

# Supplementary Materials

## S1 Roadmap to multi-scale structural diversity quantification

Three parameters must be considered for the application of structural diversity entropy as a second-order texture metric: the inner and the outer scale (as discussed above), the  $\delta$  parameter, and the number of GLs. The results from this study suggest that  $\delta \in \{0, 1, 2\}$  is adequate for multi-scale feature detection, and also for regime-separation. Even though structural diversity entropy with  $\delta = 2$  was found to detect both line and patch features, i.e., hotspots, line features detected with  $\delta = 2$  were only visible within 95% quantiles. Reduced GL numbers facilitate the use of Shannon entropy with its unique and well-known properties, while high GL numbers ensure no loss of detail due to GL reduction. It appears that the upper limit for GL numbers is restricted only by computational capacity. The number of GLs and the size of the inner scale in Table S1 are suggested as orientation, not as exact values.

## ROADMAP TO MULTI-SCALE STRUCTURAL DIVERSITY

**Scales:** Combining regional inner scales and the domain as the outer scale optimizes multi-scale feature detection. Multi-scale structural diversity features reveal the underlying diverse structure that drives the emergence of scale-specific features. Smoothing, caused by moving windows, disappears when prior information from a larger scale is included to detect multi-scale line features with a beta-binomial model in an empirical Bayesian approach. Regime-separation can be achieved with regional and also local inner scales, and the latter detects correspondent structure, which tends to be obscured by small-scale detail.

**Metric:** Using structural diversity entropy with  $\delta \in \{0, 1, 2\}$  enables the detection of both multi-scale line features and hotspots, i.e., patches, and facilitates interpretation along spatial disorder, uncertainty and value gradient intensity. Shannon entropy can also be translated to  $\beta$  structural diversity, and structural diversity entropy with  $\delta \in \{1, 2\}$  to  $\gamma$  structural diversity.

**Gray levels:** Using data both with and without reduced numbers of GL enables the detection of multi-scale features and also regime-separation. Structural diversity maps of data with high GL numbers can reveal correspondent structure when 95% quantiles are displayed.

Table S1: Suggested method specifications to quantify multi-scale structural diversity with structural diversity entropy (SDE) and a nested scales approach.

Multi-scale structure	Metric specification	Gray levels	Inner scale	Outer scale
Line features	SDE, $\delta \in \{0, 1, 2\}$	10	7 & 13	$\mathcal{D}$ / large blocks
Hotspots	SDE, $\delta = 2$	100	13	$\mathcal{D}$ / large blocks
Regime-separation	SDE, $\delta \in \{0, 1\}$	100	3, 7 & 13	$\mathcal{D}$ / large blocks
Local structure	SDE, $\delta \in \{0, 1, 2\}$	10 & 100	3	$\mathcal{D}$ / large blocks

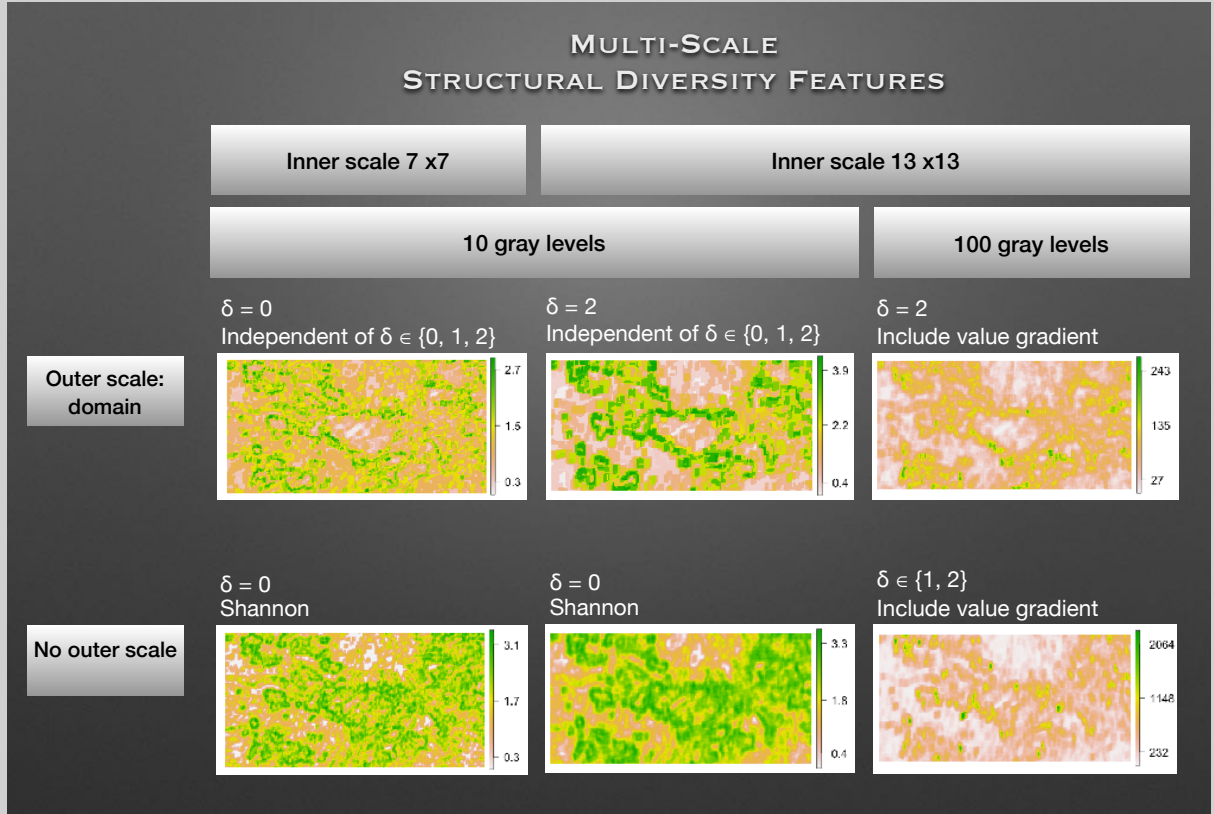


Figure S1: Multi-scale and scale-specific structural diversity features in NDVI data.

## S2 Entropy calculation on a small sample window, considering different angles and distance one

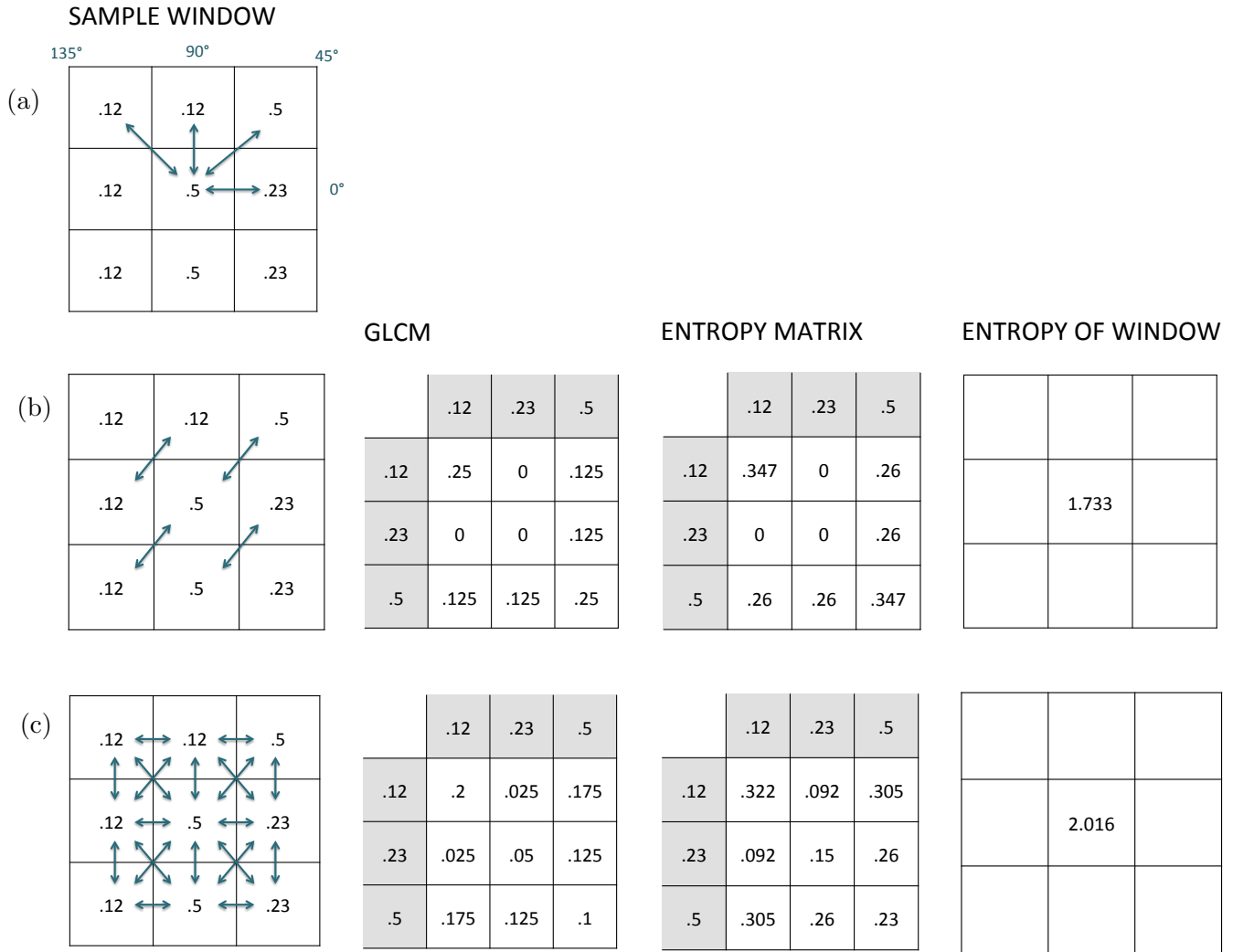


Figure S2: Left: Sample window  $MW_u$  and different options to consider angles. Middle panels: resulting GLCMs and entropy matrices. Right: final entropy value assigned to center pixel of  $MW_u$  (a) Sample window to exemplify different angles that can be considered (in both directions) (b) Considering angle  $45^\circ$  (c) Considering all angles. This figure is copied from (Schuh *et al.*, under review)

### S3 Metric specifications, ideal scale and GL ranges for scale-specific structural diversity feature detection

Table S2: Ideal GL and WSL ranges to detect scale-specific features. This table is modified from (Schuh *et al.*, under review).

Metric	Weight	Feature type	Ideal GL range	Ideal WSL range
All metrics	$\delta \in \{0, 1, 2\}$	borders	2	3 – 5
Structural diversity entropy	$\delta = 0$	line features	7 – 15	5 – 11
Structural diversity entropy	$\delta = 1$	patches	4 – max	7 – 19
Structural diversity entropy	$\delta = 2$	borders	7 – max	3 – 5
Structural diversity entropy	$\delta = 2$	hotspots	4 – max	7 – 19

### S4 Block size based on feature-inherent scales estimated with semi-variograms

We did not choose block size to be exactly two times the effective range in all cases, because then we would have tested  $WSL_B$  32 and 35 and also 80 and 84, which we expected to make no difference. Therefore, we chose 35 and 84 as representative  $WSL_B$ .

Table S3: Typical diversity features and their associated scales in unit pixels, which equals km. This table is modified from (Schuh *et al.*, under review).

Feature type	WSL to detect largest typical features	Effective range of largest typical features	WSL of block
Line features	11	27	54
Borders	5	16	35
Hotspots	19	40	84
Patches	19	42	84

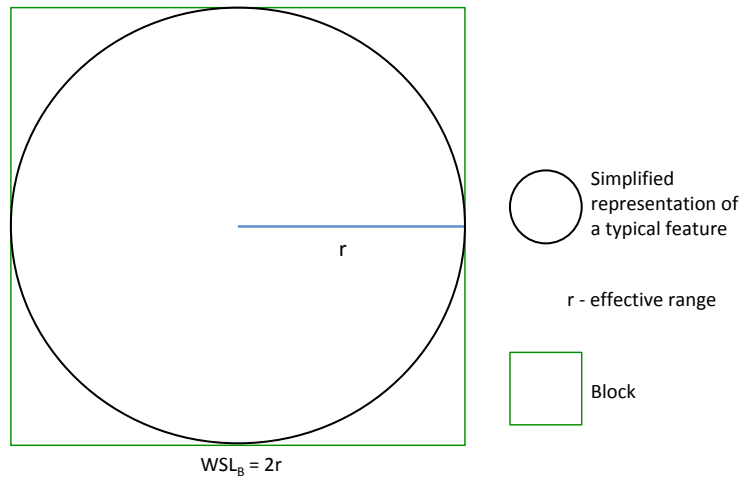


Figure S3: Simplified representation: block size based on the effective range of typical structural diversity features.



## S5 Complete experimental design - NDVI data.

Table S4: Structural diversity entropy (SDE),  $\delta \in \{0, 1, 2\}$ , 10 & 100 GL.

