Dose rate to non-human biota (NHB)

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A dose rate assessment for operational nuclear facilities in Sweden

- Protection principles
- How we calculate dose rate to NHB
- How we include all kinds of biota

- What is possible with the data we have?
- What is lacking?
- How can we fill these gaps?

What do we protect?

Principles of protection

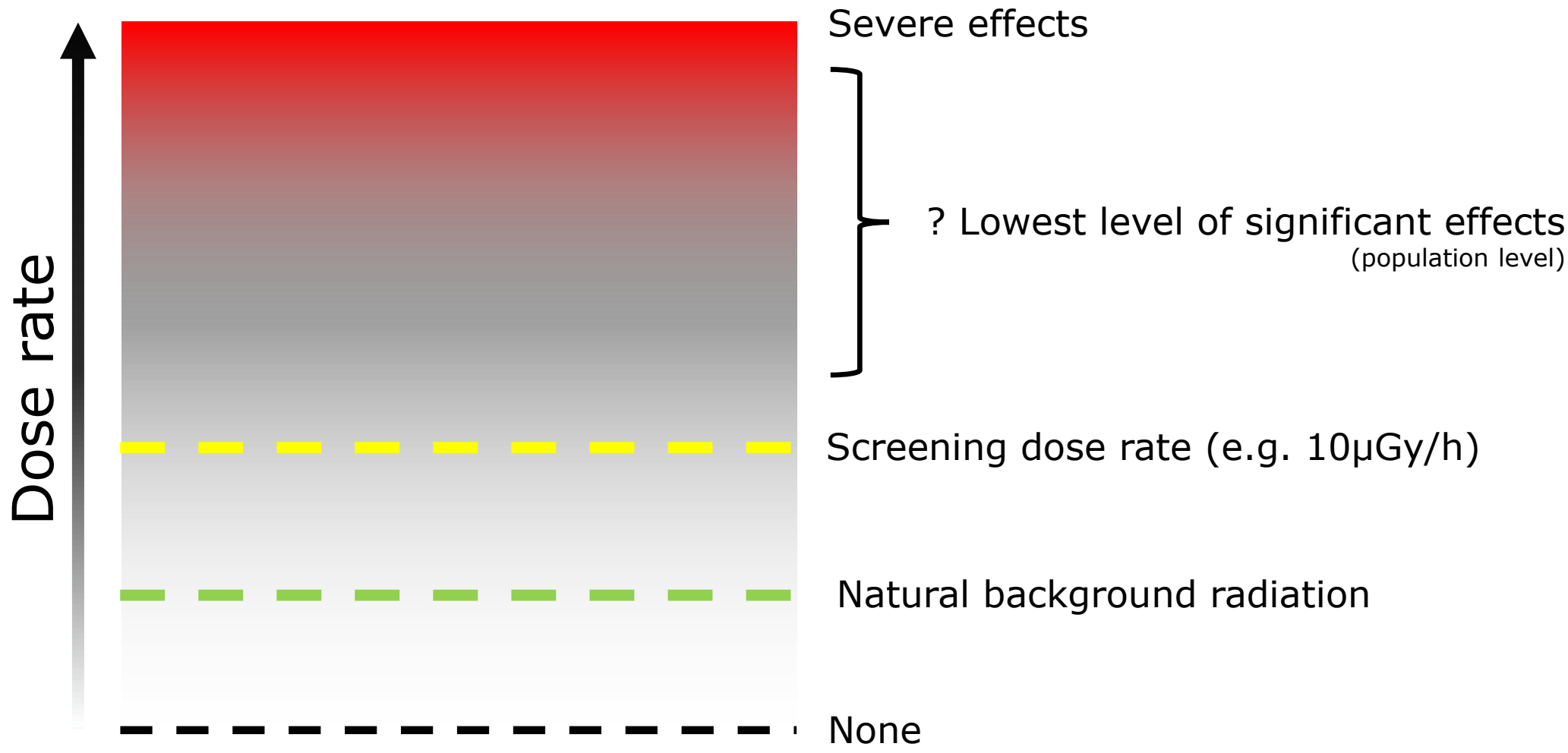
- Ecosystem function
- Biodiversity
- Resilience

Principles of protection

Individual

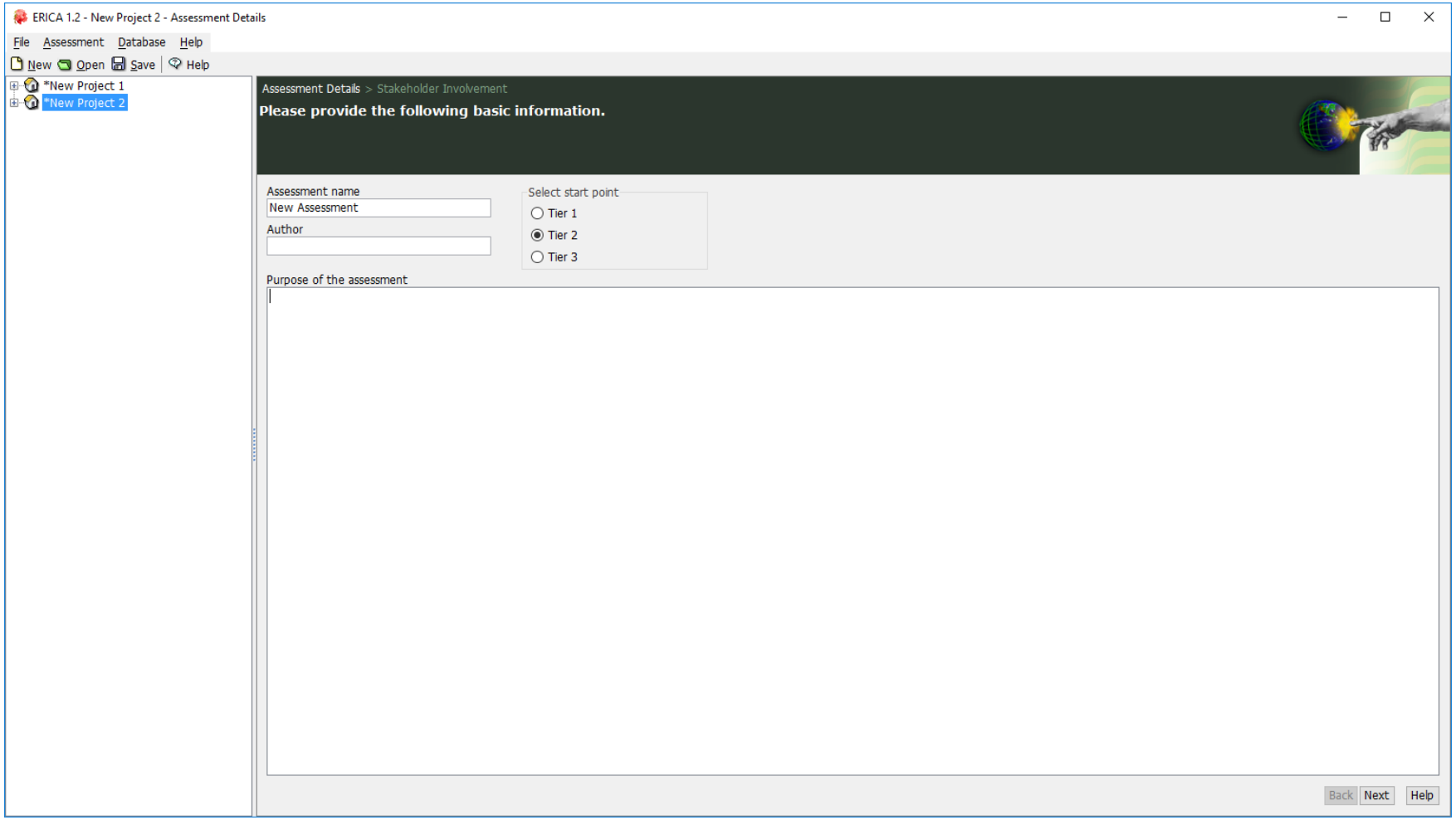
Population

Principles of protection

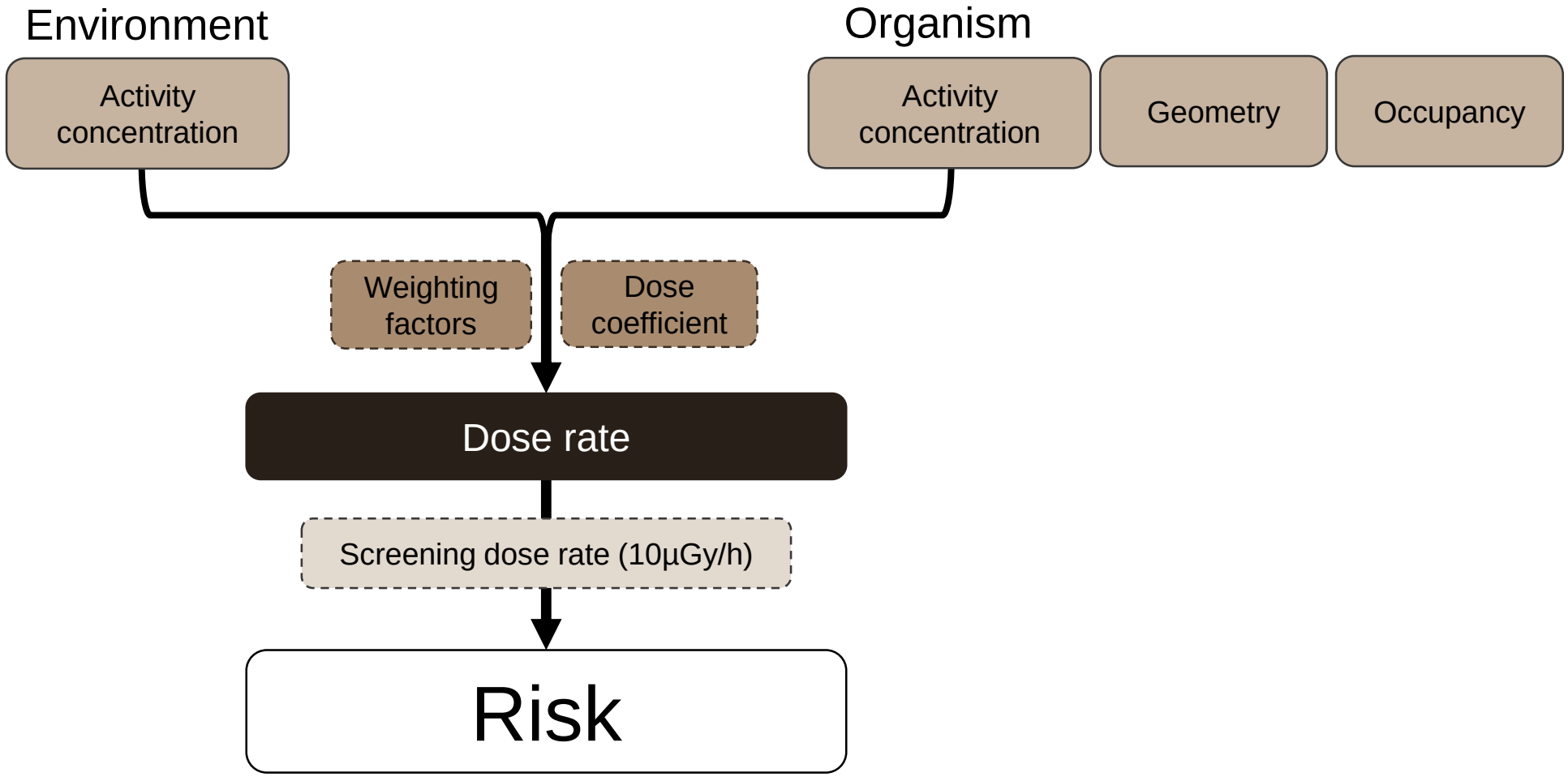


How do we calculate dose rate?

