

## Ecodosimetry Weighting Factor ( $e_R$ ) for Non-Human Biota

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### INTRODUCTION

Radiological protection of non-human biota is being addressed by several national jurisdictions, including Canada, which is soon to set guidelines for radiation protection of the environment in accordance with the principle of sustainable development (AECB, 1998; IAEA, 1999). The development of regulatory policies and standards recognizes the environment as a complex system, and now incorporates explicitly the objective of protecting all species (Chamney et al., 1998; Thompson, 1998). Methodologies such as ecological risk assessment and environmental effects monitoring have been evaluated to develop and assist in implementing an environmental radiological program for non-human biota (Suter, 1993; US EPA, 1998).

The doses of interest for non-human biota almost always represent chronic rather than acute exposures (such as occurred immediately after the Chernobyl accident). Most exposures are from naturally occurring radionuclides; others (generally much smaller, except perhaps for localized sub-populations) are due to releases of radionuclides from nuclear facilities<sup>1</sup>. Radiation exposure of non-human biota, if substantial, can potentially interfere with their growth, reproduction and survival (IAEA, 1992). The UNSCEAR report on *Effects of Radiation on the Environment* (1996) concluded that detrimental effects on the most sensitive populations would not be expected at dose-rates below 1-2 mGy d<sup>-1</sup> for low-LET radiation. Despite such judgments in regard to low-LET radiation, insufficient information exists to establish dose-rate limits for other types of radiation for plants and animals.

In human radiological protection, the International Commission on Radiological Protection (ICRP, 1990) has indicated that it is the absorbed dose averaged over a tissue or organ, and weighted for the radiation quality that is of interest for setting dose limits. The radiation weighting factor ( $w_R$ ) is used for this purpose, and is selected for the type and energy of the radiation incident on the body or, in the case of sources within the body, emitted by the source. The value of  $w_R$  for specified types and energies of radiation are prescribed by the ICRP (1990), and are based on a review of the biological information and a variety of exposure circumstances (Simmons and Watt, 1999). In practicality, the  $w_R$  value for a particular type and energy of radiation reflects to some degree values of the relative biological effectiveness (RBE<sup>2</sup>) of that radiation in inducing stochastic effects at low doses. The  $w_R$  values are also broadly comparable with the values of quality factor ( $Q$ ), which are related to the quantity linear energy transfer (LET), a measure of the density of ionization along the track of an ionizing particle.

No similar weighting factor exists for the dosimetry of non-human biota. A need for a similar dosimetric factor is indicated by RBE values of more than unity being observed for alpha- and very weak beta-emitters (e.g., tritium) for biota at dose-rates relevant in ecological risk assessment.

We propose an “ecodosimetry weighting factor”,  $e_R$ , for non-human biota to fill a role equivalent to that occupied by  $w_R$  in human radiation protection. However, what is the proper basis for choosing values for an “equivalent” weighting factor for dosimetry of non-human biota? We believe that it should not reflect values for stochastic effects at low doses, as not all non-human species develop cancer or receive doses that are considered low. Obviously, the value for  $e_R$  should represent the RBE of a specific type of radiation with respect to biological endpoints, and dose-rates, most relevant for radiological protection of non-human biota. The “ $e_R$ ” for application to biota dosimetry should also allow one to derive the weighted dose as sum of the doses from different types of radiation, or sources of exposure (both external and internal) in an organism. In general, the  $e_R$  value should: (a) consider, but not limited to, the RBE values for effects from environmental levels of doses; and (b) be representative of the  $w_R$  values in order to relate the health effects to individuals, populations or

<sup>1</sup> There are rarely any exposures to neutrons or heavy-ions. Exposures are mainly internal from alpha, beta and gamma emitters.

<sup>2</sup> RBE is the ratio of the dose of reference radiation to test radiation required to produce the same level of biological effect. In essence, RBE value is an index of the relative effectiveness of a radiation type (e.g., an  $\alpha$ -emitter, tritium  $\beta$ -rays etc.) to reference radiation (usually 200 kVp x-rays, but often  $\gamma$ -rays, such as from <sup>60</sup>Co at low dose-rates).

communities in an ecosystem. This paper illustrates approach taken by us in recommending  $e_R$  values for tritium and alpha-emitting radionuclides.

