Biological effects of chronic exposure to radionuclides in plant populations

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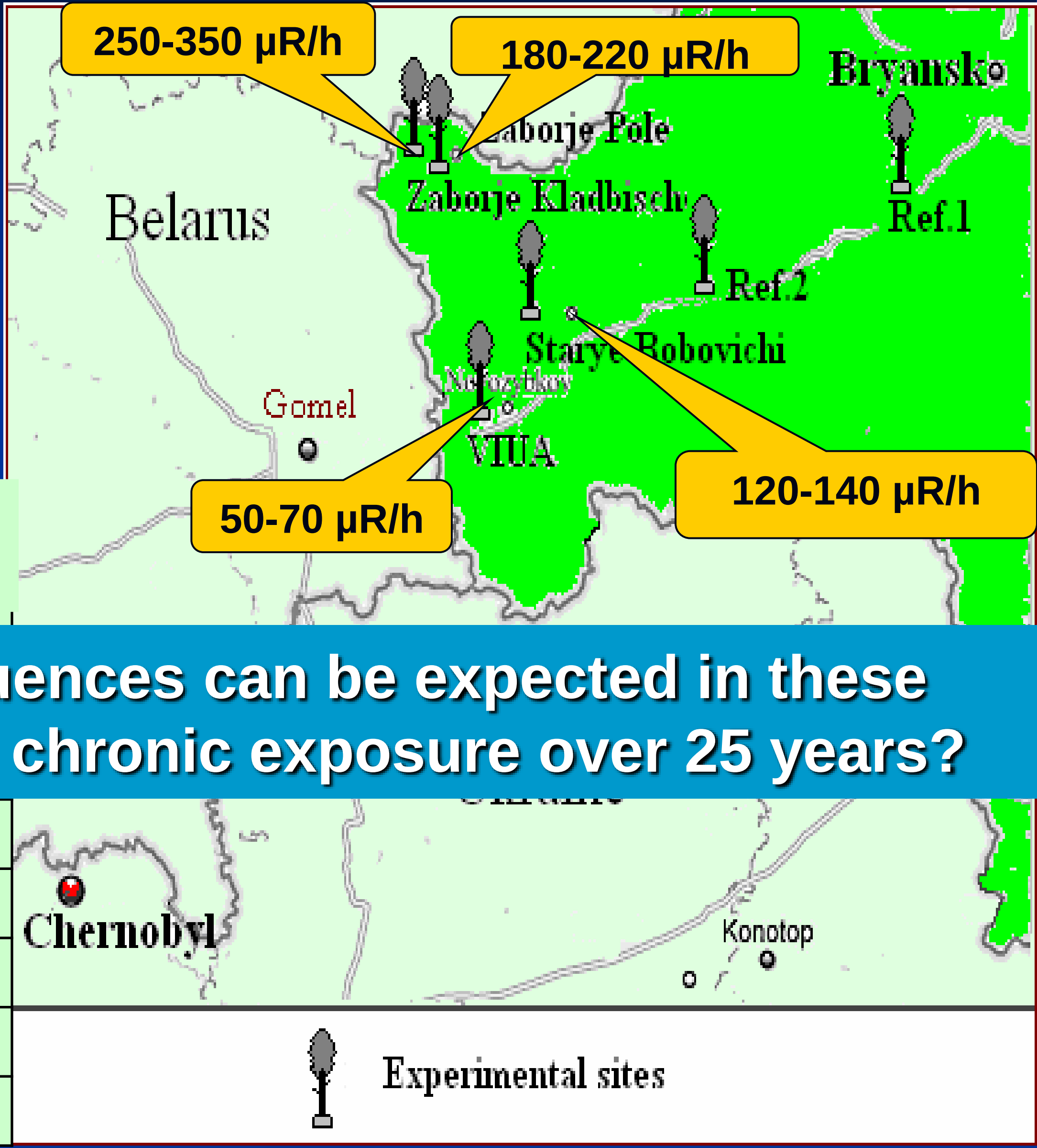
- What's actually going on in the populations inhabiting radioactively contaminated sites?
- What do we know about mutagenic effect of chronic low dose-rate radiation exposure?
- What do we know about the fate of induced by radiation mutations in altered ecological conditions?
- Can chronic low dose-rate radiation exposure be regarded as ecological factor changing the genetic make-up of a population?
- In which way chronic radiation exposure can modify reproductive ability, species diversity and community structure?

Species	Site & Time	Assay and/or endpoints
Winter rye and wheat, spring barley and oats	10-km ChNPP zone (28-4834 μGy/h), Ukraine, 1986-1989	Morphological indices of seeds viability, mitotic index, cytogenetic alterations in intercalary and seedling root meristem (Geras'kin et al., 2003a)
Scots pine, coach-grass	30-km ChNPP zone (2.5-27 μGy/h), Ukraine, 1995	Cytogenetic alterations in seedling root meristem (Geras'kin et al., 2003b)
Scots pine	Radioactive waste storage facility, Leningrad Region, Russia, 1997-2002	Cytogenetic alterations in needles intercalary and seedling root meristems (Geras'kin et al., 2005; Oudalova, Geras'kin, 2011)
Wild vetch, Scots pine	Radium production industry storage cell, Komi Republic, Russia (1-320 μGy/h), 2003-2009	Germination capacity, survival rate of sprouts, embryonic lethals, proportion of abortive seeds, cytogenetic alterations in seedling root meristem (Evseeva et al., 2009; Evseeva et al., 2011)
Scots pine	Bryansk Region radioactively contaminated in the Chernobyl accident (1-15 μGy/h), Russia, 2003-2012	Cytogenetic alterations in seedling root meristem, enzymatic loci polymorphism, abortive seeds (Geras'kin et al., 2010; Geras'kin et al., 2011; Volkova, Geras'kin, 2012)
Crested hairgrass	Semipalatinsk Test Site (0.5-32 μGy/h), Kazakhstan, 2005-2008	Cytogenetic alterations in coleoptiles of germinated seeds, length of sprouts (Geras'kin et al., 2012)
Phytoplankton communities	Industrial reservoirs, Southern Urals (2-130000 μGy/h), Russia, 2007-2012	Species diversity, abundance, biomass (Atamaniuk et al., under preparation)

Scots pine
Pinus sylvestris L.

Bryansk region, Russia 2003-2012



Doses absorbed
in generative organs of pine trees

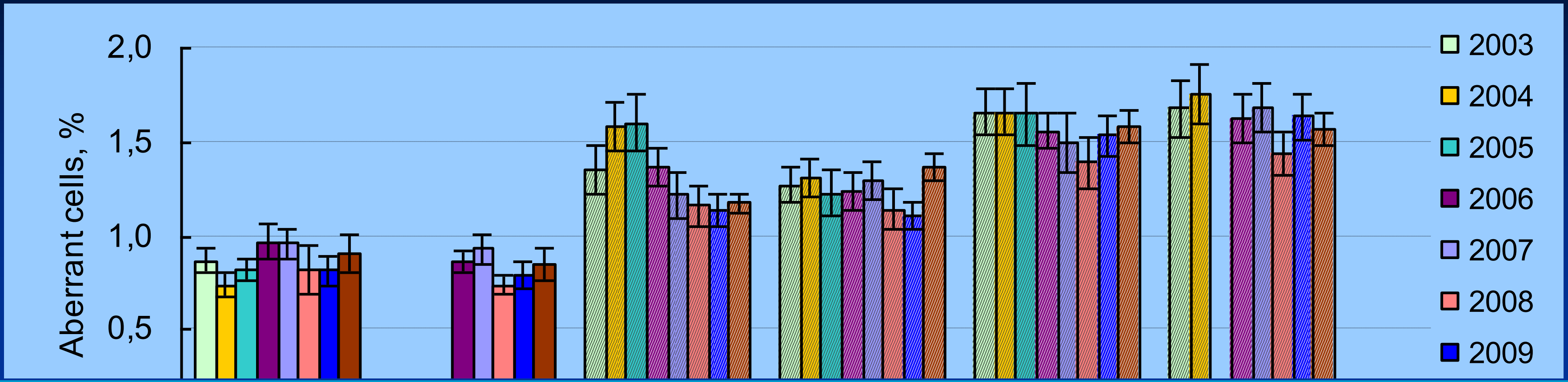
What biological consequences can be expected in these populations experiencing chronic exposure over 25 years?

Ref1	0.267	0.006	0.27
VIUA	6.62	0.344	7.
SB	22.7	0.156	23.
Z1	90.2	1.20	91.
Z2	129.4	0.506	130.