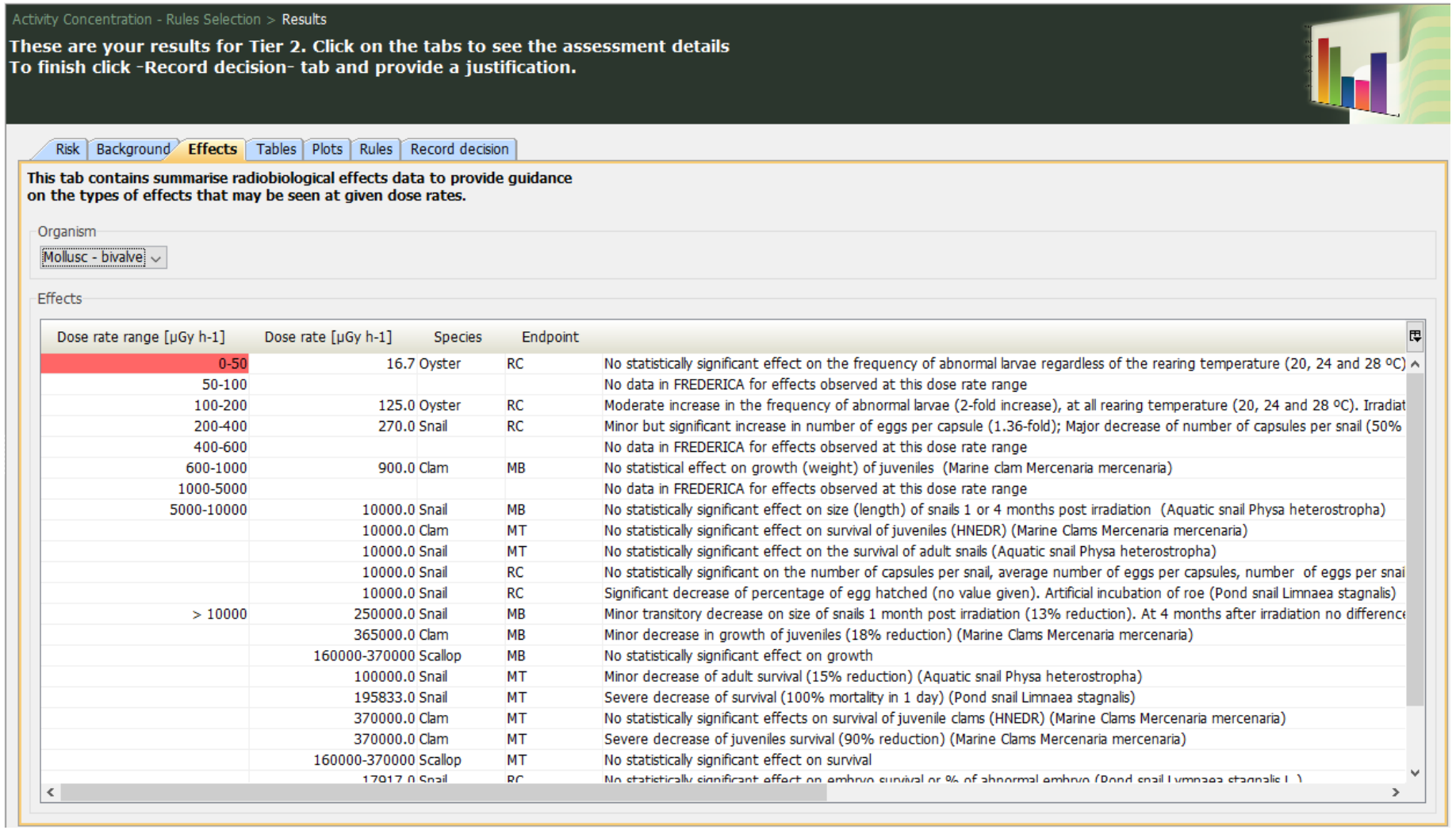
Dose rate assessment - ERICA tool



Modelling approach



FREDERICA – Effects database



Dose rate range [µGy h-1]	Dose rate [µGy h-1]	Species	Endpoint	
0-50	16.7	Oyster	RC	No statistically significant effect on the frequency of abnormal larvae regardless of the rearing temperature (20, 24 and 28 ºC)
50-100				No data in FREDERICA for effects observed at this dose rate range
100-200	125.0	Oyster	RC	Moderate increase in the frequency of abnormal larvae (2-fold increase), at all rearing temperature (20, 24 and 28 ºC). Irradiat
200-400	270.0	Snail	RC	Minor but significant increase in number of eggs per capsule (1.36-fold); Major decrease of number of capsules per snail (50%
400-600				No data in FREDERICA for effects observed at this dose rate range
600-1000	900.0	Clam	MB	No statistical effect on growth (weight) of juveniles (Marine clam Mercenaria mercenaria)
1000-5000				No data in FREDERICA for effects observed at this dose rate range
5000-10000	10000.0	Snail	MB	No statistically significant effect on size (length) of snails 1 or 4 months post irradiation (Aquatic snail Physa heterostropha)
	10000.0	Clam	MT	No statistically significant effect on survival of juveniles (HNEDR) (Marine Clams Mercenaria mercenaria)
	10000.0	Snail	MT	No statistically significant effect on the survival of adult snails (Aquatic snail Physa heterostropha)
	10000.0	Snail	RC	No statistically significant on the number of capsules per snail, average number of eggs per capsules, number of eggs per snai
	10000.0	Snail	RC	Significant decrease of percentage of egg hatched (no value given). Artificial incubation of roe (Pond snail Limnaea stagnalis)
> 10000	250000.0	Snail	MB	Minor transitory decrease on size of snails 1 month post irradiation (13% reduction). At 4 months after irradiation no differenc
	365000.0	Clam	MB	Minor decrease in growth of juveniles (18% reduction) (Marine Clams Mercenaria mercenaria)
	160000-370000	Scallop	MB	No statistically significant effect on growth
	100000.0	Snail	MT	Minor decrease of adult survival (15% reduction) (Aquatic snail Physa heterostropha)
	195833.0	Snail	MT	Severe decrease of survival (100% mortality in 1 day) (Pond snail Limnaea stagnalis)
	370000.0	Clam	MT	No statistically significant effects on survival of juvenile clams (HNEDR) (Marine Clams Mercenaria mercenaria)
	370000.0	Clam	MT	Severe decrease of juveniles survival (90% reduction) (Marine Clams Mercenaria mercenaria)
	160000-370000	Scallop	MT	No statistically significant effect on survival
	17917.0	Snail	RC	No statistically significant effect on embryo survival or % of abnormal embryo (Pond snail Lymnaea stagnalis L.)

Are *all* biota protected?

