

photobiologyWbands Version 0.4.0

User Guide

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1 Introduction

This package provides constructors for **waveband** objects, a class defined in package **photobiology**. These are convenience functions that allow definition of range of wavelengths and biological spectral weighting functions (BSWFs) following definitions in common use and ISO standards.

2 Calculating irradiances

Functions for several colour bands, in some cases according to different optional definitions, are listed in Table 1.

An example using **sun.spct** included in package **photobiology**. As the input spectral irradiance is units of $\text{W m}^{-2} \text{nm}^{-1}$ the output is in $\text{mol m}^{-2} \text{s}^{-1}$ or W m^{-2} .

```
e_irrad(sun.spct, UV()) # W m-2

## UV.ISO.tr.lo
##      28.62872
## attr(,"time.unit")
## [1] "second"
## attr(,"radiation.unit")
## [1] "energy irradiance total"

q_irrad(sun.spct, UV()) * 1e6 # umol s-1 m-2

## UV.ISO.tr.lo
##      86.49506
## attr(,"time.unit")
## [1] "second"
## attr(,"radiation.unit")
## [1] "photon irradiance total"
```

Irradiances for different wavebands can be grouped into a list of any length. If the list has named members, then these names are used instead of the default ones.

Table 1: Functions in R package `photobiologyWbands` used for constructing descriptors of wavebands used for calculation of irradiances or exposures. The boundaries of the band given as wavelengths in nm (λ). Definition according to ISO-21348 "ISO" is the default for all functions except `PAR()` for which there is only one definition in common use "Plant" which is the default.

| Waveband | Source | Dose or irradi. | Waveband (nm) |
|------------------|------------|----------------------------------|--------------------------|
| UV | ISO-21348 | UV("ISO") | $100 \leq \lambda < 400$ |
| UV-C | ISO-21348 | UVC("ISO") | $100 \leq \lambda < 280$ |
| UV-C | n.a. | UVC("medical") | $220 \leq \lambda < 290$ |
| UV-C | n.a. | UVC("none") | $200 \leq \lambda < 280$ |
| UV-B | ISO-21348 | UVB("ISO") | $280 \leq \lambda < 315$ |
| UV-B | n.a. | UVB("none") | $280 \leq \lambda < 320$ |
| UV-A | ISO-21348 | UVA("ISO") | $315 \leq \lambda < 400$ |
| UV-A | n.a. | UVA("none") | $320 \leq \lambda < 400$ |
| Visible | ISO-21348 | VIS("ISO") | $380 \leq \lambda < 760$ |
| Photosynthesis | n.a. | PAR("Plant") | $400 \leq \lambda < 700$ |
| Purple | ISO-21348 | Purple("ISO") | $360 \leq \lambda < 450$ |
| Blue | Sellaro | Blue("Sellaro") | $420 \leq \lambda < 490$ |
| Blue | ISO-21348 | Blue("ISO") | $450 \leq \lambda < 500$ |
| Green | Sellaro | Green("Sellaro") | $500 \leq \lambda < 570$ |
| Green | ISO-21348 | Green("ISO") | $500 \leq \lambda < 570$ |
| Yellow | ISO-21348 | Yellow("ISO") | $570 \leq \lambda < 591$ |
| Orange | ISO-21348 | Orange("ISO") | $591 \leq \lambda < 610$ |
| Red | ISO-21348 | Red("ISO") | $610 \leq \lambda < 760$ |
| Red | Smith | Red("Smith10") | $655 \leq \lambda < 665$ |
| Red | Smith ? | Red("Smith20") | $650 \leq \lambda < 670$ |
| Red | Inada | Red("Inada") | $600 \leq \lambda < 700$ |
| Red | Warrington | Red("Warrington") | $625 \leq \lambda < 675$ |
| Red | Sellaro | Red("Sellaro") | $620 \leq \lambda < 680$ |
| Far-red | ISO | Far_red("ISO") | not defined |
| Far-red | Smith10 | Far_red("Smith") | $725 \leq \lambda < 735$ |
| Far-red | Smith20 | Far_red("Smith") | $720 \leq \lambda < 740$ |
| Far-Red | Inada | Red("Inada") | $700 \leq \lambda < 800$ |
| Far-Red | Warrington | Red("Warrington") | $700 \leq \lambda < 850$ |
| Far-red | Sellaro | Far_red("Sellaro") | $700 \leq \lambda < 750$ |
| Far-red | BTV | Far_red("BTV") | $700 \leq \lambda < 760$ |
| <i>Arbitrary</i> | n.a. | <code>new_waveband(lo,hi)</code> | $lo \leq \lambda < hi$ |