Geras'kin et al. Ecotoxicology. 2011. V. 20. 1195-1208

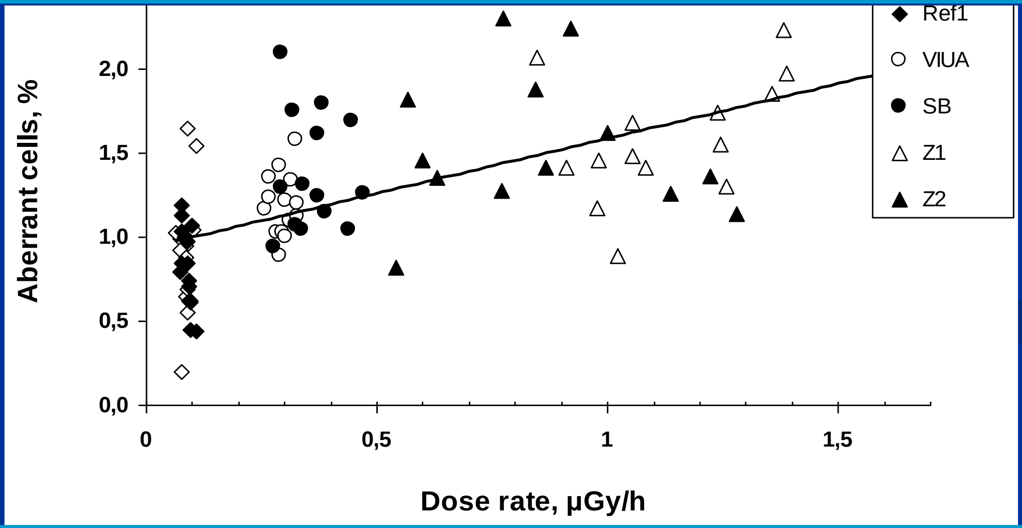
Scots pine *Pinus sylvestris* L.

Bryansk region, Russia 2003-2012



An increased level of cytogenetic alterations is a typical phenomenon for plant populations growing in areas with relatively low levels of pollution

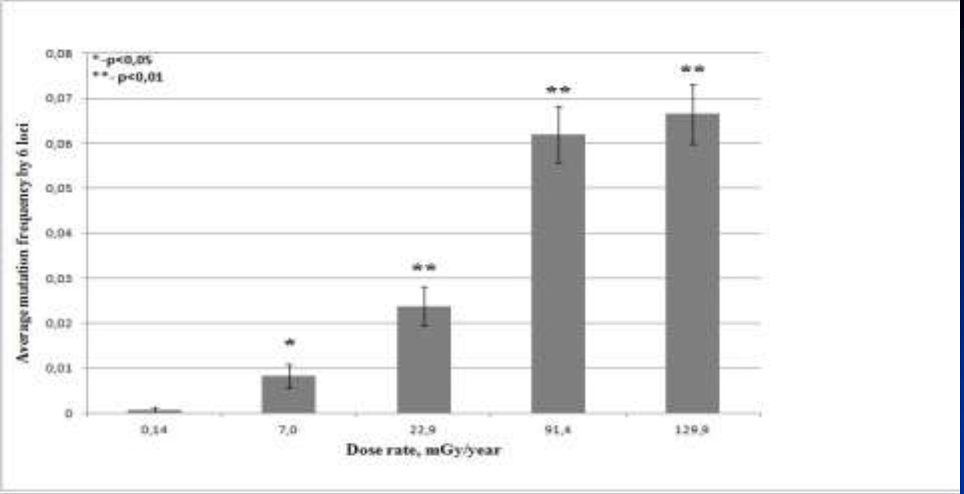
hatched bars – significant difference from reference level, p<5%



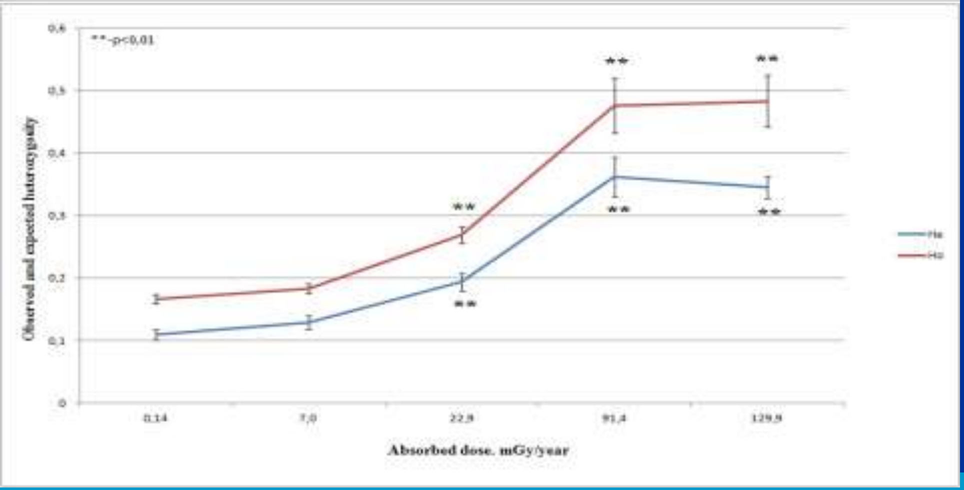
Geras'kin et al. Ecotoxicology. 2011. V. 20. 1195-1208

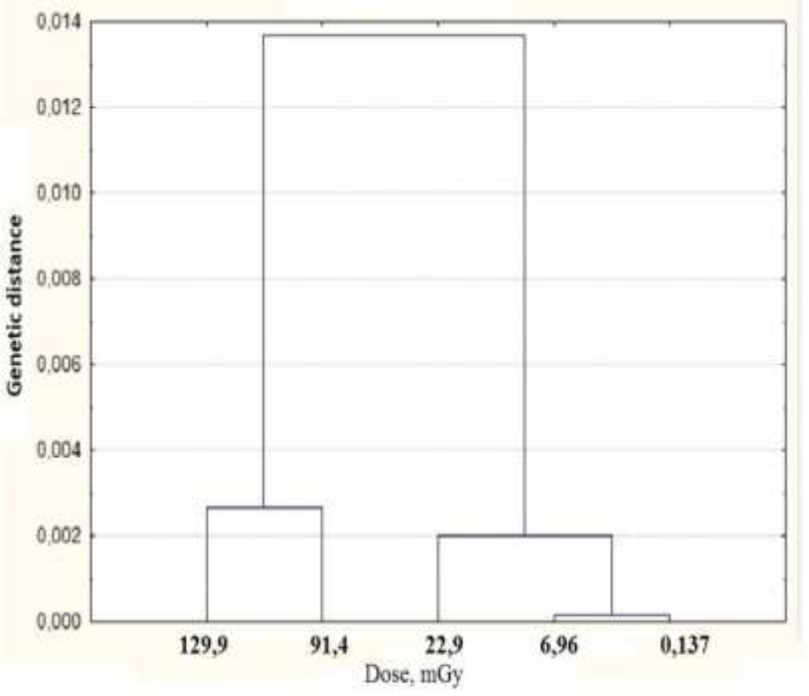
Bryansk region, Russia

Scots pine *Pinus sylvestris* L.