Different types of animals and plants

TREE

PHYTOPLANKTON

DEER

RAT

BEE

LICHEN

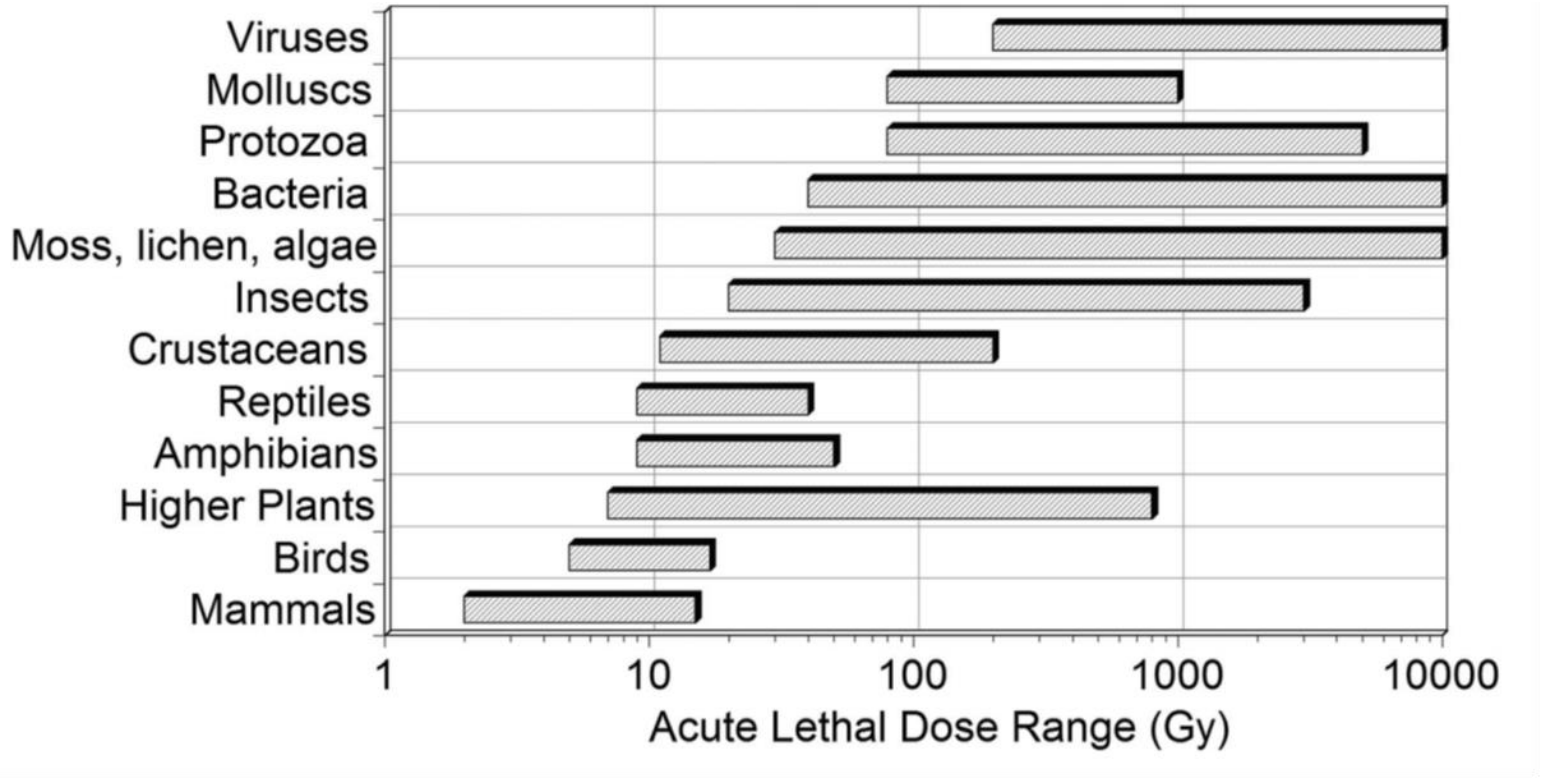
SEAWEED

CRAB

FISH

EARTHWORM

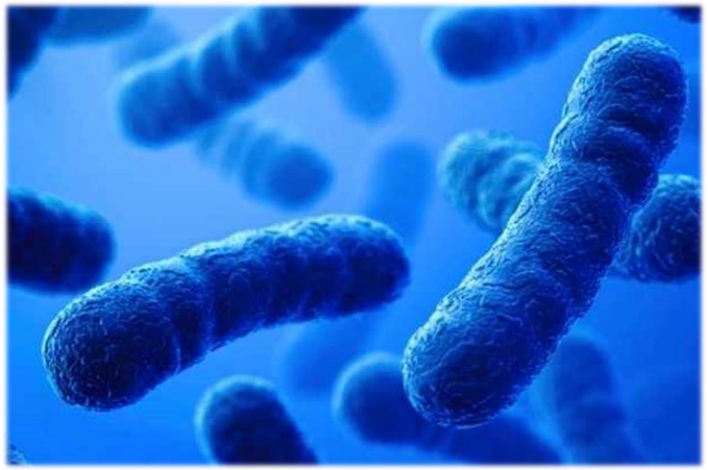
Radiosensitivity



RELATIVE RADIOSENSITIVITY

Whicker & Schultz, 1982

Vast difference in size

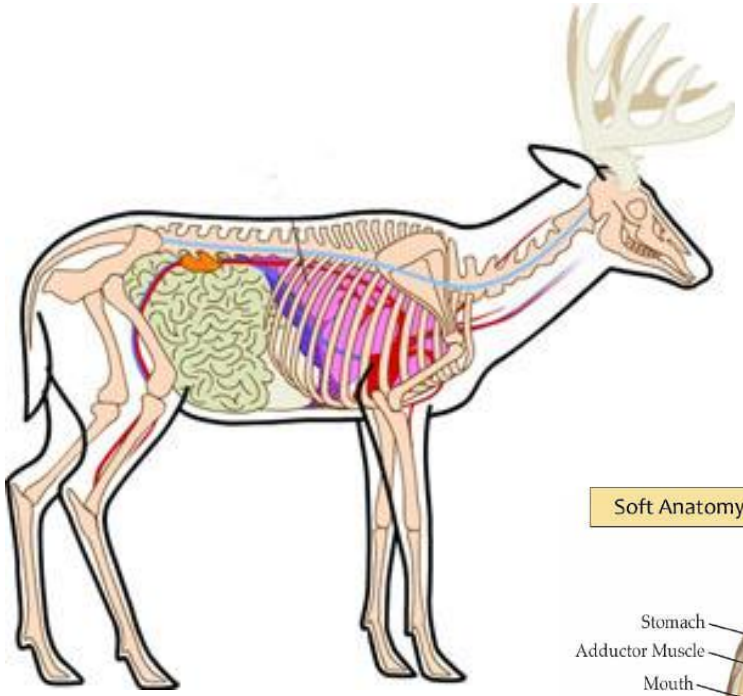


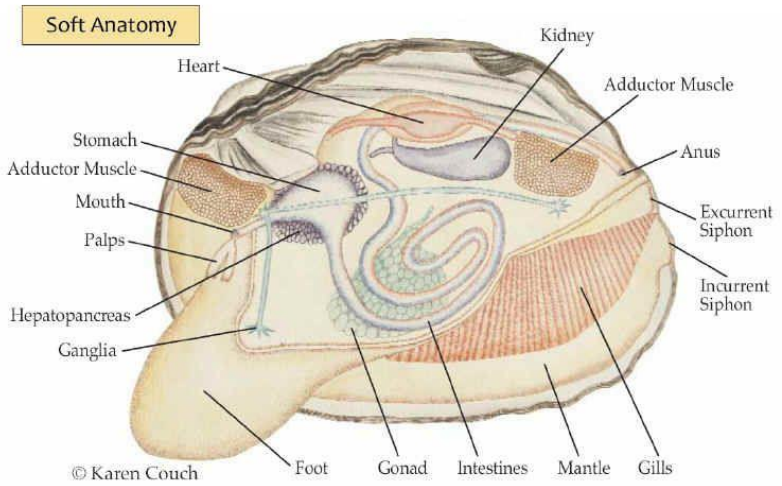
E. COLI : 9.5×10^{-16} KILOGRAMS

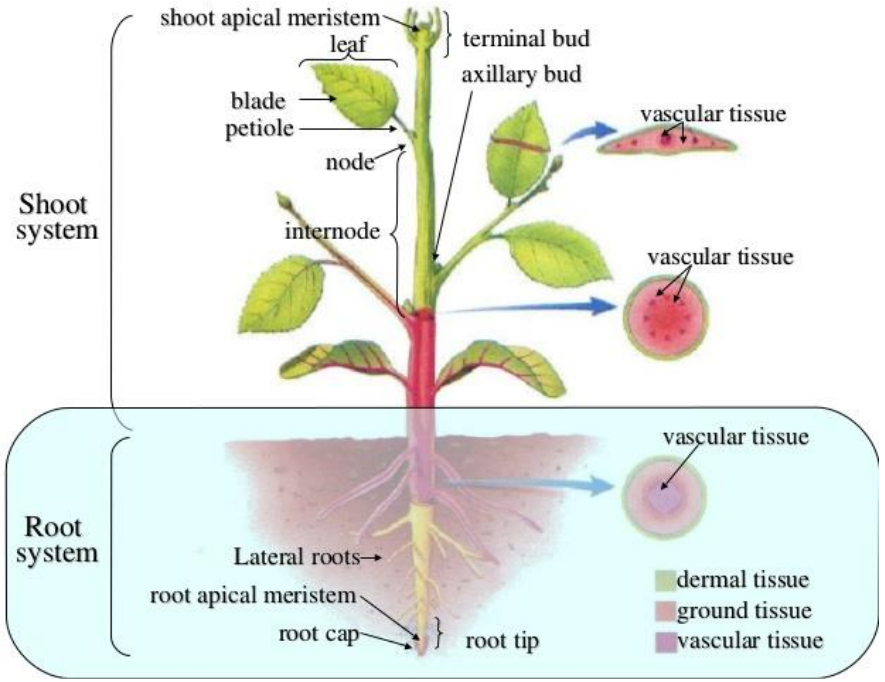
BLUE WHALE : 1.4×10^{5} KILOGRAMS

And shapes…

Complex inside







Location

Life history

Short-lived

Few offspring

Long-lived

Many offspring

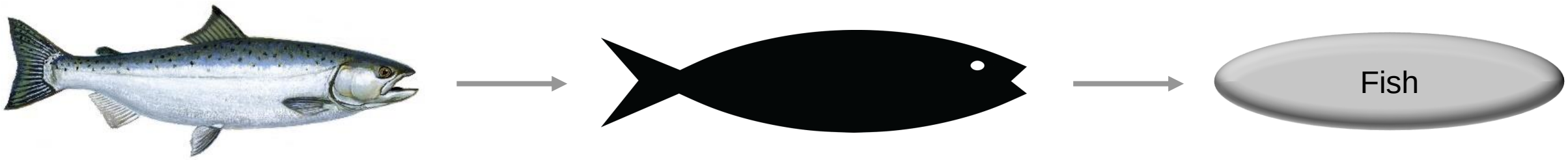
Some organisms just aren’t as you would expect…

We need to simplify

Reference organisms

Ecosystem		
Marine	**Freshwater**	**Terrestrial**
Benthic fish	Amphibian	Amphibian
Bird	Benthic fish	Annelid
Crustacean	Bird	Arthropod - detritivorous
Macroalgae	Crustacean	Bird
Mammal	Insect larvae	Flying insects
Mollusc - bivalve	Mammal	Grasses & Herbs
Pelagic fish	Mollusc - bivalve	Lichen & Bryophytes
Phytoplankton	Mollusc - gastropod	Mammal - large
Polychaete worm	Pelagic fish	Mammal - small-burrowing
Reptile	Phytoplankton	Mollusc - gastropod
Sea anemones & True coral	Reptile	Reptile
Vascular plant	Vascular plant	Shrub
Zooplankton	Zooplankton	Tree

Simplified geometry



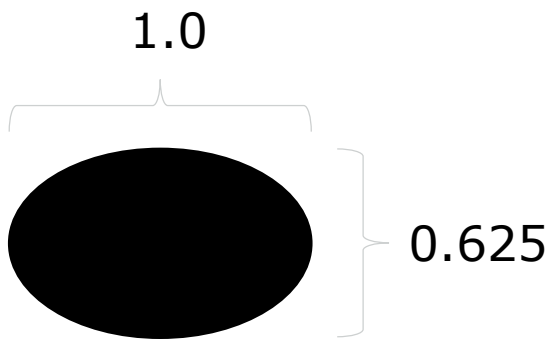
Selected organism data

Name	Benthic fish
Ecosystem	Marine
Wildlife group	Fish
Specimen	Indefinite
Mass (Kg)	1.31
Ksi	0.625
Chi	0.063
Height over ground (m)	0.0

Comment:

