A numerical comparison of indices of illuminant-induced metameric mismatch

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The Metameric Uncertainty Index, R_t

David A, **Esposito T**, **Houser KW**, **Royer MP**, Smet KAG, Whitehead LA. 2020. A Vector Field Color Rendition Model for Characterizing Color Shifts and Metameric Mismatch. LEUKOS. 16(2): 99-114. DOI: 10.1080/15502724.2018.1554369

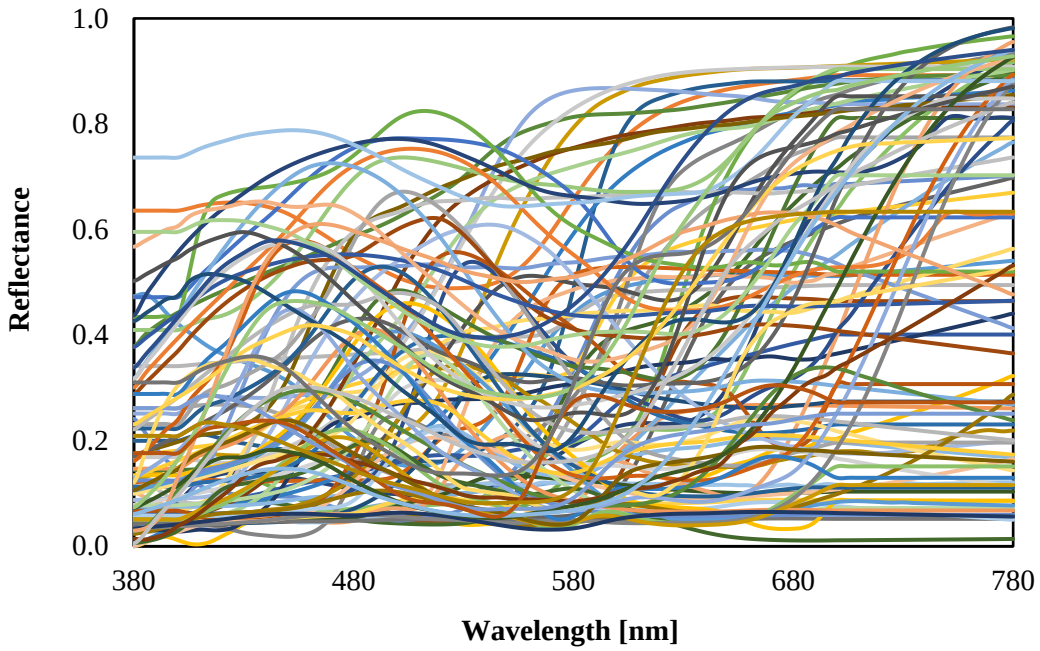
The Metamer Mismatching Color Rendering Index, *MMCRI*

H. Mirzaei and B. Funt, “Metamer mismatching as a measure of the color rendering of lights,” in Proceedings of the International Color Association Conference (2015), paper PS2-21.

Sample Set:

R_t

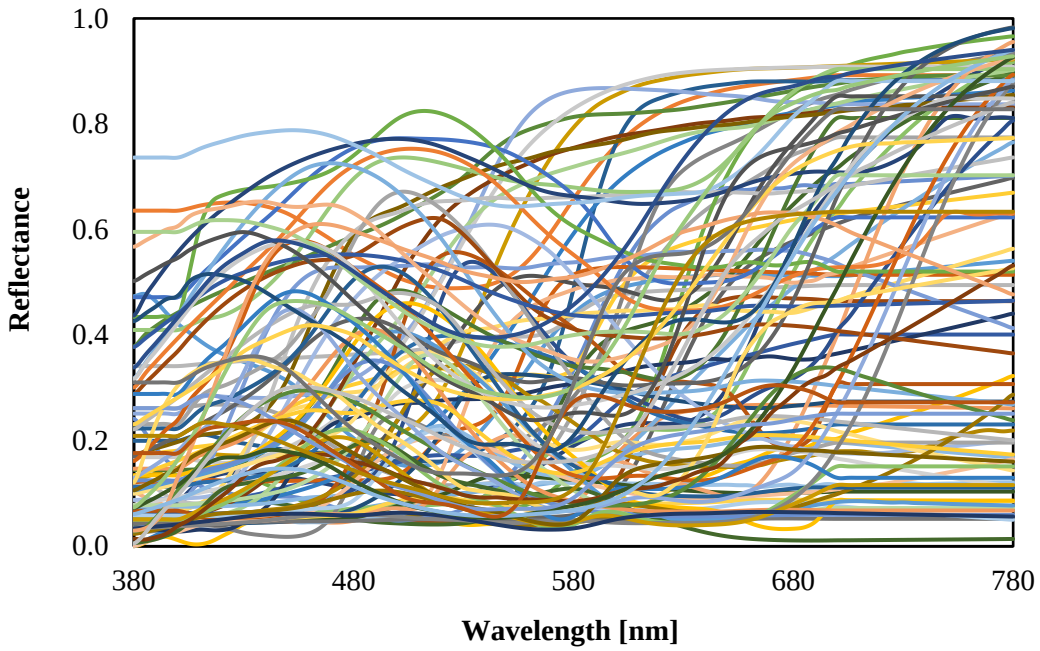
The 99 CES of IES TM-30



Sample Set:

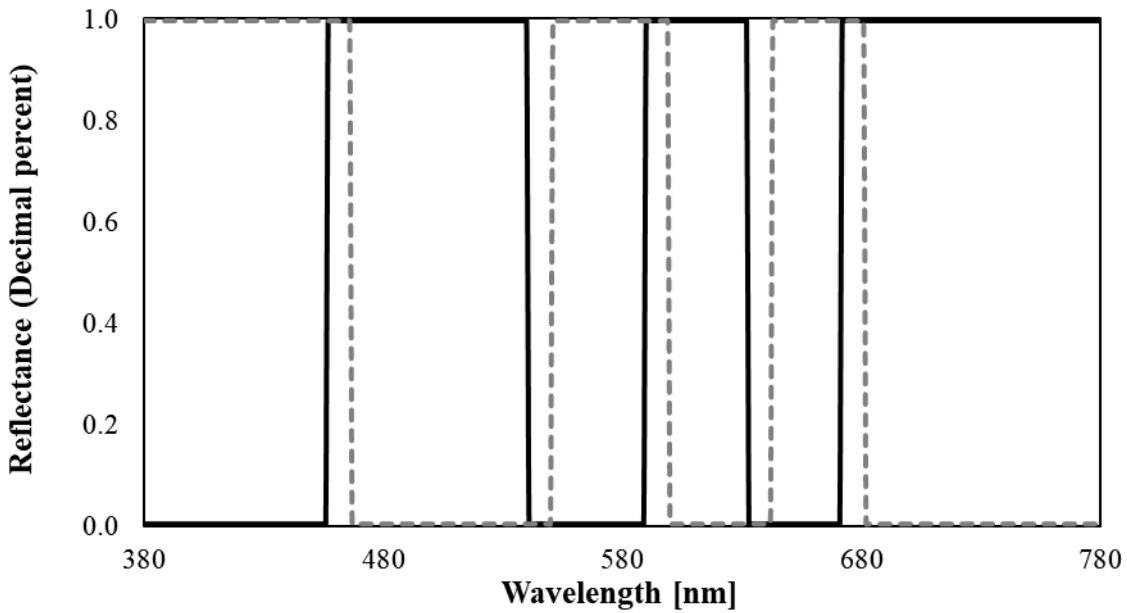
R_t

The 99 CES of IES TM-30



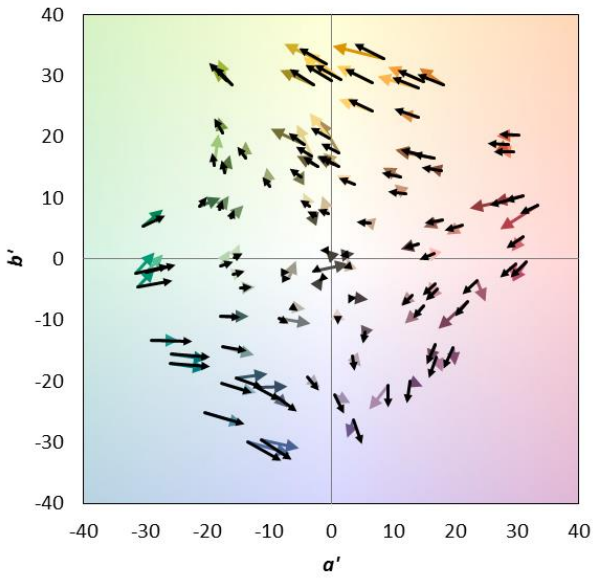
MMCRI

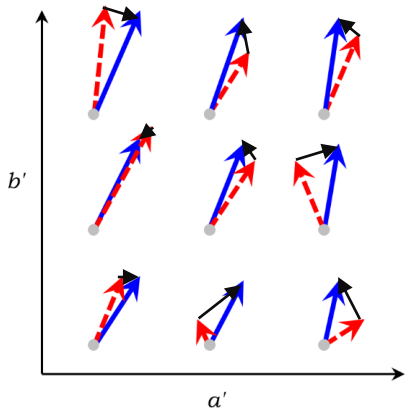
n optimal square reflectance functions with 5 transition points



Concept:

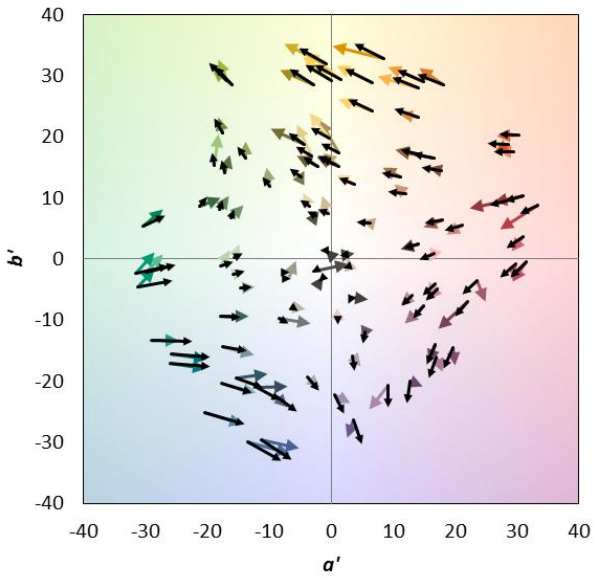
R_t

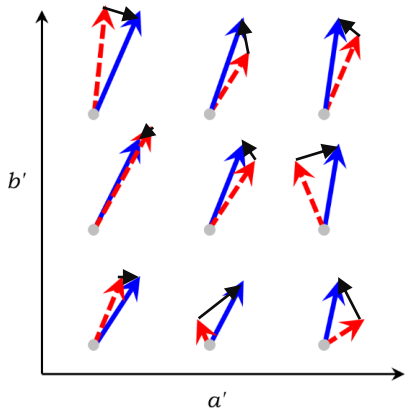




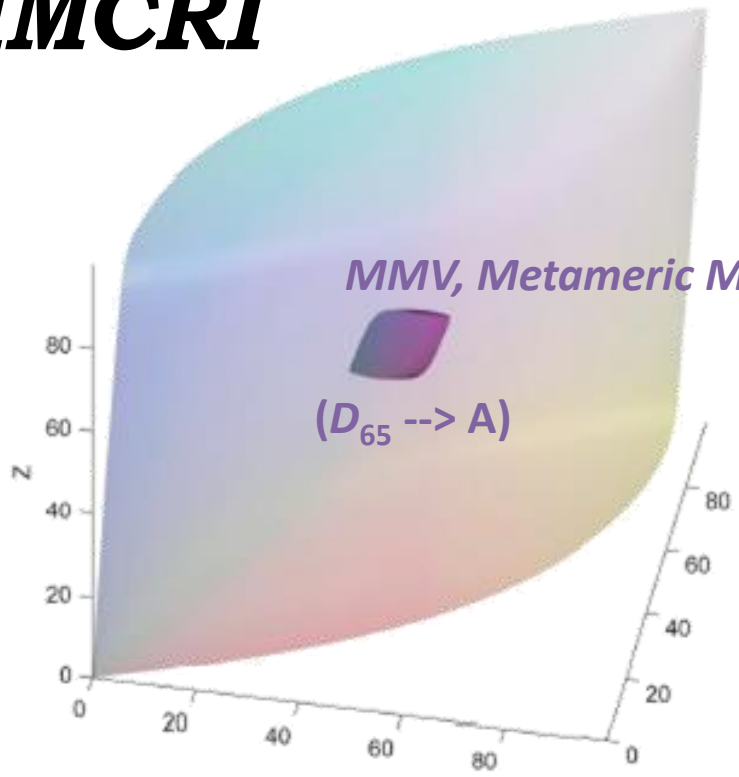
Concept:

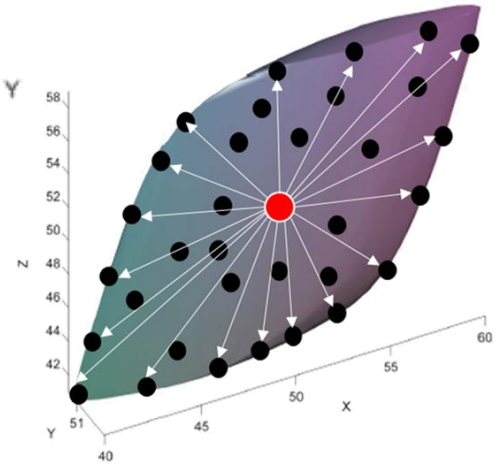
R_t



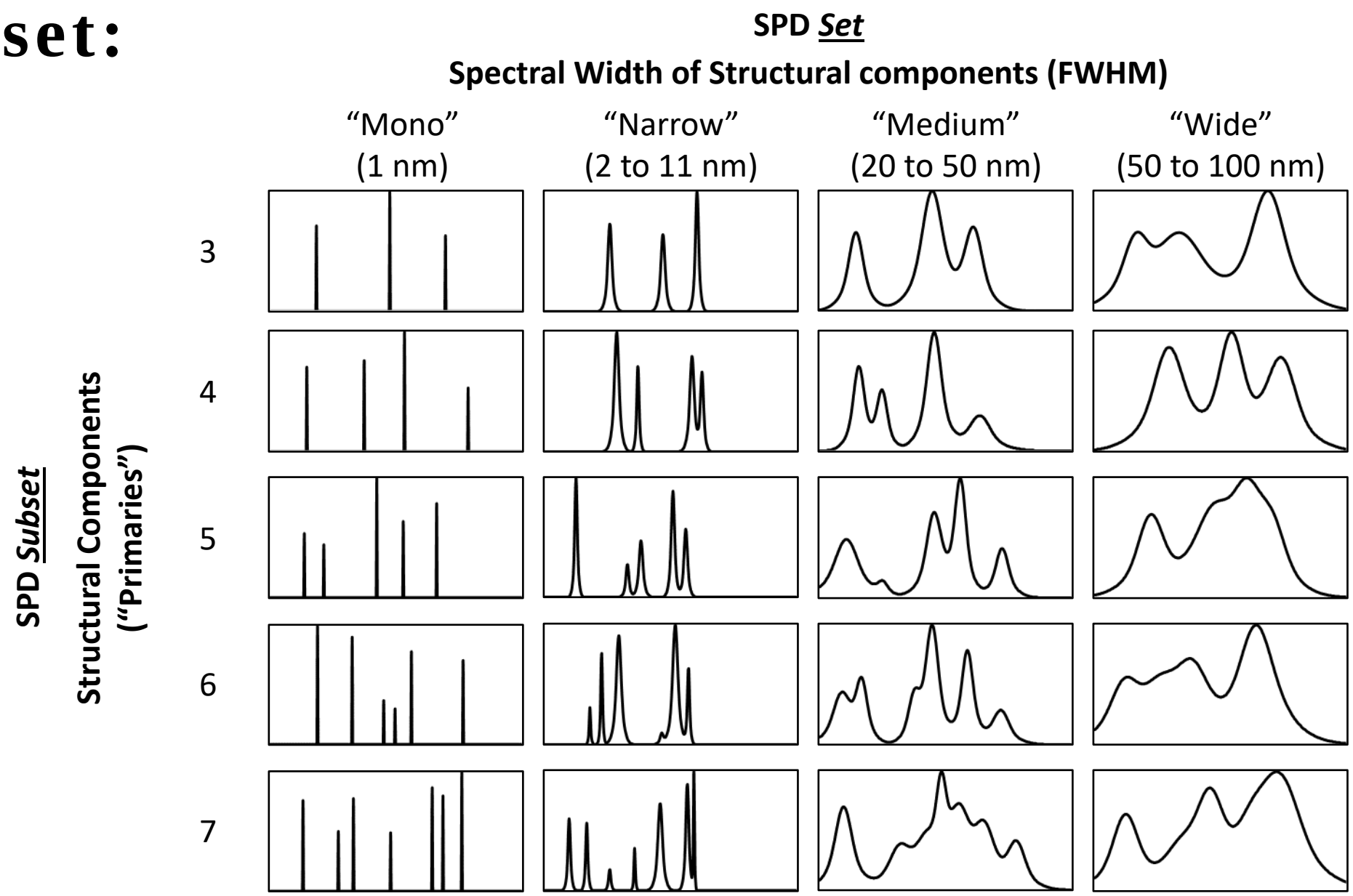


MMCRI





SPD set:


SPD Set
Spectral Width of Structural components (FWHM)
"Mono" (1 nm)
"Narrow" (2 to 11 nm)
"Medium" (20 to 50 nm)
"Wide" (50 to 100 nm)
SPD Subset
Structural Components ("Primaries")
3
4
5
6
7

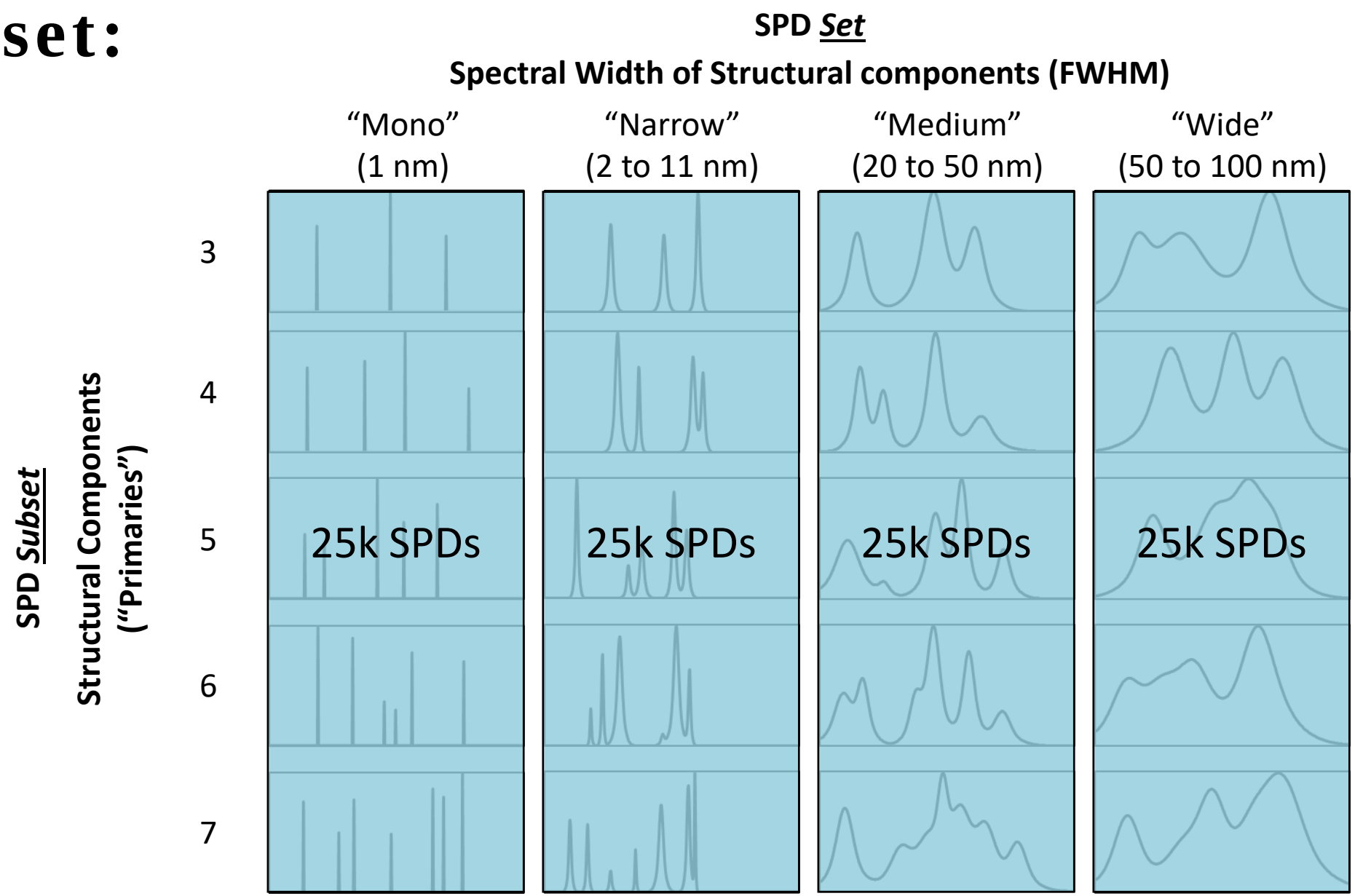
SPD set:

SPD *Set*

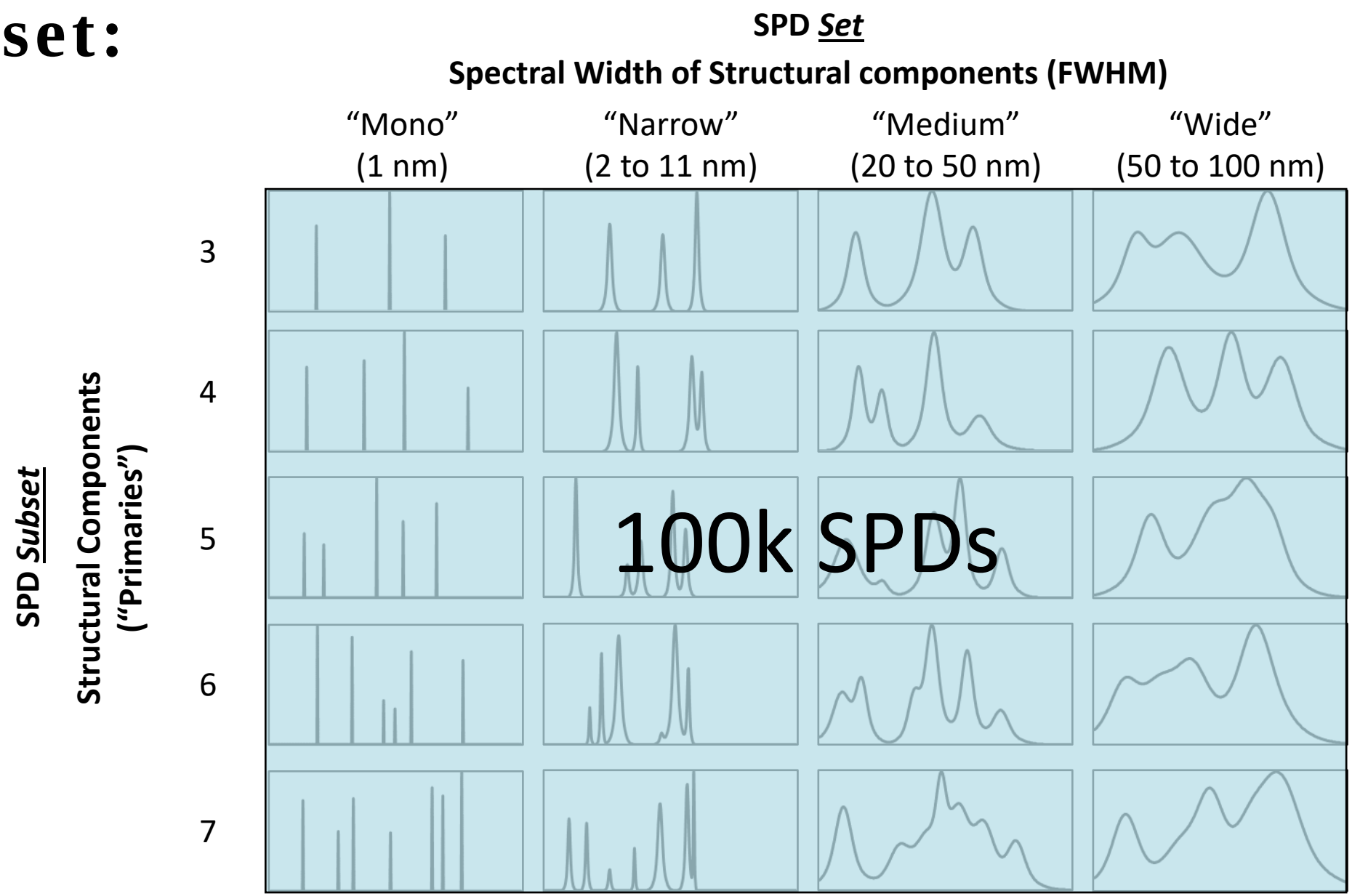
Spectral Width of Structural components (FWHM)

SPD *Subset* Structural Components ("Primaries")	"Mono" (1 nm)	"Narrow" (2 to 11 nm)	"Medium" (20 to 50 nm)	"Wide" (50 to 100 nm)
3	5k SPDs	5k SPDs	5k SPDs	5k SPDs
4	5k SPDs	5k SPDs	5k SPDs	5k SPDs
5	5k SPDs	5k SPDs	5k SPDs	5k SPDs
6	5k SPDs	5k SPDs	5k SPDs	5k SPDs
7	5k SPDs	5k SPDs	5k SPDs	5k SPDs