## RADIATION QUALITY, RBE AND $e_R$

Radiation quality can be specified basically by the fluence spectrum of the ionizing particles of different charge and velocity that deposit energy in the system considered. For example, a  $\gamma$ -ray electron track traversing the nucleus of a mammalian cell gives rise to 60-80 ionizations; this is equivalent to  $\sim 1$  mGy absorbed dose. An  $\alpha$ -particle traversing the same nucleus might give rise to  $\sim 23,000$  ionizations within this volume, and an absorbed dose approaching 400 mGy (Goodhead, 1992). This results in a fundamental difference in energy deposition patterns (*viz.*, dose). Attempts to produce an RBE for alpha particles at doses below 400 mGy are really trying to compare the outcomes of two different and noncomparable irradiation conditions. Hence, at low doses and dose-rates, the effects of high-LET irradiation are best considered in absolute terms.

However, the radiobiological data suggest that RBE values for various radiations are broadly related to specific type and energy of the ionizing radiation at high doses and dose rates. In human radiological protection, however, values of the RBE do not directly lead to the values for  $w_R$ . Since for a specific type of radiation  $w_R$  applies to all tissues and organs in the body, a substantial degree of simplification was introduced by the ICRP. The prescribed  $w_R$  values average the effectiveness of a particular type of radiation over a body of any size or gender for typical stochastic effects at low doses (ICRP-60, 1990). The ICRP considers that such approximation is sufficiently accurate for practical applications in radiological protection. We envisage a similar approach for values of  $e_R$ .

Pentreath (1999) points out that a major difference between the protection of human and non-humans is the difference in goals, in terms of the particular biological endpoints concerned. Human radiological protection is designed to provide protection against both stochastic and deterministic effects through a wide range of different circumstances. In ecological dosimetry, however, alleged harm attributed to radiation exposure is seldom related to stochastic effects (e.g., cancer) in exposed organisms. Any harm attributed due to radiation is judged primarily as deterministic effects, expressed at the population and community levels. Radiation effects at the chromosome and cellular levels are usually do not translate into detriment at the population level. For example, effects on fertility, fecundity, growth and survival are identifiable only at the population, and not at the individual level. Hence, the RBE for stochastic effects in an individual member of the species is of limited concern. The sorts of effects judged most important for ecological risk assessment are generally deterministic effects.

The preliminary assessment and measurement endpoints proposed for Canadian nuclear facilities (Table 1), in order to monitor the impact of radionuclide releases on non-human biota, relate solely to deterministic effects: survival, fecundity and reproduction. This makes the inputs to selection of  $e_R$  fundamentally different than those for selection of values for  $w_R$ . Furthermore, choosing suitable values for  $e_R$  for various radiations is complicated by the need to perform dosimetry for an apparently limitless number of species. This means that values for  $e_R$  for a particular type of radiation can vary not only because of a range of values for RBE for a particular endpoint in different organisms, but also because of the significance of different endpoints for an ecologically significant species or most radiosensitive species in the ecosystem. As such,  $e_R$  values for various types of radiation can be graded for "realistic" ecological risk assessment. At level 1, values for  $e_R$  can utilize the effects observed solely at the individual level as guidance for evaluating whether there will be an impact on health of flora and fauna. At level 2,  $e_R$  values can be used to assess whether effects observed will have impact on sustainability of the ecosystem. At level 3,  $e_R$  values can include impact of genetic and hereditary effects (about which less is known at present) on the long-term survival of the critical biota (e.g., threatened/ endangered species) in an ecosystem. In this regard, RBE values for reproduction, fecundity and survival in biota will often become the critical bases for selection of  $e_R$  values.

Table 1. Potential assessment and measurement endpoints for non-human biota for Canadian nuclear facilities (adapted from Thompson, 1997).

Exposure pathway	Assessment endpoint	Measurement endpoint
Surface water	Reduction in fish population	Survival and reproduction (e.g., fecundity, embryotoxicity, teratogenicity)
Water-	Decline in population density of	Survival and reproduction.

sediment	benthic invertebrates.	
Soil	Decline in population density of earthworms.	Survival and reproduction.
Airborne	Damage to terrestrial plants	Annual stem growth, reproduction
Combined	Potential harm to muskrats	Survival and reproduction

## RBE DATABASE

Numerous RBE values for various biological endpoints can be considered for radiological protection of the environment. These can range from molecular changes in individual cells, to complete devastation of an ecosystem. However, particular types of endpoints which have received scientific attention in relation to environmental radiation protection include: (1) at the individual level, mutation frequency, chromosomal aberrations, physiological changes, lethality and related changes; and (2) at the population level, productivity reduction, reproductive impairment, altered life-span, community diversity reduction and alteration of community structure (Barnhouse, 1995).