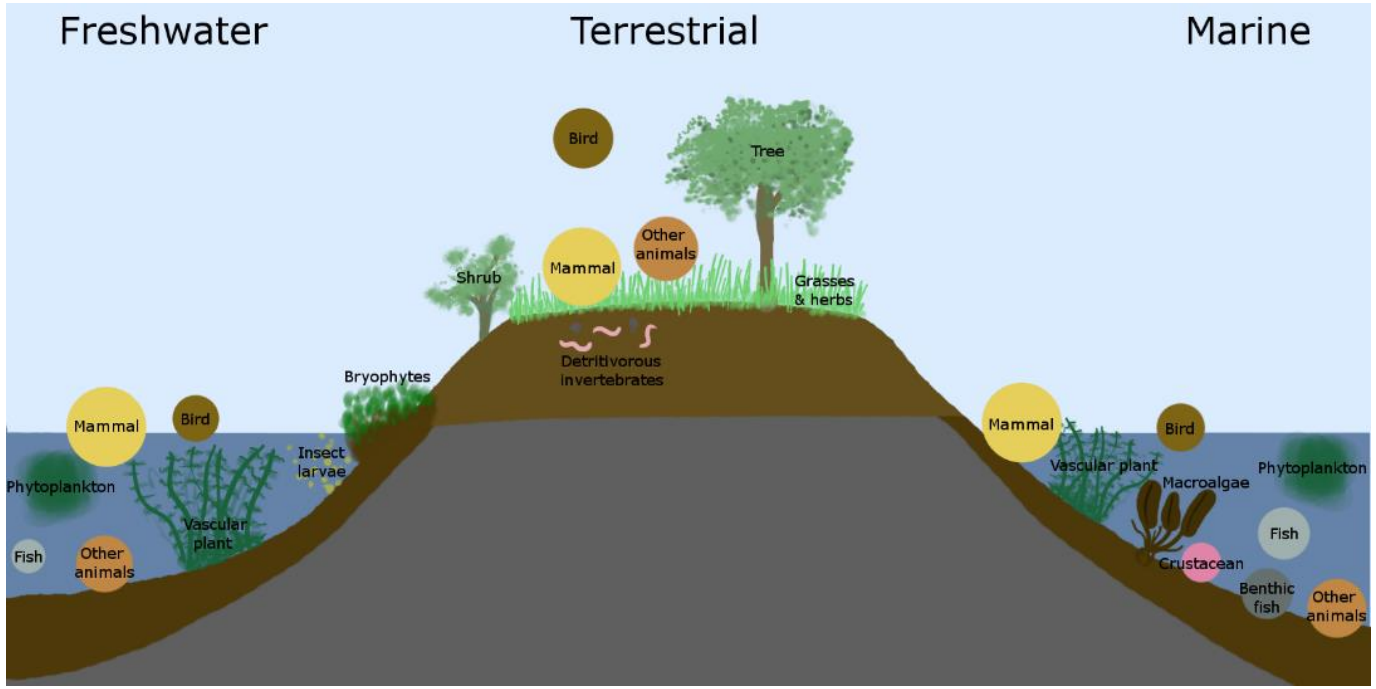
Geometry defined by ICRP - Flat fish

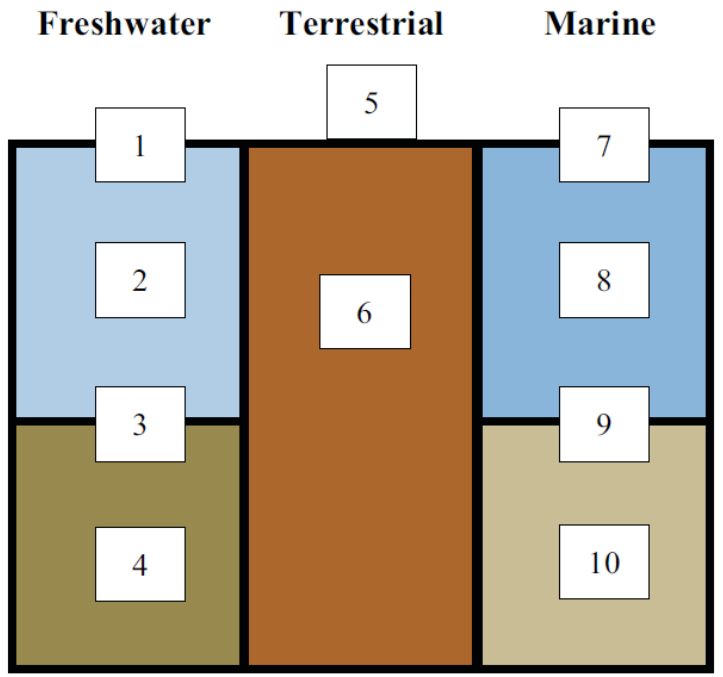
Ksi: Length to width ratio
Smaller value = thinner
0.625 is slightly elongated



Chi: Length to depth ratio
Smaller value = flatter
0.063 is very flat (like a plate)