Structural diversity entropy (SDE)	WSL <sub>I</sub>	WSL <sub>O</sub>	WSL <sub>B</sub>	$\mathcal{D}$	GL	compare with non- nested WSL
SDE, $\delta \in \{0, 1, 2\}$	3	7	–	–	10 & 100	3
SDE, $\delta \in \{0, 1, 2\}$	3	13	–	–	10 & 100	3
SDE, $\delta \in \{0, 1, 2\}$	3	19	–	–	10 & 100	3
SDE, $\delta \in \{0, 1, 2\}$	3	35	–	–	10 & 100	3
SDE, $\delta \in \{0, 1, 2\}$	3	–	35 (OL 10)	–	10 & 100	3
SDE, $\delta \in \{0, 1, 2\}$	3	–	54 (OL 15)	–	10 & 100	3
SDE, $\delta \in \{0, 1, 2\}$	3	–	72 (OL 19)	–	10 & 100	3
SDE, $\delta \in \{0, 1, 2\}$	3	–	84 (OL 22)	–	10 & 100	3
SDE, $\delta \in \{0, 1, 2\}$	3	–	–	$\mathcal{D}$	10 & 100	3
SDE, $\delta \in \{0, 1, 2\}$	7	13	–	–	10 & 100	7
SDE, $\delta \in \{0, 1, 2\}$	7	19	–	–	10 & 100	7
SDE, $\delta \in \{0, 1, 2\}$	7	35	–	–	10 & 100	7
SDE, $\delta \in \{0, 1, 2\}$	7	–	35 (OL 12)	–	10 & 100	7
SDE, $\delta \in \{0, 1, 2\}$	7	–	54 (OL 17)	–	10 & 100	7
SDE, $\delta \in \{0, 1, 2\}$	7	–	72 (OL 21)	–	10 & 100	7
SDE, $\delta \in \{0, 1, 2\}$	7	–	84 (OL 24)	–	10 & 100	7
SDE, $\delta \in \{0, 1, 2\}$	7	–	–	$\mathcal{D}$	10 & 100	7
SDE, $\delta \in \{0, 1, 2\}$	13	19	–	–	10 & 100	13
SDE, $\delta \in \{0, 1, 2\}$	13	35	–	–	10 & 100	13
SDE, $\delta \in \{0, 1, 2\}$	13	–	35 (OL 15)	–	10 & 100	13
SDE, $\delta \in \{0, 1, 2\}$	13	–	54 (OL 20)	–	10 & 100	13
SDE, $\delta \in \{0, 1, 2\}$	13	–	72 (OL 24)	–	10 & 100	13
SDE, $\delta \in \{0, 1, 2\}$	13	–	84 (OL 27)	–	10 & 100	13
SDE, $\delta \in \{0, 1, 2\}$	13	–	–	$\mathcal{D}$	10 & 100	13

## S6 Relation between the number of pixel pairs and the extent

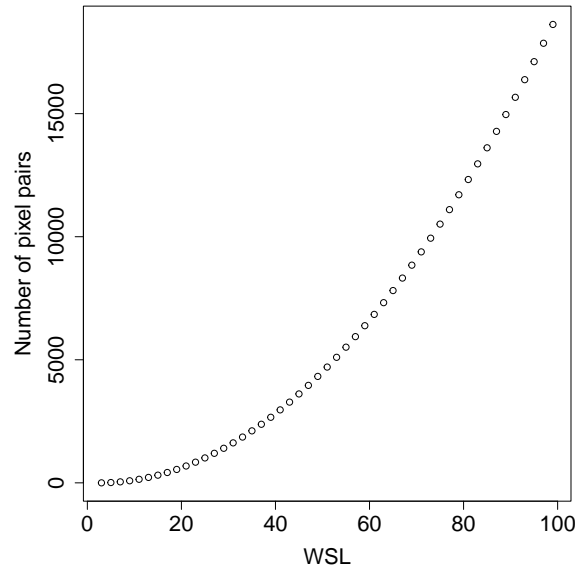


Figure S4: Increase of the number of pixel pairs,  $n$ , with WSL.

## S7 Spatial structural diversity features

For Structural diversity entropy with  $\delta = 0$  and  $WSL_I$  3 see Figures 7 in the main text. For Structural diversity entropy with  $\delta = 0$  and  $WSL_I$  7 see Figure 5 in the main text.

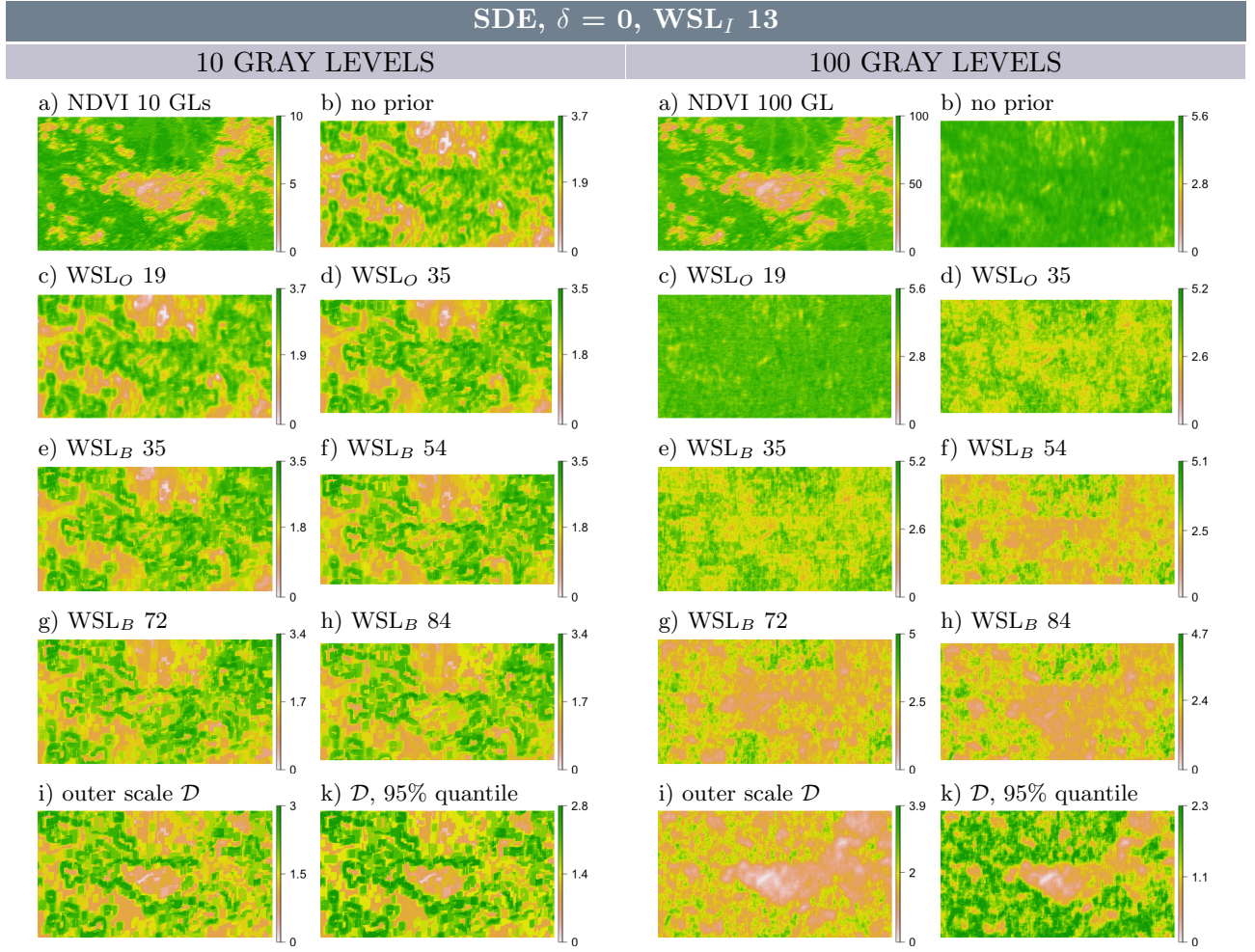


Figure S5: Structural diversity entropy (SDE),  $\delta = 0$ ,  $WSL_I$  13. Minimum values displayed are set to 0.  
A) and B) k) outer scale  $\mathcal{D}$ , 95% quantiles.

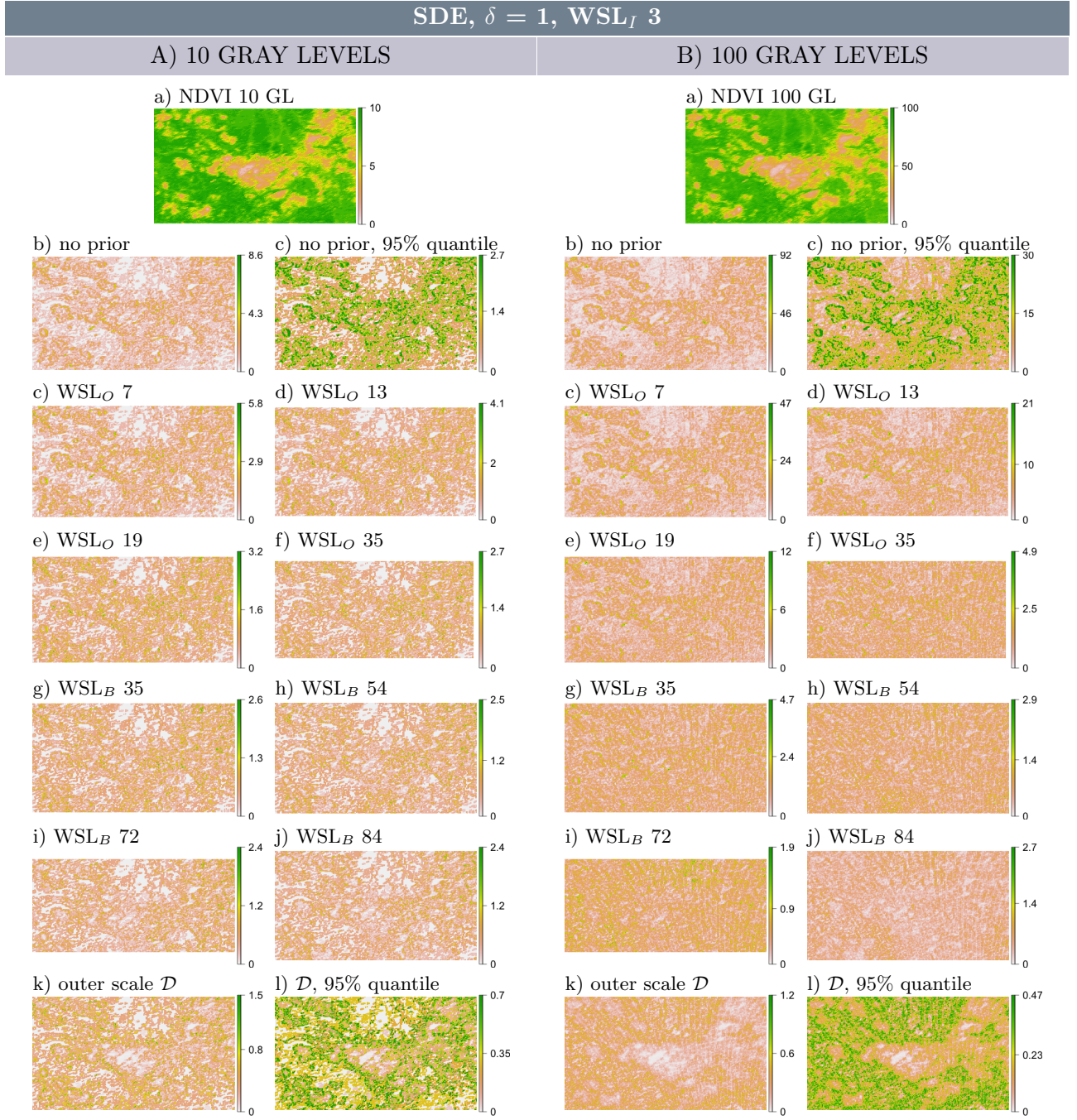


Figure S6: Structural diversity entropy (SDE),  $\delta = 1$ ,  $WSL_I = 3$ . Minimum values displayed are set to 0. A) and B) j) outer scale  $\mathcal{D}$ , 95% quantiles.