Table 2: Functions in R package **photobiologyWbands** used for constructing lists descriptors of wavebands used for calculation of irradiances or exposures.

| Waveband | Source | Function | std values used |
|-------------|-----------|--------------------------|-------------------------------|
| VIS defs. | ISO-21348 | VIS_bands("ISO") | "ISO" |
| UV defs. | ISO-21348 | UV_bands("ISO") | "ISO" |
| UV defs. | n.a. | UV_bands("none") | "none" |
| Plant sens. | n.a. | Plant_bands("sensory20") | "ISO", "Sellar" and "Smith20" |
| Plant sens. | n.a. | Plant_bands("sensory") | "ISO", "Sellar" and "Smith20" |
| Plant sens. | n.a. | Plant_bands("sensory10") | "ISO", "Sellar" and "Smith10" |
| Plant sens. | n.a. | Plant_bands("energy") | "ISO" and "McCree" |

```
e_irrad(sun.spct, list(Blue(), VIS()))

## Blue.ISO   VIS.ISO
## 37.55207 231.86345
## attr("time.unit")
## [1] "second"
## attr("radiation.unit")
## [1] "energy irradiance total"

e_irrad(sun.spct, list(B = Blue(), VIS()))

## Blue.ISO   VIS.ISO
## 37.55207 231.86345
## attr("time.unit")
## [1] "second"
## attr("radiation.unit")
## [1] "energy irradiance total"
```

A few functions for generating coherent lists of wavebands are also defined (Table 2).

```
e_irrad(sun.spct, VIS_bands())

## Purple.ISO   Blue.ISO   Green.ISO   Yellow.ISO
## 47.75529    37.55207    49.26860    13.67971
## Orange.ISO   Red.ISO
## 12.00432     79.38159
## attr("time.unit")
## [1] "second"
## attr("radiation.unit")
## [1] "energy irradiance total"
```

3 Calculating photon ratios

Photon ratios can be calculated from any pair of waveband objects. This a convenient and very flexible way of doing this type of calculations.

```
q_ratio(sun.spct, Blue(), VIS())

## Blue.ISO: VIS.ISO(q:q)
##           0.1371157
## attr("radiation.unit")
## [1] "q:q ratio"
```

4 Calculating effective irradiances and exposures

The waveband definitions and SWFs are stored in **waveband** objects, that can be created with function **waveband**. The same functions described above for unweighted irradiances are used to calculate effective irradiances and doses.

Currently functions for constructing **waveband** objects describing several BSWFs are implemented (see Table 3). These functions take three arguments in most cases as they have been used and continue to be used inconsistently in the scientific literature. By supplying these arguments different variations of the BSWFs can be obtained. The defaults used are those values which we consider best, usually the most frequently used ones, except in cases when we consider the use of those values problematic for the reliability of the calculations.

```
e_irrad(sun.spct, CIE())

## CIE98.298.tr.lo
##           0.08181583
## attr("time.unit")
## [1] "second"
## attr("radiation.unit")
## [1] "energy irradiance total"
```

5 Calculating an action spectrum at given wavelengths

The functions available for calculating action spectra take as argument a vector of wavelengths, and return a vector of effectiveness (either quantum/photon or energy based) depending on how the original source describes them. These functions are listed in Table 4, and an example of their use follows.

```
# at 1 nm intervals
wavelengths1 <- 285:400
action.spectrum1 <- CIE_e_fun(wavelengths1)
```

All functions accept a wavelengths vector with variable and arbitrary step sizes, with the condition that the wavelengths are sorted in strictly increasing order.

Table 3: Functions in R package `photobiologyWbands` used for constructing `waveband` objects describing BSWFs used for calculation of effective irradiances or doses. The functions for BSWFs available in this package, are by default as in the original source. Optionally they can be normalized to any wavelength within their non-zero range by providing the `norm` argument with a wavelength in nm. The range of wavelengths included when calculating integrals is given by `w.low` and `w.high`. The values in the table below are the defaults.