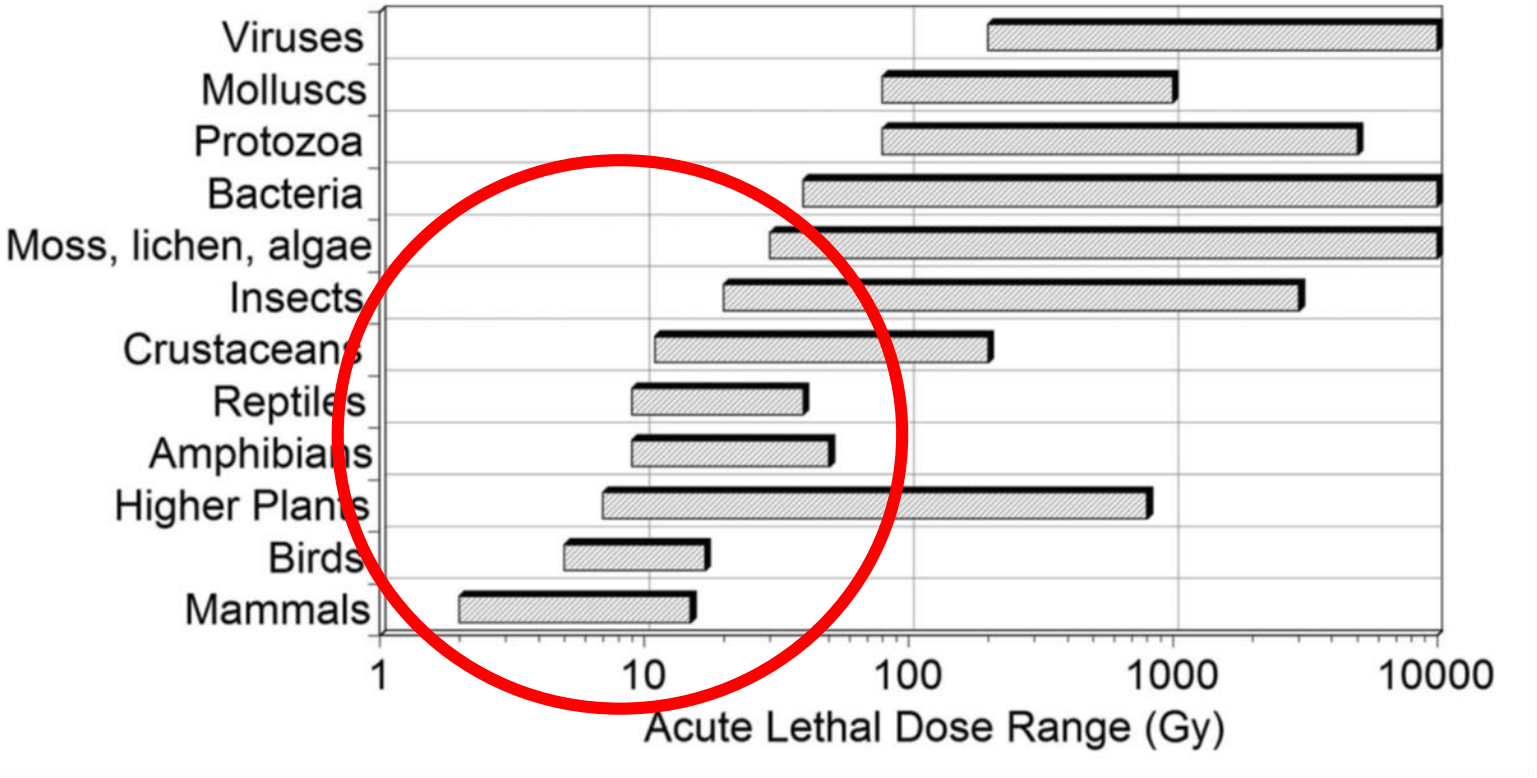
Simplified occupancy





Simplified occupancy

Simplification: radiosensitivity



RELATIVE RADIOSENSITIVITY

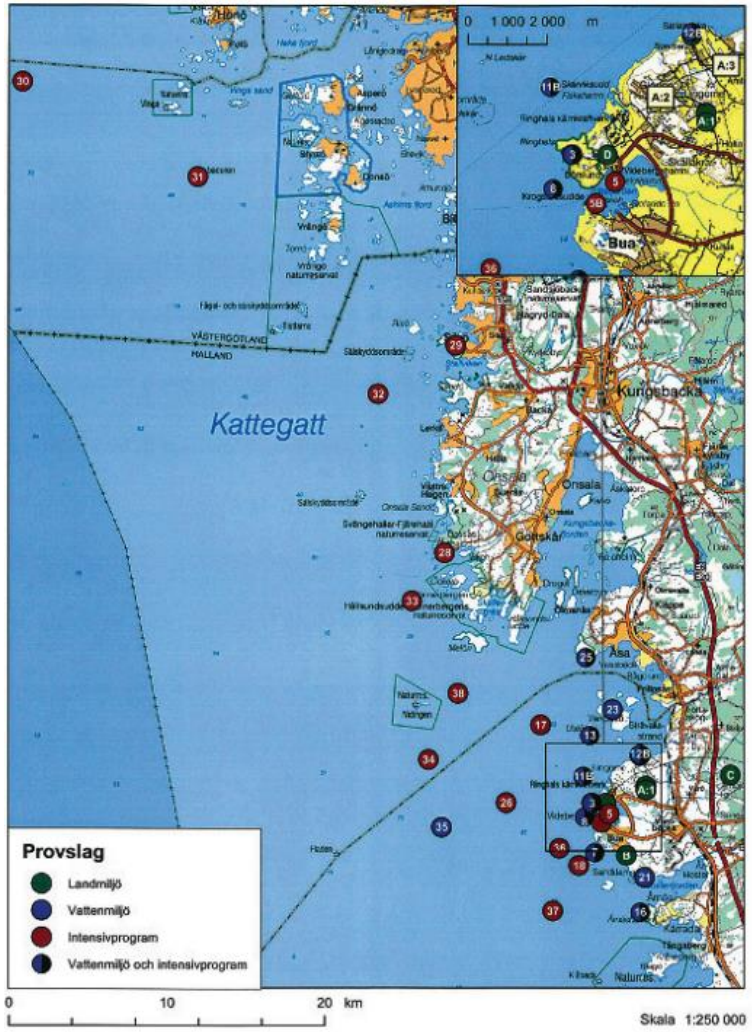
Whicker & Schultz, 1982

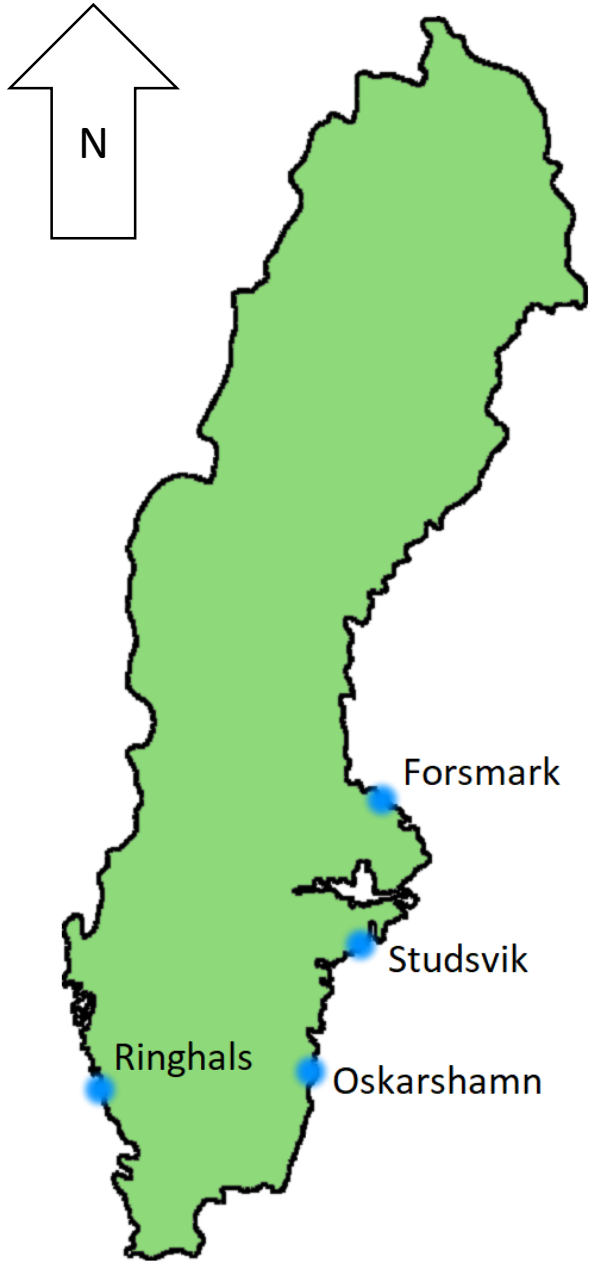
What data *do* we have?

Environmental sampling

Activity concentration in:

- Biota
- Sediment / soil
- Water / seawater





Environmental sampling

Anläggning	Studsvik
Period	Våren
År	2016
Provslag	Blåstång
Provdel	Homogenat
Station	30
Provtagningsdatum	2016-05-09
Analysdatum	2016-06-05
Mättid	60000s
Resultatenhet	Torrvikt, kg
Provbehandling	Askat
Provdata	
Våtvikt, kg	5,91E-1
Torrvikt, kg	1,16E-1
Analysmängd, kg	7,31E-2
Askvikt, kg	2,77E-2

Nuklid	Koncentration	
	Bq/kg	std. dev., %
Be-7	2,54E1	13
K-40	7,61E2	3
Cr-51	<2,2E1	
Mn-54	<1,8E0	
Co-58	<2,0E0	
Fe-59	<5,3E0	
Co-60	4,03E1	2
Zn-65	<4,7E0	
Nb-95	<2,3E0	
Ag-110m	<2,5E0	
Sn-113	<2,1E0	
Cs-134	<1,7E0	
Cs-137	2,20E1	4
Eu-152	<2,6E0	

Organisms measured

Ecosystem		
Marine	**Freshwater**	**Terrestrial**
Benthic fish	Amphibian	Amphibian
Bird	Benthic fish	Annelid
Crustacean	Bird	Arthropod - detritivorous
Macroalgae	Crustacean	Bird
Mammal	Insect larvae	Flying insects
Mollusc - bivalve	Mammal	Grasses & Herbs
Pelagic fish	Mollusc - bivalve	Lichen & Bryophytes
Phytoplankton	Mollusc - gastropod	Mammal - large
Polychaete worm	Pelagic fish	Mammal - small-burrowing
Reptile	Phytoplankton	Mollusc - gastropod
Sea anemones & True coral	Reptile	Reptile
Vascular plant	Vascular plant	Shrub
Zooplankton	Zooplankton	Tree

Environmental media measured

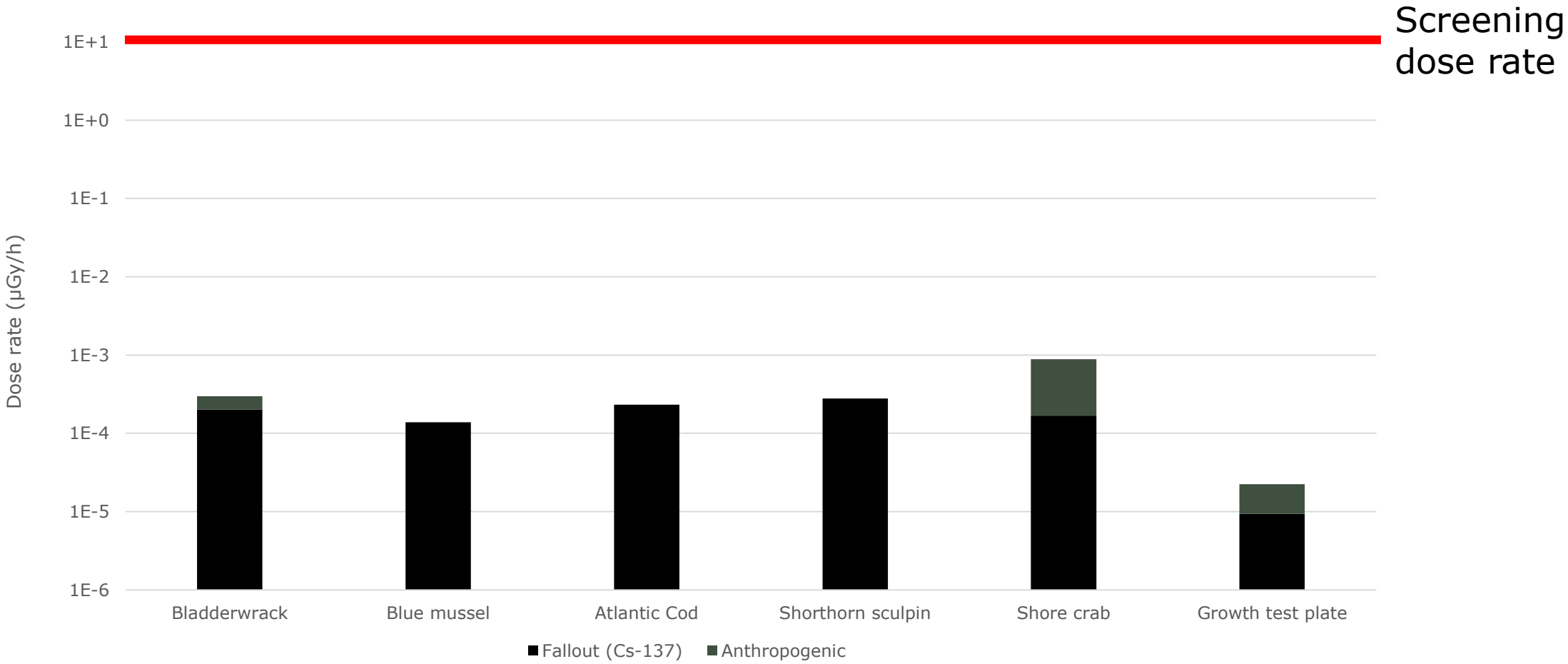
Marine sediment

Seawater

Terrestrial
- No soil

Freshwater
- No water
- No sediment

Dose assessment possible

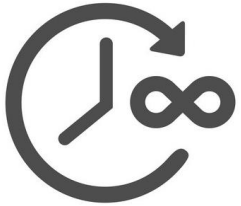


Solution?