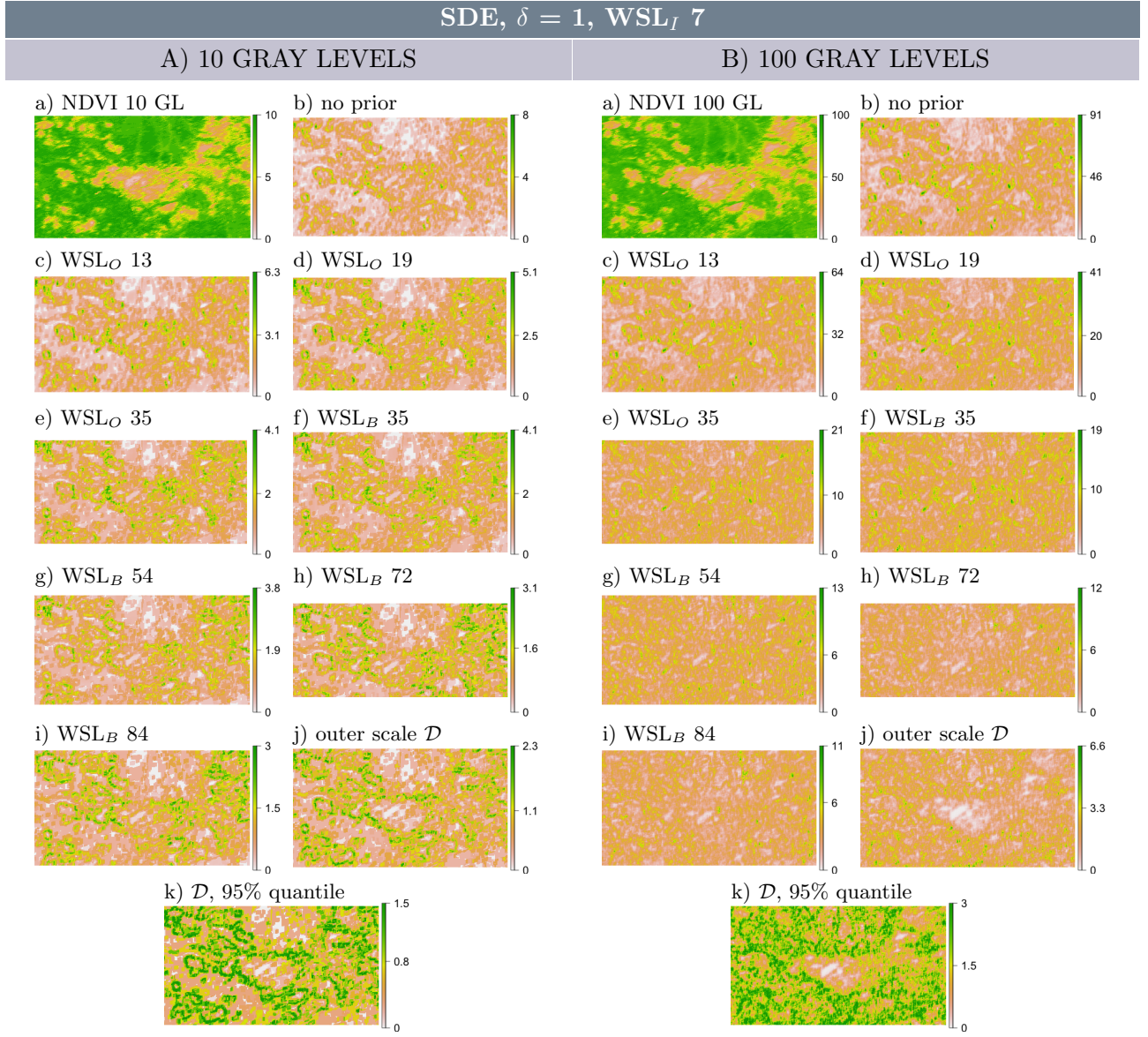


Figure S7: Structural diversity entropy (SDE),  $\delta = 1$ ,  $WSL_I = 7$ . Minimum values displayed are set to 0. A) and B) k) outer scale  $\mathcal{D}$ , 95% quantiles.

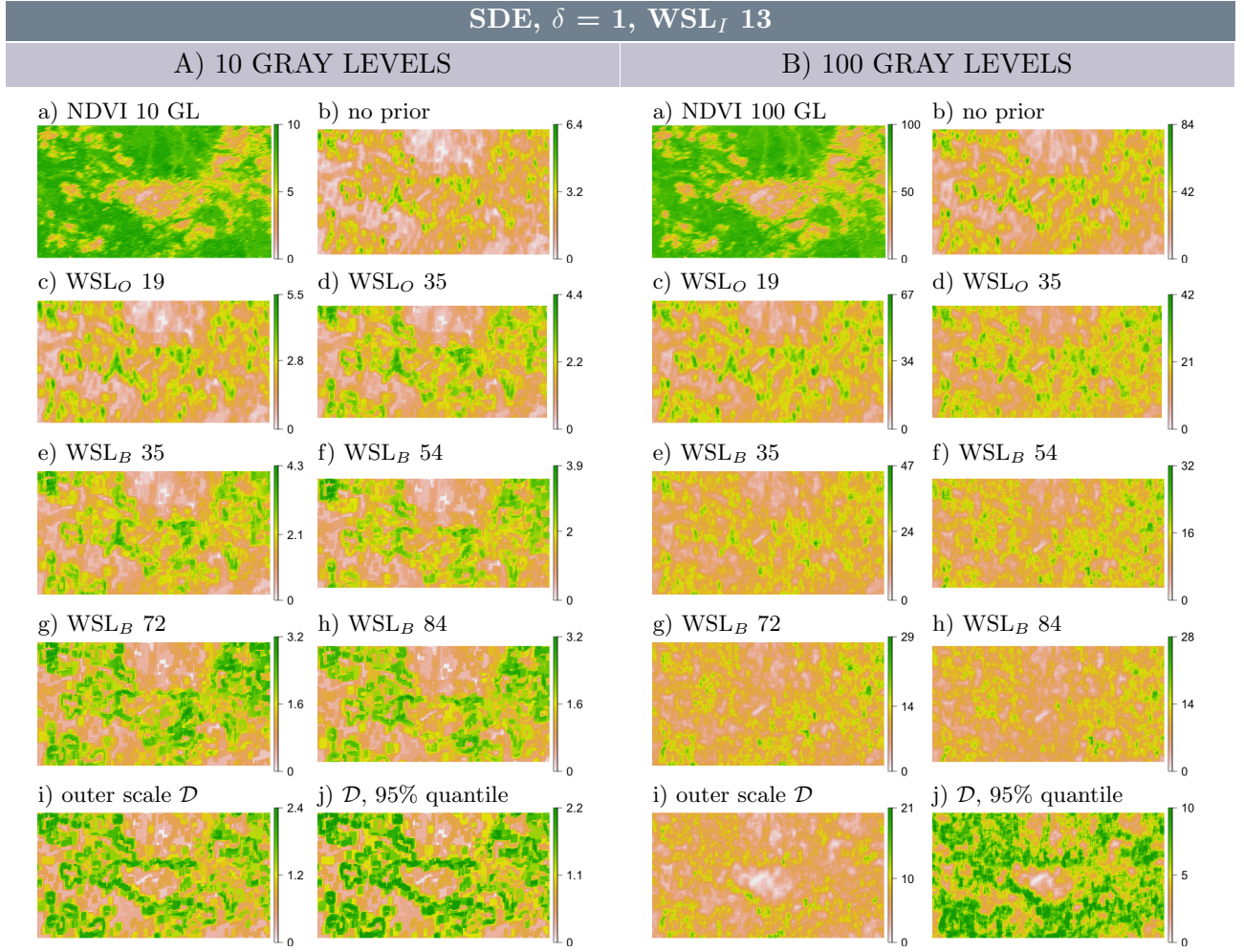


Figure S8: Structural diversity entropy (SDE),  $\delta = 1$ ,  $WSL_I$  13. Minimum values displayed are set to 0. A) and B) 1) outer scale  $\mathcal{D}$ , 95% quantiles.



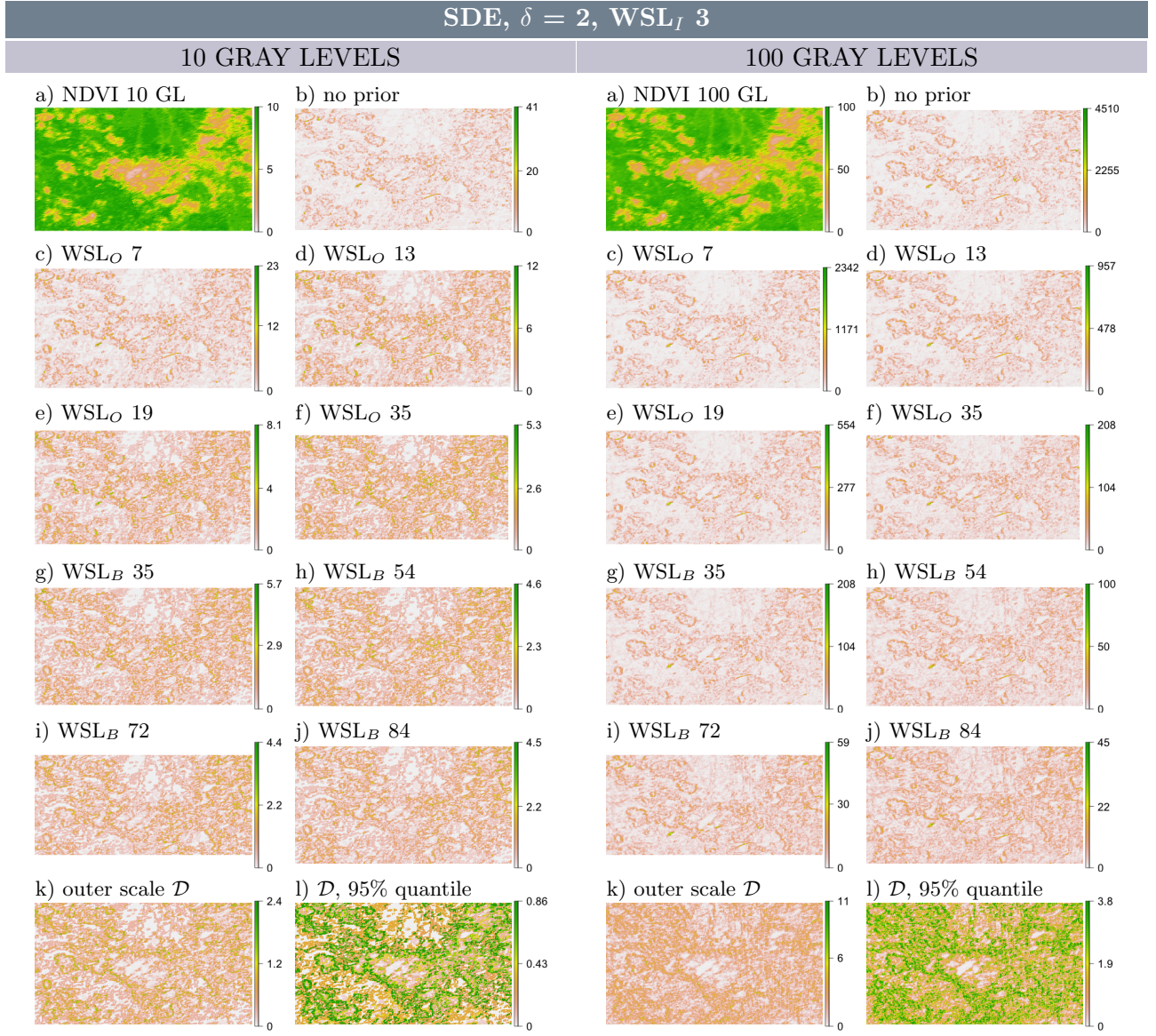


Figure S9: Structural diversity entropy (SDE),  $\delta = 2$ ,  $WSL_I = 3$ . Minimum values displayed are set to 0. A) and B) l) outer scale  $\mathcal{D}$ , 95% quantiles.