Significant increase with dose





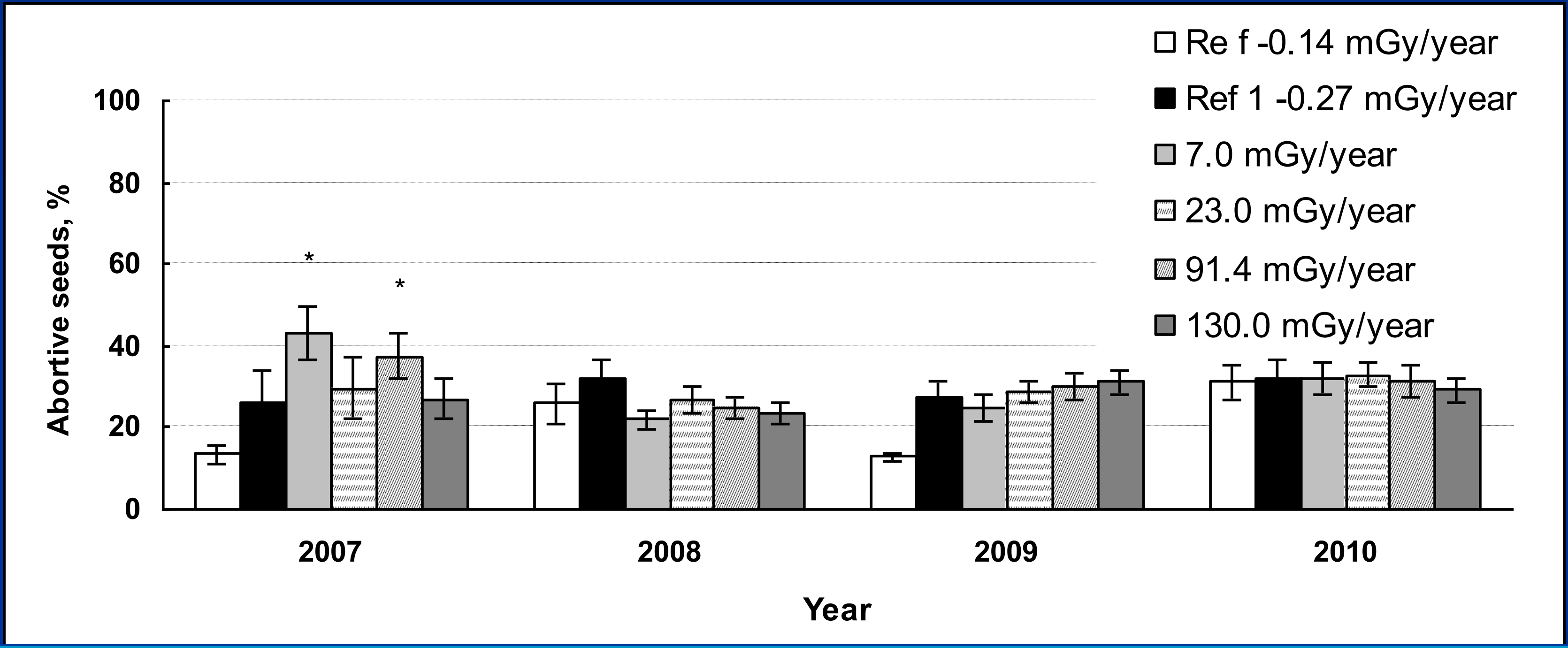
High mutation rates is intrinsic for progeny of the affected pine trees, and genetic diversity is essentially influenced by radiation exposure

Volkova, Geras'kin Radiation Biology. Radioecology. 2012. V. 52. p. 370-380 (in Russian)

Could the high mutation rates revealed have any effect on population fitness? Are there any consequences for a reproductive ability of pine trees?

Bryansk region, Russia

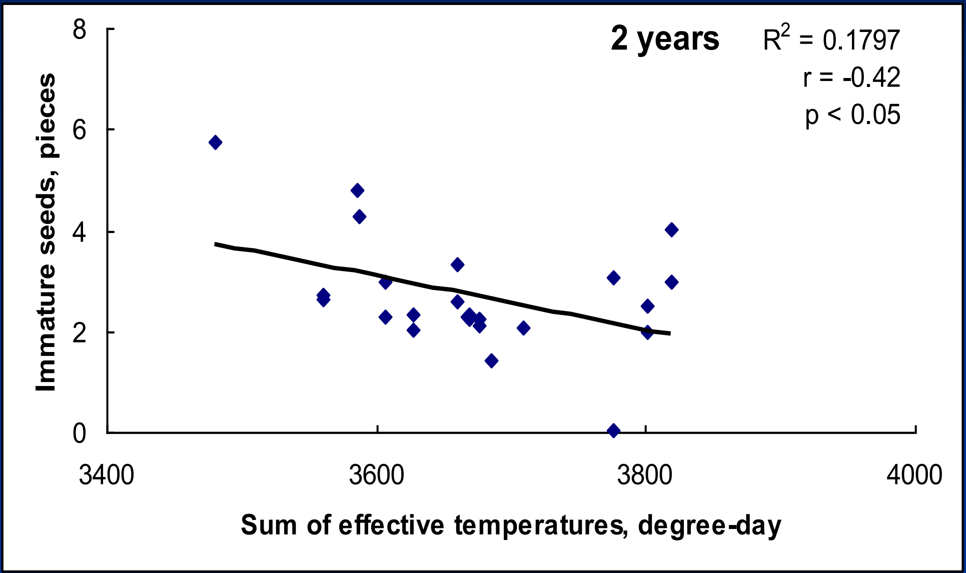
Scots pine *Pinus sylvestris* L.

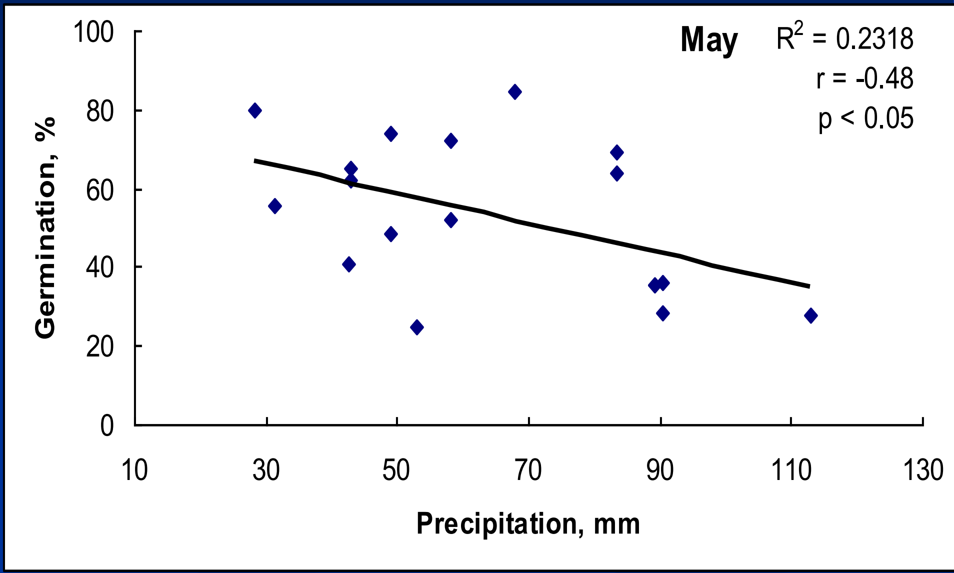


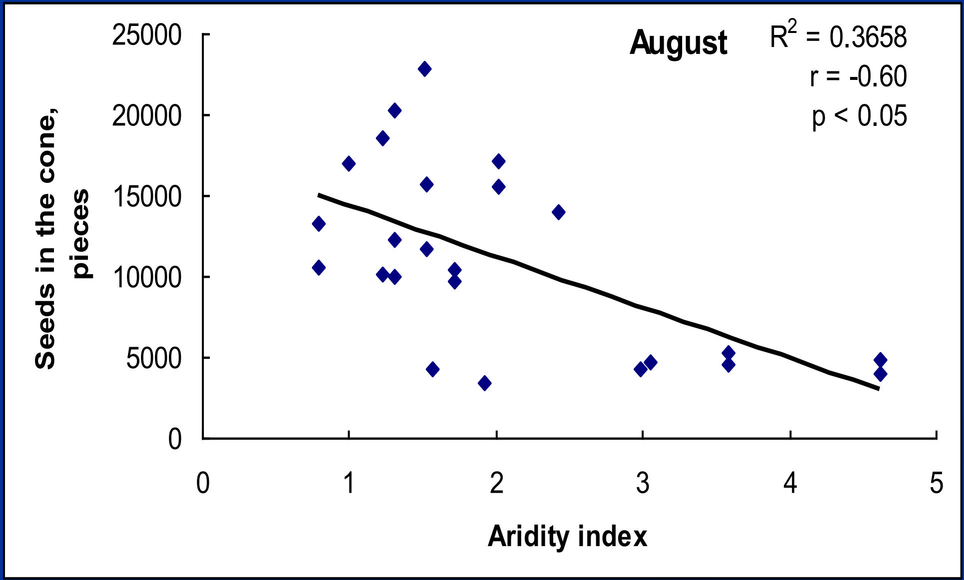
Chronic exposure at dose rates studied had no effect on the reproductive ability of the exposed populations

Geras'kin et al. Ecotoxicology. 2011. V. 20. 1195-1208

Are there any relationship between reproductive ability and weather conditions?