The critical biological endpoint, for sustainable development of an ecosystem, appears to be impairment of the reproductive ability (UNSCEAR, 1996). Other endpoints affecting the viability of the species occur only at high doses, and are chiefly deterministic (IAEA, 1992). The experimental evidence, reviewed in ICRP Publication 58 (1989), clearly indicates that RBE values for deterministic effects are considerably smaller by a factor in the range of 2-5 than the values of RBE for various types of stochastic effects. This suggested that any radiation weighting factor for deterministic effects ought to be appreciably lower than the  $w_R$  for stochastic effects, for the same type of radiation.

When recommending  $e_R$  values for tritium  $\beta$ -rays and  $\alpha$ -emitters, we will use the RBE values for the stochastic effects as an upper bound limit, but RBE values for deterministic effects will be applied in deriving the most "realistic" values. A list of RBE values for tritium  $\beta$ -rays and  $\alpha$  particles, which were derived in a broad range of studies, and that are relevant to biological endpoints in ecological risk assessment, are summarized in Table 2.

### Tritium $\beta$ -rays

Straume and Carsten (1993) reviewed a wide range of literature, and listed RBE values from the studies which used x-rays or high-energy gamma ( $^{60}\text{Co}$  or  $^{137}\text{Cs}$ ) as reference radiation. The RBE values varied from 1 to 10 for tritiated compounds for a variety of stochastic and deterministic endpoints (see Table 2). Straume claimed that the appropriate RBE value for tritium is about 2. Recently, an *in vitro* study using developmental and related effects as biological endpoints claimed RBE values ranging from 4 to 9 for tritium-labeled organic compounds compared to x-rays (Wang et al., 1996). However, the methodology and assumptions used in this study were strongly criticized on several grounds, and it appeared that the dosimetry for tritium was not accurate (Trivedi et al., 1997).

A much lower range of RBE values for tritium was evident when carcinogenesis (a stochastic effect) was the endpoint. For example, two animal studies evaluating the RBE of HTO exposures were carried out at Chalk River using cancer as an endpoint. The first was based on acceleration of the appearance of breast cancers in female rats (Gragtmans et al., 1984). The second investigation used induction of myeloid leukemia in male mice (Johnson et al., 1995). Both studies used x-rays as reference radiation and yielded RBE values for tritium beta-rays of about 1.2.

The choice of reference radiations in these studies may explain why the reported range and mean value of RBE for tritium has been claimed to be appreciably higher than unity. The explanation appears to relate to what reference radiation was used in the experiments. Normally, the experimental studies use either x-rays with an energy of few hundred keV or gamma rays of energy of about 1 MeV. While these radiations are about equally effective at high doses and high dose-rates, there is a factor of about two in biological effectiveness

between these two energy bands at low doses (Sinclair, 1996). Put another way, the RBE of 250 kVp x-rays relative to  $^{60}\text{Co}$  gamma radiation is about 2. While x-rays are the reference radiation of choice, gamma rays are more convenient operationally and tend to be used more often. The use of gamma rays as reference radiation tends to make the tritium RBE appear twice as large. Therefore, Straume's claim (1993) for tritium RBE of 2 is inappropriate.

The ICRP Publication 60 (1991) decision to equate the relative effectiveness of x-rays and gamma-rays has further exacerbated the confusion related to tritium  $\beta$ -rays. Since the ICRP equates  $w_R$  value for all photons and all electrons including tritium  $\beta$ -rays to 1, it is justifiable to propose  $e_R = 1$  for tritium  $\beta$ -rays in environmental radiation protection.

### $\alpha$ -emitters

Extensive experimental investigations have been conducted to determine the RBE values for alpha-emitting radionuclides. A typical summary of the relevant results is listed in Table 2. For mutations and chromatid breaks, the RBEs of alpha-particles were 0.29 and 1.1, respectively (ICRP 58, 1989). Some studies indicate that RBE values for alpha particles can range from less than 1 for double strand breaks to >100 for sister chromatid exchange (as cited by Prestwich et al. 1991).