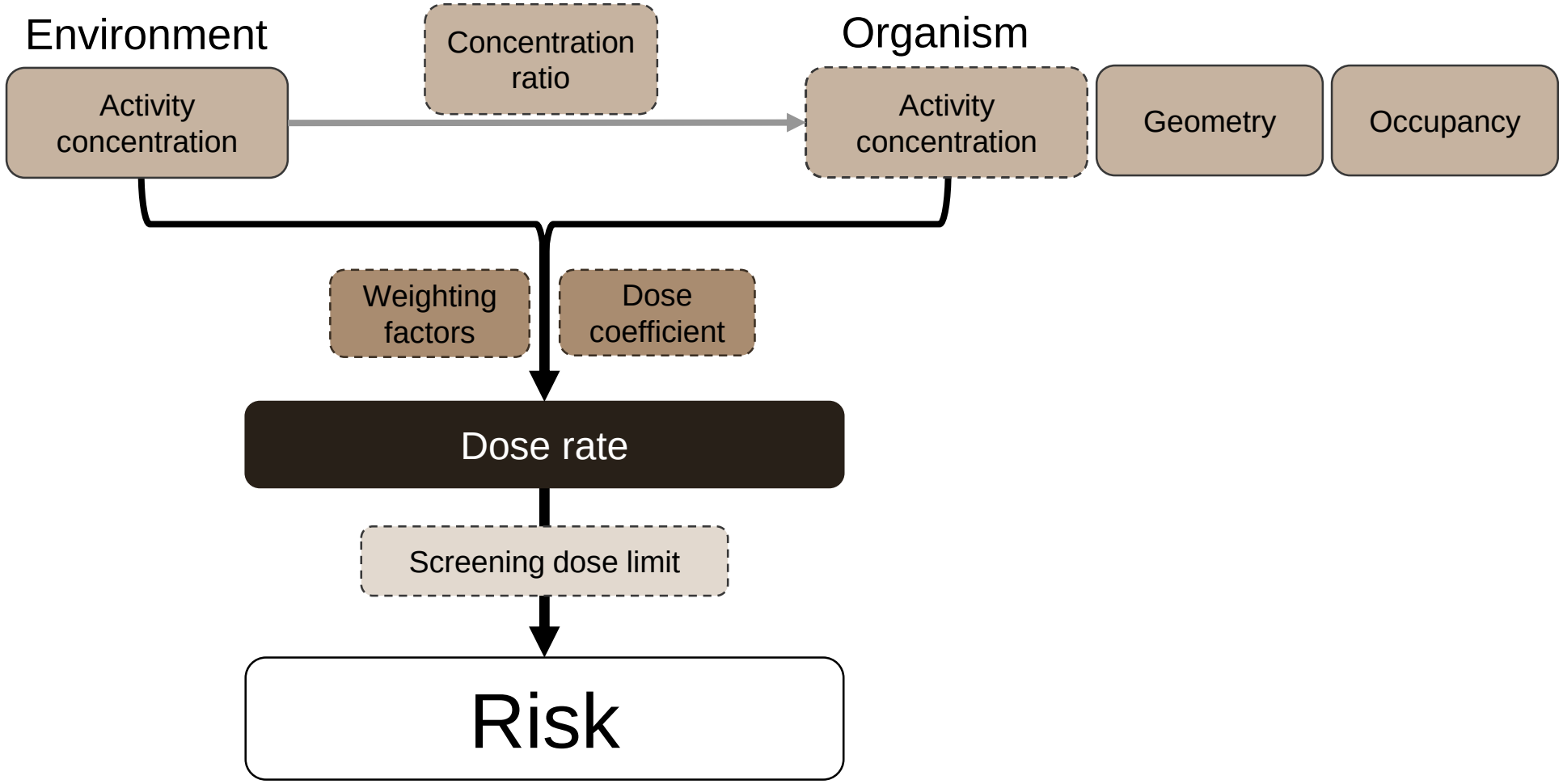
Organisms measured

Ecosystem		
Marine	**Freshwater**	**Terrestrial**
Benthic fish	Amphibian	Amphibian
Bird	Benthic fish	Annelid
Crustacean	Bird	Arthropod - detritivorous
Macroalgae	Crustacean	Bird
Mammal	Insect larvae	Flying insects
Mollusc - bivalve	Mammal	**Grasses & Herbs**
Pelagic fish	Mollusc - bivalve	**Lichen & Bryophytes**
Phytoplankton	Mollusc - gastropod	Mammal - large
Polychaete worm	Pelagic fish	Mammal - small-burrowing
Reptile	Phytoplankton	Mollusc - gastropod
Sea anemones & True coral	Reptile	Reptile
Vascular plant	Vascular plant	**Shrub**
Zooplankton	Zooplankton	**Tree**

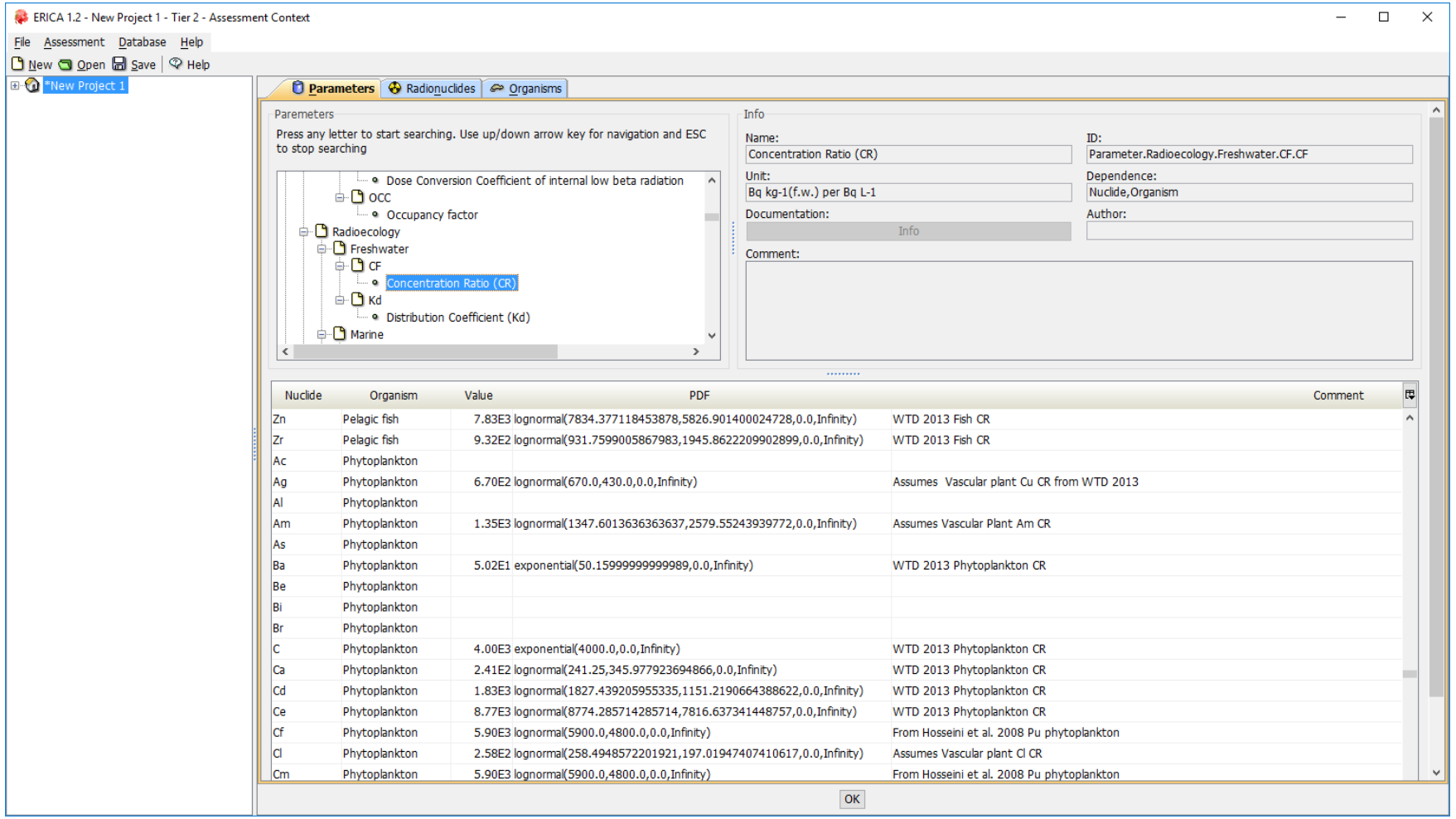
More sampling…



Modelling approach



The ERICA tool parameter database



Nuclide	Organism	Value	PDF	Comment
Zn	Pelagic fish	7.83E3	lognormal(7834.377118453878,5826.901400024728,0.0,Infinity)	WTD 2013 Fish CR
Zr	Pelagic fish	9.32E2	lognormal(931.7599005867983,1945.8622209902899,0.0,Infinity)	WTD 2013 Fish CR
Ac	Phytoplankton			
Ag	Phytoplankton	6.70E2	lognormal(670.0,430.0,0.0,Infinity)	Assumes Vascular plant Cu CR from WTD 2013
Al	Phytoplankton			
Am	Phytoplankton	1.35E3	lognormal(1347.6013636363637,2579.55243939772,0.0,Infinity)	Assumes Vascular Plant Am CR
As	Phytoplankton			
Ba	Phytoplankton	5.02E1	exponential(50.15999999999989,0.0,Infinity)	WTD 2013 Phytoplankton CR
Be	Phytoplankton			
Bi	Phytoplankton			
Br	Phytoplankton			
C	Phytoplankton	4.00E3	exponential(4000.0,0.0,Infinity)	WTD 2013 Phytoplankton CR
Ca	Phytoplankton	2.41E2	lognormal(241.25,345.977923694866,0.0,Infinity)	WTD 2013 Phytoplankton CR
Cd	Phytoplankton	1.83E3	lognormal(1827.439205955335,1151.2190664388622,0.0,Infinity)	WTD 2013 Phytoplankton CR
Ce	Phytoplankton	8.77E3	lognormal(8774.285714285714,7816.637341448757,0.0,Infinity)	WTD 2013 Phytoplankton CR
Cf	Phytoplankton	5.90E3	lognormal(5900.0,4800.0,0.0,Infinity)	From Hosseini et al. 2008 Pu phytoplankton
Cl	Phytoplankton	2.58E2	lognormal(258.4948572201921,197.01947407410617,0.0,Infinity)	Assumes Vascular plant Cl CR
Cm	Phytoplankton	5.90E3	lognormal(5900.0,4800.0,0.0,Infinity)	From Hosseini et al. 2008 Pu phytoplankton

Seawater (Ringhals)

Nuklid	Koncentration (Bq/kg) Uppmätt	Det.gräns	sd (%)
Be-7		< 5,81E-01	
Na-22		< 5,86E-02	
Cr-51		< 4,28E-01	
Mn-54		< 8,13E-02	
Fe-59		< 8,09E-02	
Co-57		< 4,09E-02	
Co-58		< 3,33E-02	
Co-60		< 8,39E-02	
Zn-65		< 7,21E-02	
Zr-95		< 1,02E-01	
Nb-95		< 7,03E-02	
Ag-110m		< 2,33E-01	
Sn-113		< 4,36E-02	
Sb-124		< 1,76E-01	
Sb-125		< 1,55E-01	
Ru-103		< 4,60E-02	
Ru-106		< 5,09E-01	
Rh-105		< 1,27E+00	
Te-129m		< 1,36E+00	
Cs-134		< 8,66E-02	
Cs-136		< 8,56E-02	
Cs-137		< 8,99E-02	
Ba-140		< 1,29E-01	
La-140		< 7,48E-02	
Ce-141		< 6,90E-02	
Ce-144		< 3,36E-01	
K-40	8,25E+00	< 1,54E+00	8,5
Tl-208		< 8,81E-02	
Pb-212		< 1,35E-01	
Pb-214		< 1,73E-01	
Bi-214		< 1,78E-01	
Ra-226		< 1,62E+00	
Ac-228		< 2,90E-01	
U-235		< 9,38E-02	
I-131		< 3,53E-02	
H-3	4,66E+00	< 4,18E+00	27,7

Sediment (Ringhals)

Nuklid	Koncentration (Bq/kg) Uppmätt	Det.gräns	sd (%)
Be-7	4,15E+00	3,84E+00	30,1
Na-22		3,69E-01	
Cr-51		2,09E+00	
Mn-54		3,09E-01	
Fe-59		1,07E+00	
Co-57		1,83E-01	
Co-58		2,76E-01	
Co-60		5,29E-01	
Zn-65		7,99E-01	
Zr-95		4,77E-01	
Nb-95		4,13E-01	
Ag-110m		1,22E+00	
Sn-113		5,81E-01	
Sb-124		5,58E-01	
Sb-125		1,33E+00	
Ru-103		2,41E-01	
Ru-106		3,35E+00	
Rh-105		2,01E+02	
Te-129m		1,67E+01	
Cs-134		5,99E-01	
Cs-136		9,61E-01	
Cs-137	8,66E-01	5,05E-01	20,2
Ba-140		2,27E+00	
La-140		4,06E-01	
Ce-141		4,91E-01	
Ce-144		1,63E+00	
K-40	5,76E+02	7,67E+00	1,2
Tl-208	1,81E+00	6,07E-01	14,6
Pb-212	5,83E+00	7,67E-01	5,9
Pb-214	9,04E+00	1,17E+00	5,8
Bi-214	8,47E+00	1,19E+00	6,6
Ra-226		1,17E+01	
Ac-228	6,80E+00	2,11E+00	14,5
U-235		6,58E-01	
I-131		4,21E-01	