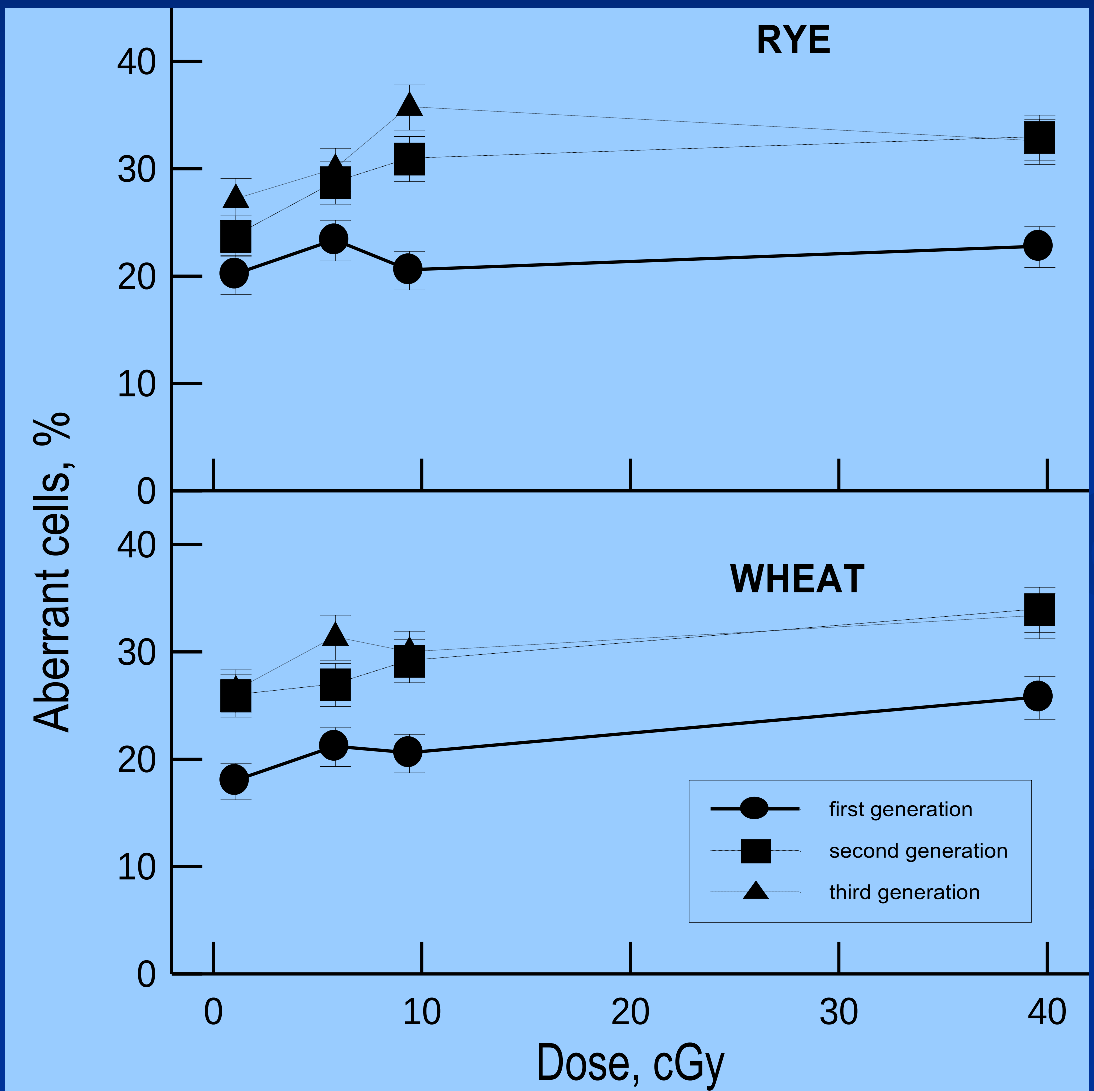






$$IA = \frac{\sum P \times 10}{\sum T_n}$$

What do we know about biological effects in plants exposed to radiation over several generations in natural setting?



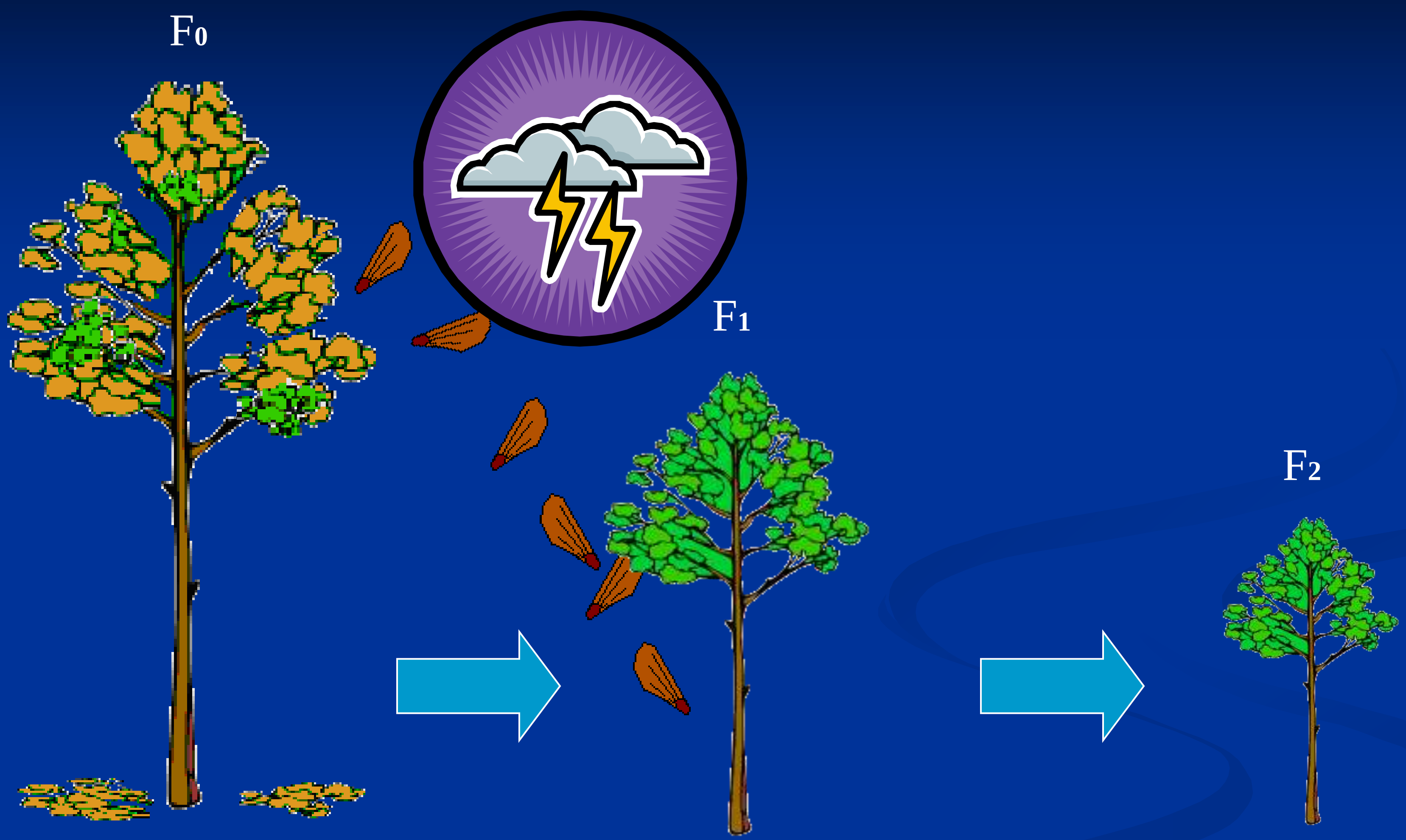
The 10 km Chernobyl NPP zone
1987-1989

Autumn 1989

Rye, wheat

Geras'kin et al. J. Environmental Radioactivity. 2003. V. 66. p. 155-169

Origin of plants from RIARAE’s experimental site



Chernobyl, Red Forest, 1986

Chernobyl, Red Forest Self-seeding in 1987, collection of seeds in 2004

2005 seeding in Moscow Region, 2010 transfer to the RIARAE’s experimental site

Mass appearance of morphological disorders in second generation after exposure

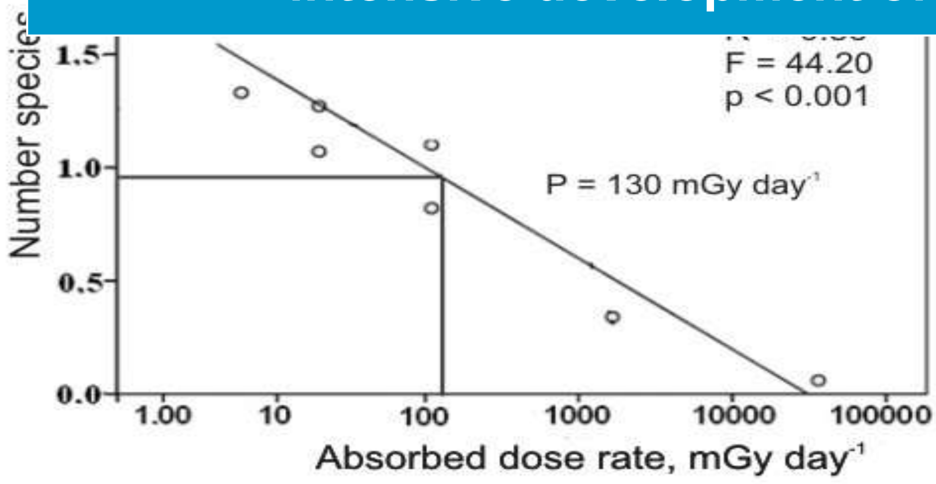
A memory of acute irradiation years ago may influence plant response in subsequent years and generations