A considerable range of RBE values has been reported for endpoints involving reproductive and haemopoietic systems. Howell *et al.* (1997) reported an RBE value of 6.4 from alpha exposure for sperm head survival in mice. Rao *et al.* (1991) report an RBE of 245 for sperm head abnormalities from  $^{210}\text{Po}$  exposure. Similar large values (>80) are reported for mortality of oocytes in mice (ICRP 58, 1989). High RBE values have also been reported for the effects to the haemopoietic system from  $^{239}\text{Pu}$  exposure. Tests with endpoints such as spleen colony forming units, bone progenitor cells give RBE values of 150 and above for  $^{239}\text{Pu}$  (Lord and Mason, 1996). Typically, uniform distribution of the radionuclides are assumed, which may not reflect the "real" dose to the critical target.

Data for bone carcinoma induction in mice and beagle dogs were reviewed and interpreted in terms of RBE comparing  $\alpha$ -emitting  $^{226}\text{Ra}$  and  $\beta$ -emitting  $^{90}\text{Sr}$  (NCRP-104, 1990). The data indicated that RBE approached or was greater than 20 for the lowest dose-ranges (less at high doses). It was concluded that RBE for  $\alpha$ -emitter increased as an inverse function of dose, mainly due to the low effectiveness per gray of  $\beta$ -rays of  $^{90}\text{Sr}$  in the low dose and low dose-rate range. Thus, it may be inferred that the reported high values of RBE, notably those higher than 20, reflect strong dose and dose-rate dependency effects relating to the reference low-LET exposure, and may not be suitable for consideration in radiological protection. Furthermore, the variation in RBE can result from many other factors as discussed in ICRP Publication 58 (1989). For example, variation in RBE for induction of cell reproductive death can arise from: difference in cell or tissue of origin (factor of 3); differences in ion charge and energy (factor of 10); and dose, dose per fraction or dose-rate from internally deposited radionuclides (factor of 5).

This difficulty can be overcome, however, by comparing the animal data obtained from studies where animals were exposed to gamma rays versus fission neutrons (high-LET) from external sources. We propose that RBE values from experiments with fission neutron, where dosimetry is not an issue, be used to guide selection of  $e_R$  for high-LET  $\alpha$ -emitters.

ICRP Publication 58 (1989) and NCRP Publication 104 (1996) reviewed the literature and listed RBE values for fission neutrons. The RBE values are between 4 and 12 for 1-5 MeV neutrons, and 3 and 10 for 5-50 MeV neutrons, respectively. Similar to the ICRP interpretation of fission neutron data, if we evaluate the reported values for RBE for alpha-emitters, most "realistic" values range between 2 to 12 (Table 2). This comparison clearly indicates that the appropriate RBE values for alpha-emitters are between 5-10.

However, setting a single value for ecodosimetry weighting factor ( $e_R$ ) for  $\alpha$ -particles which represents a proper balance between "realistic" and "conservative" estimates is difficult. Since the majority of studies report RBE values  $\leq 10$  for endpoints, and doses and dose rates that are more ecologically significant, a value of 10 might be appropriate for weighting doses to evaluate the impact of  $\alpha$ -emitters at the population level, if any. This value can be lowered by a factor of 2, i.e.,  $e_R$  value of 5, to observe "realistic" impact on the biota at the individual level (this impact will likely to have a trivial effect on the survivability of a species in a given ecosystem unless a large proportion of individuals express it). If an individual species is considered socio-

economically valuable (e.g., threatened/endangered species), or more substantive assurance that the long-term viability of an ecosystem must be protected, an  $e_R$  value of 20 could be used. This value has the benefit of being the representative value for  $w_R$ , being conservative and relevant in evaluating the genetic and hereditary effects in the populations and communities, over many generations, for environmental protection.