Bladderwrack (Ringhals)

Nuklid	Koncentration (Bq/kg) Uppmätt	Det.gräns	sd (%)
Be-7	3,69E+01	< 1,38E+00	1,9
Na-22		< 2,32E-01	
Cr-51		< 1,26E+00	
Mn-54	1,04E+00	< 2,19E-01	8,2
Fe-59		< 4,69E-01	
Co-57		< 1,18E-01	
Co-58	1,44E+00	< 2,08E-01	5,8
Co-60	1,78E+00	< 2,70E-01	6,8
Zn-65		< 3,70E-01	
Zr-95		< 2,11E-01	
Nb-95		< 1,89E-01	
Ag-110m	1,65E+00	< 5,71E-01	11,4
Sn-113		< 1,70E-01	
Sb-124		< 3,01E-01	
Sb-125		< 4,03E-01	
Ru-103		< 1,17E-01	
Ru-106		< 1,31E+00	
Rh-105		< 2,77E+01	
Te-129m		< 4,35E+00	
Cs-134		< 2,47E-01	
Cs-136		< 3,16E-01	
Cs-137	1,61E+00	< 1,90E-01	4,5
Ba-140		< 8,41E-01	
La-140		< 1,72E-01	
Ce-141		< 1,96E-01	
Ce-144		< 9,24E-01	
K-40	5,80E+02	< 2,89E+00	,6
Tl-208	4,67E-01	< 1,97E-01	15,9
Pb-212	1,55E+00	< 2,57E-01	6,3
Pb-214	1,73E+00	< 3,56E-01	8,0
Bi-214	1,40E+00	< 4,09E-01	11,9
Ra-226	4,12E+00	< 3,75E+00	27,9
Ac-228	7,00E+00	< 8,82E-01	5,6
U-235	4,94E-01	< 2,14E-01	15,6
I-131		< 2,16E-01	

Seawater (Ringhals)

Nuklid	Koncentration (Bq/kg) Uppmätt	Det.gräns	sd (%)
Be-7		< 5,81E-01	
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Co-57		< 4,09E-02	
Co-58		< 3,33E-02	
Co-60		< 8,39E-02	
Zn-65		< 7,21E-02	
Zr-95		< 1,02E-01	
Nb-95		< 7,03E-02	
Ag-110m		< 2,33E-01	
Sn-113		< 4,36E-02	
Sb-124		< 1,76E-01	
Sb-125		< 1,55E-01	
Ru-103		< 4,60E-02	
Ru-106		< 5,09E-01	
Rh-105		< 1,27E+00	
Te-129m		< 1,36E+00	
Cs-134		< 8,66E-02	
Cs-136		< 8,56E-02	
Cs-137		< 8,99E-02	
Ba-140		< 1,29E-01	
La-140		< 7,48E-02	
Ce-141		< 6,90E-02	
Ce-144		< 3,36E-01	
K-40	8,25E+00	< 1,54E+00	8,5
Tl-208		< 8,81E-02	
Pb-212		< 1,35E-01	
Pb-214		< 1,73E-01	
Bi-214		< 1,78E-01	
Ra-226		< 1,62E+00	
Ac-228		< 2,90E-01	
U-235		< 9,38E-02	
I-131		< 3,53E-02	
H-3	4,66E+00	< 4,18E+00	27,7

Sediment (Ringhals)

Nuklid	Koncentration (Bq/kg) Uppmätt	Det.gräns	sd (%)
Be-7	4,15E+00	< 3,84E+00	30,1
Na-22		< 3,69E-01	
Cr-51		< 2,09E+00	
Mn-54		< 3,09E-01	
Fe-59		< 1,07E+00	
Co-57		< 1,83E-01	
Co-58		< 2,76E-01	
Co-60		< 5,29E-01	
Zn-65		< 7,99E-01	
Zr-95		< 4,77E-01	
Nb-95		< 4,13E-01	
Ag-110m		< 1,22E+00	
Sn-113		< 5,81E-01	
Sb-124		< 5,58E-01	
Sb-125		< 1,33E+00	
Ru-103		< 2,41E-01	
Ru-106		< 3,35E+00	
Rh-105		< 2,01E+02	
Te-129m		< 1,67E+01	
Cs-134		< 5,99E-01	
Cs-136		< 9,61E-01	
Cs-137	8,66E-01	< 5,05E-01	20,2
Ba-140		< 2,27E+00	
La-140		< 4,06E-01	
Ce-141		< 4,91E-01	
Ce-144		< 1,63E+00	
K-40	5,76E+02	< 7,67E+00	1,2
Tl-208	1,81E+00	< 6,07E-01	14,6
Pb-212	5,83E+00	< 7,67E-01	5,9
Pb-214	9,04E+00	< 1,17E+00	5,8
Bi-214	8,47E+00	< 1,19E+00	6,6
Ra-226		< 1,17E+01	
Ac-228	6,80E+00	< 2,11E+00	14,5
U-235		< 6,58E-01	
I-131		< 4,21E-01	

Bladderwrack (Ringhals)

Nuklid	Koncentration (Bq/kg) Uppmätt	Det.gräns	sd (%)
Be-7	3,69E+01	< 1,38E+00	1,9
Na-22		< 2,32E-01	
Cr-51		< 1,26E+00	
Mn-54	1,04E+00	< 2,19E-01	8,2
Fe-59		< 4,69E-01	
Co-57		< 1,18E-01	
Co-58	1,44E+00	< 2,08E-01	5,8
Co-60	1,78E+00	< 2,70E-01	6,8
Zn-65		< 3,70E-01	
Zr-95		< 2,11E-01	
Nb-95		< 1,89E-01	
Ag-110m	1,65E+00	< 5,71E-01	11,4
Sn-113		< 1,70E-01	
Sb-124		< 3,01E-01	
Sb-125		< 4,03E-01	
Ru-103		< 1,17E-01	
Ru-106		< 1,31E+00	
Rh-105		< 2,77E+01	
Te-129m		< 4,35E+00	
Cs-134		< 2,47E-01	
Cs-136		< 3,16E-01	
Cs-137	1,61E+00	< 1,90E-01	4,5
Ba-140		< 8,41E-01	
La-140		< 1,72E-01	
Ce-141		< 1,96E-01	
Ce-144		< 9,24E-01	
K-40	5,80E+02	< 2,89E+00	,6
Tl-208	4,67E-01	< 1,97E-01	15,9
Pb-212	1,55E+00	< 2,57E-01	6,3
Pb-214	1,73E+00	< 3,56E-01	8,0
Bi-214	1,40E+00	< 4,09E-01	11,9
Ra-226	4,12E+00	< 3,75E+00	27,9
Ac-228	7,00E+00	< 8,82E-01	5,6
U-235	4,94E-01	< 2,14E-01	15,6
I-131		< 2,16E-01	