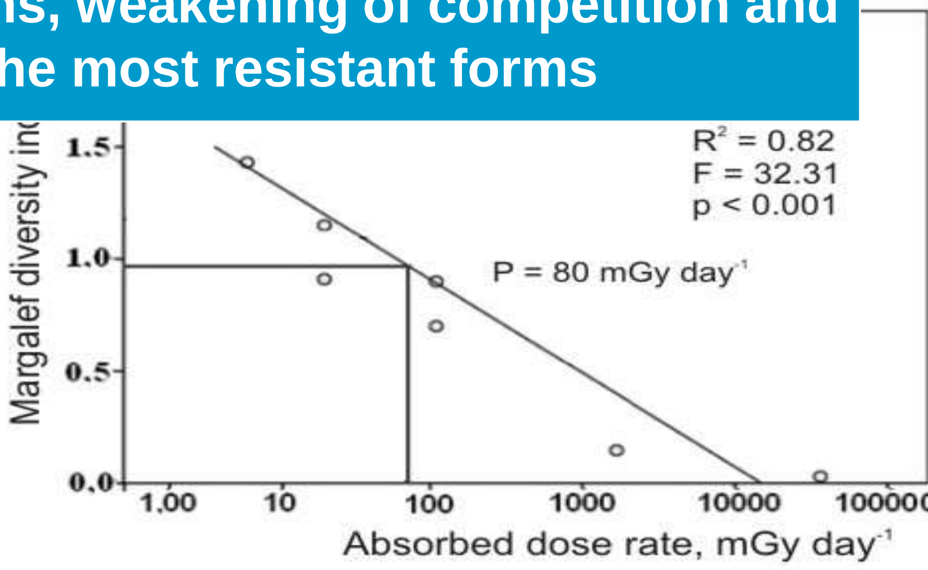
Southern Urals, the PA Mayak reservoirs, 2007-2012

Exposure	Absorbed by phytoplankton dose rate, µGy/h						
	ShR	N-2	R-11	R-4	R-10	Old Swamp	Karachai
External	0.00015	1.1	1.2	34.9	4.3	249.6	124167
Internal	0.0098	0.02	0.8	27.2	91.3	258.3	2883
Total	**0.01**	**1.1**	**2.0**	**62.1**	**95.6**	**507.9**	**127050**

Southern Urals, the PA Mayak Reservoirs, 2007-2012

Under chronic exposure to radionuclides species diversity can reduced due to a loss of sensitive species, which leads to destruction of biocenotic connections, weakening of competition and intensive development of the most resistant forms

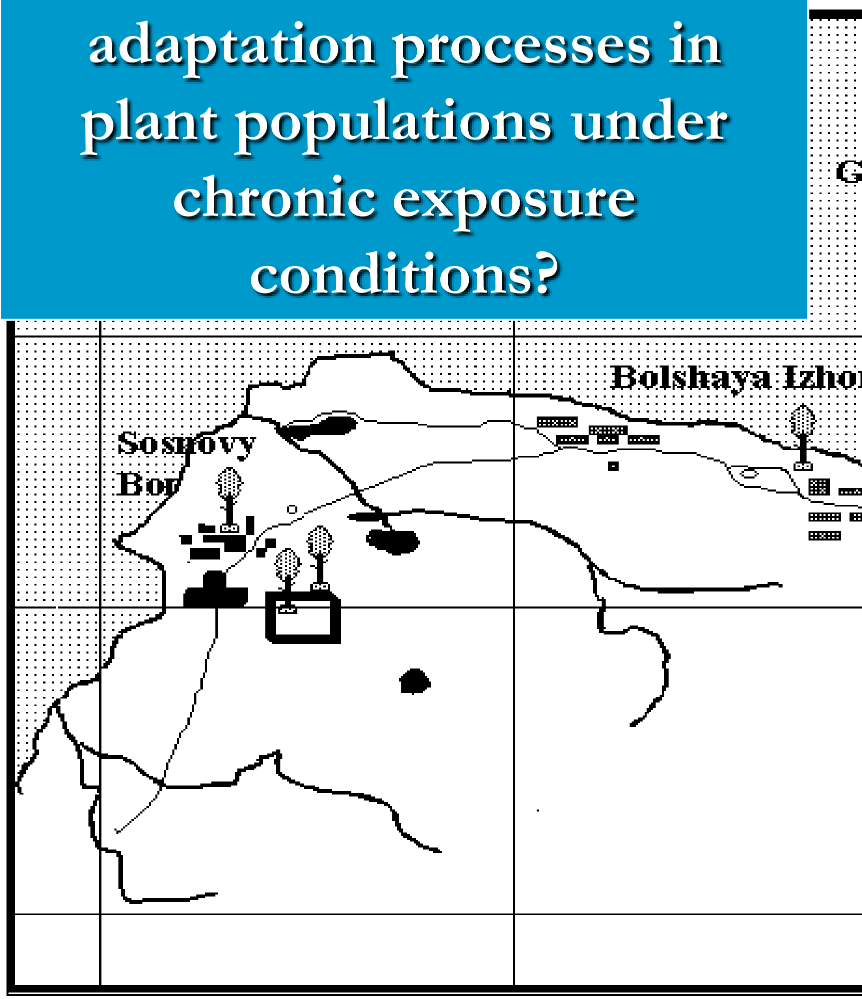




What do we know about adaptation processes in plant populations under chronic exposure conditions?

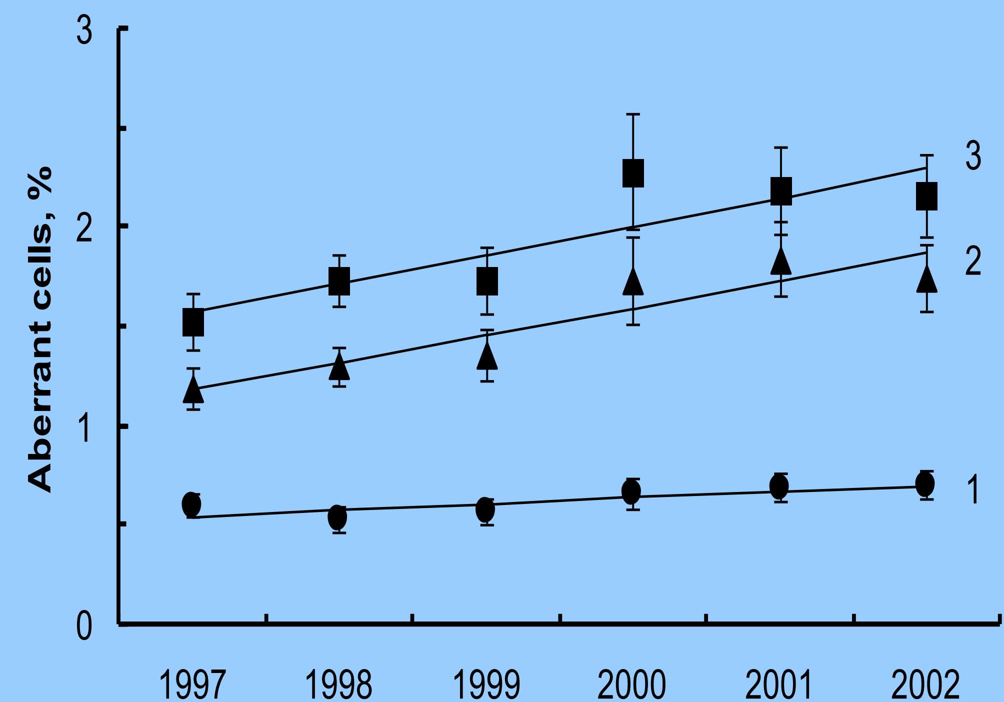
Radioactive waste storage facility Leningrad Region, Russia, 1997-2002

Scots pine *Pinus sylvestris* L.