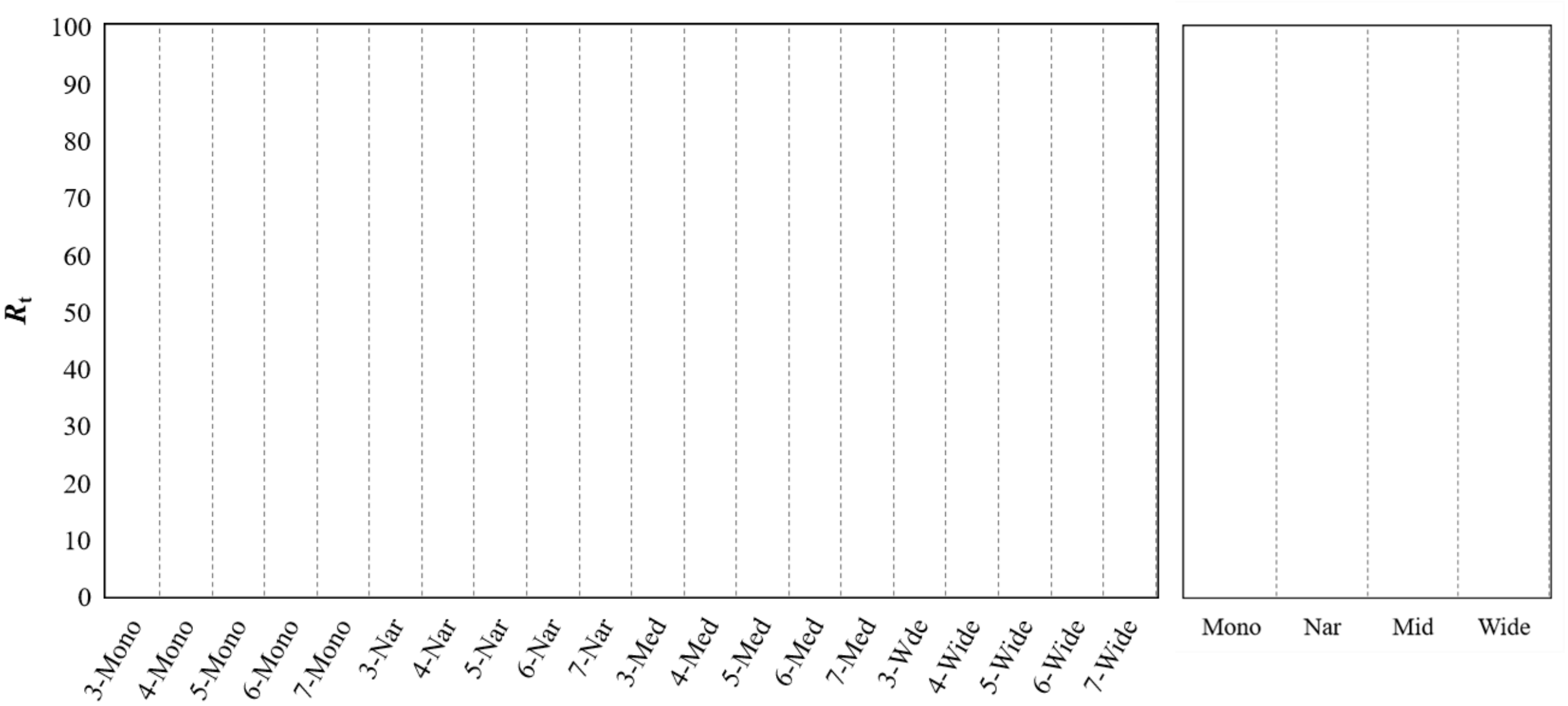
SPD set:


SPD Set
Spectral Width of Structural components (FWHM)
"Mono" (1 nm)
"Narrow" (2 to 11 nm)
"Medium" (20 to 50 nm)
"Wide" (50 to 100 nm)
SPD Subset
Structural Components ("Primaries")
3
4
5
6
7
25k SPDs
25k SPDs
25k SPDs
25k SPDs

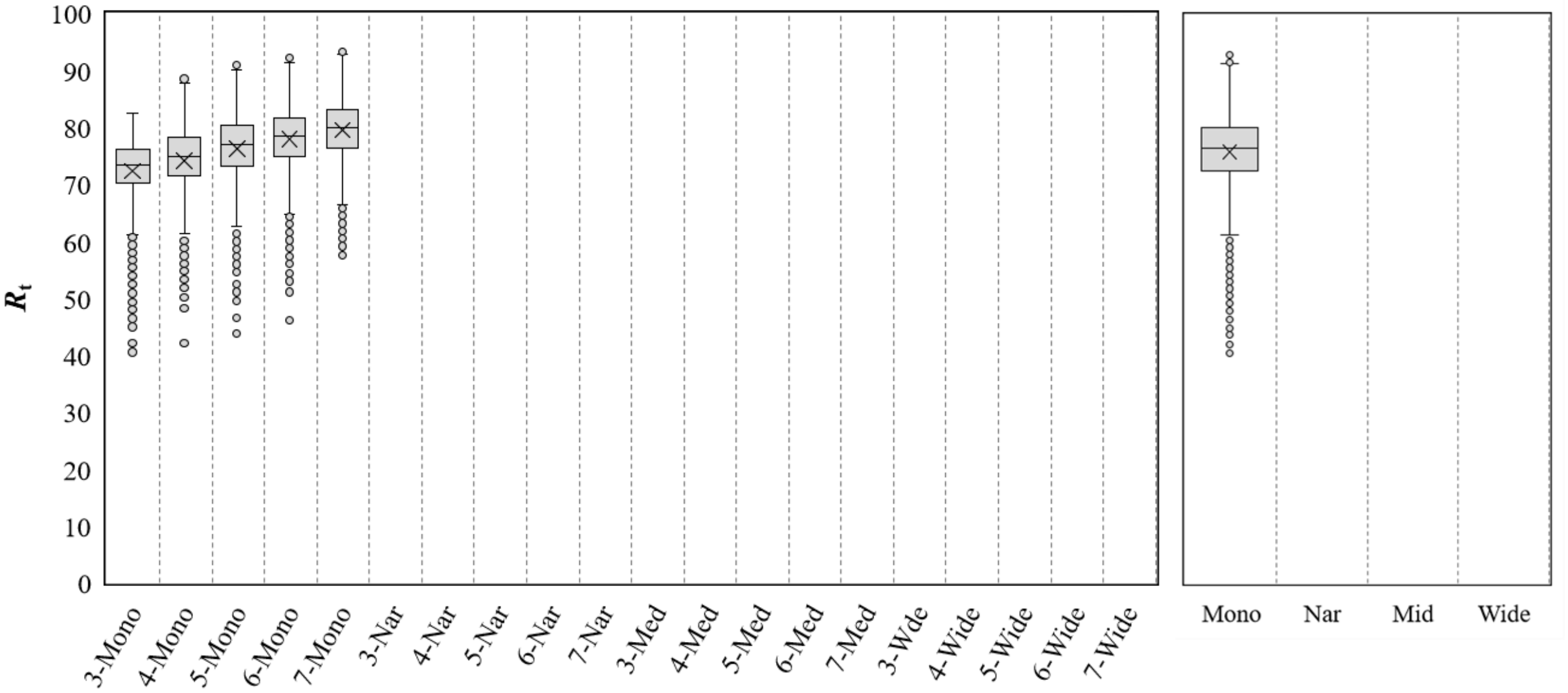
SPD set:


SPD Set
Spectral Width of Structural components (FWHM)
"Mono" (1 nm)
"Narrow" (2 to 11 nm)
"Medium" (20 to 50 nm)
"Wide" (50 to 100 nm)
SPD Subset
Structural Components ("Primaries")
3
4
5
6
7
100k SPDs

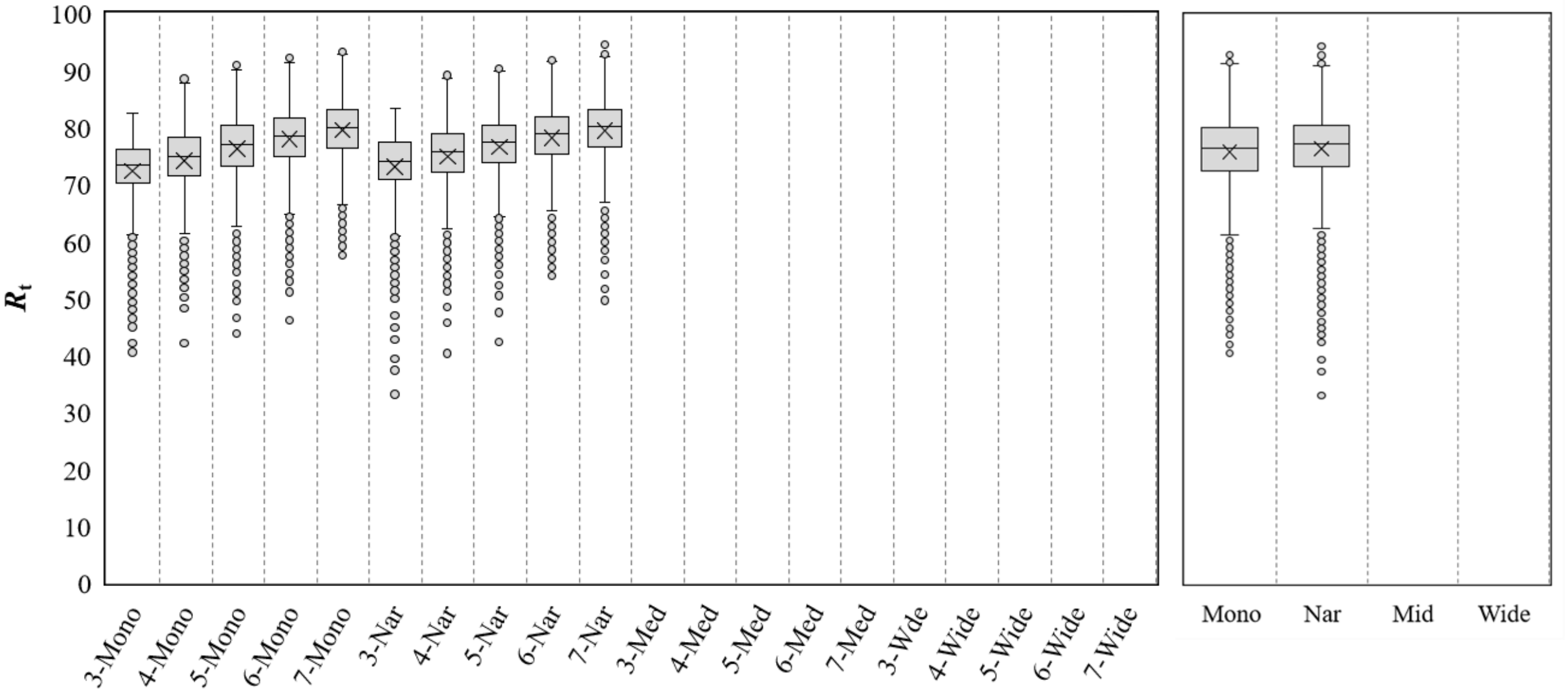
Results: R_t


100
90
80
70
60
50
40
30
20
10
0
R_t
3-Mono
4-Mono
5-Mono
6-Mono
7-Mono
3-Nar
4-Nar
5-Nar
6-Nar
7-Nar
3-Med
4-Med
5-Med
6-Med
7-Med
3-Wde
4-Wide
5-Wide
6-Wide
7-Wide
Mono
Nar
Mid
Wide

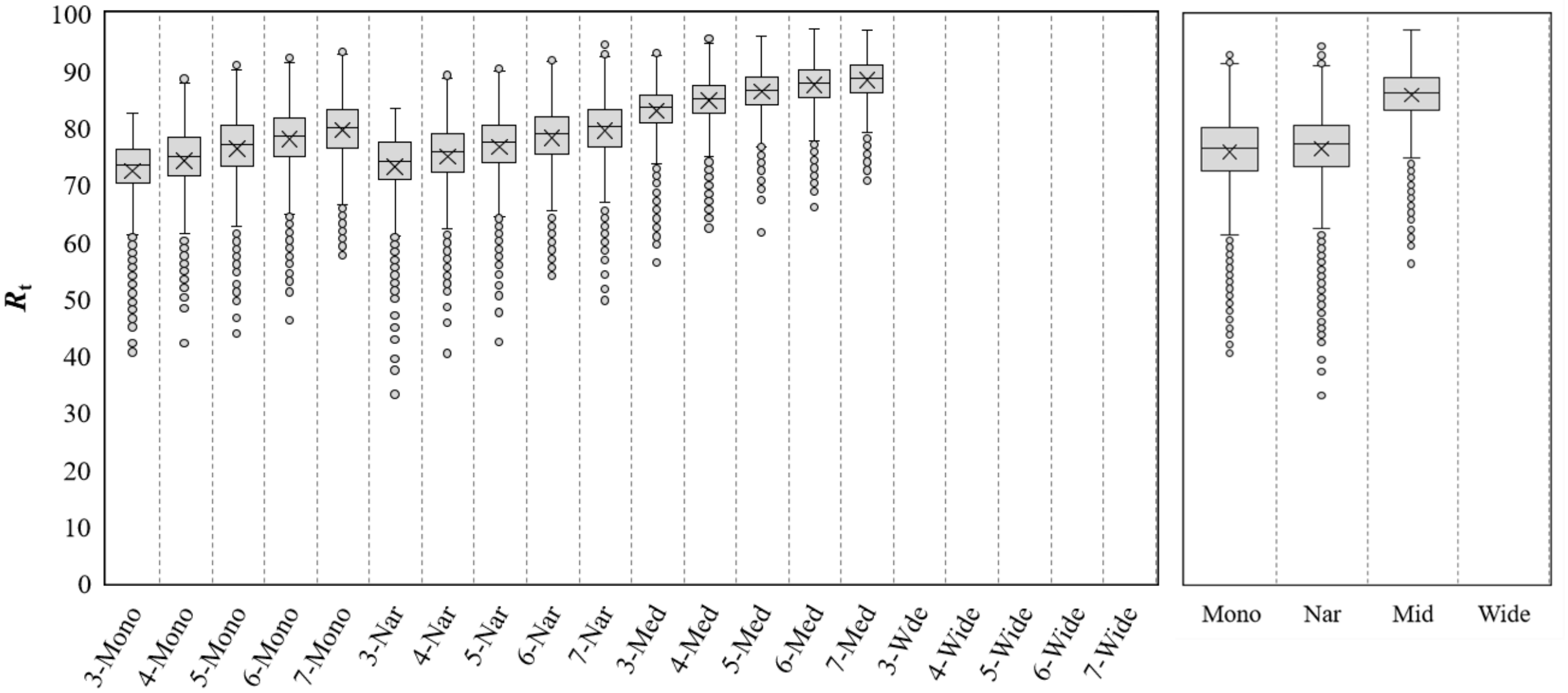
Results: R_t


100
90
80
70
60
50
40
30
20
10
0
R_t
3-Mono
4-Mono
5-Mono
6-Mono
7-Mono
3-Nar
4-Nar
5-Nar
6-Nar
7-Nar
3-Med
4-Med
5-Med
6-Med
7-Med
3-Wde
4-Wide
5-Wide
6-Wide
7-Wide
Mono
Nar
Mid
Wide