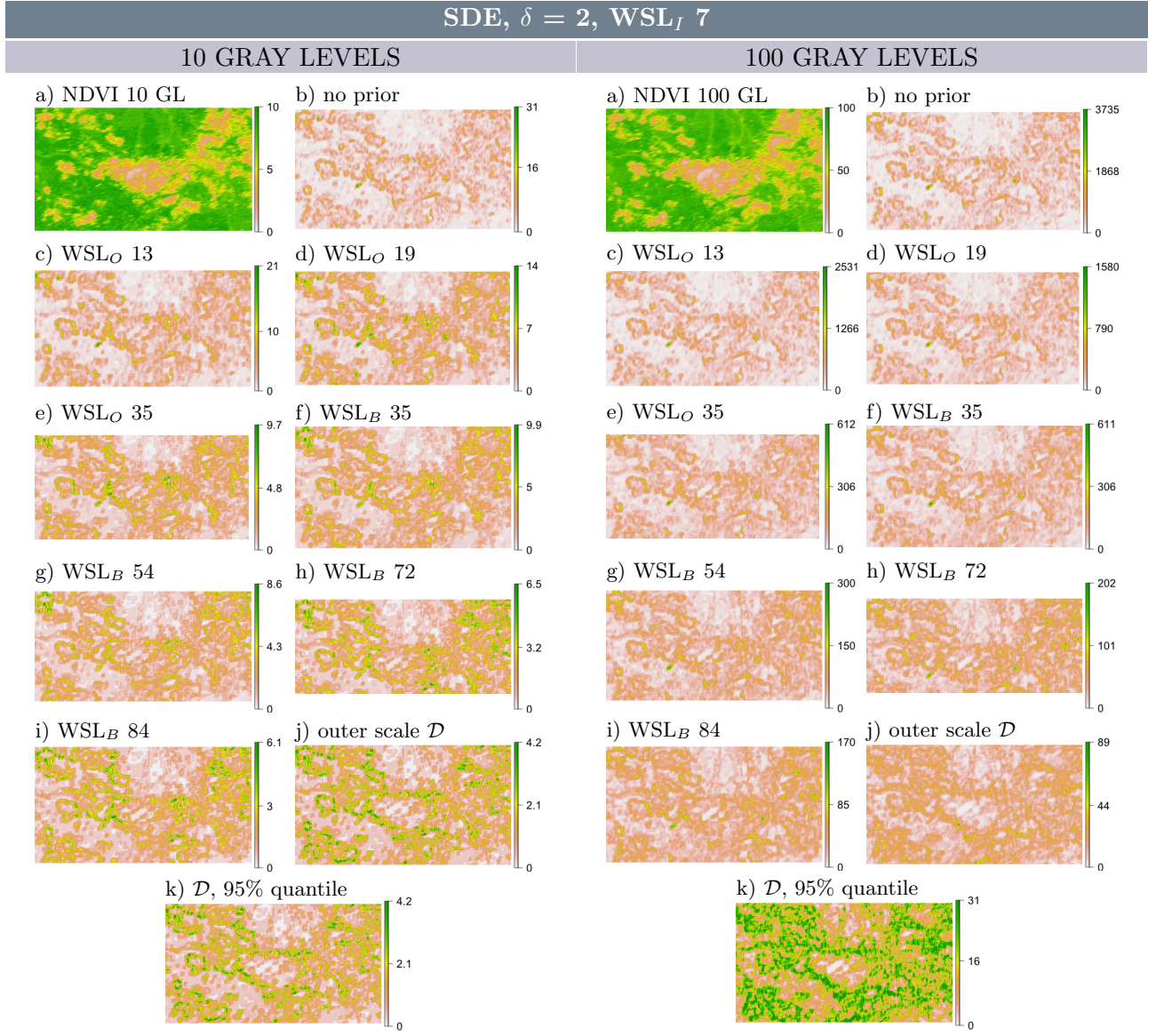


Figure S10: Structural diversity entropy (SDE),  $\delta = 2$ ,  $WSL_I = 7$ . Minimum values displayed are set to 0. A) and B) k) outer scale  $\mathcal{D}$ , 95% quantiles.

For Structural diversity entropy with  $\delta = 2$  and  $WSL_I = 13$  see Figure 6 in the main text.



## S7.1 Structural diversity in simulated random patch data

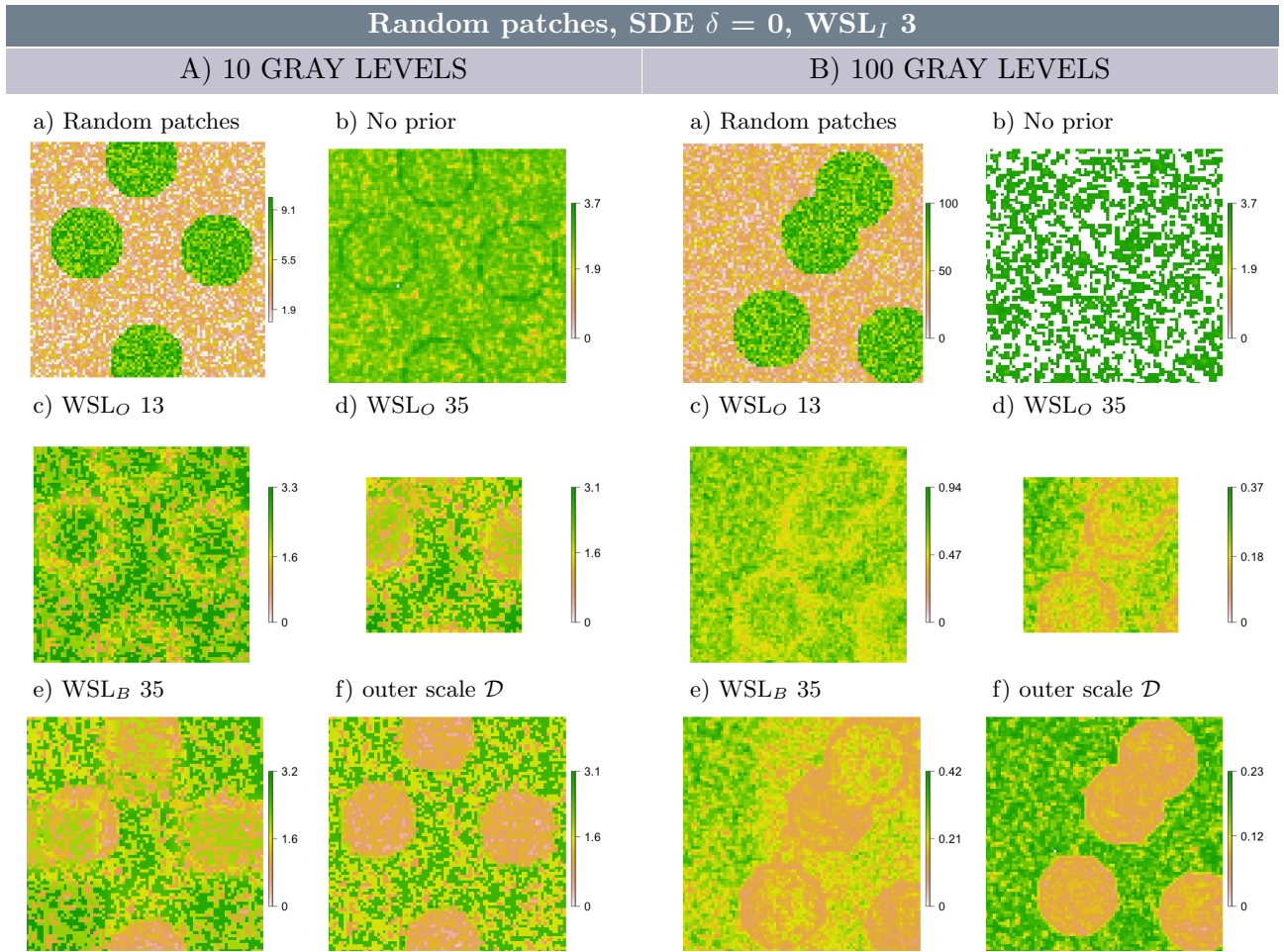


Figure S11: Random patches, structural diversity entropy (SDE),  $\delta = 0$ ,  $WSL_I$  3.

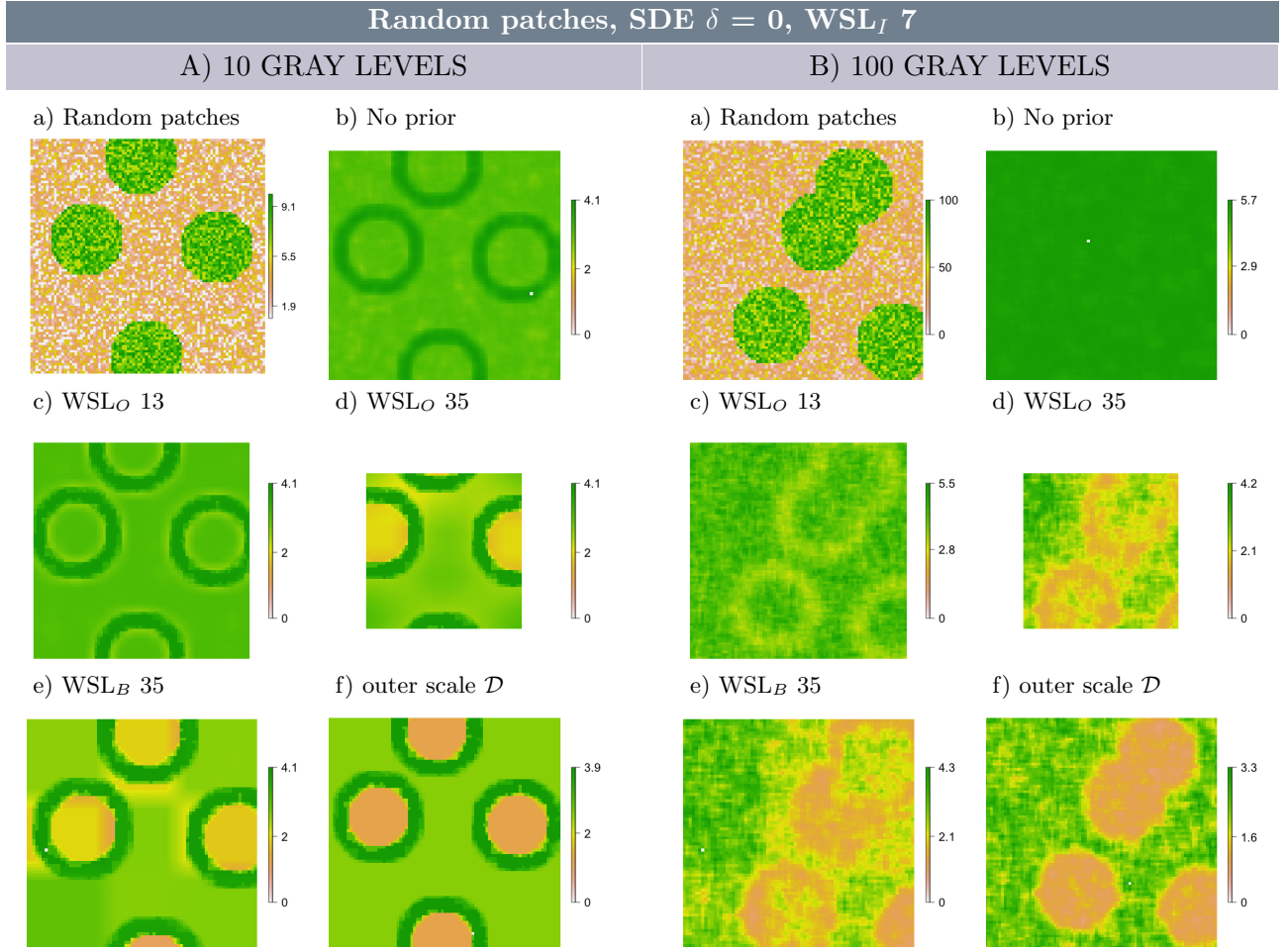


Figure S12: Random patches, structural diversity entropy (SDE),  $\delta = 0$ , WSL<sub>I</sub> 7.

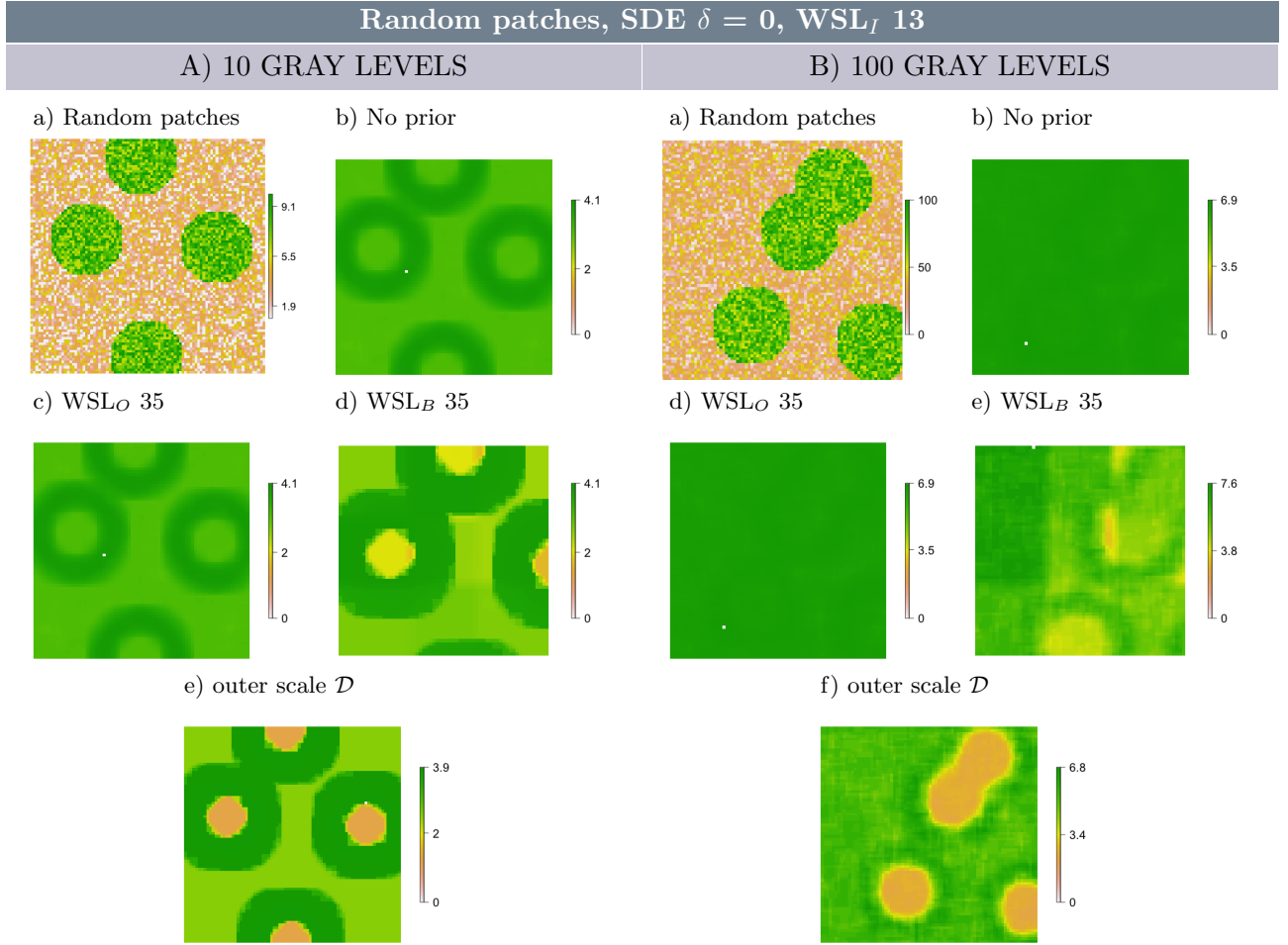


Figure S13: Random patches, structural diversity entropy (SDE),  $\delta = 0$ ,  $WSL_I$  13.