Leningrad NPP

"Radon" Leningrad regional wast
processing enterprise (LWPE)



The seeds from the impacted Scots pine populations show a higher resistance than seeds from the reference population

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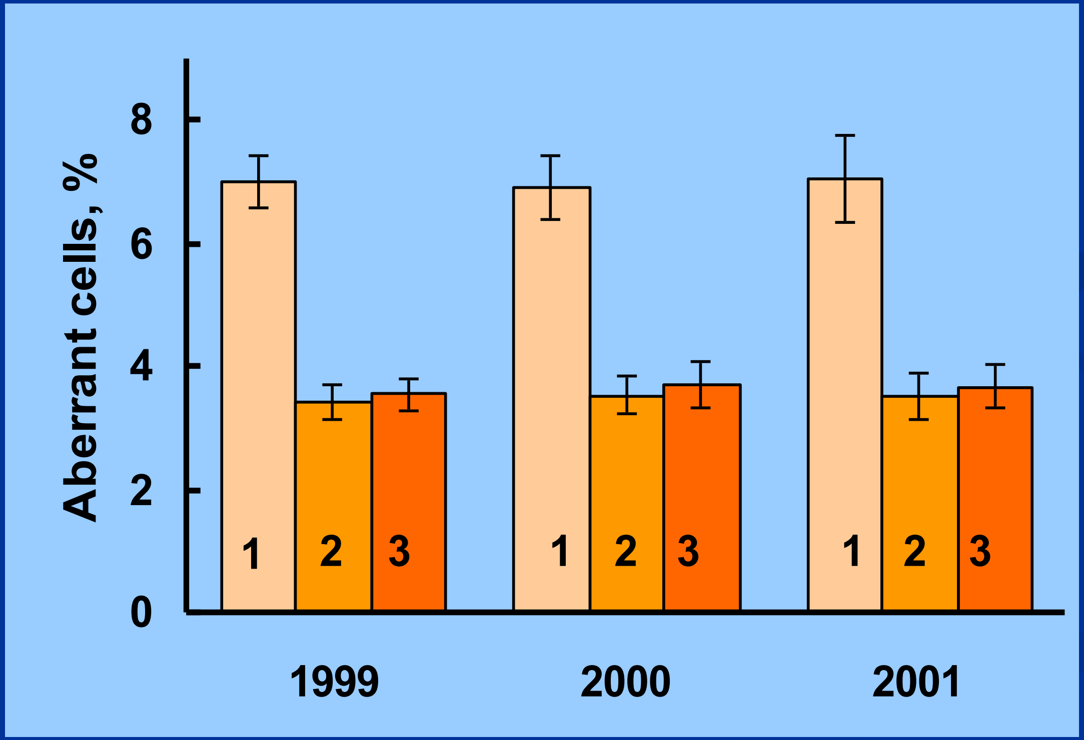
Scots pine *Pinus sylvestris* L.

Radio-adaptation phenomenon

A divergence of populations in terms of radioresistance is connected with a selection on the effectiveness of repair systems



Experimental plots:
1 – Bolshaya Izhora (control);
2 – Sosnovy Bor town ;
3 – 'Radon' waste processing plant

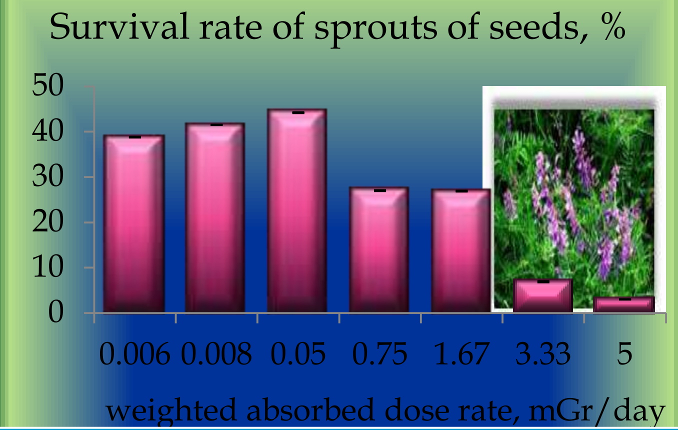
Geras'kin et al. Mutat. Res. 2005. V. 583. p. 55-66

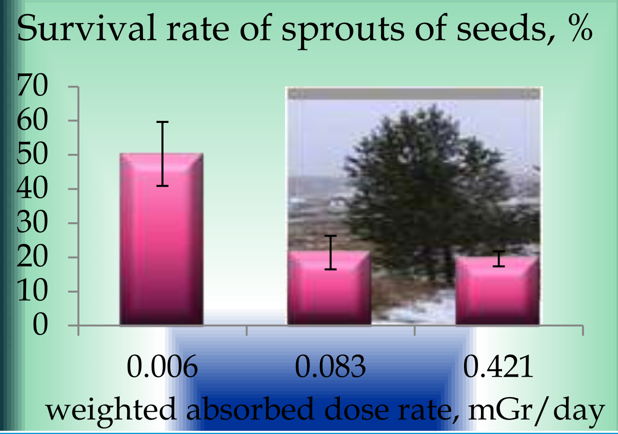
Radium production industry storage cell territory
The Komi Republic, 2003-2009

up to 275 backgrounds

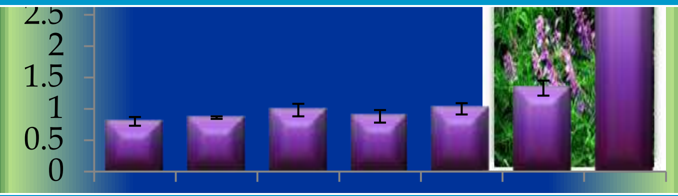
‘black’ dumps

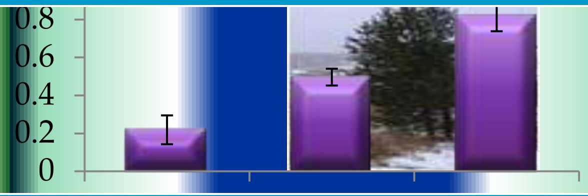
Geras’kin et al. J. Env. Radioact. 2007. V. 94. p. 151-182

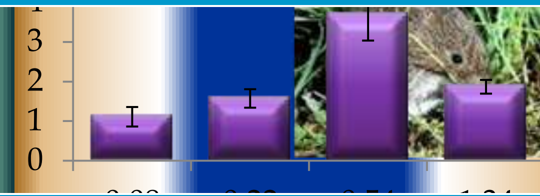




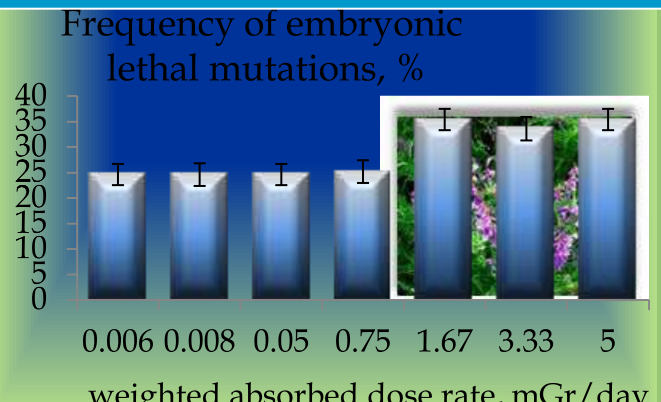
Comparison of findings from 1980 and 2003: the high levels of both genetic and morphologic intrapopulation variability still persist

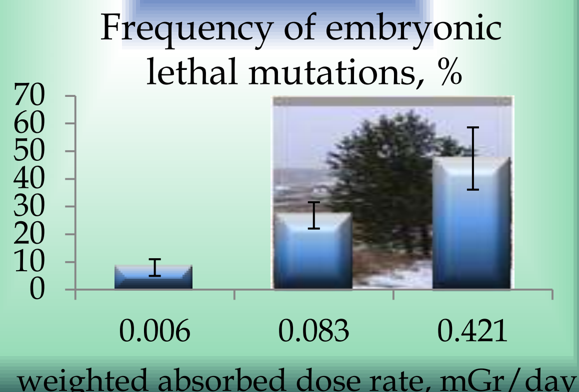






Seeds from the affected wild vetch populations show rather high radiosensitivity. An inherited character of this phenomenon was demonstrated.