## CONCLUSIONS

Since ecological risk to populations of non-human biota generally appears only when doses are moderately high, the most logical and reasonable choice of values for the proposed ecodosimetry weighting factor ( $e_R$ ) for tritium  $\beta$ -rays and  $\alpha$ -particles relate to deterministic effects in populations. The larger, limiting values of RBE value observed at low doses and dose-rates for stochastic effects are inappropriate, and moreover reflect not so much increased effectiveness of the  $\alpha$ -particles as they do lower effectiveness of the reference radiation. These limitations of the "RBE concept" have to be kept in mind when discussing and deciding on  $e_R$  values. *Recommendations on  $e_R$  for particular radiations cannot be divorced from concomitant consideration of the assessment endpoint involved and the ecological entity which is to be protected.* Keeping these precepts in mind, and applying them to ecological risk assessment of radionuclide releases from nuclear facilities, the defensible values of  $e_R$  which we recommend, according to the graded approach we outlined, are summarized in Table 3.

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## REFERENCES

- AECB (Atomic Energy Control Board) *Policy on protection of the environment, proposed regulatory policy*. Atomic Energy Control Board Consultative Document, C-223 (1998).
- Barnthouse, L.W. *Effects of ionizing radiation on terrestrial plants and animals: A workshop report*. ORNL/TM-13141, National Technical Information Service, Springfield, VA, USA (1995).
- Chamney, L.; Thompson, P.; Maloney, R. *Development of an expanded regulatory environmental protection program at the Atomic Energy Control Board*. Presentation to the Canadian Nuclear Society, 1998 October 20 (1998).
- Goodhead, D.T., *Track structure considerations in low dose and low dose rate effects of ionizing radiation*. Adv. Radiat. Biol. 16: 7-44 (1992).
- Gragtmans, N.J., Myers, D.K., Johnson, J.R., Jones, A.R., Johnson, L.D. *Occurrence of mammary tumors in rats after exposure to tritium beta rays and 200 kVp x-rays*. Radiat. Res. 99: 636-650, 1984.
- Howell, R.W.; Goddu, S.M.; Narra, V.R.; Fisher, D.R.; Schenter, R.E.; Rao, D.V. *Radiotoxicity of gadolinium-148 and radium-223 in mouse testes: relative biological effectiveness of alpha-particle emitters in vivo*. Radiat. Res. 128:282-292 (1997).
- IAEA (International Atomic Energy Agency) *Effects of ionizing radiation on plants and animals at levels implied by current radiation protection standards*. International Atomic Energy Agency, Vienna, Austria, Technical Reports Series No. 332 (1992).
- IAEA (International Atomic Energy Agency). *Protection of the environment from the effects of ionizing radiation: A report for discussion*. International Atomic Energy Agency, Vienna, Austria, Technical Reports Series No. 332 (1999).
- ICRP (International Commission on Radiological Protection). *Recommendations of the International Commission on Radiological Protection*. Publication 60, Pergamon Press, New York, USA (1990).
- ICRP (International Commission on Radiological Protection). *RBE of deterministic effects*. Publication 58,

Pergamon Press, New York, USA (1989).

Johnson, J.R., Myers, D.K., Jackson, J.S., Dunford, D.W., Gragtmans, N.J., Wyatt, H.W., Jones, A.R., Percey, D.H. *Relative biological effectiveness of tritium for induction of myeloid leukaemia in CBA/H mice*. Radiat. Res. 144: 82-89 (1995).

Lord, B.I.; Mason, T.M. *On the relative biological effectiveness of alpha-particle irradiation with respect to haemopoietic tissue*. Radiat. Res. 145:510-518 (1996).

NCRP (National Council on Radiation Protection and Measurements) *The relative biological effectiveness radiations of different quality*. NCRP Report # 104, Washington, DC, USA (1990).

Pentreath, R.J. *A system for radiological protection of the environment: some initial thoughts and ideas*. J. Radiol. Prot. 19: 117-128 (1999).

Prestwich, W.V.J.; Nunes, J.; Kwok, C.S. *RBE from a microdosimetric approach*. AECB INFO-0593. Atomic Energy Control Board of Canada, Ottawa, Canada (1995).

Rao, D.V.; Narra, V.R.; Howell, R.W.; Lanka, V.K.; Sastry, K.S.R. *Induction of sperm head abnormalities by incorporated radionuclides: dependence on subcellular distribution, type of radiation, dose rate, and presence of radioprotectors*. Radiat. Res. 125:89-97 (1991).

Simmons, J.A. and Watt, D.E. *Radiation Protection Dosimetry: A Radical Reappraisal*. Medical Physics Publishing, Madison, Wisconsin, USA (1999).