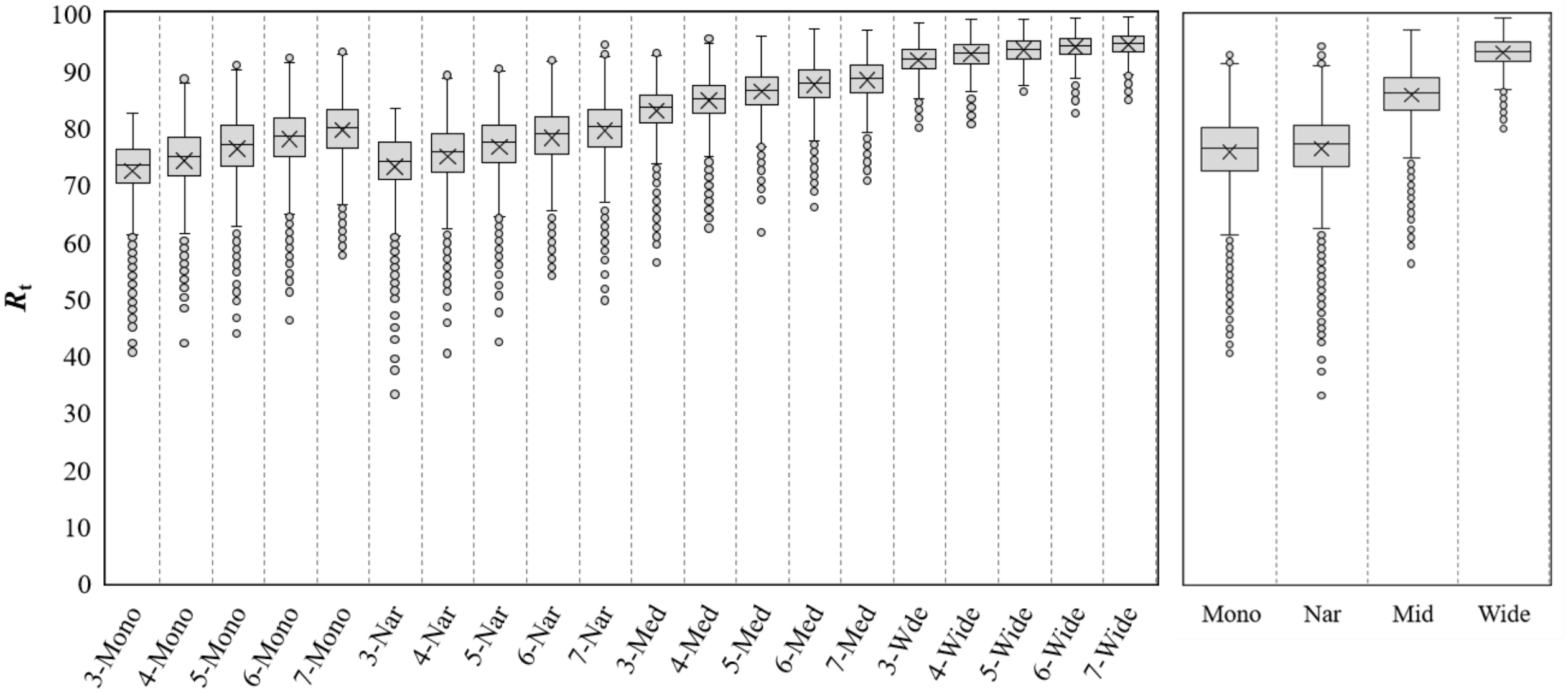
Results: R_t


100
90
80
70
60
50
40
30
20
10
0
R_t
3-Mono
4-Mono
5-Mono
6-Mono
7-Mono
3-Nar
4-Nar
5-Nar
6-Nar
7-Nar
3-Med
4-Med
5-Med
6-Med
7-Med
3-Wde
4-Wide
5-Wide
6-Wide
7-Wide
Mono
Nar
Mid
Wide

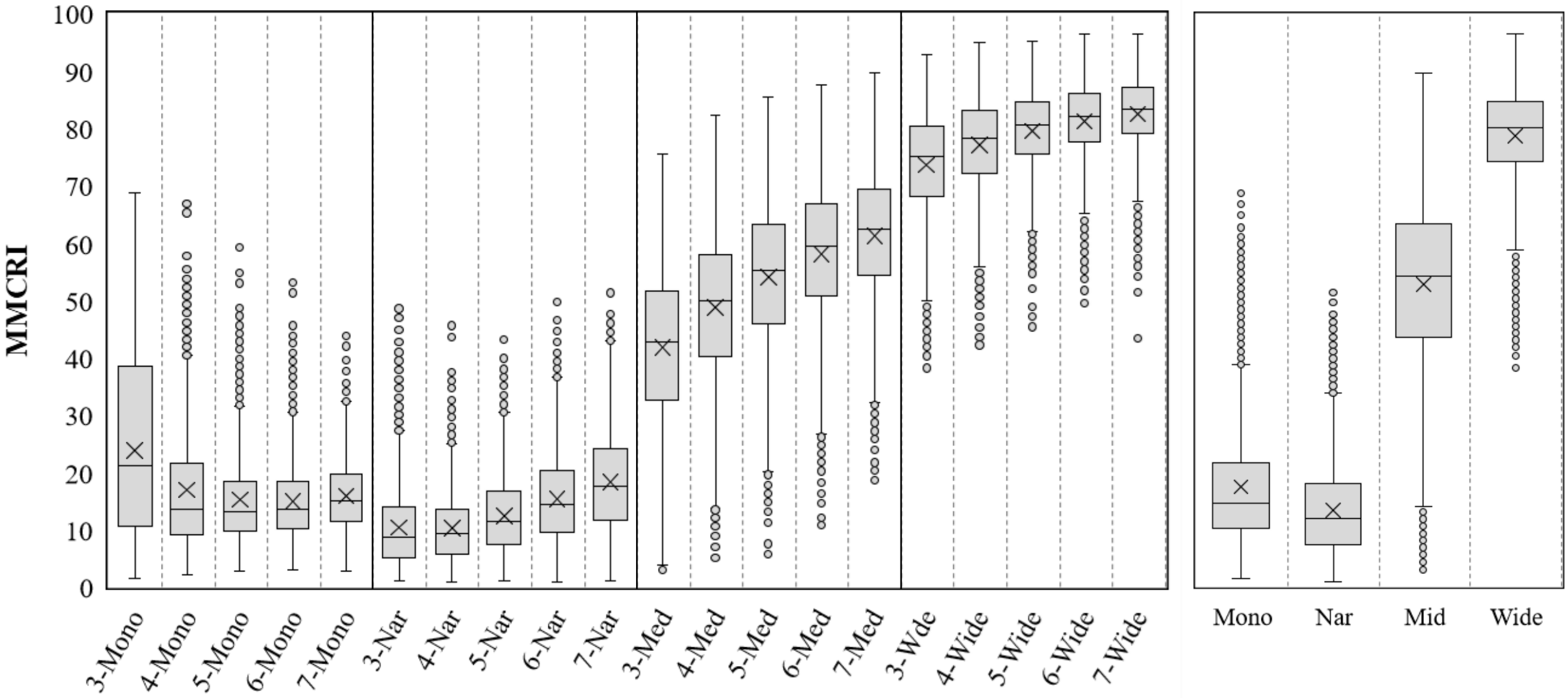
Results: R_t


R_t
100
90
80
70
60
50
40
30
20
10
0
3-Mono
4-Mono
5-Mono
6-Mono
7-Mono
3-Nar
4-Nar
5-Nar
6-Nar
7-Nar
3-Med
4-Med
5-Med
6-Med
7-Med
3-Wde
4-Wide
5-Wide
6-Wide
7-Wide
Mono
Nar
Mid
Wide

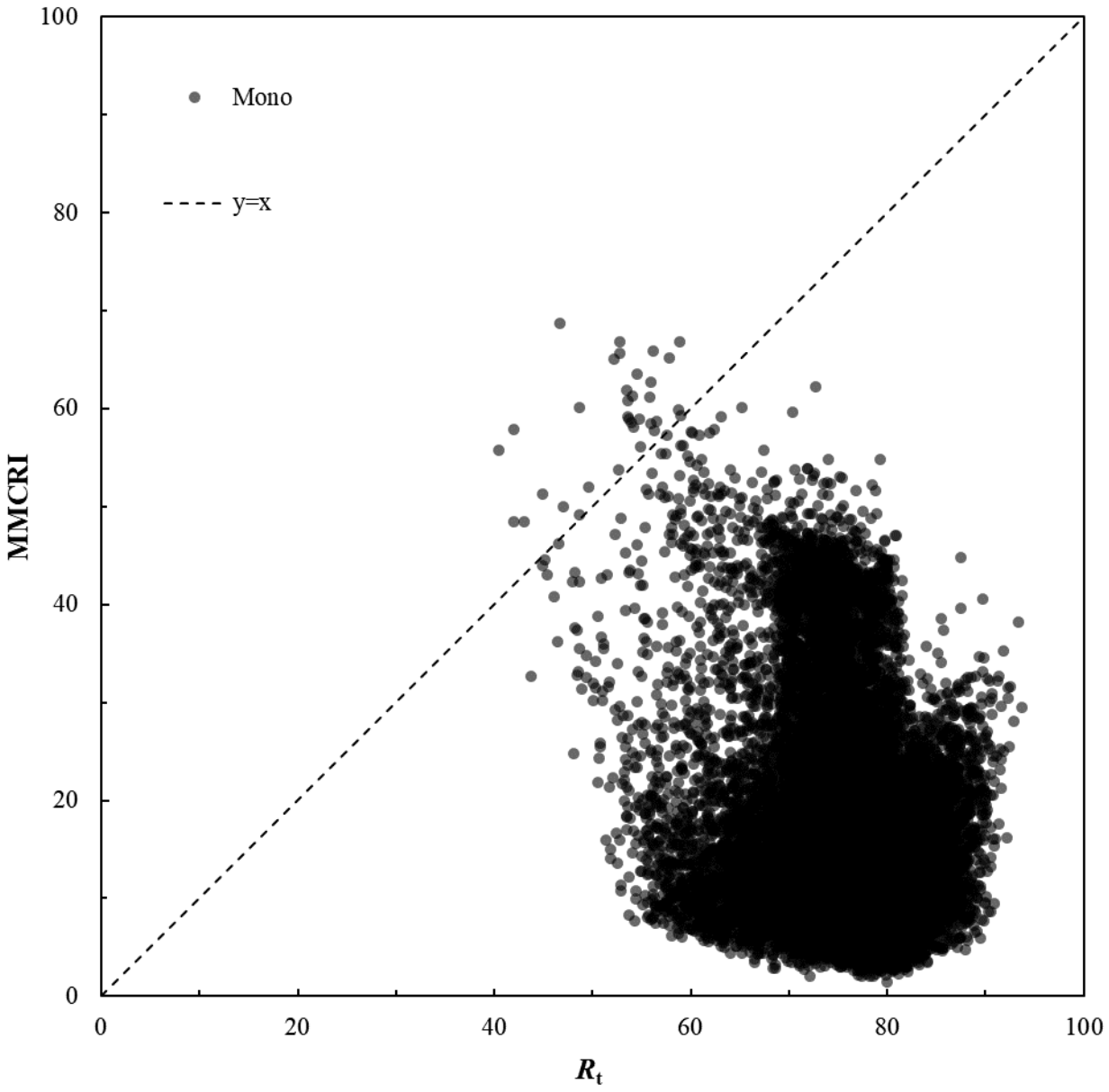
Results: R_t


100
90
80
70
60
50
40
30
20
10
0
R_t
3-Mono
4-Mono
5-Mono
6-Mono
7-Mono
3-Nar
4-Nar
5-Nar
6-Nar
7-Nar
3-Med
4-Med
5-Med
6-Med
7-Med
3-Wde
4-Wide
5-Wide
6-Wide
7-Wide
Mono
Nar
Mid
Wide