Evseeva et al. Sci. Total Environment. 2009. V. 407. p. 5335-5343.
Evseeva et al., Russian J Ecology. 2011. V. 42, p. 382-387

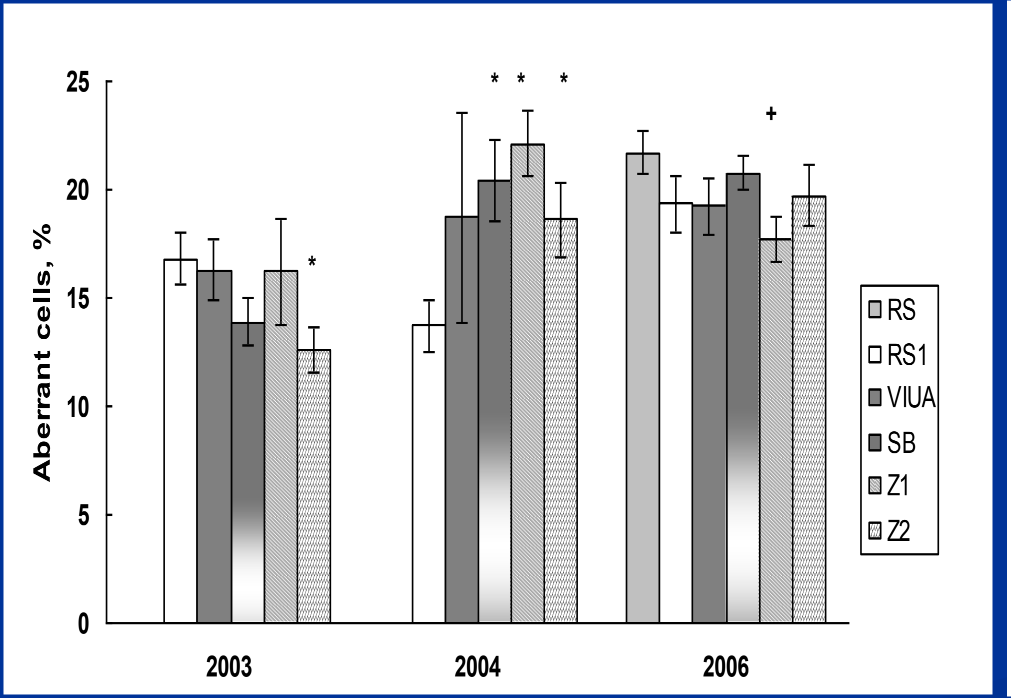
Why sometimes we failed to detect any signs of radio-adaptation in plant populations?

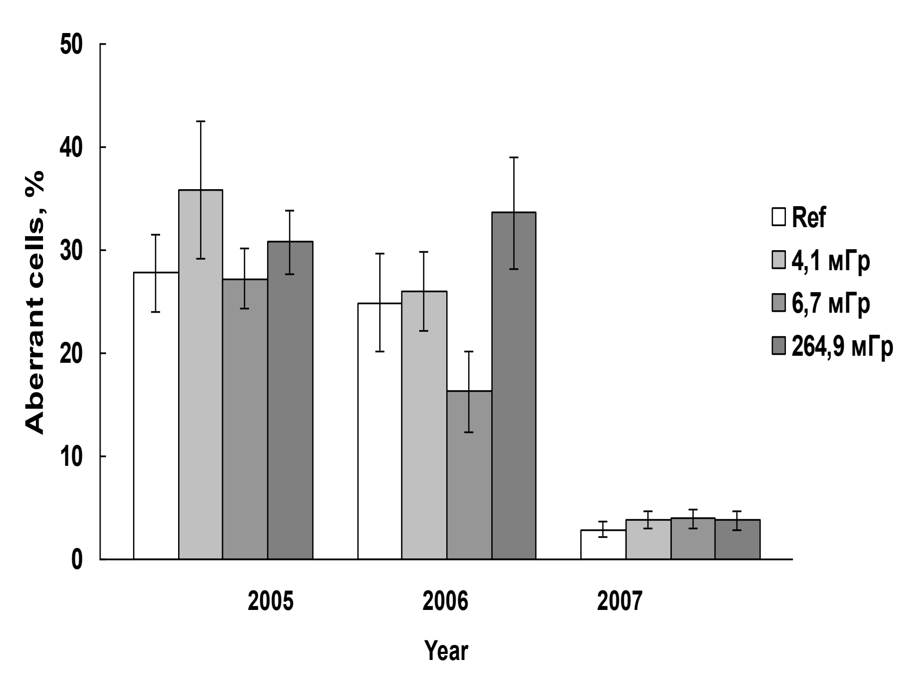
- Increased fitness in unfavorable environment is associated with decreased fitness in favorable environment. As a result, there are situations in which enhanced radioresistance has not evolved or has not persisted
- In situations where radio-adaptation is observed in one species often none is found in other despite equivalent opportunity
- The response of a population to radiation exposure depends both on the type of organism and on the biophysical characteristics of the radiation

Examples of lack of radio-adaptation in plant populations

γ-exposure of pine seeds from the Bryansk region (dose of 15 Gy, dose rate of 36 Gy/h)

γ-exposure of crested hairgrass seeds from the Semipalatinsk Test Site (2005, 2006 - dose of 69 Gy, dose rate of 2790 Gy/h; 2007- dose of 50 Gy, dose rate of 39 Gy/h)





Geras'kin et al. Ecotoxicology. 2011. V. 20. 1195-1208

Geras'kin et al. J. Env. Radioactivity. 2012. V. 104. 55-63

Main sources of uncertainty in field studies -1
Our ability to correctly estimate actual exposures:

- spatial and temporal heterogeneity of the factors influencing the effect under study;
- non-radiation factors that may modify the effect of radiation exposure;
- weighting factors for different radiation types;
- non-homogeneous radionuclides distribution within the organism;
- it is not always clear: to which organ and to what period of time we should assess the absorbed dose?

Main sources of uncertainty in field studies -2
Our ability to correctly estimate biological effects:

- radio-adaptation;
- sinergistic and antagonistic effects of combined exposure;
- information about status of biological system before exposure;
- non-target effects: epigenetics, genomic instability, and bystander effect

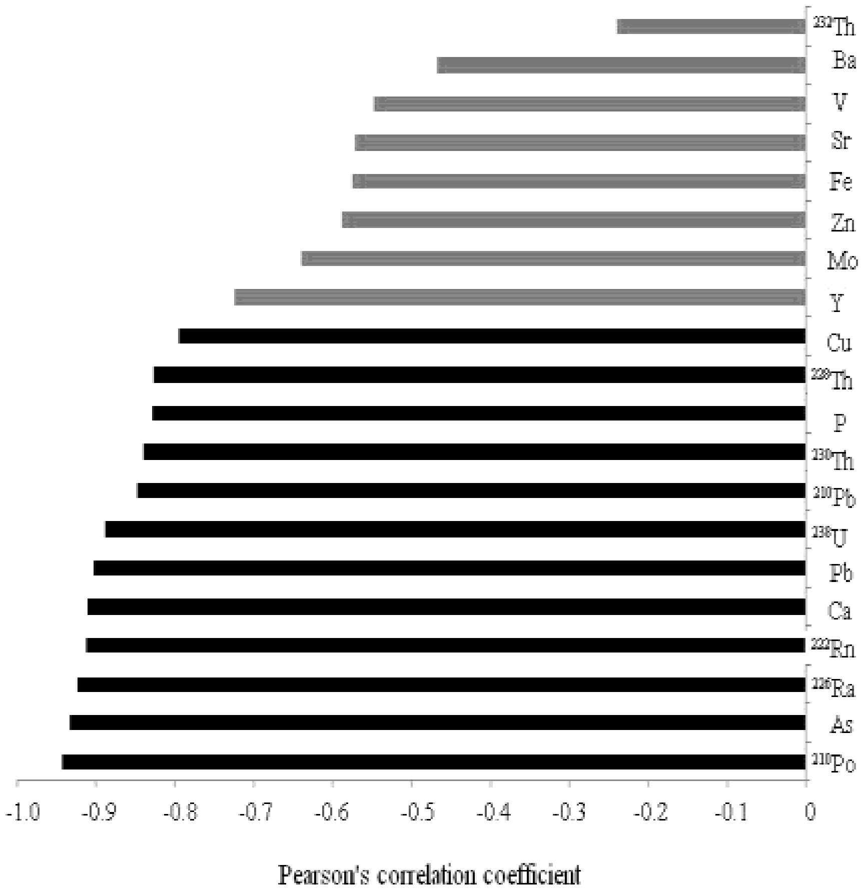
Temporal heterogeneity in radiation exposure in early days after the Chernobyl accident