| Action spectrum | Formulation | Constructor function | norm λ (nm) | w.low λ (nm) | w.high λ (nm) |
|-------------------|-------------------|-----------------------------|------------------------|-------------------------|--------------------------|
| Gen. plant action | Green | GEN_G(norm, w.low, w.high) | 300 | 275 | 313.3 |
| Gen. plant action | Thimijan | GEN_I(norm, w.low, w.high) | 300 | 275 | 345.0 |
| Gen. plant action | Micheletti | GEN_M(norm, w.low, w.high) | 300 | 275 | 313.3 |
| Plant growth | Flint & Caldwell | PG(norm, w.low, w.high) | 300 | 275 | 390.0 |
| Erythema | CIE98 | CIE(norm, w.low, w.high) | 298 | 250 | 400.0 |
| ICNIRP | ICNIRP2004 | ICNIRP(norm, w.low, w.high) | 270 | 210 | 400.0 |
| 'Naked' DNA | TUV, from Setlow | DNA_N(norm, w.low, w.high) | 300 | 250 | 400.0 |
| 'Naked' DNA | Green & Miller | DNA_GM(norm, w.low, w.high) | 300 | 250 | 400.0 |
| 'Plant' DNA | Musil, from Quate | DNA_P(norm, w.low, w.high) | 300 | 250 | 400.0 |
| Flavonoid | Ibdah | FLAV(norm, w.low, w.high) | 300 | 275 | 346.0 |

Table 4: Biological spectral weighting functions predefined in R package **photobiologyWbands**. The functions for BSWFs available in this package, implement the functions as defined in the original publications. When the original ‘definition’ is available as tabulated data, or we have tabulated it by digitizing a figure, the values returned are calculated by spline interpolation.

| Action spectrum | Formulation | Function | Norm. λ (nm) |
|-------------------|--------------------|------------------------|----------------------|
| Gen. plant action | Green | GEN_G_q_fun(w.length) | 280 |
| Gen. plant action | Thimijan | GEN_T_q_fun(w.length) | 300 |
| Gen. plant action | Micheletti | GEN_M_q_fun(w.length) | 300 |
| Plant growth | Flint & Caldwell | PG_q_fun(w.length) | 300 |
| Erythema | CIE98 | CIE_e_fun(w.length) | 298 |
| ICNIRP | ICNIRP2004 | ICNIRP_e_fun(w.length) | 270 |
| ‘Naked’ DNA | TUV, from Setlow | DNA_N_q_fun(w.length) | n.a. |
| ‘Naked’ DNA | Green & Miller | DNA_GM_q_fun(w.length) | n.a. |
| ‘Plant’ DNA | Musil, from Quaite | DNA_P_q_fun(w.length) | 290 |
| Flavonoid | Ibdah | FLAV_q_fun(w.length) | 300 |

In practice these functions are mainly used internally by the package, and very rarely in user code, as the same output can be obtained by multiplication of **source_spct** objects by **waveband** objects.

Compare the following two plots,

```
sun.spct * CIE()

## Object: source_spct [122 x 2]
## Wavelength (nm): range 280 to 400, step 0.9230769 to 1
## Time unit: 1s
## Data weighted using 'CIE98.298' BSWF
##
##   w.length s.e.irrad
##   (dbl)      (dbl)
## 1 280.0000      0
## 2 280.9231      0
## 3 281.8462      0
## 4 282.7692      0
## 5 283.6923      0
## 6 284.6154      0
## 7 285.5385      0
## 8 286.4615      0
## 9 287.3846      0
## 10 288.3077      0
## ..      ...      ...
```

6 Luminous flux

The luminous flux per unit area in lux can be calculated as follows using the original luminous efficiency function for the human eye using for defining the

lumen. As we start with spectral irradiance we obtain luminous flux per unit area expressed in lux.

```
e_response(sun.spct * CIE1924_lef.spct) * photopic_sensitivity

##      Total
## 49579.93
## attr(,"time.unit")
## [1] "second"
## attr(,"radiation.unit")
## [1] "energy response total"
```

The luminous flux per unit area in lux can be calculated as follows using the latest luminous efficiency function for the human eye.

```
e_response(sun.spct * CIE2008_lef2deg.spct) * photopic_sensitivity

##      Total
## 53057.78
## attr(,"time.unit")
## [1] "second"
## attr(,"radiation.unit")
## [1] "energy response total"
```

As the luminous efficiency functions vary slightly in the wavelength at which the maximum is located, and the wavelength used for the sensitivity constant is fixed by the definition of the Lumen, a small correction is need for exact results.

```
e_response(sun.spct * CIE2008_lef2deg.spct) * photopic_sensitivity *
  interpolate_spct(CIE2008_lef2deg.spct, 555)$s.e.response

##      Total
## 53910.01
## attr(,"time.unit")
## [1] "second"
## attr(,"radiation.unit")
## [1] "energy response total"
```

An equivalent quantity can be calculated for scotopic vision, using the corresponding function and constant.

```
e_response(sun.spct * 1e-6 * CIE1951_scotopic_lef.spct) * scotopic_sensitivity

##      Total
## 0.1186256
## attr(,"time.unit")
## [1] "second"
## attr(,"radiation.unit")
## [1] "energy response total"
```