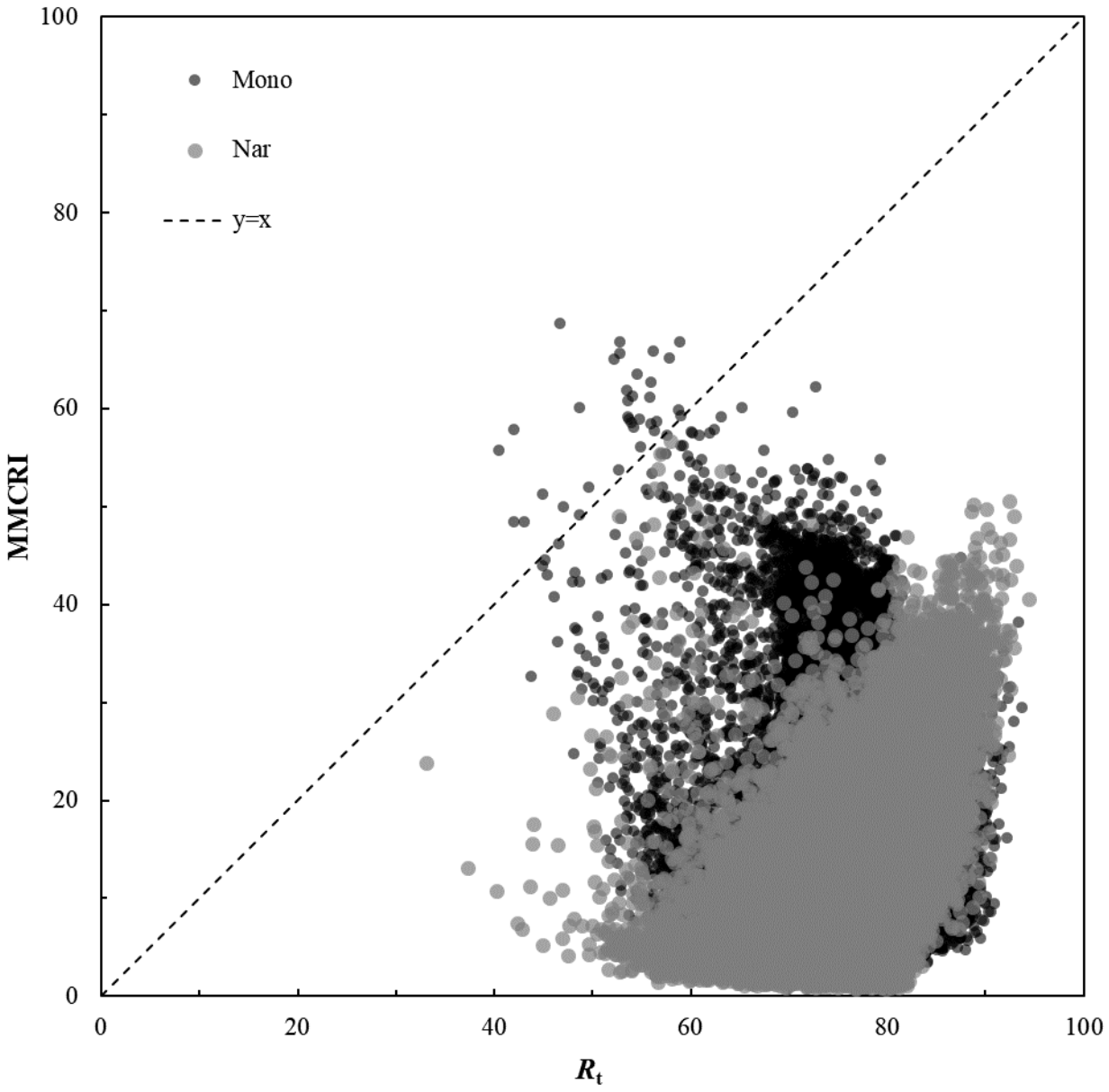
Results: MMCRI



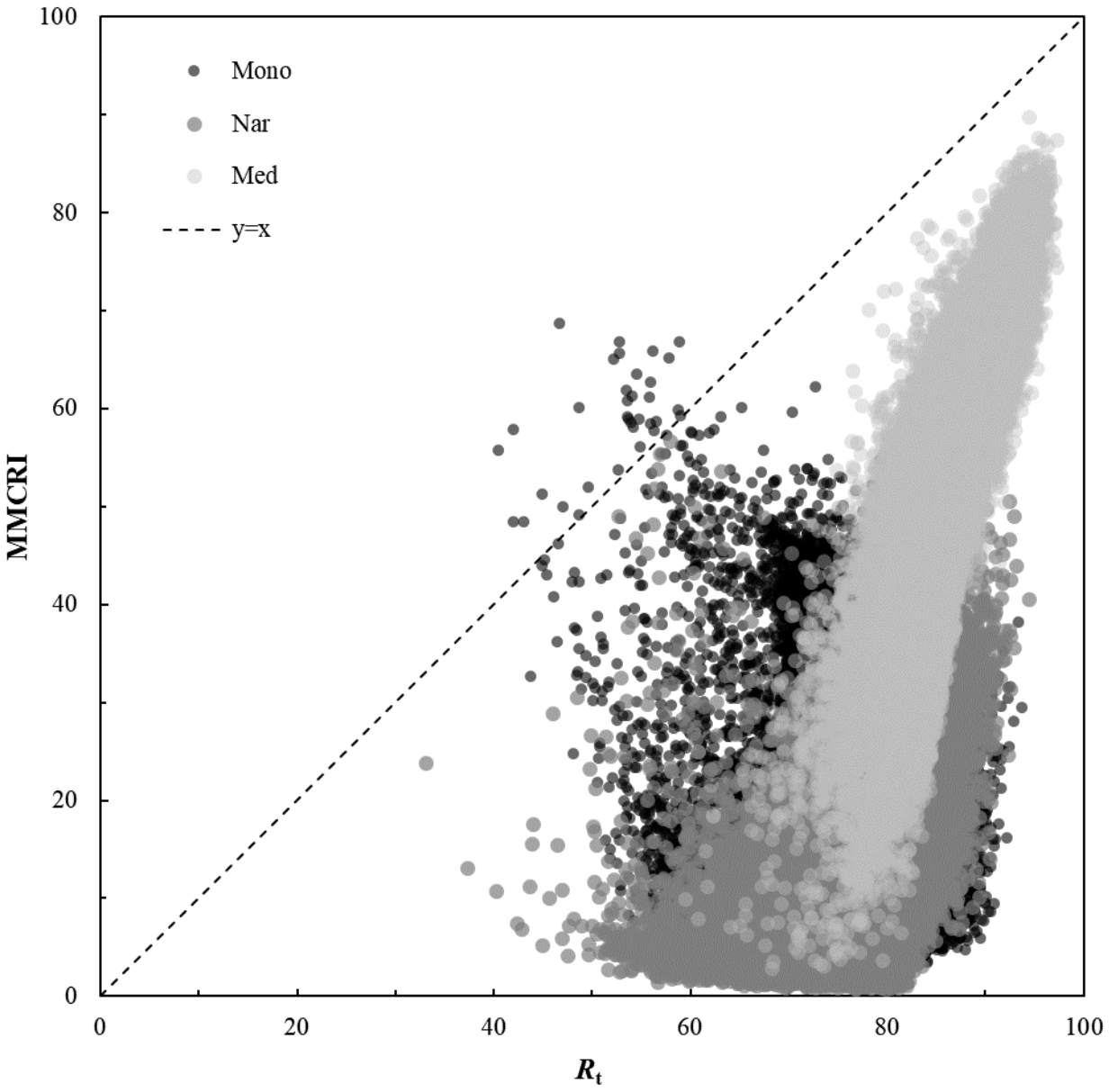
Results: comparison



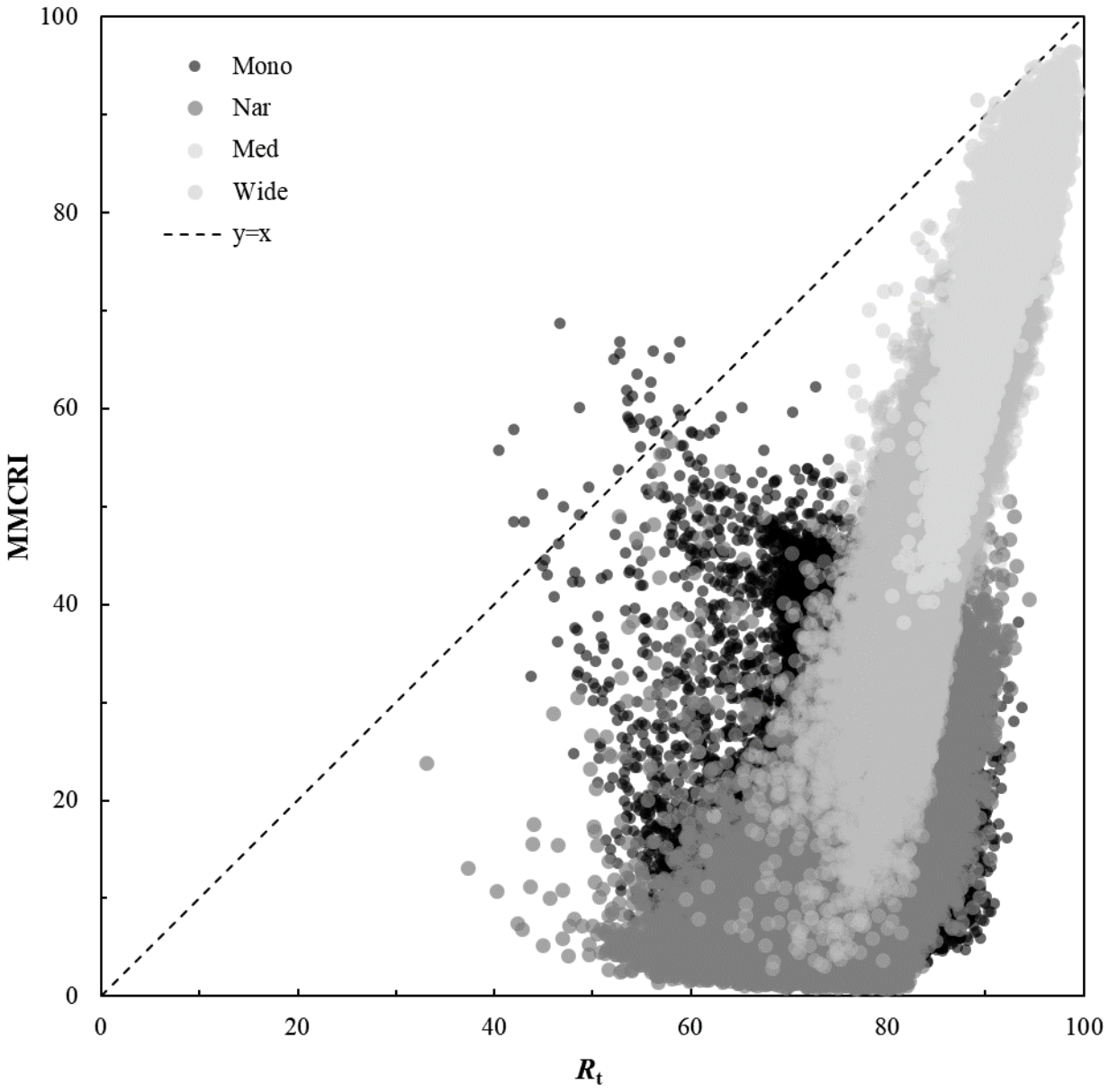
Results: comparison



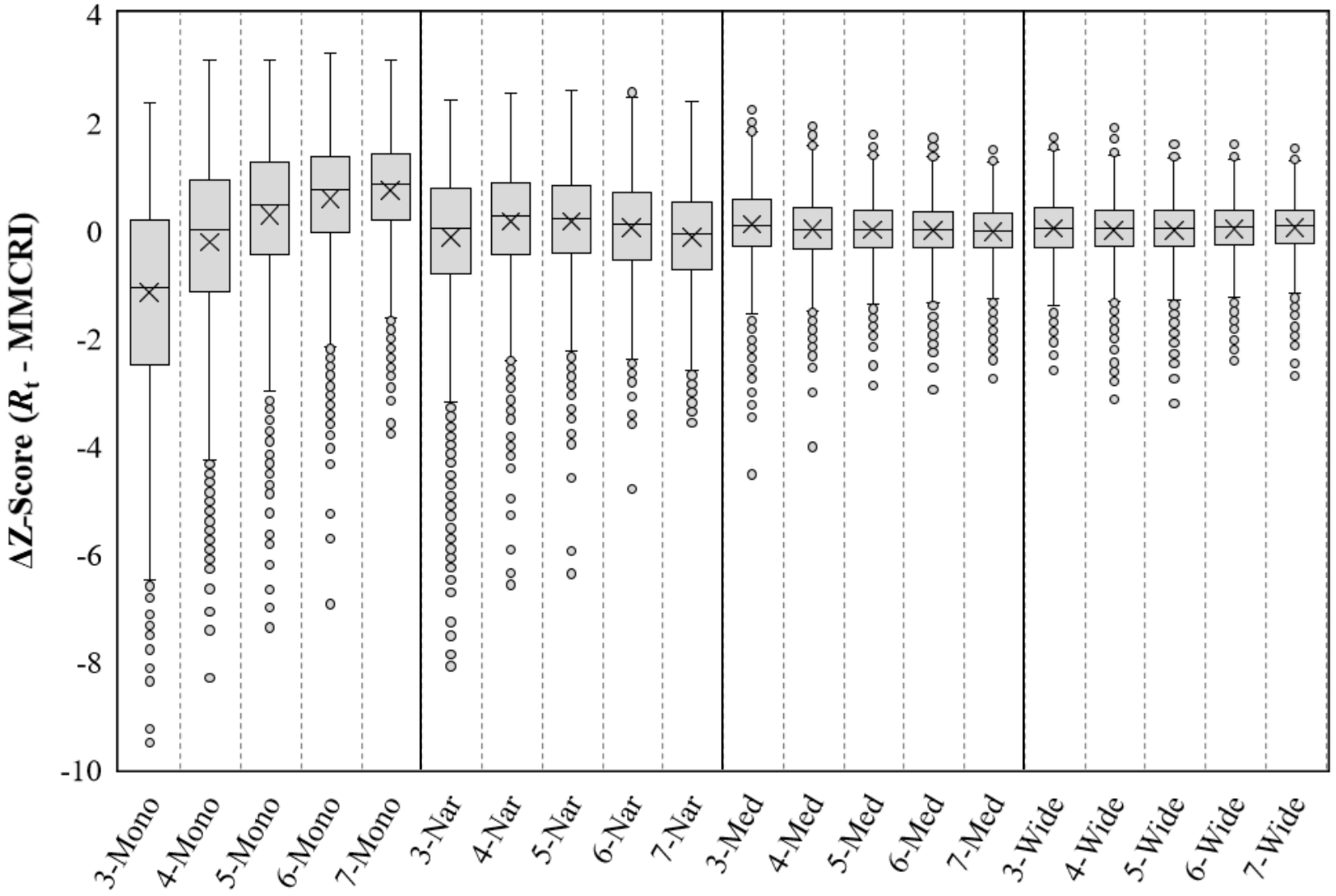
Results: comparison

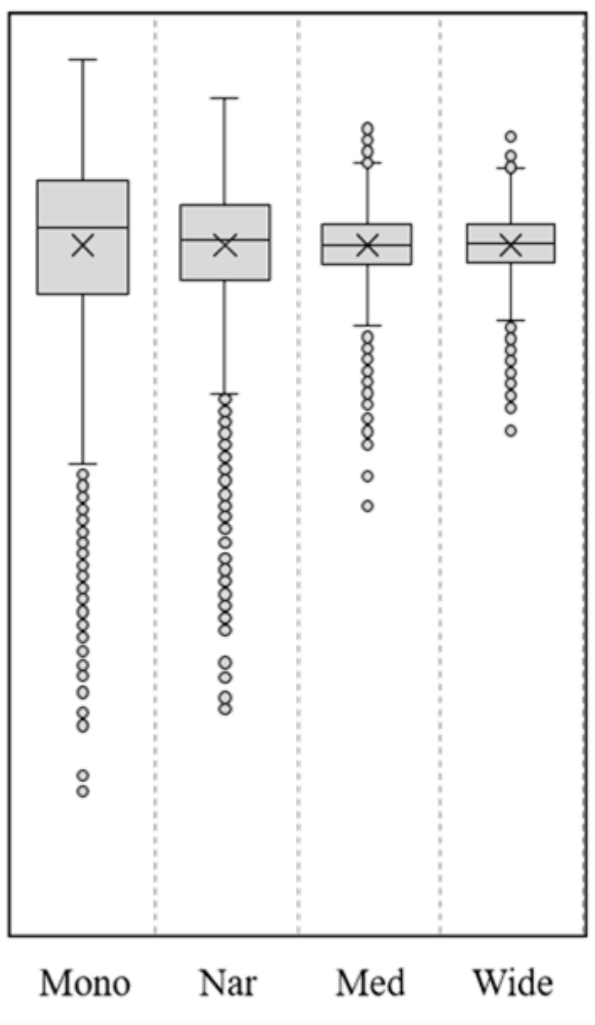


Results: comparison



Results: comparison





Results: characterization of SPDs

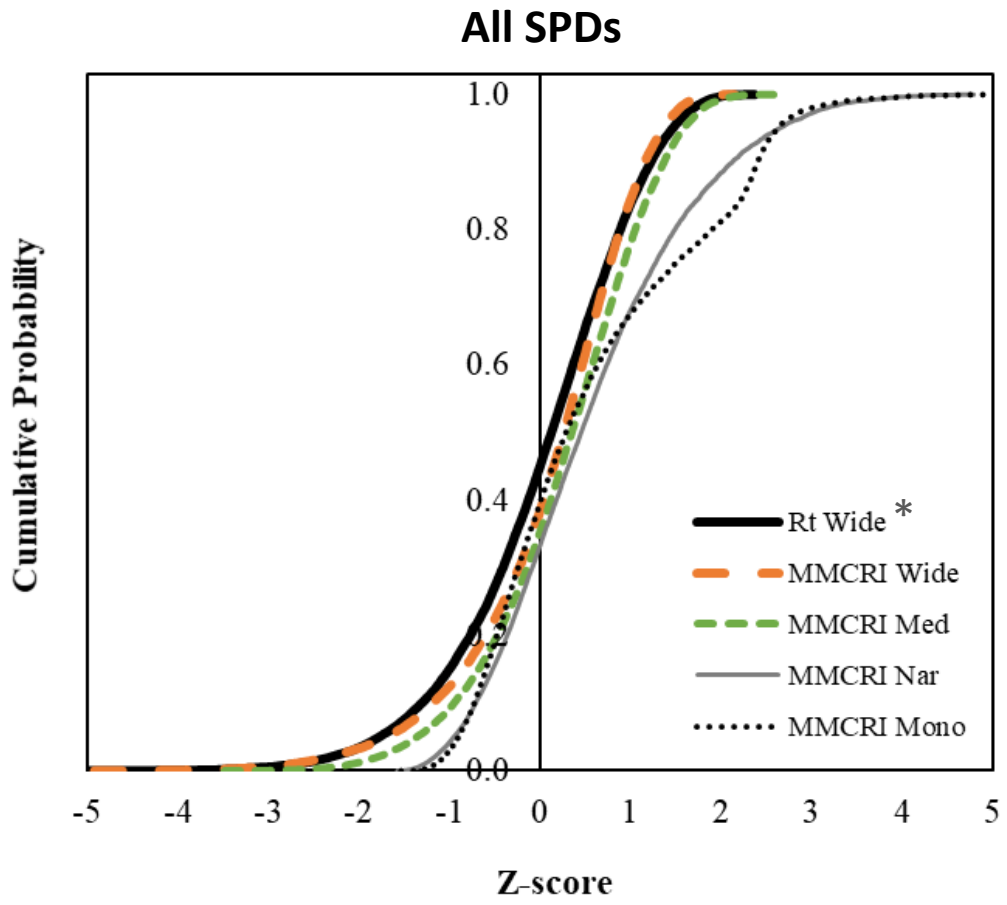
Two-sample Kolmogorov–Smirnov test (K-S)

a nonparametric test of the equality of continuous one-dimensional probability distributions,

H_0: the two samples are drawn from the same distribution

H_0 (rephrase): R_t and MMCRI are equivalent assessments of illuminant-induced metameric mismatch.

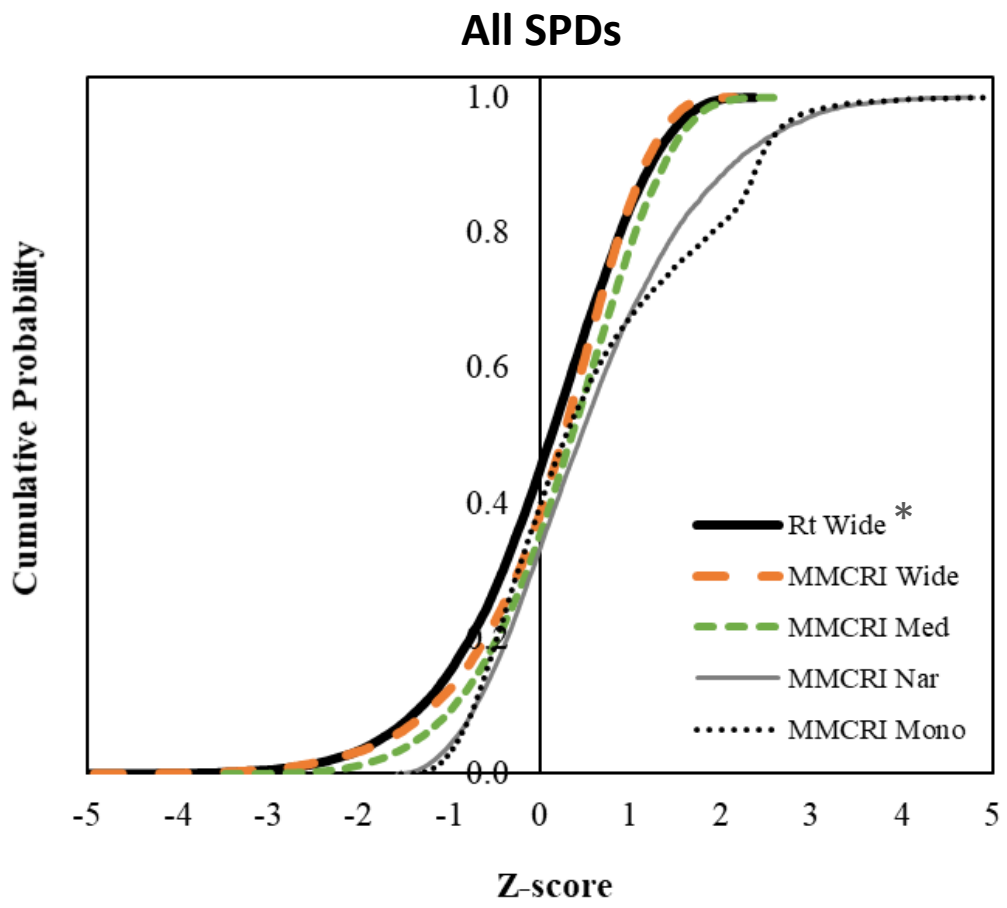
Results: K-S test

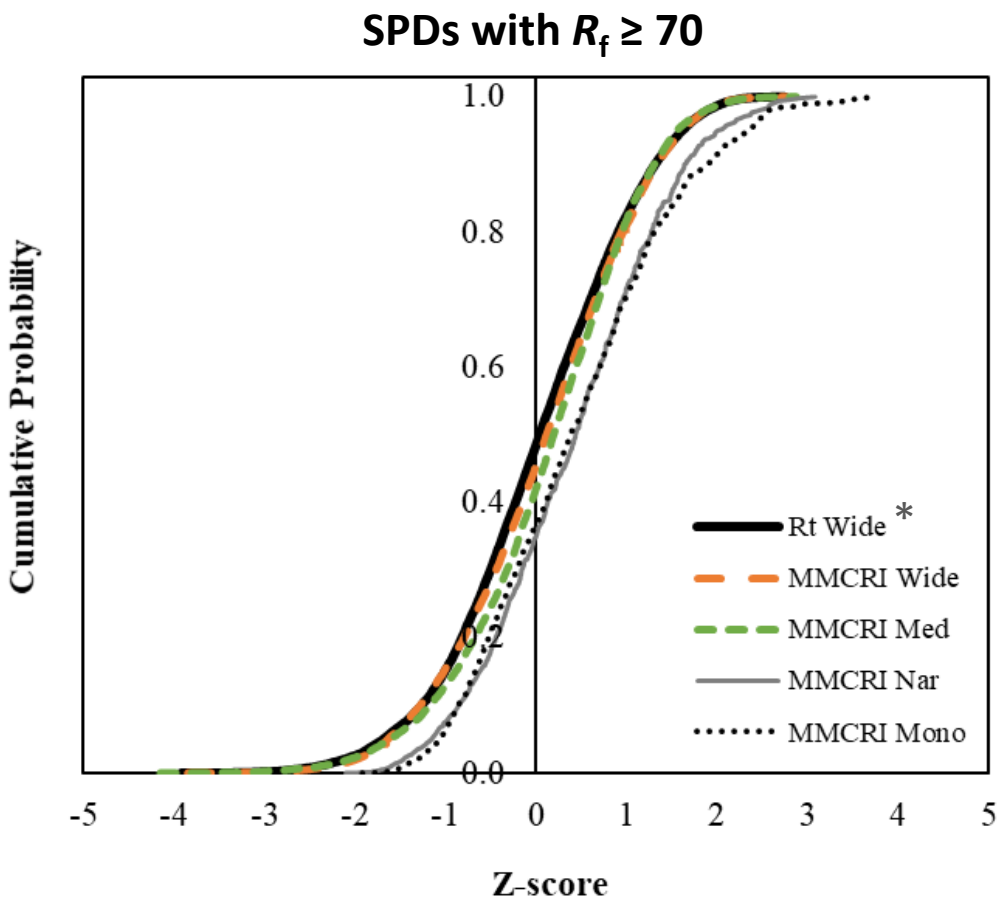


***p* < 0.0001 for all comparisons**

* The distributions for R_t nearly overlap, so only the distribution for the Wide SPD set is shown to avoid clutter.

Results: K-S test





$p < 0.0001$ for all comparisons

* The distributions for R_t nearly overlap, so only the distribution for the Wide SPD set is shown to avoid clutter.

Discussion

Wavelength range stability

MMCRI varies substantially as a function of the wavelength range of an SPD. R_t much less so.

Computational Errors

MMCRI unpredictably produces errors in the computation of some SPDs. R_t does not.

Computation Time

With default settings, MMCRI takes 600 times as long to compute at R_t.

Determinism

With default settings, MMCRI is not deterministic. R_t is.

Sample Set

MMCRI uses mathematical (square) SRDs that are not found in the real world. R_t uses SRFs from real objects.

Looking forward

What is the role of SRF shape in calculations?

-

Does metameric uncertainty vary throughout color space? (i.e., does neutral grey capture everything?)

-

What is the role of metameric uncertainty in practice?

-

What wavelength range is most important?

-

Psychophysical experimentation. How does one or both measures relate to predicting mismatch? (Statistical vs. Practical Difference)

-

Conclusion

- Generated SPD set strategically varying spectral width and number of structural spectral components
- R_t and *MMCRI* behave similarly for broadband SPDs, but the relationship diminishes for more narrowband SPDs.
- Importantly, significant KS tests suggest that R_t and *MMCRI* are significantly different quantifications of metameric mismatch
- We have demonstrated some characteristics of MMCRI that are potentially problematic for use in applied lighting (see previous slide).
- We believe that measures of color rendition should use a sample set that is balanced in color space, wavelength space, and is comprised of real objects.
- Future work in this are should include psychophysical experimentation.

Thank you!

