ERM Illustrative Example

Scott Coffin

7/30/2021

## -- Attaching packages --------------------------------------- tidyverse 1.3.1 --

## v ggplot2 3.3.5 v purrr 0.3.4  
## v tibble 3.1.2 v dplyr 1.0.7  
## v tidyr 1.1.3 v stringr 1.4.0  
## v readr 1.4.0 v forcats 0.5.1

## -- Conflicts ------------------------------------------ tidyverse\_conflicts() --  
## x dplyr::filter() masks stats::filter()  
## x dplyr::lag() masks stats::lag()

# Illustrative Example

## Re-scaling effect concentrations according to Ecological Relevent Metrics (ERMs)

### Particles

A monodisperse effect concentration (e.g. 10 micron polyethylene fragments) may be re-scaled to a default size range (e.g. 1 - 5,000 microns) using methods described in Kooi et al (2021). Re-scaling to a default size range allows direct comparison to exposure concentrations for a default size range (which may also be re-scaled).

The effect concentration must first be corrected for bioavailability. If the suspected effect mechanism depends on ingestion of the particle, particles that are too large to be ingested by the organism of interest should be considered to not be bioavailable. Further, if toxicity depends on tissue translocation, particles too large to be translocated will be considered to be unavailable.

For an example, the tox database is queried to determine a real-world example. Studies in the database are filtered for all ‘red’ criteria, and only organismal and population-level biological organizations are considered, then default assessment metrics are applied.

The resulting real-life example of a *monodisperse* effect concentration is for a of a 40 um PE fragment for *C. Daphnia*. The minimum NOEC for acute mortality endpoints from these studies is:

## [1] "40 um PE fragment Monodisperse Effect Concentration (C. Daphnia, acute mortality): 562.3413252 (particles/L)"

In order to convert the *monodisperse* effect concentration to a *polydisperse* mixture of microplastic particles, a correction must occur which takes into consideration the ecologically relevant metric (ERM) [(Koelmans et al 2017)](https://europepmc.org/article/med/28971682). For a given ERM, the threshold may be related to both mono- or polydisperse particles interchangeably so long as the total magnitude of ERM remains the same (Koelmans et al, 2020).

In this example of a monodisperse effect concentration for *C.Daphnia*, is in particle count per volume (i.e. 1e+05 particles/L), and is the mean value of the ERM of interest in this study, which in the case of particle count, is 1.

Particles follow a power law regime in the marine environment, so may be calculated using the following equation (equation 4, Kooi et al 2021):

Where relates to the power law distribution of microplastic particles in the marine environment (i.e. particle length; 2.07; Kooi et al 2021), and UL and LL are the upper and lower limits of bioavailability for this species/life stage/effect metric, respectively.

In this example, the organism of interest is *Cerodaphnia magna*, which has an average body length of 0.5 cm, and an estimated maximum ingestible particle width of 115 um particles based on average mouth size opening. Therefore, would be equivalent to 115 um, and would be the lower size range of the bin for which the SSD is built- in this example, 1 um as a lower limit.

Note that if bioavailability for an ERM of interest is based on a different parameter (for example, tissue translocation potential), would be equivalent to that size. A default assumption for an upper limit of tissue translocation for this exercise is 10 um.

for particles for the 1-115 um fraction in the marine environment is then calculated:

## [1] "mu\_x\_poly: 4.35"

Now that , , and are known for this example, the *bioavailable* *polydisperse* effect concentration may then be calculated using the equation:

## [1] "EC\_poly: 129.36 particles/L"

Now that the *bioavailable*, *polydisperse* effect concentration is known for this example, in order to relate this threshold effect concentration to an *environmentally relevant* (e.g. 1 - 5,000 um) range of particles (; particles/L) a further correction must occur using the following equation (equation 2; Kooi et al 2021):

Where is a dimensionless correction factor for the bioavailable effect concentration. This equation rescales the bioavailable effect concentration (particles/L) to an environmentally relevant concentration for the microplastics default (D) size range (e.g. 1 to 5,000 um) according to the power law distribution for length (L) with slope in Table S4 of Kooi et al (2021). is calculated as follows (Kooi et al 2021):

In this example, the organism of interest is *Cerodaphnia magna*, which has an average body length of 0.5 cm, and an estimated maximum ingestible size range of 115 um particles, would be equivalent to 115 um, and would be the lower size range of the bin for which the SSD is built- in this example, 1 um as a lower limit. Further, the upper limit (UL,D) and lower limit (LL,D) of the default size range are 5,000 and 1 um, respectively.

## [1] "CF\_bio = 1.006 (unitless)"

Finally, the is calculated for particles/L as an ERM:

## [1] "EC\_env = 130.2 Particles/L (1-5,000 um; marine surface water )"

### Volume

In the case of an ERM of interest being volume, is equivalent to the average volume of a the monodisperse particle (i.e. ), calculated as follows:

Where is the volume for a given particle *i*, and a, b, and c are radii along the principal axes, corresponding to one-half times the length, width, and height of an ellipsoid. Upper and lower limits of bioavailability for volume correspond to the maximum ingestible size of particles and the lower limit of the size range to be aligned to (typically 1 micron).