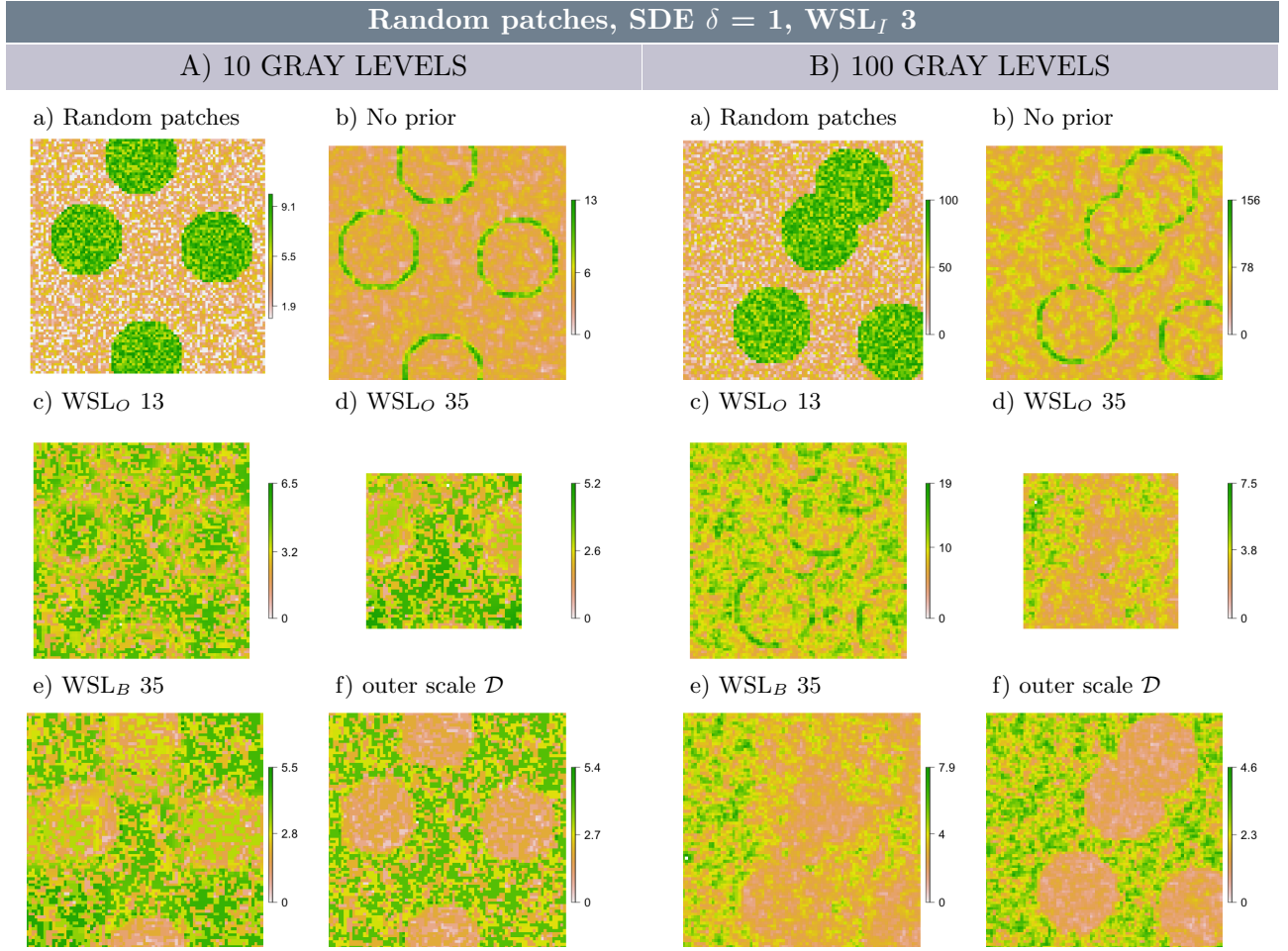


Figure S14: Random patches, structural diversity entropy SDE),  $\delta = 1$ , WSL<sub>I</sub> 3.

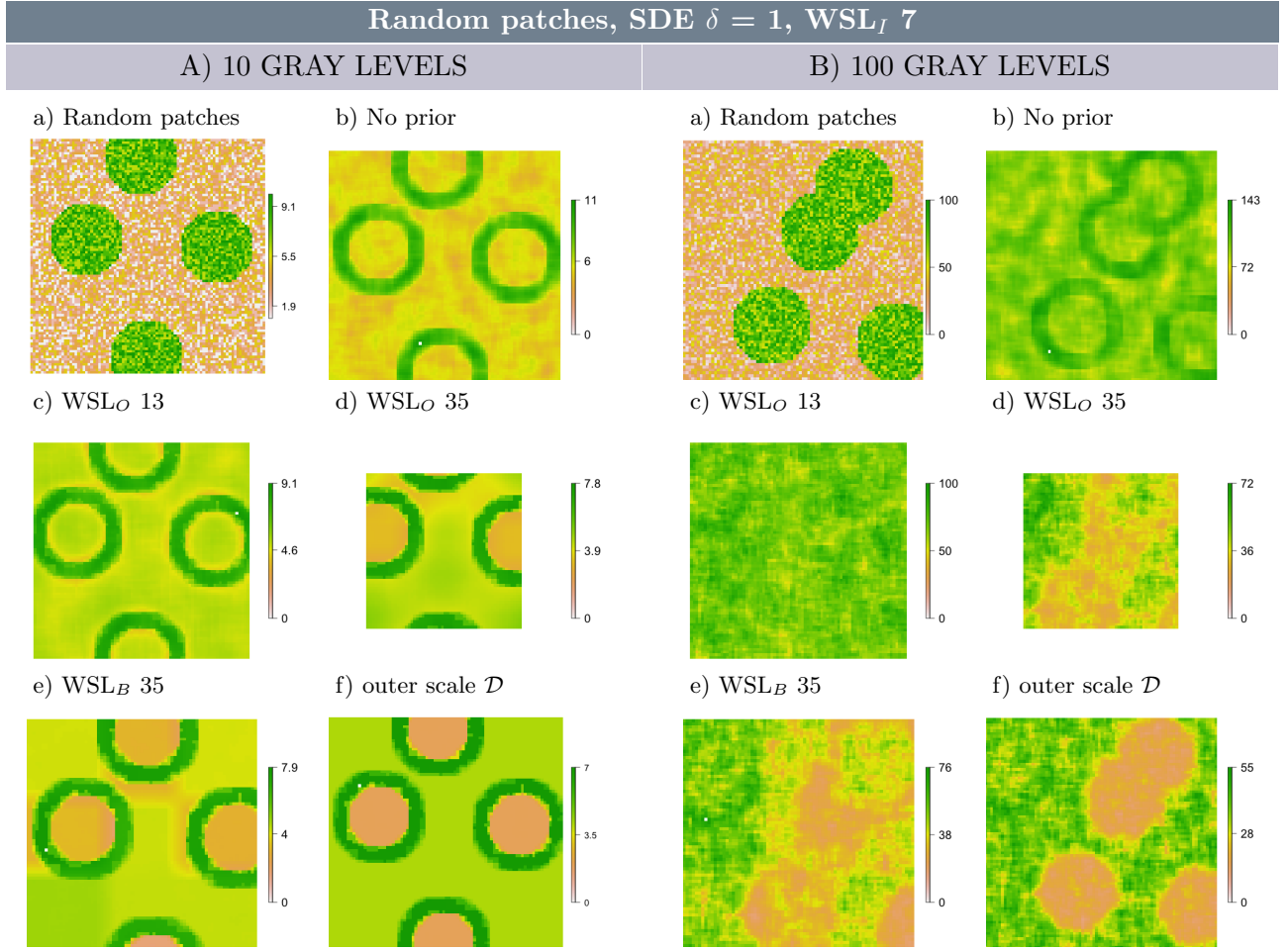


Figure S15: Random patches, structural diversity entropy SDE),  $\delta = 1$ , WSL<sub>I</sub> 7.

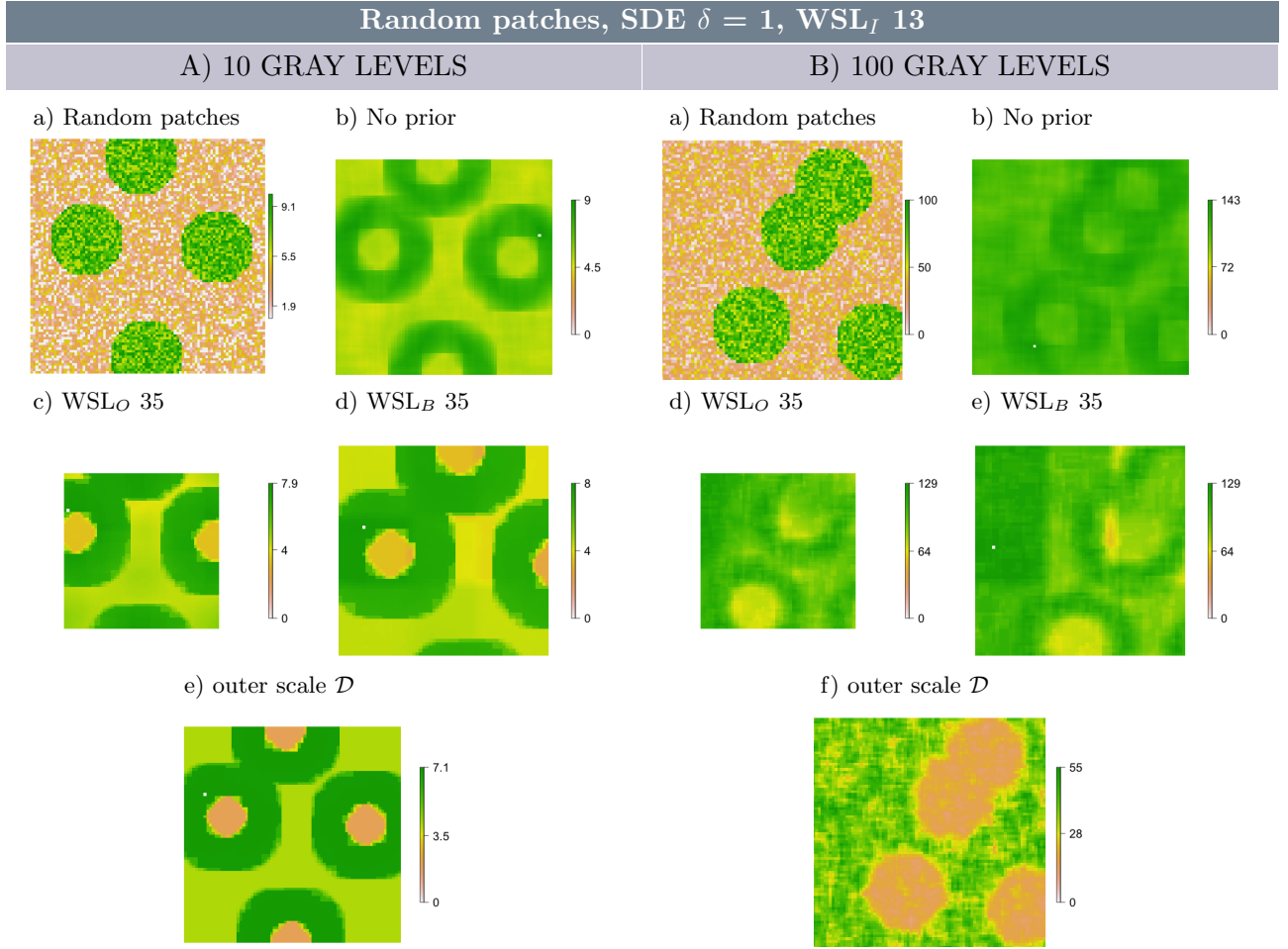


Figure S16: Random patches, structural diversity entropy (SDE),  $\delta = 1$ , WSL<sub>I</sub> 13.