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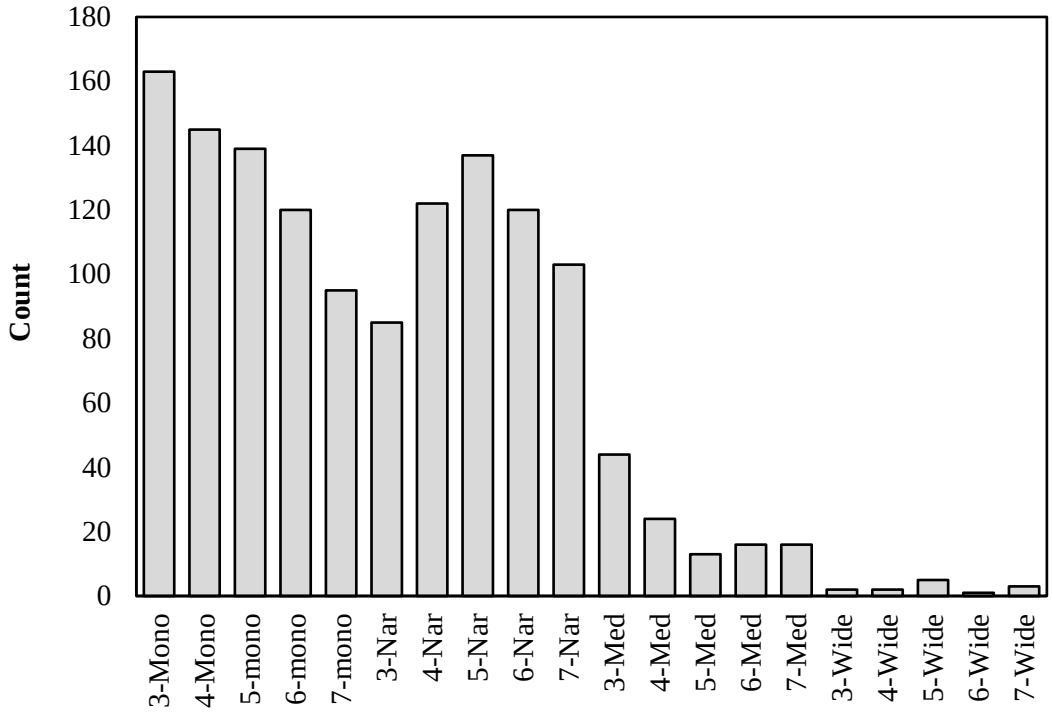
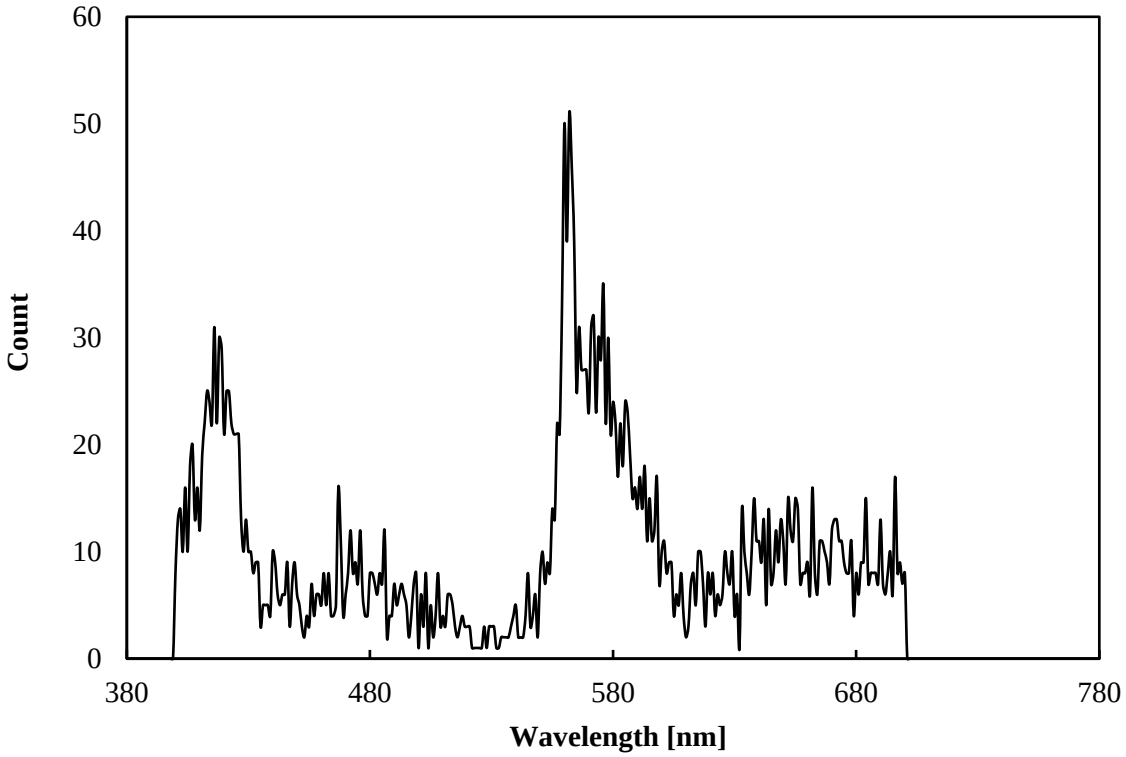
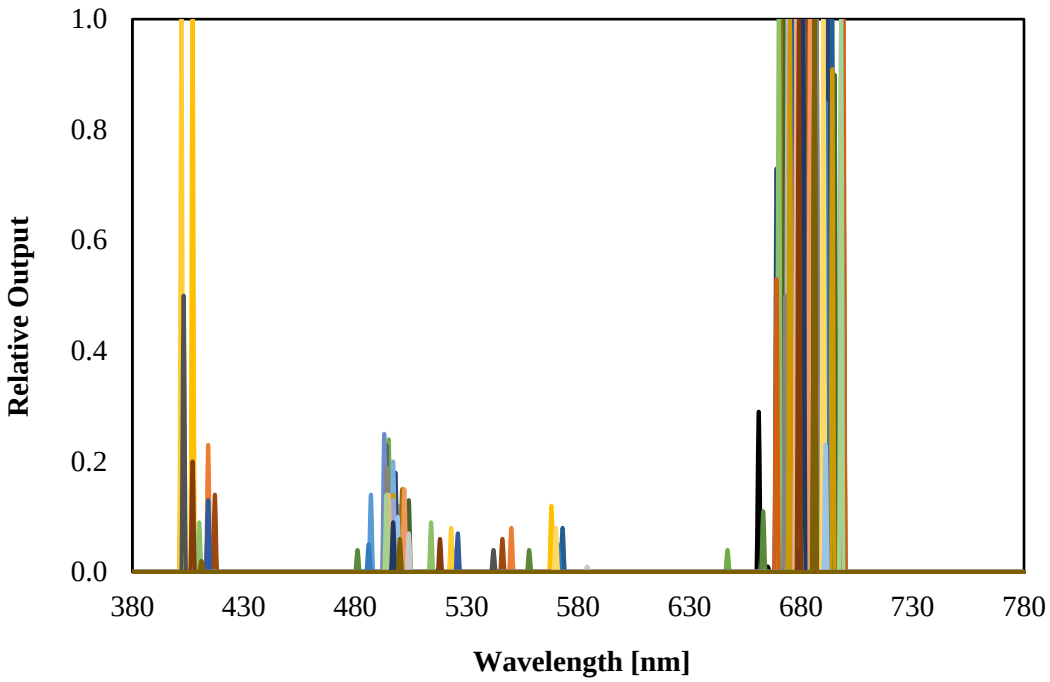
REFERENCE SLIDES

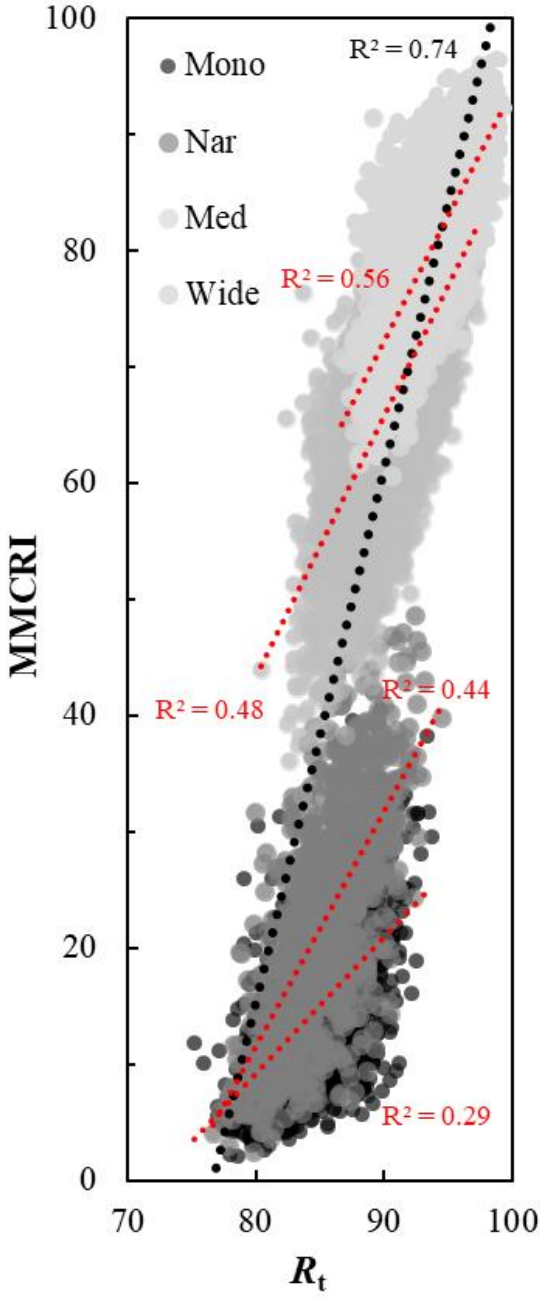
(Top) The number of SPDs from each SPD subset that produced an error during the MMCRI computation. On average, the number of errors is highest for SPDs with narrowband radiation and few primaries. (Bottom) The number of errored SPDs with maximum relative output at the specified wavelength. SPDs that errored during the MMCRI calculation have peak wavelengths concentrated near 560 nm, shorter than approximately 450 nm, and to a lesser extent longer than approximately 610 nm. The sharp cutoff at 400 and 700 nm is because the peak wavelengths of the generated SPDs were constrained between those two wavelengths.

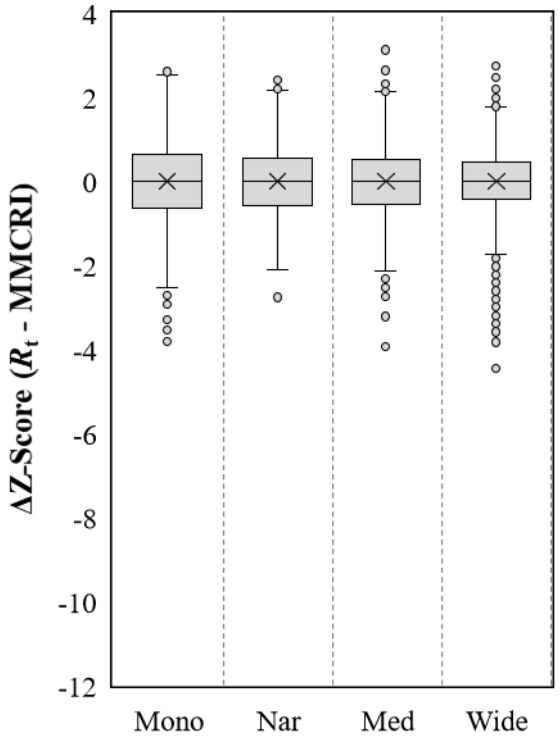




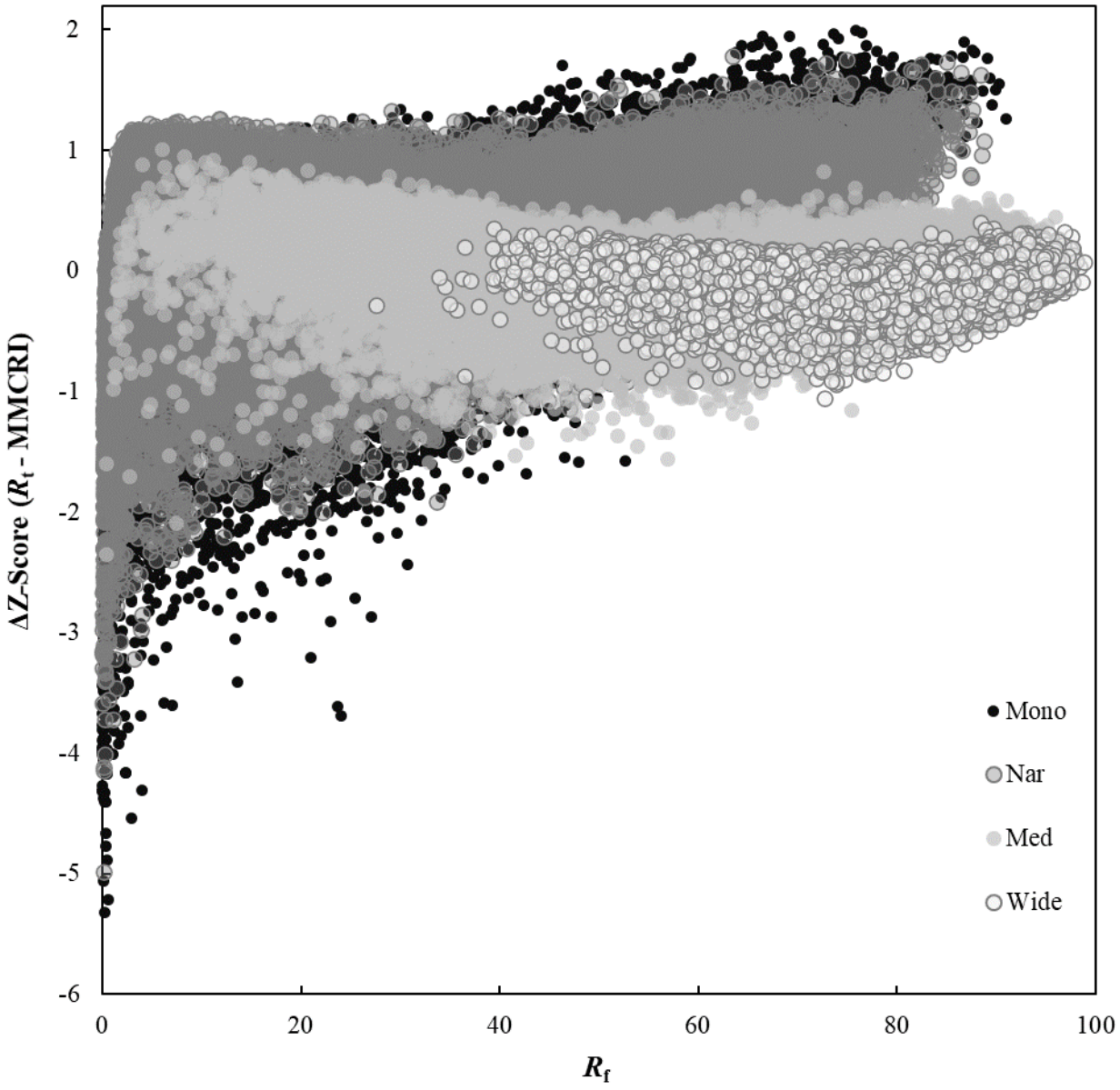
SPDs from Monochromatic subset which have disproportionately high value of MMCRI. Radiation in these SPDs is concentrated at the extents of the visible spectrum.