Sinclair, W.K. *The present system of quantities and units for radiation protection*. Health Phys. 70:781-786 (1996).

Straume, T., Carsten, A.L. *Tritium radiobiology and relative biological effectiveness*. Health Phys. 65:657-672 (1993).

Straume, T. *Tritium risk assessment*. Health Phys. 65:673-682 (1993).

Thompson, P. *Status of the assessment of "releases of radionuclides" under the Canadian Environmental Protection Act*. Presentation to the Canadian Nuclear Society, 1998 October 20 (1998).

Thompson, P. *Assessment of radionuclides under the Canadian Environmental Protection Act*. Proceedings of the Symposium on *Radiological Impacts from Nuclear Facilities on Non-human Species*, Ottawa, 1996; Canadian Nuclear Society, Toronto, Canada (1997).

Suter, G.W.II. *Ecological Risk Assessment*. Lewis Publishers, Chelsea, Michigan, USA (1993).

Trivedi, A., Morrison, D.P., Gentner, N.E. *Relative biological effectiveness for organically bound tritium*. Health Phys. 73: 397-398 (1997).

UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation). *"Effects of ionizing radiation on the environment", Annex to Sources and effects of ionizing radiation*. Report to the General Assembly, United Nations, New York, NY (1996).

US EPA (United States Environmental Protection Agency) *Guidelines for ecological risk assessment*. Risk Assessment Forum, U.S. Environmental Protection Agency. Washington, DC, USA: EPA/630/R-95/002F (1998).

Wang, B., Watanabe, K., Yamada, T., Shima, A. *Effects of beta radiation from organically bound tritium on cultured mouse embryonic mid brain cells*. Health Phys. 71:915-921 (1996).

Table 2 A typical range of RBE values for biological endpoints in non-human biota relevant for ecological risk assessment.

Effect	Ecological endpoint	Suitable Biological Endpoint	RBE		
			tritium $\beta$ -rays <sup>1</sup> $\alpha$ -emitters <sup>2</sup>		
Deterministic	Reproductive impairment and developmental effects	Immature oocyte survival in rat (LD <sub>50</sub> )	0.03-2.9	80	
		Spermatogonial/spermhead survival in mice (LD <sub>50</sub> )	1.6-2.4	6.4	
		Testis weight loss in mice	1.4-2.1*		
		Female germ cells in mice (LD <sub>50</sub> )	2.2*		
		Reproductive capacity in fish	2*		
		Oocyte killing in monkeys	2.2*		
	Survival and Fecundity	and	Impaired development of embryos	1.7	3-6
			Cell killing in vitro	1.3-1.7	4.6-11.8
			Physiological changes (body size, litters, etc.)	1.8	2.6-3.3
			Average life-span/lethality/fitness	1.5	24
		Haemopoietic cells		130-360	
Stochastic	Carcinogenesis	Mammary tumors in rats	1.2 ± 0.3		
		Leukemia in mice	1.2 ± 0.3		
		Cell transformation	1-2	3-6	
		Tumors in mice	~1		
		Double strand breaks		1.2-3.8	
	Genetic		Micronuclei in mammalian cells	2.0-2.7*	6.9-18.1
			Mutation in mice	2.7*	13
			Dominant lethal in male mice	2.5*	
			Chromosome aberration in fish	1.9	
			mice lymphocytes	1.1	15-20
		mouse zygotes, sperms	1.2-1.8		

<sup>1</sup>Straume and Carsten (1993); x-rays are orthovoltage, \*gamma rays are from <sup>60</sup>Co or <sup>137</sup>Cs.<sup>2</sup>Values taken from larger tables or data given in an unpublished report (Personal communication, C. Macdonald, Northern Environmental Consultants, Whiteshell, Manitoba, Canada).

Table 3. Value for ecodosimetry weighting factor ( $e_R$ ) for non-human biota.

Grade	Assessment Endpoints	Ecological Integrity	Alpha emitters	Photons and electron (including tritium $\beta$ -rays)
1	Survival, fitness ( <i>Deterministic</i> )	Individuals	5	1
2	Reproduction, fecundity ( <i>Deterministic/Stochastic</i> )	Population, Community	10	1
3	Mutation, genomic instability ( <i>Stochastic</i> )	Ecosystem, Future generations	20	1