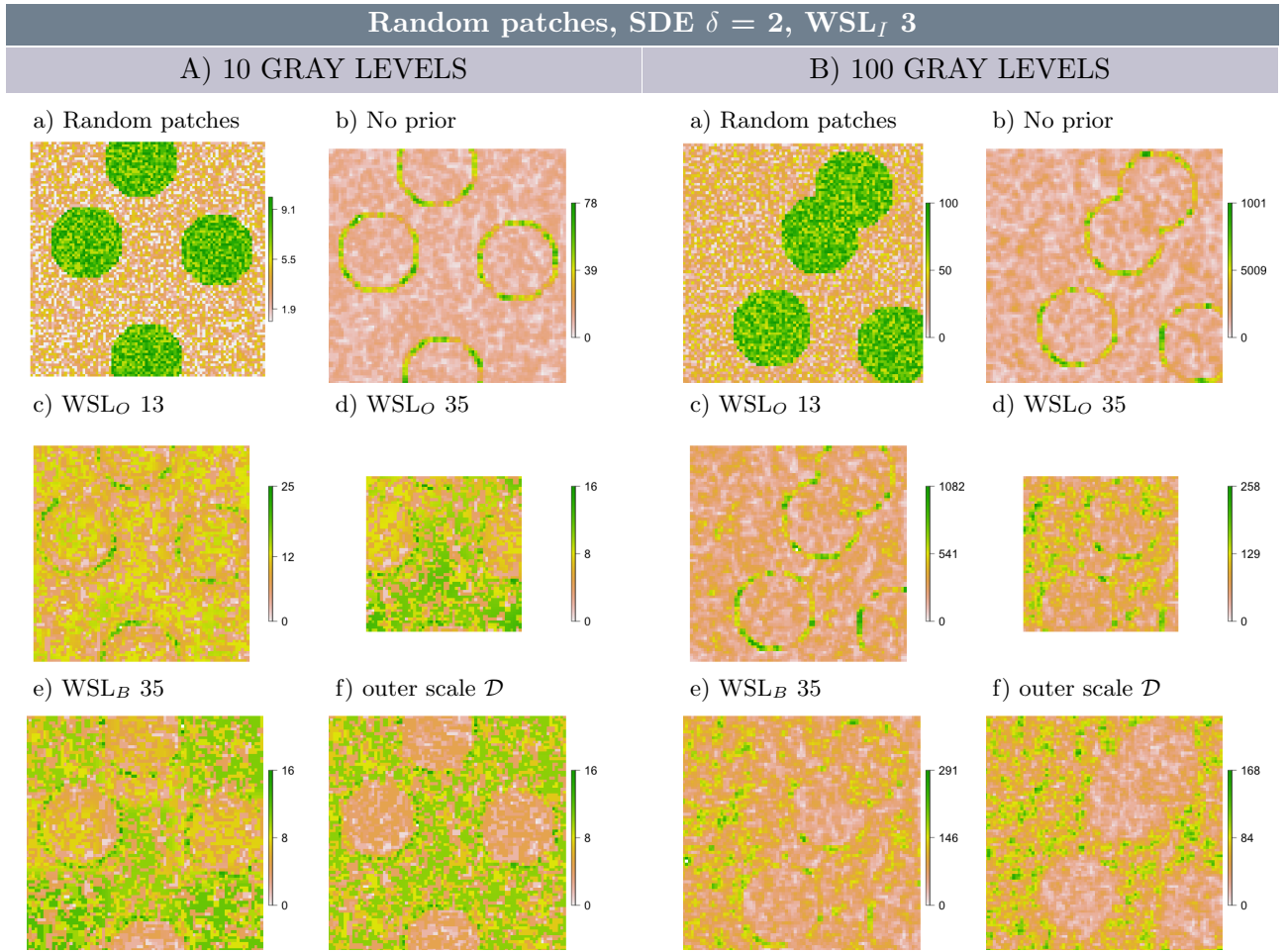


Figure S17: Random patches, structural diversity entropy (SDE),  $\delta = 2$ , WSL<sub>I</sub> 3.



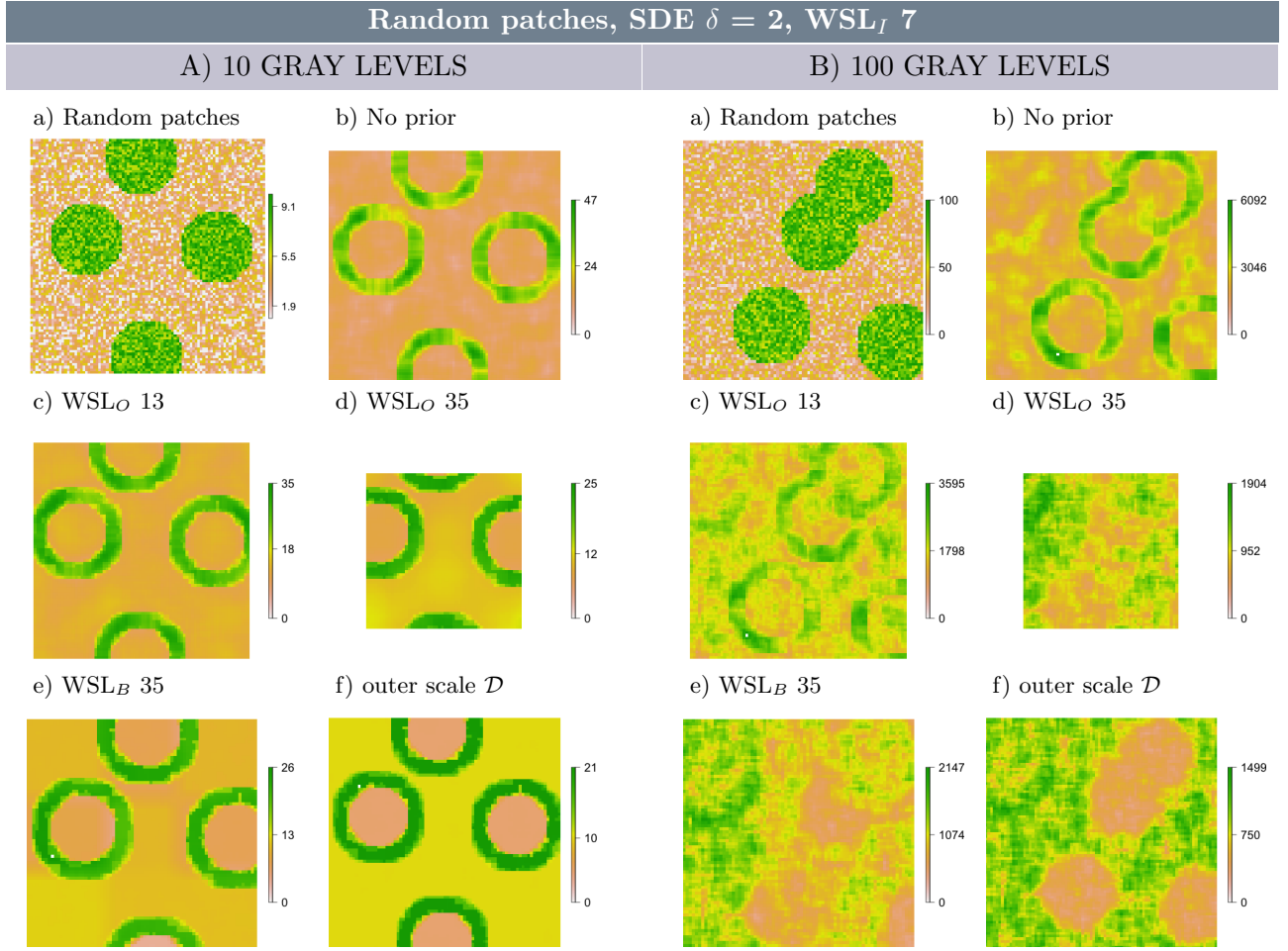


Figure S18: Random patches, structural diversity entropy (SDE),  $\delta = 2$ , WSL<sub>I</sub> 7.



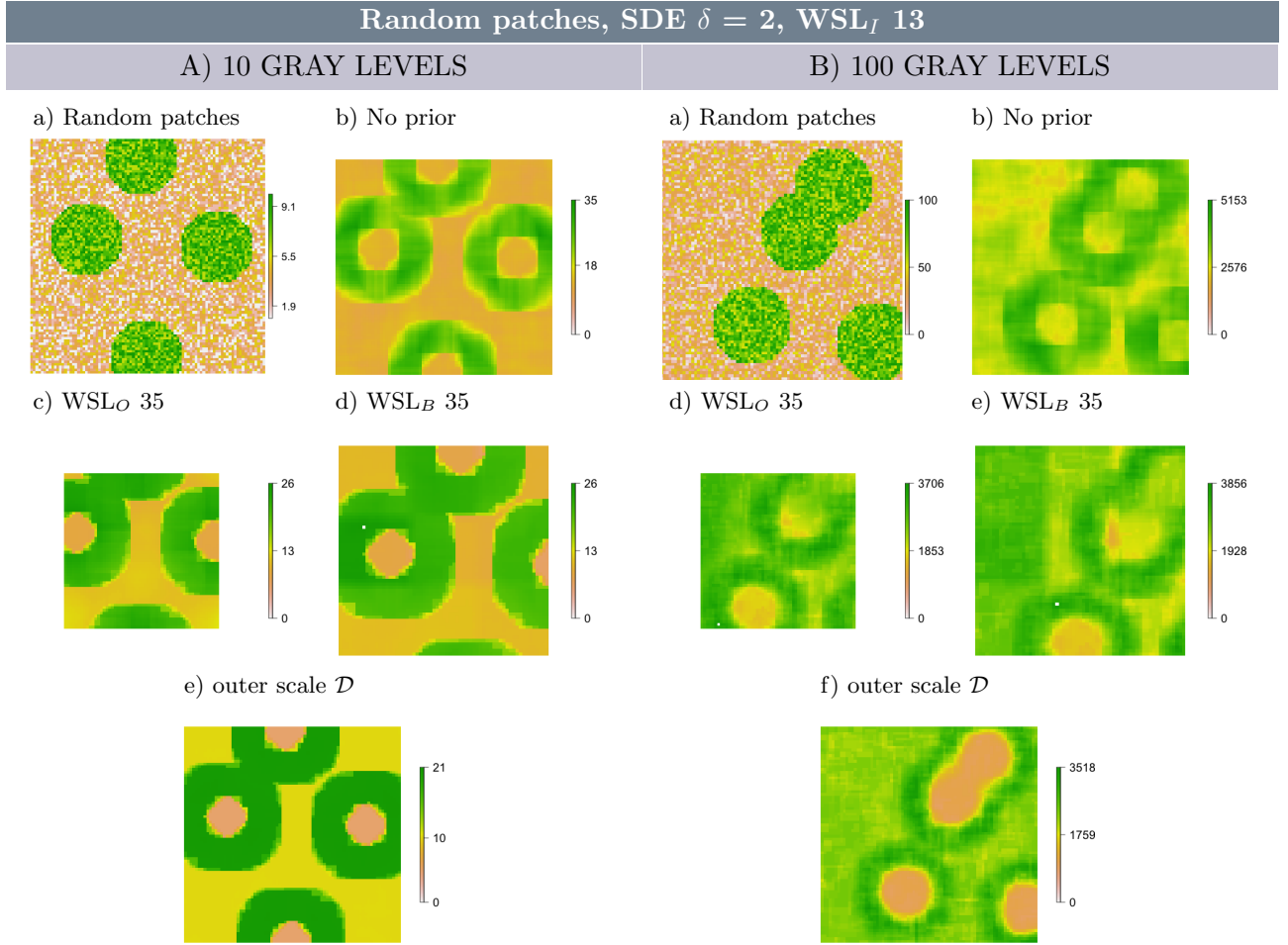


Figure S19: Random patches, structural diversity entropy (SDE),  $\delta = 2$ ,  $WSL_I$  13.