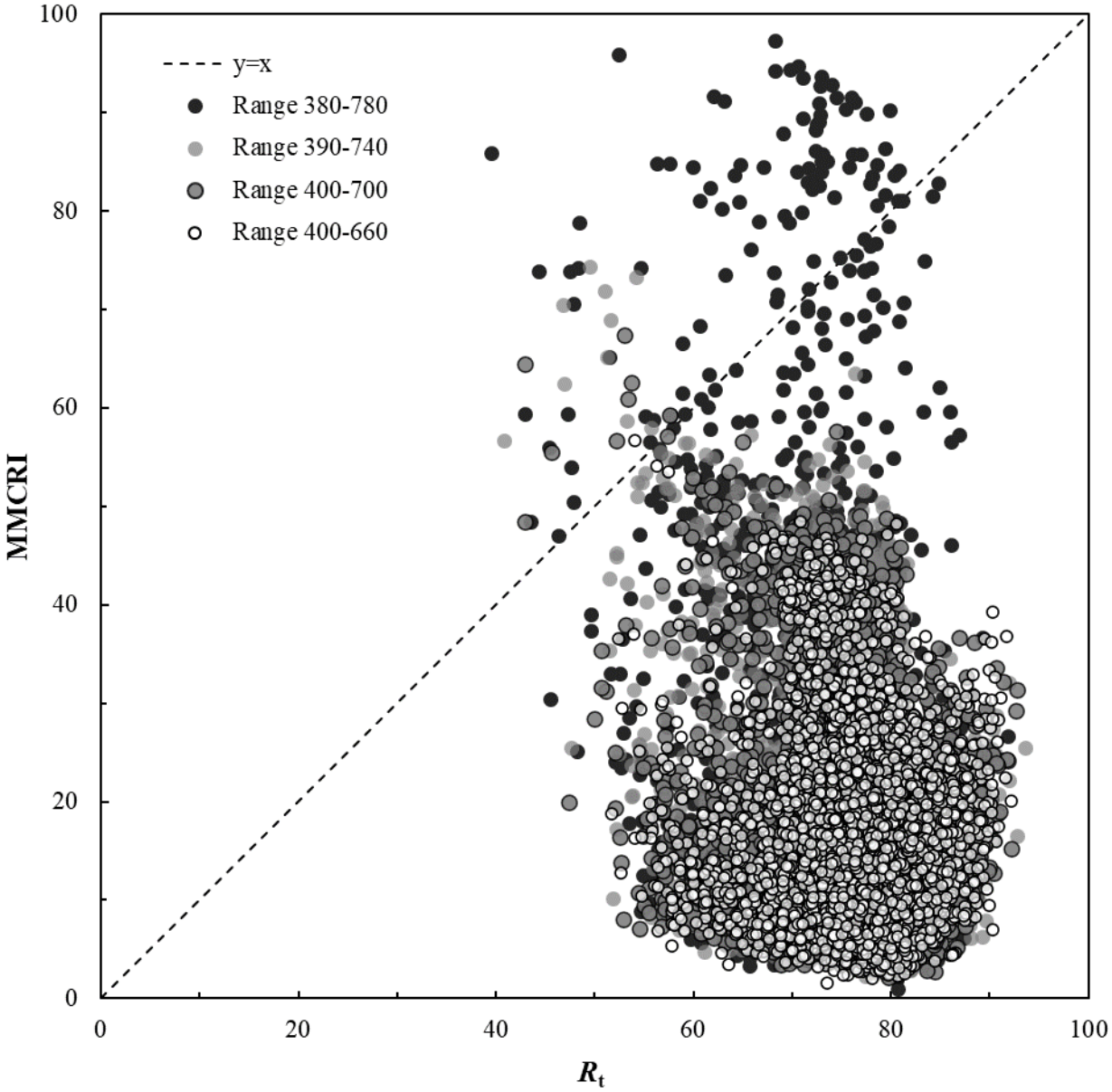




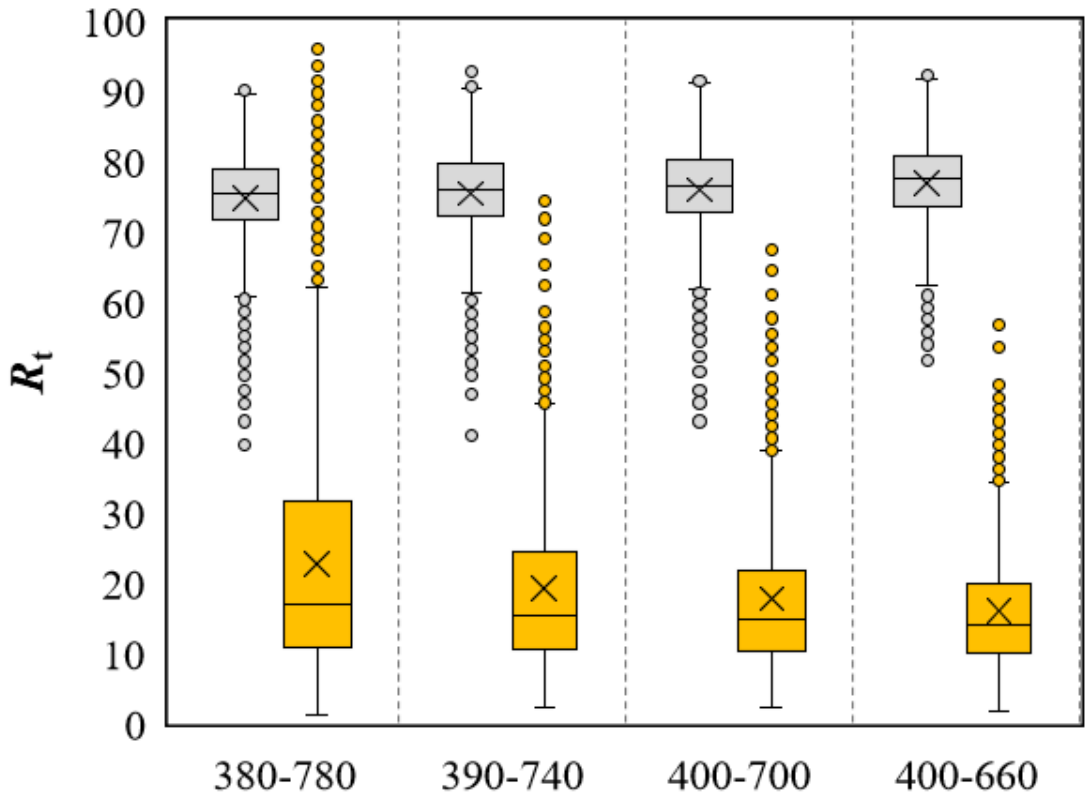
(Left) MMCRI versus R_t for light sources with $R_f \geq 70$. When constraining to $R_f \geq 70$, the relationship between MMCRI and R_t is tighter and there are no SPDs with MMCRI values disproportionately higher than other SPDs in their set. (Right) The difference between the z-scores of R_t and MMCRI as a function of SPD set. The differences between R_t and MMCRI agree more strongly for the Med and Wide sets than for the Nar and Mono sets.



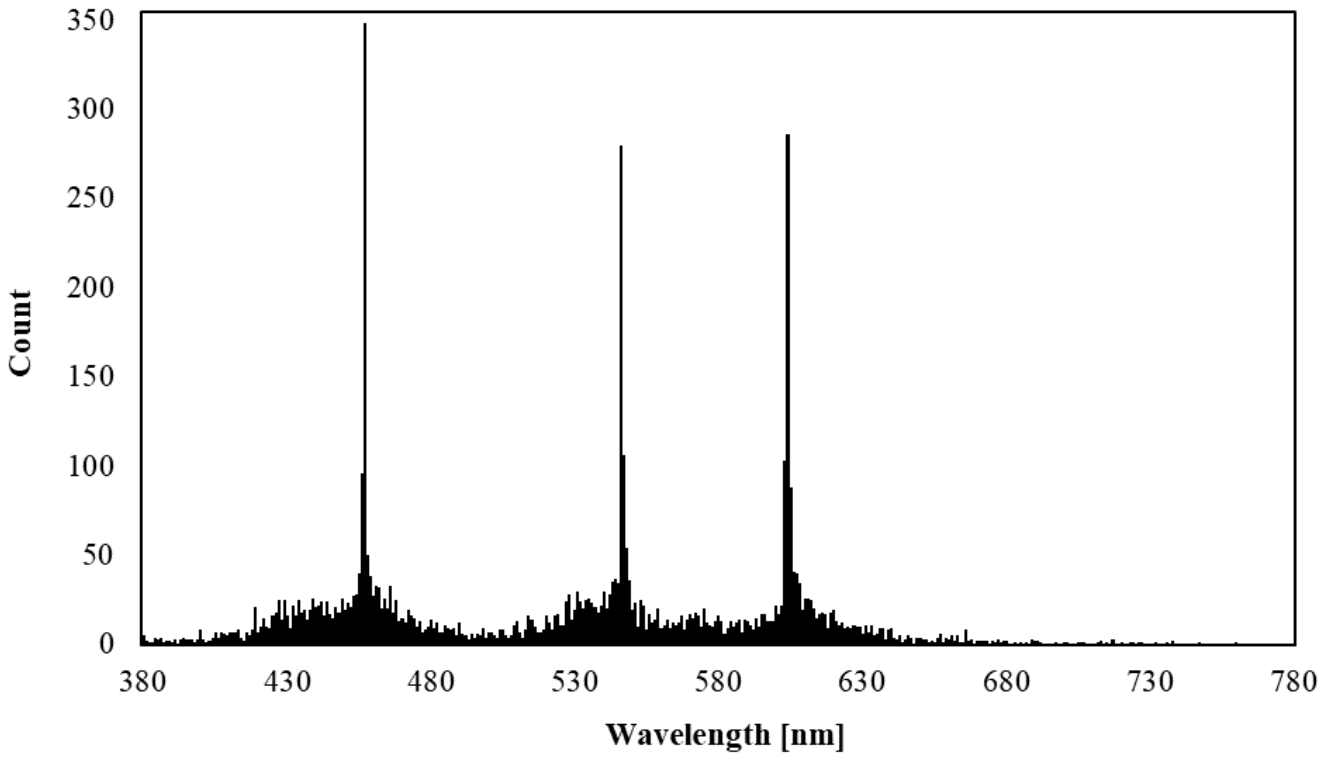
(Top) The difference between the z-scores of R_t and MMCRI as a function of IES TM-30 R_f. The difference between R_t and MMCRI is larger for narrower spectra, expressed by the large variation in z-scores for those SPD sets. The difference is particularly large for the Narrow and Monochromatic SPD sets, suggesting that R_t and MMCRI characterize these SPDs differently.



Scatterplot of MMCRI versus R_t for four monochromatic SPD sets generated according to the parameters of Table 2 but with varying spectral ranges. The spread of achievable MMCRI values decreases as the spectral range is narrowed. There are also more SPDs that appear to have disproportionately large values of MMCRI with wider spectral ranges.



Boxplot for R_t (top) and MMCRI (bottom) for four monochromatic SPD sets generated according to the parameters of Table 2 but with varying spectral ranges. MMCRI and R_t both decrease as the spectral range is narrowed, though the variation is larger for MMCRI. The large variation in MMCRI with the wider spectral range is notable, with achievable values as high as 97.



$$MMVI = \frac{vol.\,of\ MMV}{vol\ of.\,OCS\ (test\ ill.)}$$

The number of times (y-axis) the indicated wavelength (x-axis) was included as a transition wavelength for each of the five transitions in the 1,000 SRFs of the MMCRI computation. Transition wavelengths are disproportionately high near 457, 546, and 604 nm which are consistent with the crossover wavelengths of metamers documented by others [Thornton [1979], Ohta [1987], Bern [1990], Finlayson (2000)].