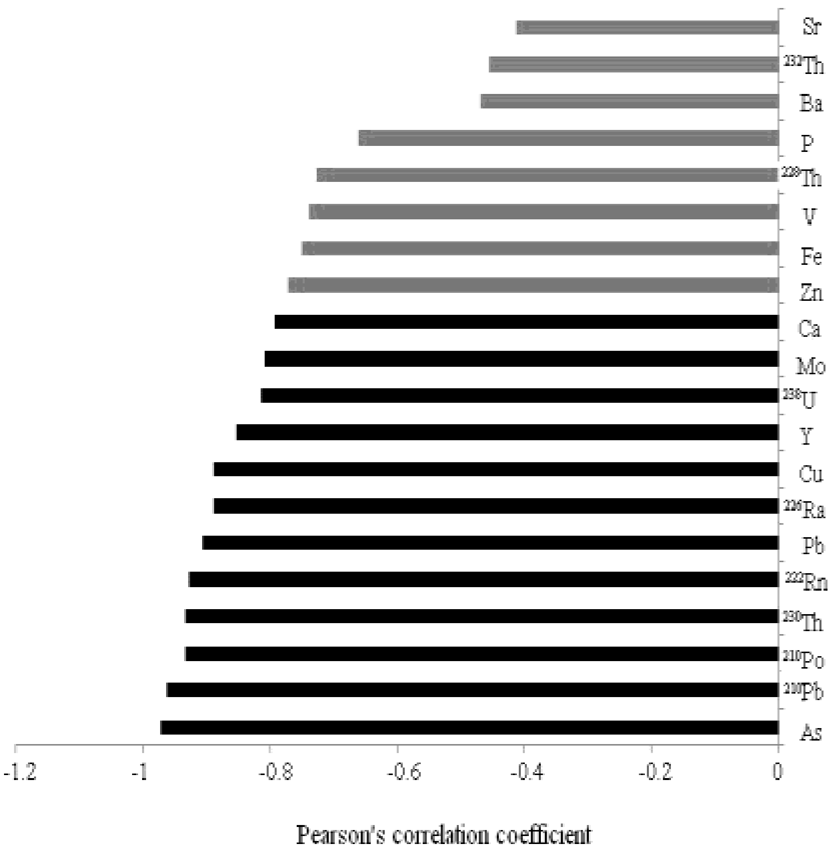
- The maximum biota exposure fell within the first 10–20 days after the accident
- First large-scale and reliable estimation of radioactive contamination and dose

We have very limited and poor information about the first, most important period when up to 90% of the doses absorbed by non-human biota was accumulated

Geras'kin et al. Env. Internat. 2008. V. 34. 880-897

Non-radiation factors play an important role in biological effects formation in wild vetch population from radium production industry storage cell territory





Germination **Survival of seedlings**

Evseeva et al. Radiation Biology. Radioecology. 2013. V. 53. in press (in Russian)

Multi-pollutant exposures

acute γ-radiation | chronic γ-radiation | heavy metals | pesticides

artificial and naturally occurring radionuclides

Chlorella vulgaris

Allium cepa

Hordeum vulgare

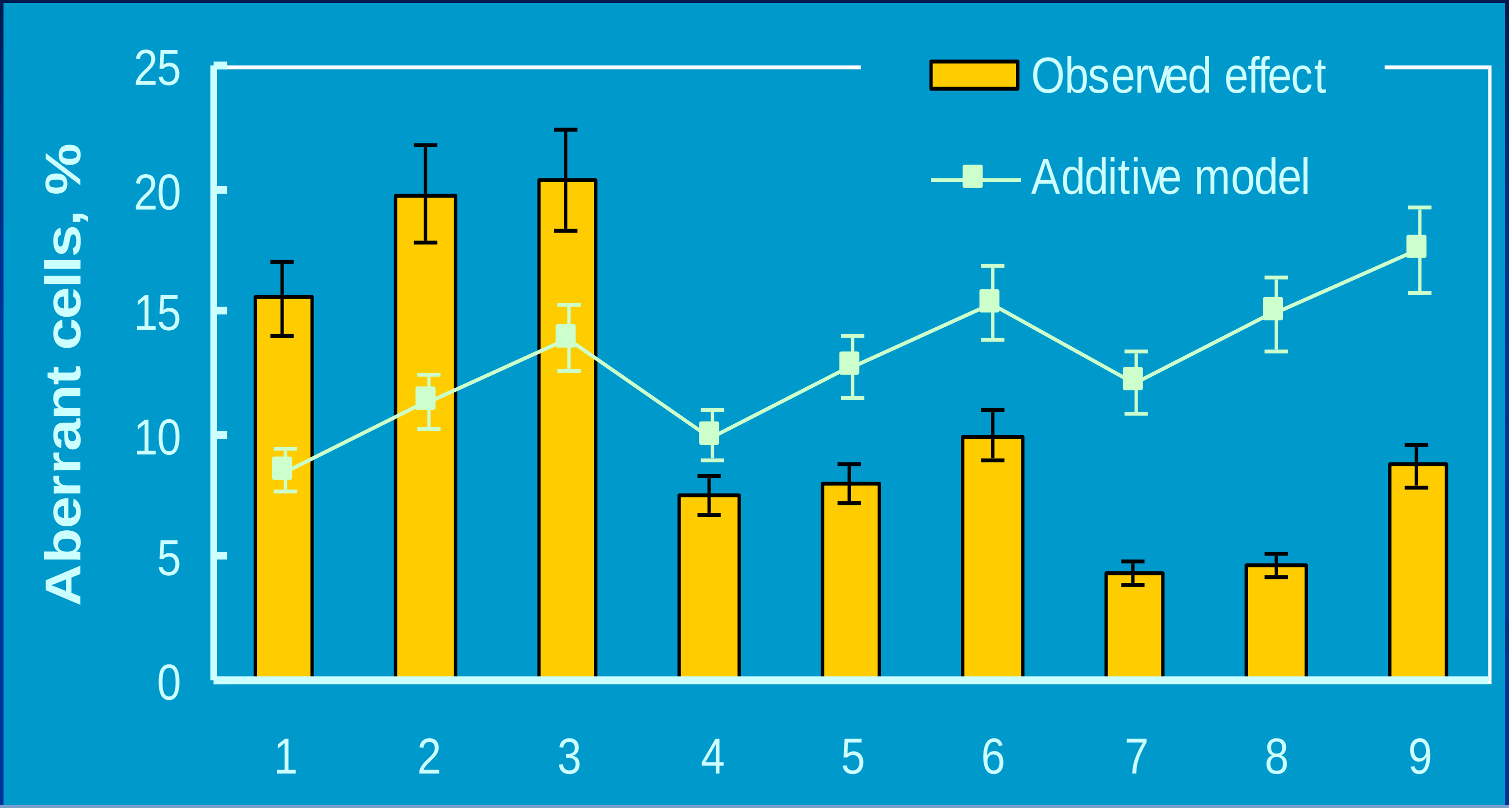
Tradescantia (clon 02)

Synergetic and antagonistic effects are most often registered at combinations of low doses and concentrations

Moreover, these nonlinear effects can make substantial contribution to a plant response

Combined exposure *Hordeum vulgare* L.

(*Geras'kin et al. Mutat. Res. 2005. V. 586. p. 147-159*)



An application of findings from single impacts to predict biological effects of combined exposure is unacceptable and may cause essential deviations from actually observed data

Uncertainties related with ecological dosimetry issues

The ERICA Tool, default values

Exposure	Absorbed by phytoplankton dose rate, µGy/h						
	ShR	**N-2**	**R-11**	**R-4**	**R-10**	**Old Swamp**	**Karachai**
External	0.00019	0.79	0.92	54.2	2.2	750	170833
Internal	0.19	1.8×10^{-6}	225	833	833	70833	1500000
Total	**0.19**	**0.79**	**226**	**887.2**	**835.2**	**71 583**	**1 670 833**

Our calculations, weighting factor of 5 for α-radiation + actual data on radionuclides content in phytoplankton

Exposure	Absorbed by phytoplankton dose rate, µGy/h						
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Total	**0.01**	**1.1**	**2.0**	**62.1**	**95.6**	**507.9**	**127 050**

CONCLUSIONS

- To properly understand the effect of real-world contaminant exposures, we should consider actual field conditions. Specifically, we need to plan new well-directed field studies to fill a major gaps in our knowledge
- To reduce the uncertainties associated with the spatial and temporal heterogeneity it will be useful to develop the unified standards for sampling in field studies

CONCLUSIONS-2

- To predict radiation exposure in a robust way it is necessary to develop a process-based transfer and dosimetric models taking into account current, a more profound understanding of environmental processes
- To reduce the uncertainties associated with the biological effects assessment, we should pay more

effects of combined exposure and non-target effects

To address all these issues, a close international cooperation in radioecological research is needed

That's all!