	Internal Dose-rate (µGy/h)												
Radioisotope	Benthic fish	Bird	Crustacean	Macroalgae	Mammal	Mollusc - bivalve	Pelagic fish	Phytoplankton	Polychaete worm	Reptile	Sea anemones & True coral	Vascular plant	Zooplankton
H-3	3.4E-5	3.4E-5	3.4E-5	3.4E-5	3.4E-5	3.4E-5	3.4E-5	3.4E-5	3.4E-5	3.4E-5	3.4E-5	3.4E-5	3.4E-5
Be-7	5.0E-2	6.2E-2	6.3E-1	5.0E-3	2.4E-1	4.8E-2	5.9E-2	7.2E-3	1.7E-2	2.4E-1	9.6E-3	2.0E-2	8.4E-3
Na-22	4.2E-1	4.1E-1	4.5E+0	8.9E-2	1.1E+0	7.1E-1	4.5E-1	1.8E+0	3.2E-1	1.1E+0	2.4E-1	2.7E-1	6.0E-1
K-40	**1.5E+1**	**1.2E+1**	**1.4E+2**	4.1E+0	**1.3E+1**	**3.5E+1**	**1.5E+1**	**3.9E+1**	**1.6E+1**	**1.3E+1**	**1.3E+1**	**1.3E+1**	**2.6E+1**
Cr-51	7.7E-4	8.6E-3	4.1E-4	2.0E-2	1.6E-2	6.8E-3	7.9E-4	1.5E-2	6.6E-3	1.5E-2	6.4E-3	2.0E-2	3.1E-3
Mn-54	1.0E-2	2.7E-2	2.4E-1	1.4E-2	9.7E-2	2.3E-2	1.2E-2	2.2E-3	4.8E-3	9.7E-2	1.3E-5	6.2E-2	1.9E-3
Fe-59	3.2E-1	3.1E-1	3.5E+0	7.3E-2	8.4E-1	5.7E-1	3.5E-1	1.9E+0	2.6E-1	8.3E-1	2.0E-1	2.2E-1	5.3E-1
Co-57	7.6E-3	8.0E-4	5.3E-3	2.1E-3	1.5E-3	6.4E-3	7.8E-3	3.4E-3	1.0E-2	1.5E-3	7.3E-4	4.2E-4	5.7E-3
Co-58	1.3E-2	1.7E-3	1.1E-2	2.2E-3	5.6E-3	7.8E-3	1.5E-2	1.9E-3	1.0E-2	5.4E-3	6.7E-4	4.9E-4	4.0E-3
Co-60	7.6E-2	1.0E-2	6.2E-2	1.3E-2	3.3E-2	4.4E-2	8.4E-2	1.2E-2	5.7E-2	3.2E-2	3.7E-3	2.7E-3	2.3E-2
Zn-65	6.8E-2	9.8E-2	1.0E+0	2.7E-3	3.3E-1	1.2E-1	7.7E-2	7.0E-3	3.3E-2	3.3E-1	2.8E-2	3.2E-3	8.1E-2
Zr-95	8.7E-4	1.1E-3	6.0E-4	1.3E-2	2.6E-3	2.8E-2	9.6E-4	1.7E-1	2.6E-2	2.6E-3	9.7E-4	9.3E-3	1.4E-1
Nb-95	1.4E-4	5.5E-3	5.6E-4	1.3E-3	1.7E-2	2.6E-3	1.5E-4	1.8E-3	2.3E-3	1.6E-2	2.1E-3	1.5E-3	3.9E-2
Ru-103	1.3E-4	8.5E-3	4.8E-4	4.2E-3	1.7E-2	5.8E-3	1.3E-4	1.8E-2	5.7E-3	1.7E-2	9.6E-5	4.4E-3	9.4E-2
Ru-106	1.1E-2	6.5E-1	4.0E-2	3.1E-1	7.3E-1	5.4E-1	1.2E-2	2.0E-1	5.0E-1	7.3E-1	7.1E-3	4.2E-1	3.1E+0
Rh-105	3.9E+0	3.0E+0	**3.6E+1**	1.2E+0	3.7E+0	9.0E+0	3.9E+0	**3.4E+1**	4.5E+0	3.7E+0	3.6E+0	3.4E+0	**1.0E+1**
Ag-110m	4.6E-1	1.3E+0	1.9E+0	7.8E-2	4.6E+0	8.6E-1	5.4E-1	4.9E-1	5.4E-1	4.5E+0	2.2E-3	1.0E-1	6.7E-2
Sn-113	1.5E-1	1.3E-1	1.5E+0	4.2E-2	2.0E-1	3.3E-1	1.6E-1	8.0E-1	1.6E-1	2.0E-1	1.2E-1	1.2E-1	3.2E-1
Sb-124	3.1E-2	5.1E-1	1.7E-2	7.8E-3	1.1E+0	1.9E-2	3.3E-2	1.0E-2	1.7E-1	1.1E+0	3.2E-3	9.5E-3	3.0E-2
Sb-125	8.3E-3	1.3E-1	4.5E-3	2.4E-3	2.6E-1	5.3E-3	8.6E-3	7.6E-3	4.9E-2	2.6E-1	9.4E-4	2.6E-3	1.2E-2
Te-129m	3.4E-1	4.1E+0	5.0E-1	1.7E-1	4.4E+0	6.9E-1	3.4E-1	1.9E+0	2.0E+0	4.4E+0	4.3E-3	2.0E-1	3.1E-1
I-131	4.1E-5	4.3E-2	1.9E-4	1.6E-2	7.5E-2	3.7E-2	4.1E-5	2.1E-3	3.4E-2	7.5E-2	3.4E-2	1.0E-4	1.1E-2
Cs-134	1.2E-3	9.1E-3	9.2E-4	9.3E-4	1.1E-2	5.2E-4	1.4E-3	3.7E-5	1.7E-3	2.4E-2	2.0E-3	1.1E-4	9.5E-4
Cs-136	1.3E-3	1.0E-2	1.0E-3	9.1E-4	1.4E-2	5.2E-4	1.4E-3	4.7E-5	1.7E-3	3.0E-2	1.9E-3	1.0E-4	9.0E-4
Cs-137	1.3E-3	8.2E-3	8.6E-4	1.2E-3	6.5E-3	6.7E-4	1.4E-3	5.1E-5	2.3E-3	1.4E-2	2.9E-3	1.3E-4	1.4E-3
Ba-140	2.1E-3	1.6E-2	4.6E-3	1.9E-3	2.9E-2	1.1E-2	2.2E-3	4.0E-3	3.2E-5	2.9E-2	6.2E-3	2.2E-4	3.2E-3
La-140	3.4E-1	4.0E-1	1.9E-1	2.3E-1	8.2E-1	2.7E-1	3.6E-1	5.1E-2	2.5E-1	8.1E-1	2.4E-1	2.7E-1	1.5E-1
Ce-141	2.7E-3	1.7E-2	7.0E-4	1.4E-2	2.0E-2	1.5E-2	2.7E-3	5.4E-2	1.5E-2	2.0E-2	8.9E-4	1.1E-3	3.8E-2
Ce-144	8.8E-2	5.3E-1	2.4E-2	3.4E-1	5.6E-1	4.7E-1	9.3E-2	[illegible]	4.3E-1	5.6E-1	2.2E-2	3.4E-2	5.0E-1
Tl-208	1.3E+0	1.2E+0	**1.4E+1**	3.0E-1	2.7E+0	2.6E+0	[illegible]	2.8E+0	1.2E+[illegible]	2.7E+0	8.9E-1	9.8E-1	1.7E+0
Pb-212	**2.2E+2**	**1.3E+2**	**1.4E+2**	6.8E+0	**1.3E+2**	**4.3E+1**	**2.2E+2**	**3.2E+3**	**2.7E+2**	**1.3E+2**	**2.2E+2**	6.8E+0	**1.1E+2**
Pb-214	**9.9E+2**	**5.7E+2**	**6.3E+2**	**3.0E+1**	**5.8E+2**	**1.9E+2**	**9.9E+2**	**1.4E+4**	**1.2E+3**	**5.8E+2**	**9.9E+2**	**3.0E+1**	**5.1E+2**
Bi-214	**2.6E+2**	**2.0E+2**	**2.4E+3**	**8.8E+1**	**2.0E+2**	**6.4E+2**	**2.6E+2**	**3.8E+3**	**3.2E+2**	**2.0E+2**	**2.6E+2**	**2.4E+2**	**7.9E+2**
Ra-226	**3.1E+1**	**3.8E+1**	**2.0E+1**	**2.0E+1**	**3.7E+1**	**1.4E+1**	[illegible]	**2.6E+2**	[illegible]	**3.7E+1**	**3.1E+1**	**2.0E+1**	**1.8E+1**
Ac-228	3.1E+0	2.6E+0	**3.0E+1**	8.1E-1	4.2E+0	6.6E+0	3.2E+0	[illegible]	3.1E+0	4.2E+0	2.5E+0	2.5E+0	5.7E+0
U-235	2.1E-2	2.1E-2	8.7E-3	2.0E-1	2.1E-2	7.7E-2	2.1E-2	5.2E-1	2.4E+0	2.1E-2	2.4E+0	5.7E-1	9.0E-3

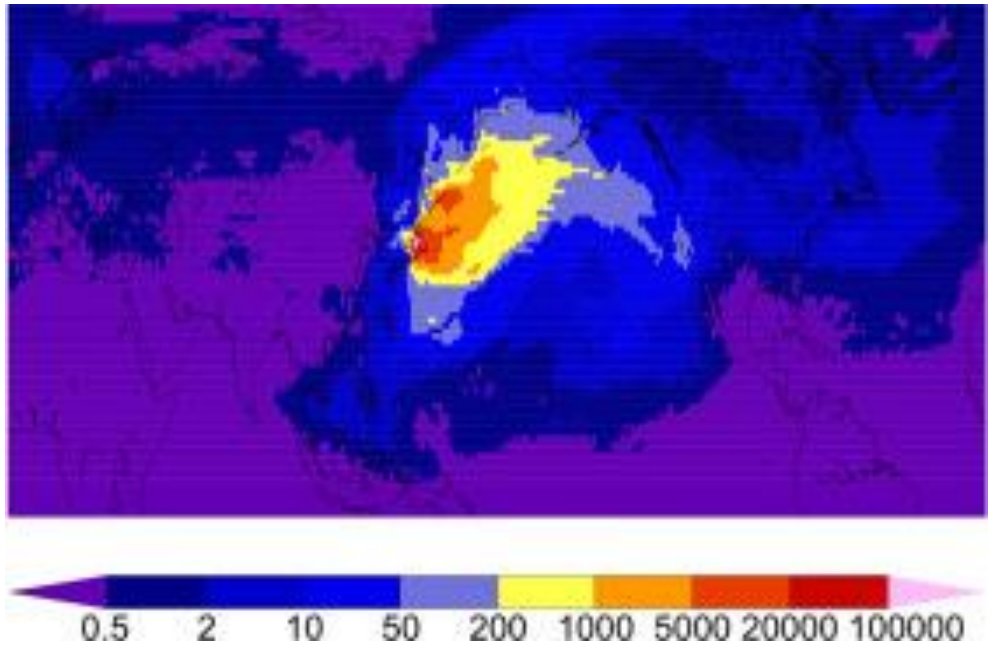
Alternatives

Transport modelling of radioactive releases

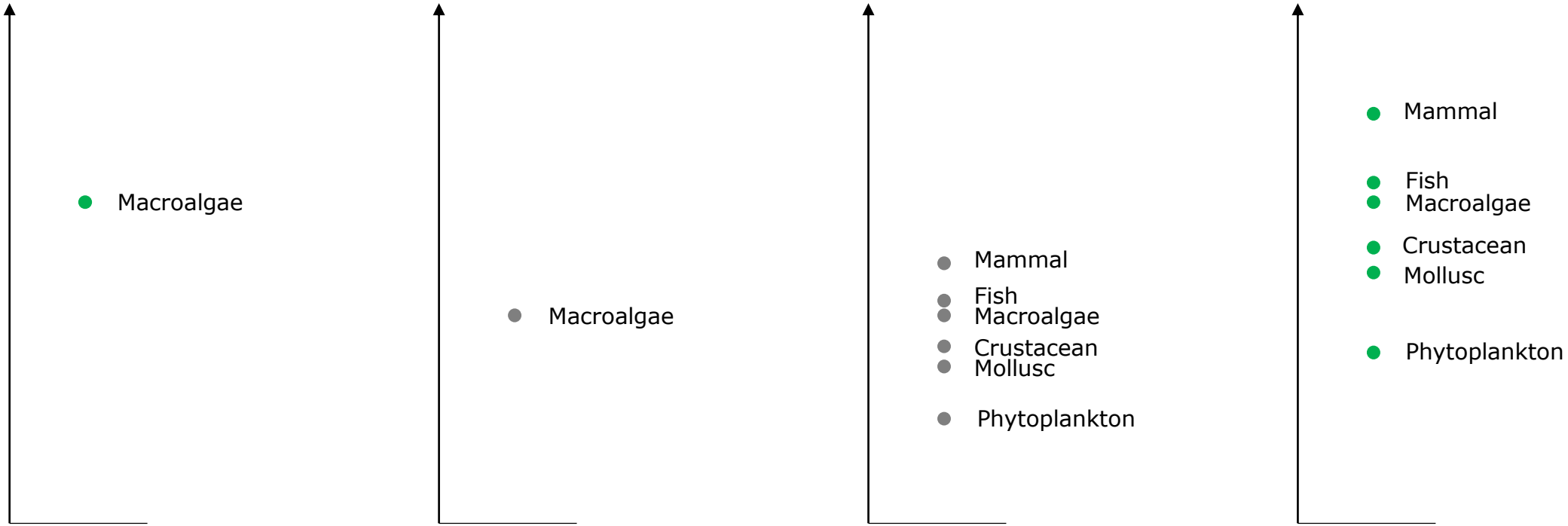
Predict activity concentrations in water, sediment and soil, based on the release term

These can be used to more accurately determine ACs in all biota

e.g.
PREDO – PREdiction of DOses from normal releases of radionuclides to the environment



REstricted Maximum Likelihood (REML) approach (in development)



Thank you