Image source: Wikipedia.com

The above equation can be applied to fragments, thin films, microbeads, spheres, or fibers given a known length to width ratios for such shapes, with the height assumed to be equivalent to 0.67 x width (Kooi et al 2021). Width to length ratios differ for microplastics differ by compartment, with averages ranging from 0.67 to 0.77 (Kooi et al 2021; Table S3). Averaged values may be used to estimate the volume of polydisperse environmental mixtures of microplastics.

Substituting for the length to width ratio of a particles, the formula simplifies to:

Where is the length of the particle (um) and is the width:length ratio of the particle (unitless).

For the example of a 40 um PE fragment, the length was reported (), however the width was not reported by the authors, so a default value of 0.77 is used, which is the average for marine surface water ().

is calculated:

## [1] "mu\_v.mono = 208 um^3"

is then calculated using the volume of particles that are bioaccessible (based on mouth opening and particle length), the volume of particles for the lower limit of the size range of interest.

As discussed above, for the example of an organism of interest of *Cerodaphnia magna*, the estimated maximum ingestible size range is 115 um particles, would be equivalent to 115 um, and would be the lower size range of the bin for which the SSD is built- in this example, 1 um as a lower limit. Volumetric limits are calculated:

## [1] "x\_UL\_v = 316000 um^3 ;x\_LL\_v = 0.208 um^3"

may now be calculated given these limits, using an alpha value of 1.48 for volume in the marine surface water environment (Kooi et al 2021):

## [1] "mu\_v\_poly: 314.91 um^3"

Now that , , and are known for this example for volume, the *bioavailable* *polydisperse* effect concentration for the volume ERM may then be calculated:

## [1] "EC\_poly\_v: 371.42 particles/L"

Again, to relate this *bioavailable*, *polydisperse* effect threshold () to an environmentally relevant *polydisperse* mixture of particles for the volume ERM, an additional correction must be applied to rescale the threshold to the size range of interest (e.g. 1-5,000 um) using , identical as for particles.

## [1] "EC\_env\_v = 373.7 Particles/L (1-5,000 um; marine surface water )"

### Surface Area

For surface area as an ERM, is equivalent to the average surface area () of the *monodisperse* particle for the effect threshold, calculated as follows:

With a, b, c being equal to 0.5x length, 0.5x width, and 0.5x height, respectively.

For the example of a 40 um PE fragment, the length was reported (), however the width was not reported by the authors, so a default value of 0.77 is used (), which is the average for marine surface water, and height is assumed to be 0.67 times the width () (Kooi et al 2021). Surface area is calculated:

## [1] "mu\_sa.mono = 2880 um^2"

Since the probability distribution of ERM (surface area) follows a power law regime, the mean ERM value for the polydisperse particles, , can be calculated. For surface area of environmentally disperse particles, UL and LL are calculated using the equation for the surface area of an ellipsoid (above).

## [1] "x\_UL = 23838.26 um^2 ;x\_LL = 1.8 um^2"

may now be calculated given these limits, using an alpha value of 1.98 for surface area in the marine surface water environment (Kooi et al 2021):

## [1] "mu\_sa\_poly: 207.29 um^2"

Now that , , and are known for this example for surface area, the *bioavailable* *polydisperse* effect concentration for the surface area ERM may then be calculated:

## [1] "EC\_poly\_sa: 7823.9 particles/L"

Again, to relate this *bioavailable*, *polydisperse* effect threshold () to an environmentally relevant *polydisperse* mixture of particles for the surface area ERM, an additional correction must be applied to rescale the threshold to the size range of interest (e.g. 1-5,000 um) using , identical as for particles.

## [1] "EC\_env\_sa = 7872 Particles/L (1-5,000 um; marine surface water )"

### Mass

In the case of an ERM of interest being total mass, is equivalent to the average mass of a the monodisperse particle (i.e. ), calculated as follows:

Where *m* is the mass (ug), *p* is density (g/cm^3), *V* is volume (um^3) - which is calculated by the cube of the radius of each particle (i.e. 1/2 \* length, or 2.5 um), and additional conversion factors for g to ug (1e6) and cm^3 to um^3 (1e-12).

For the example of a 40 um polyethylene fragment, the volume was calculated above (~ ), and the density of polyethylene was is estimated to be 0.935 g/cm^3. is calculated:

## [1] "mu\_m,mono: 0.0124 ug"

Since the probability distribution of ERM (mass) follows a power law regime, the mean ERM value for the polydisperse particles, , can be calculated by first calculating the lower and upper ingestible masses of particles based on the length of the ingestible particle. The UL and LL are respectively defined as the upper and lower limit in ERM (mass) for which the mean is calculated, and is the power law exponent of mass. In the case of marine surface water,an of 1.32 is utilized (Kooi et al 2021; Table S4).

For mass, UL and LL are mass-based upper and lower limits of bioaccessibility based on the width of particles, respectively. To estimate mass-based limits based on size, the volume of bioaccessible particles is first calculated using the equation for the volume of an ellipsoid, then multipied by the average density of particles in the 1-5,000 um distribution in the environmental compartment of interest (e.g.surface marine water: 1.10 g/cm^3) (Kooi et al 2021; table S3).

