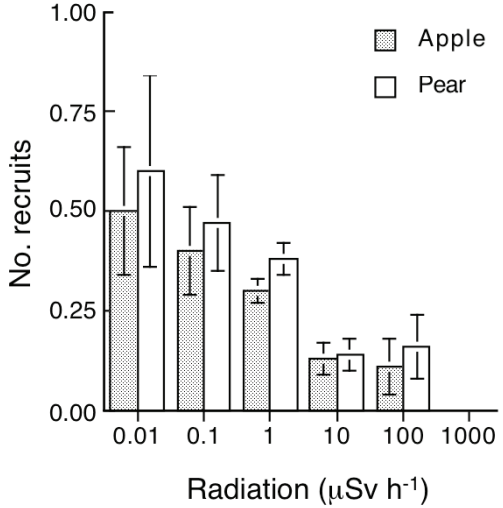


Fungal attacks on Chernobyl logs

Ecosystem effects



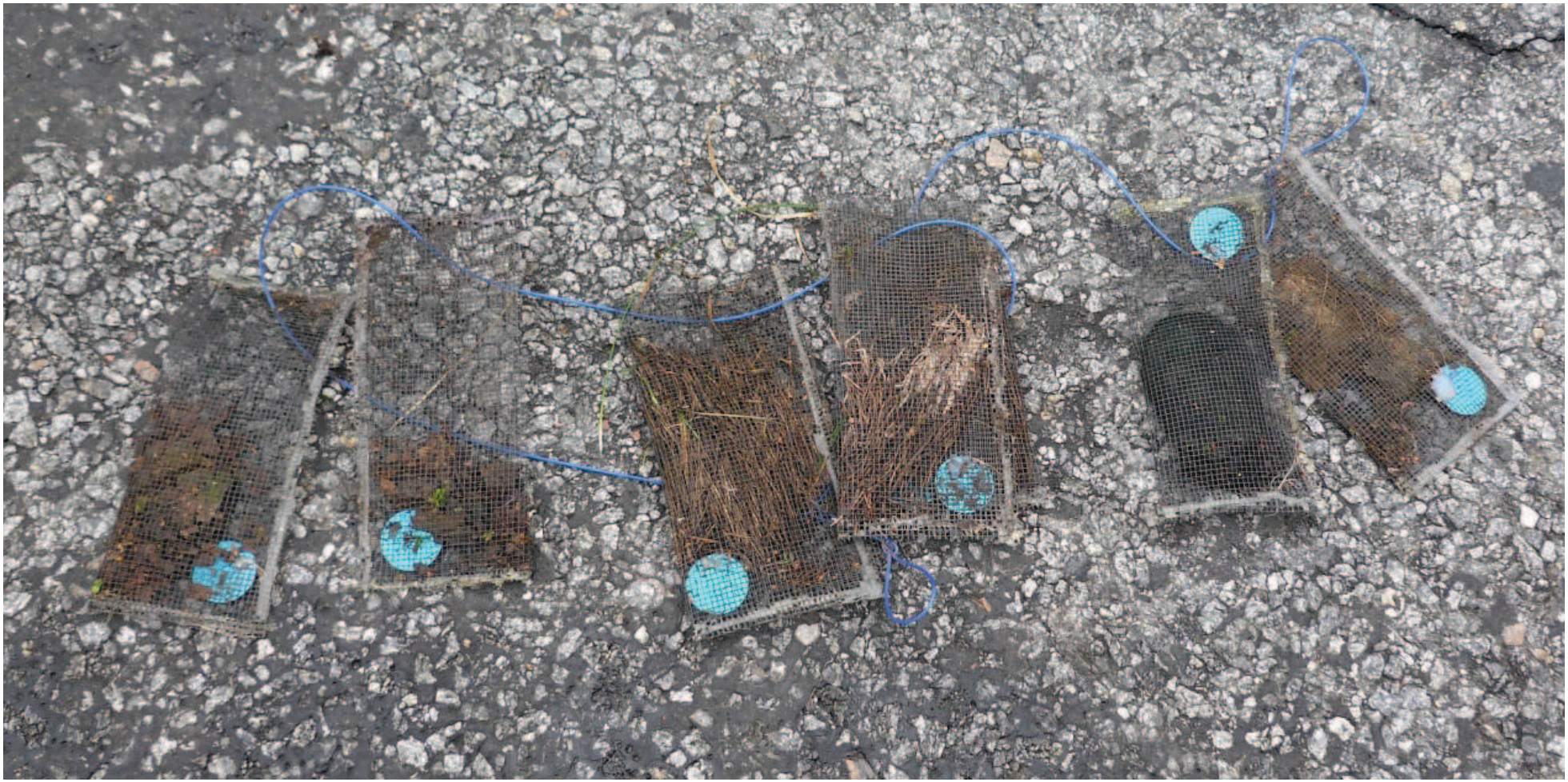




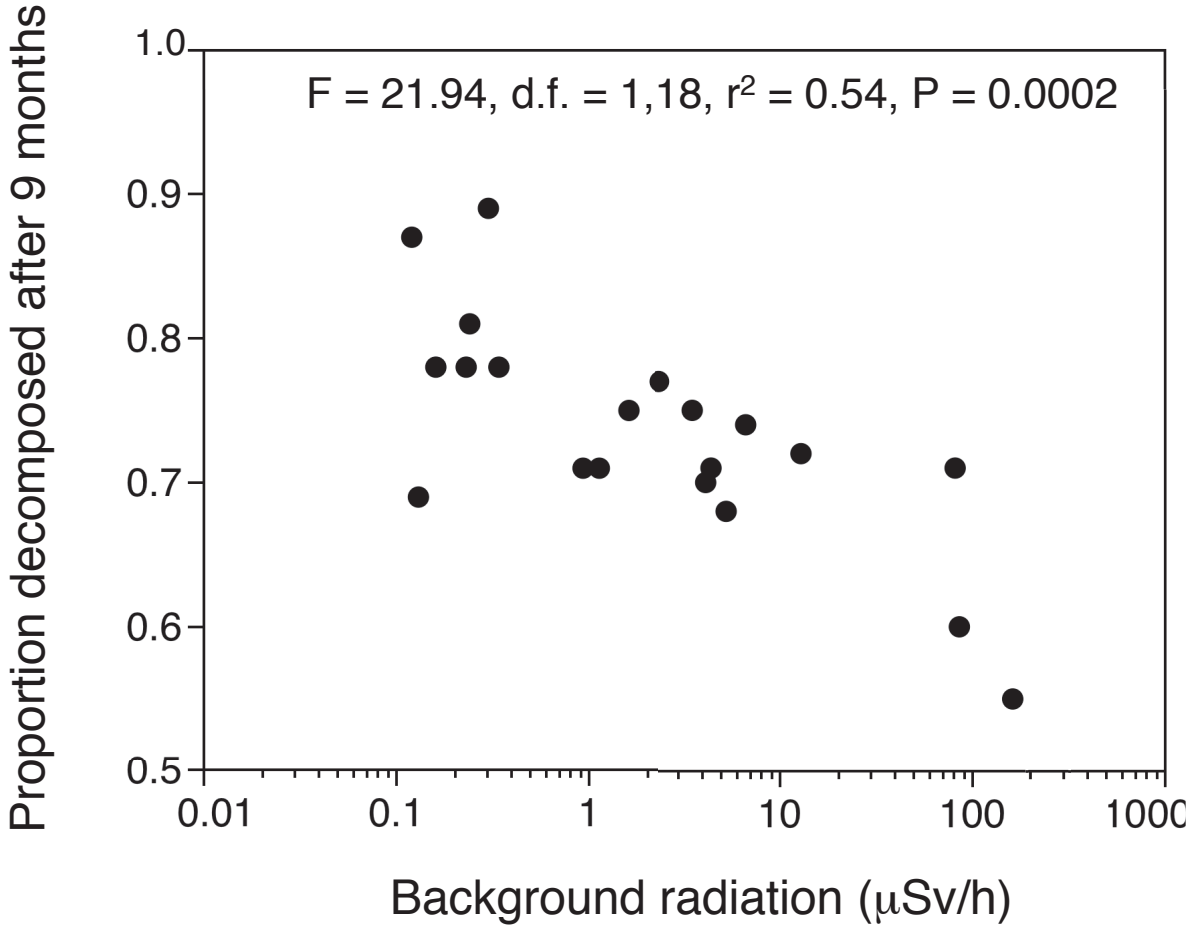
(Møller et al., Oecologia 170:1155-1165, 2012)

Decomposition (1)

Decomposition (2)



Decomposition and radiation (3)



50% difference!!!

First epidemiological study of contamination through diet

(Dancause et al., AJHB 22:667-674, 2010)

TABLE 6. Estimated ^{137}Cs exposure through diet

Food Type	Mean ^{137}Cs Level in Polissia (Bq/kg)	Daily Intake (kg)	Mean Daily ^{137}Cs intake in Polissia (Bq)	MOH 1997 Accepted ^{137} Levels (Bq)
Milk and Milk products	113.88	1.02	116.38	100.00
Meat[a]	84.45	0.19	15.71	200.00
Potatoes	31.76	0.36	11.40	60.00
Vegetables	15.71	0.28	4.38	40.00
Fruits[b]	5.73	0.13	2.21	70.00
Mushrooms[c]	13875.00	0.01	87.37	2.30
Berries[c]	2200.00	0.01	30.80	500.00
Estimated Dietary Intake			268.25	
Accepted MOH 1997 Levels			210.0	

[a]Mean ^{137}Cs level is based on estimates for pork, which was the main meat consumed. Beef is estimated to have a much higher ^{137}Cs level (301.6 Bq/kg).
[b]Mean ^{137}Cs level is based on estimates for apples, which was the main fruit consumed.
[c]Mean ^{137}Cs levels based on estimates from Karachov, 2006, corrected for half-life reduction since 1999.

Conclusions

- Associations between background radiation and biological effects at all organisational levels
- Evidence for direct and indirect effects
- Scope for basic ecological and evolutionary research
- We can learn about the consequences of the next radiation accident now