## S7.2 Structural diversity in simulated random noise data

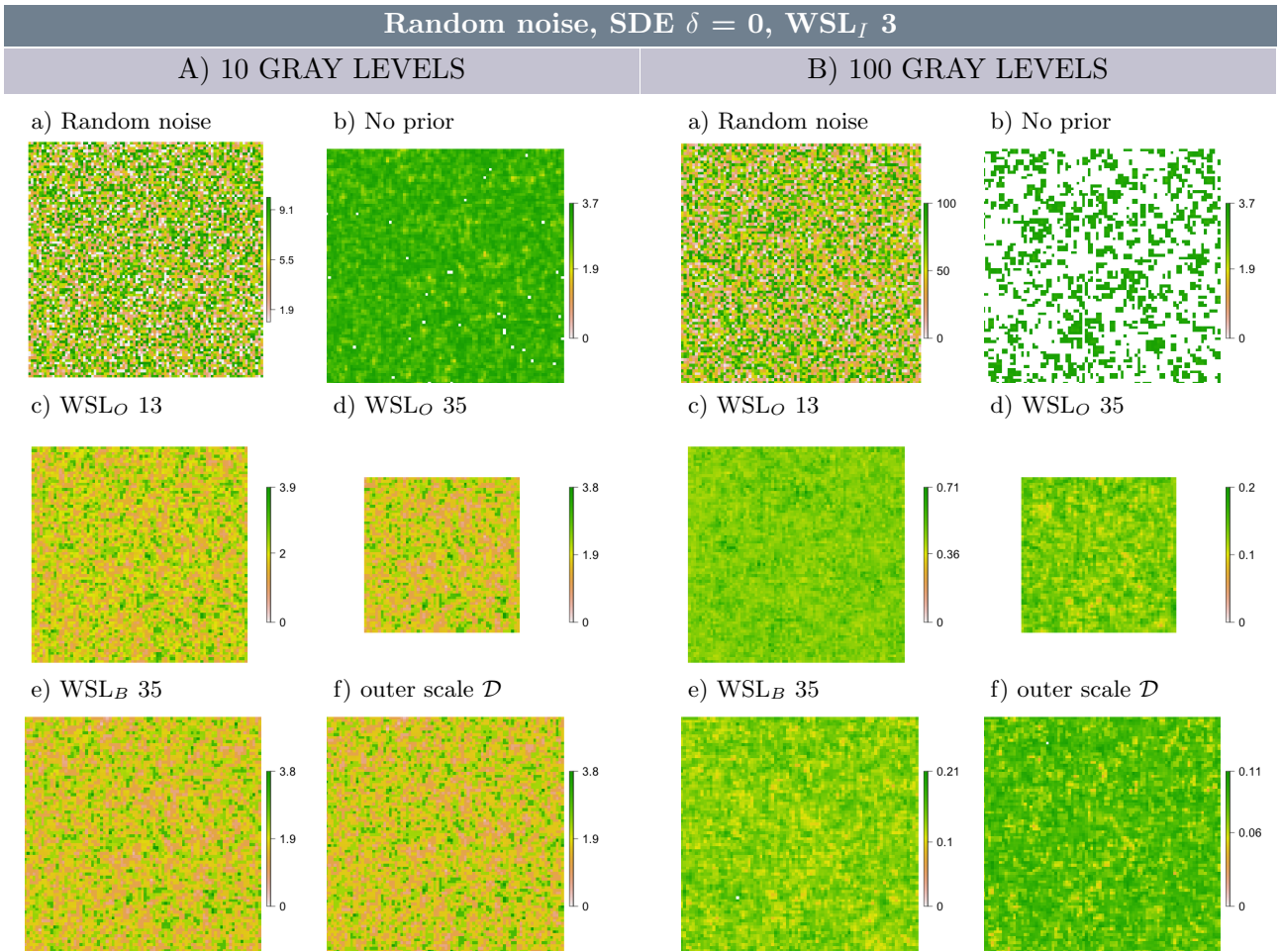


Figure S20: Random noise, structural diversity entropy (SDE),  $\delta = 0$ ,  $WSL_I$  3.

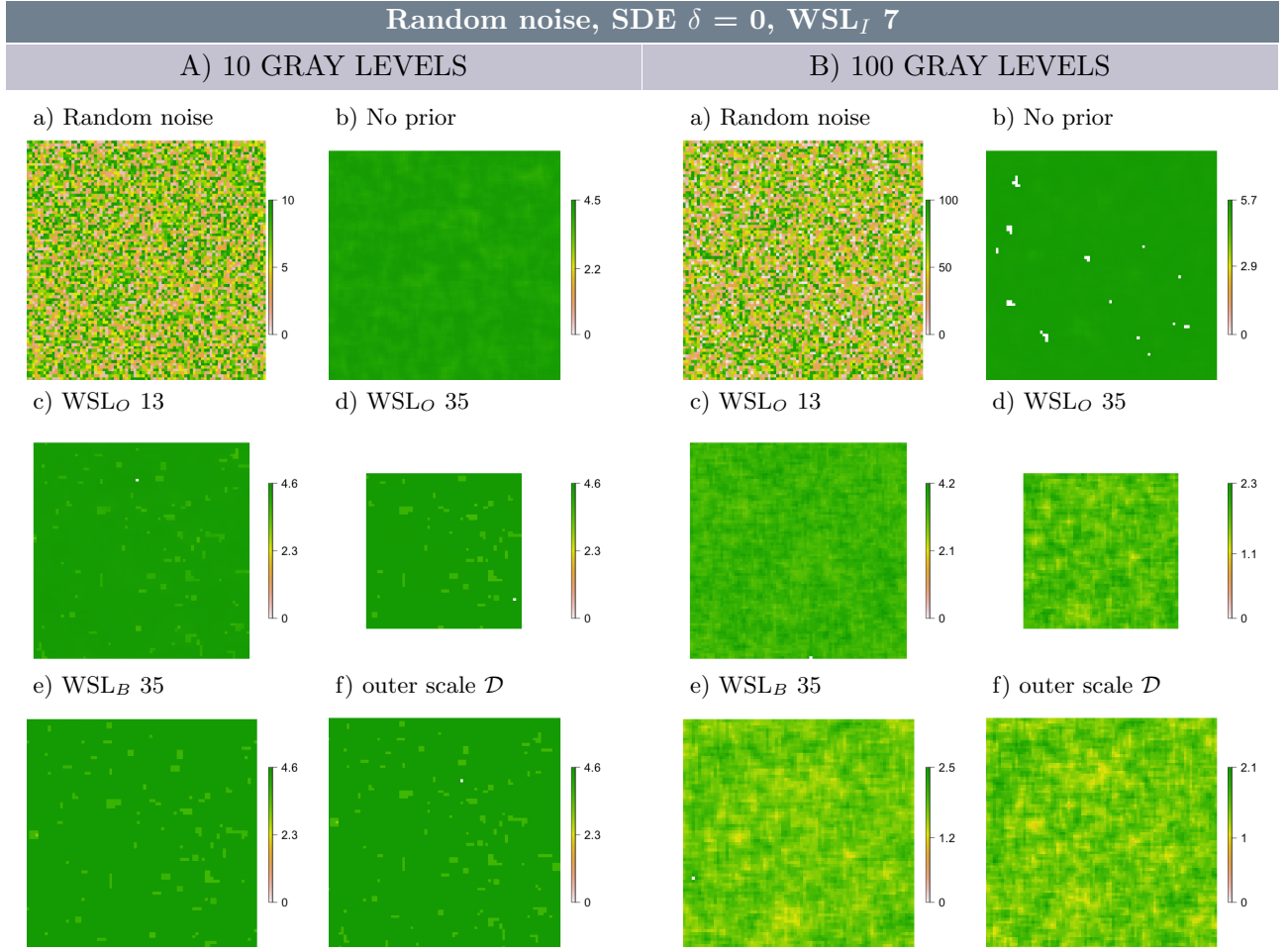


Figure S21: Random noise, structural diversity entropy (SDE),  $\delta = 0$ ,  $WSL_I$  7.

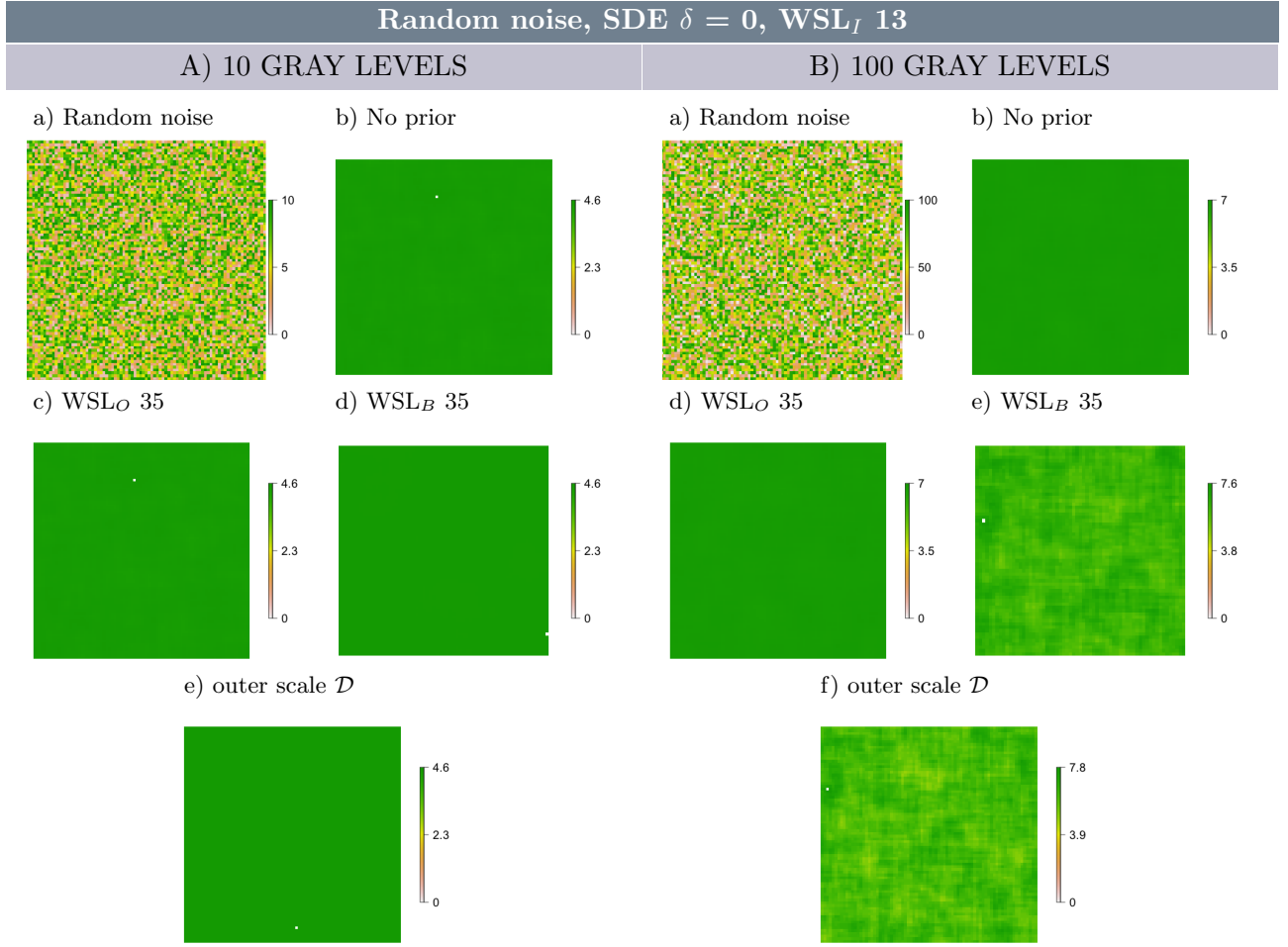


Figure S22: Random noise, structural diversity entropy (SDE),  $\delta = 0$ , WSL<sub>I</sub> 13.

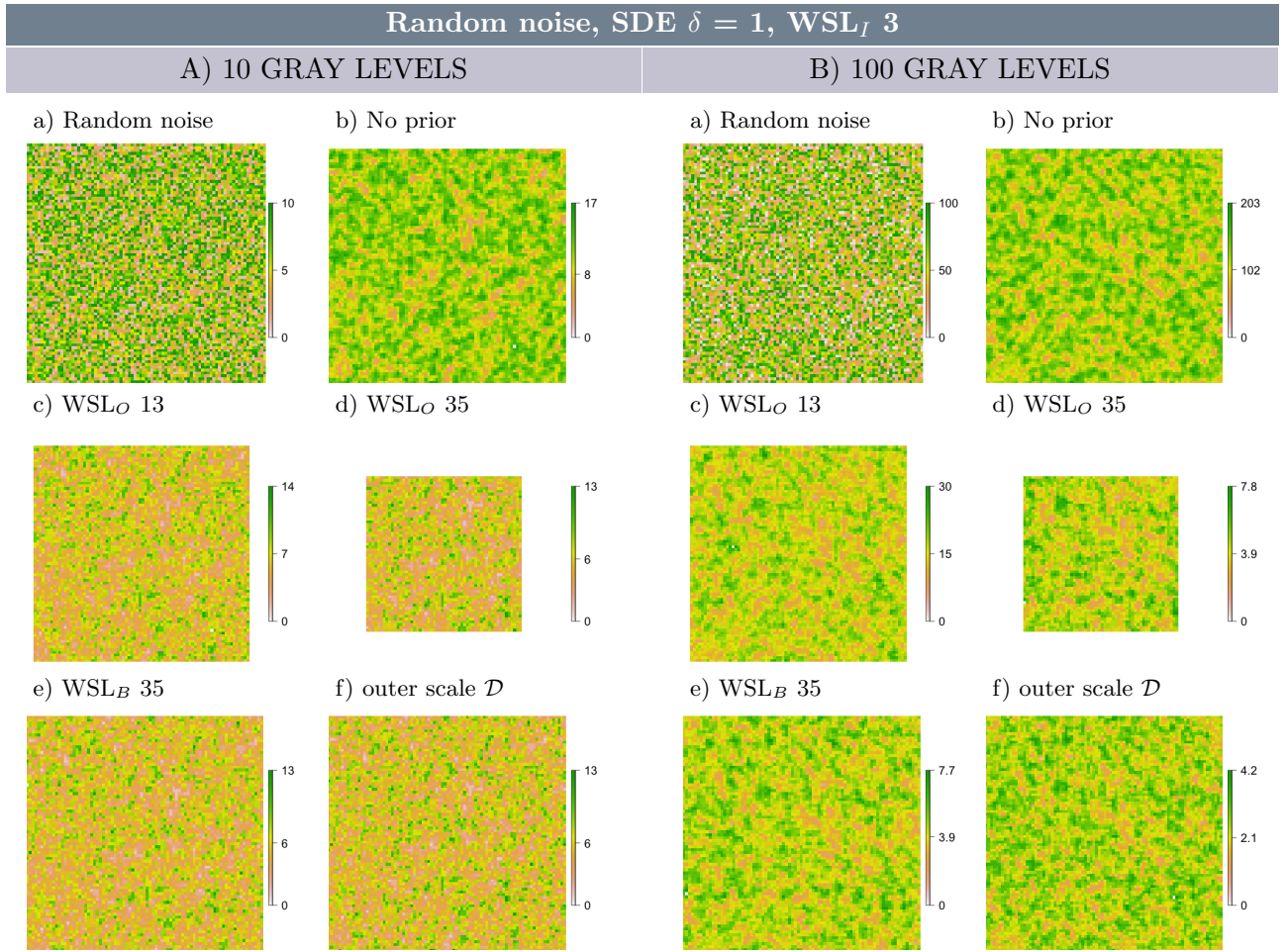


Figure S23: Random noise, structural diversity entropy (SDE),  $\delta = 1$ ,  $WSL_I$  3.