## [1] "x\_UL = 0.35 ug ;x\_LL = 2.3e-07 ug"

may now be calculated given these limits, using an alpha value of of 1.32 for the marine surface water environment (Kooi et al 2021):

## [1] "mu\_m\_poly: 0.0017 ug"

Now that , , and are known for this example for mass, the *bioavailable* *polydisperse* effect concentration for the mass ERM may then be calculated:

## [1] "EC\_poly\_m: 4023.2 particles/L"

Again, to relate this *bioavailable*, *polydisperse* effect threshold () to an environmentally relevant *polydisperse* mixture of particles for the mass ERM, an additional correction must be applied to rescale the threshold to the size range of interest (e.g. 1-5,000 um) using , identical as for particles.

## [1] "EC\_env\_m = 4048 Particles/L (1-5,000 um; marine surface water)"

### Specific Surface Area

In the case of an ERM of interest being specific surface area, is equivalent to the surface area of a 5 um PS sphere (i.e. ) divided by the mass (i.e. ), calculated as follows:

Where *SA* is the surface area (um^2) of the particle, and *m* is the mass (ug).

## [1] "mu\_ssa,mono: 2.32e+05 um^2/ug"

Since the probability distribution of ERM (specific surface area) follows a power law regime, the mean ERM value for the polydisperse particles, , can be calculated, where UL and LL are respectively defined as the upper and lower limit in ERM (ssa) for which the mean is calculated, and is the power law exponent of specific surface area. For example, marine surface water has an of 1.98 (Kooi et al 2021; Table S4). For specific surface area, UL and LL are area/mass-based upper and lower limits of bioaccessibility based on the width of particles, respectively. To estimate area/mass-based limits based on size, the volume of bioaccessible particles is first calculated using the equation for the surface area of an ellipsoid, then divided by the lower and upper bioavailable mass of particles in the 1-5,000 um distribution in surface marine water, as calculated above.

## [1] "x\_UL\_ssa = 68500 um^2/ug ;x\_LL\_ssa = 7880000 um^2/ug"

may now be calculated given these limits, using an alpha value of of 1.98 for the marine surface water environment (Kooi et al 2021):

## [1] "mu\_ssa,poly = 337000 um^2/ug"

Now that , , and are known for this example for specific surface area, the *bioavailable* *polydisperse* effect concentration for the specific surface area ERM may then be calculated:

## [1] "EC\_poly\_ssa: 386.21 particles/L"

Again, to relate this *bioavailable*, *polydisperse* effect threshold () to an environmentally relevant *polydisperse* mixture of particles for the specific surface area ERM, an additional correction must be applied to rescale the threshold to the size range of interest (e.g. 1-5,000 um) using , identical as for particles.

## [1] "EC\_env\_ssa = 388.6 Particles/L (1-5,000 um; marine surface water)"

## Aligning Occurence Data for Risk Characterization

Given an upper limit (UL) and lower limit (LL) of the measured (M) and default size range (D), a dimensionless correction factor () for measured environmental concentrations may be calculated, which rescales the measured (M) number concentrations for a certain size range to the number concentration for the microplastics default (D) size range (e.g. 1 to 5,000 um) according to the power law distribution for length (L) with slope in Table S4 of Kooi et al (2021).

The following equation for is identical for effect concentration () except the bioavailable fraction of particles is denoted as UL,B and LL,B on the denominator (Koelmans et al., 2020; Kooi et al., 2021).

For example, a marine surface water concentration of 10 particles/L for 300 - 5,000 um is used.

## [1] "C\_meas = 10 particles/L (300 - 5,000 um; marine surface water)"

To compare this concentration to the environmentally relevant (1 - 5,000 um) effect threshold (EC\_env) in particles/L (calculated above), is first calculated.

## [1] "CF\_meas = 470.3 (unitless)"

The resulting correction factor ( (unitless) is then multiplied by the measured concentration () to obtain a rescaled exposure number concentration .

## [1] "C\_env = 4703 particles/L (1 - 5,000 um; marine surface water)"

This measured rescaled environmental concentration may then be directly compared to the rescaled effect thresholds for various ERM to determine if risk is present using the traditional PNEC/PEC formula:

## Warning: `columns = vars(...)` has been deprecated in gt 0.3.0:  
## \* please use `columns = c(...)` instead  
  
## Warning: `columns = vars(...)` has been deprecated in gt 0.3.0:  
## \* please use `columns = c(...)` instead

In this case, the environmental concentration is nearly 5x lower than the effect threshold for particles, so exceedance of a NOEC for this particular endpoint/species (i.e. mortality,*C.Daphnia*) would not be expected to occur for that ERM. However, in the case of specific surface area as an ERM, risk is exceeded by a factor of 1.32.

The above approach used for particles as an ecologically relevent metric may be applied for any other ecologically relevent metric for which particle distributions are characterized in the environmental compartment of interest. Below are proofs for additional ERM, including surface area, volume, mass, and specific surface area.