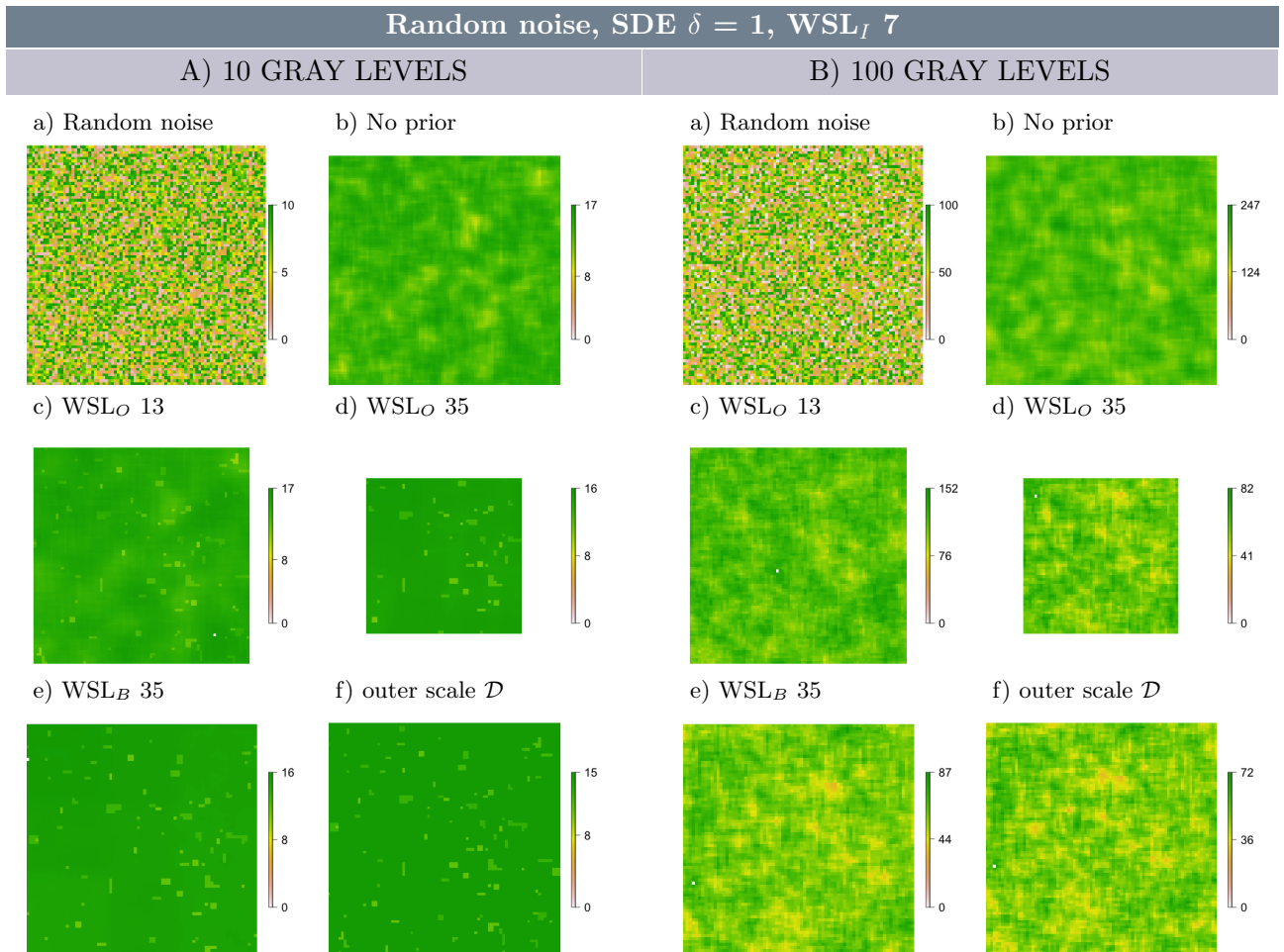


Figure S24: Random noise, structural diversity entropy (SDE),  $\delta = 1$ ,  $WSL_I$  7.

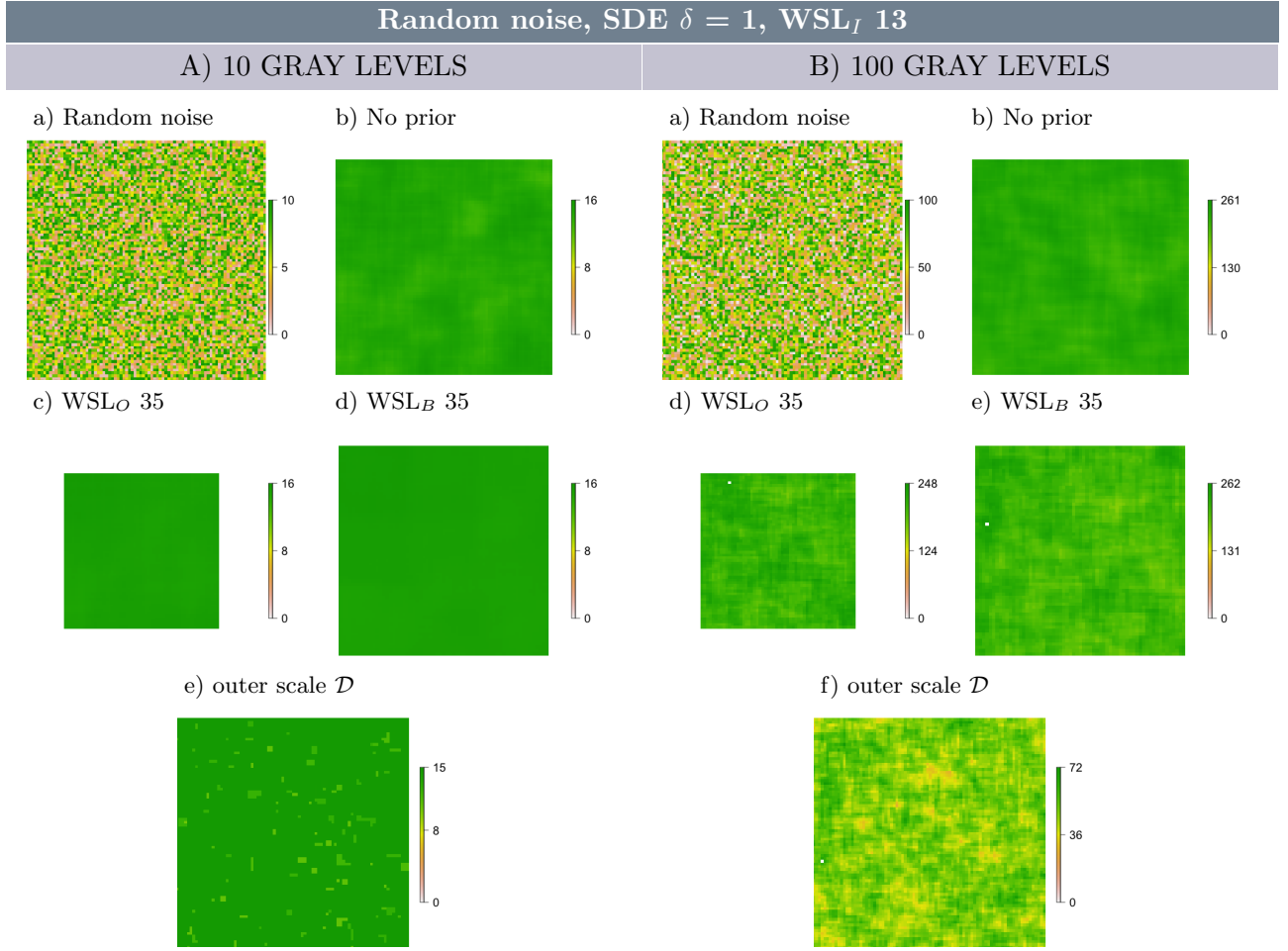


Figure S25: Random noise, structural diversity entropy (SDE),  $\delta = 1$ , WSL<sub>I</sub> 13.



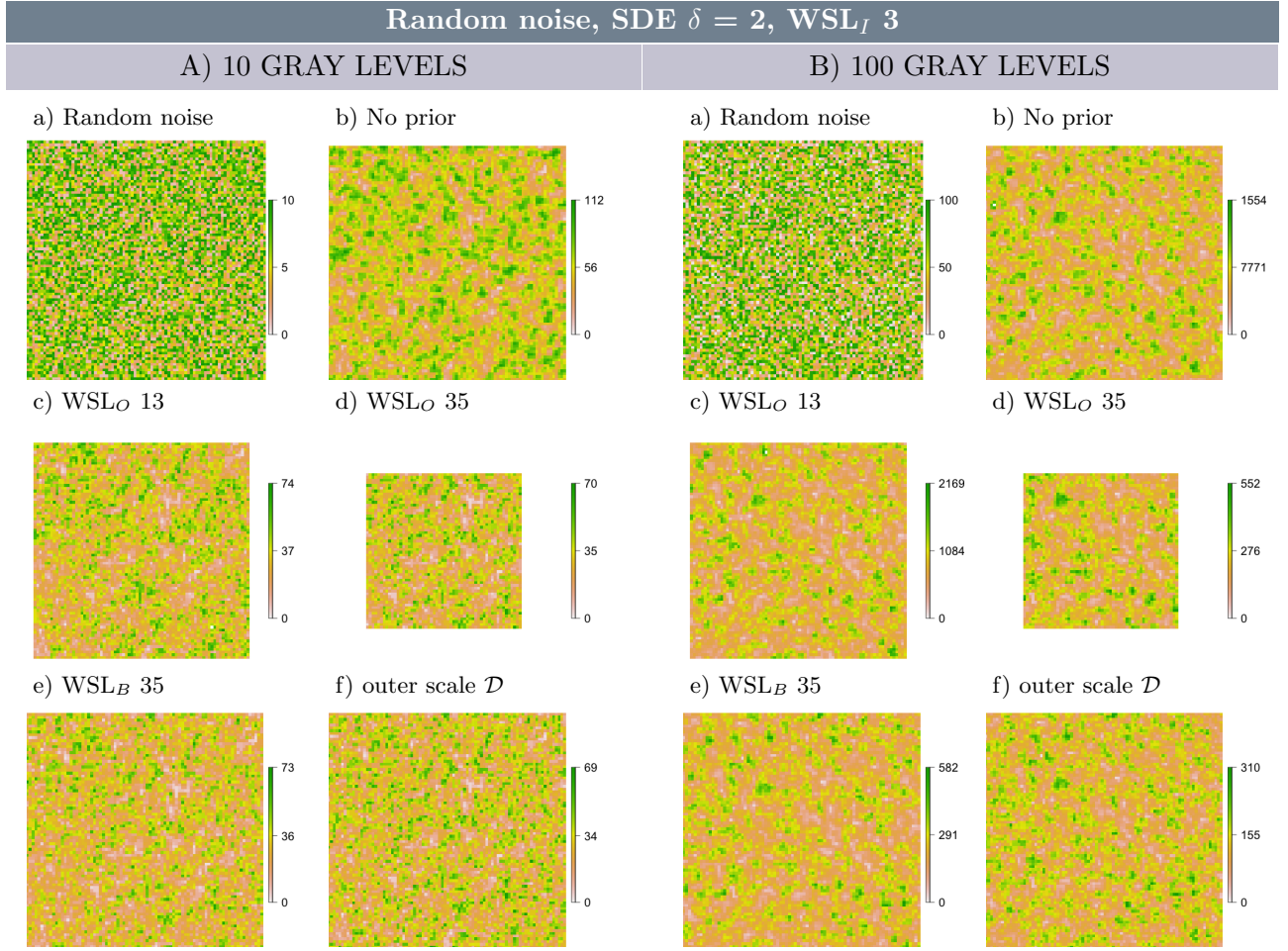


Figure S26: Random noise, structural diversity entropy (SDE),  $\delta = 2$ , WSL<sub>I</sub> 3.



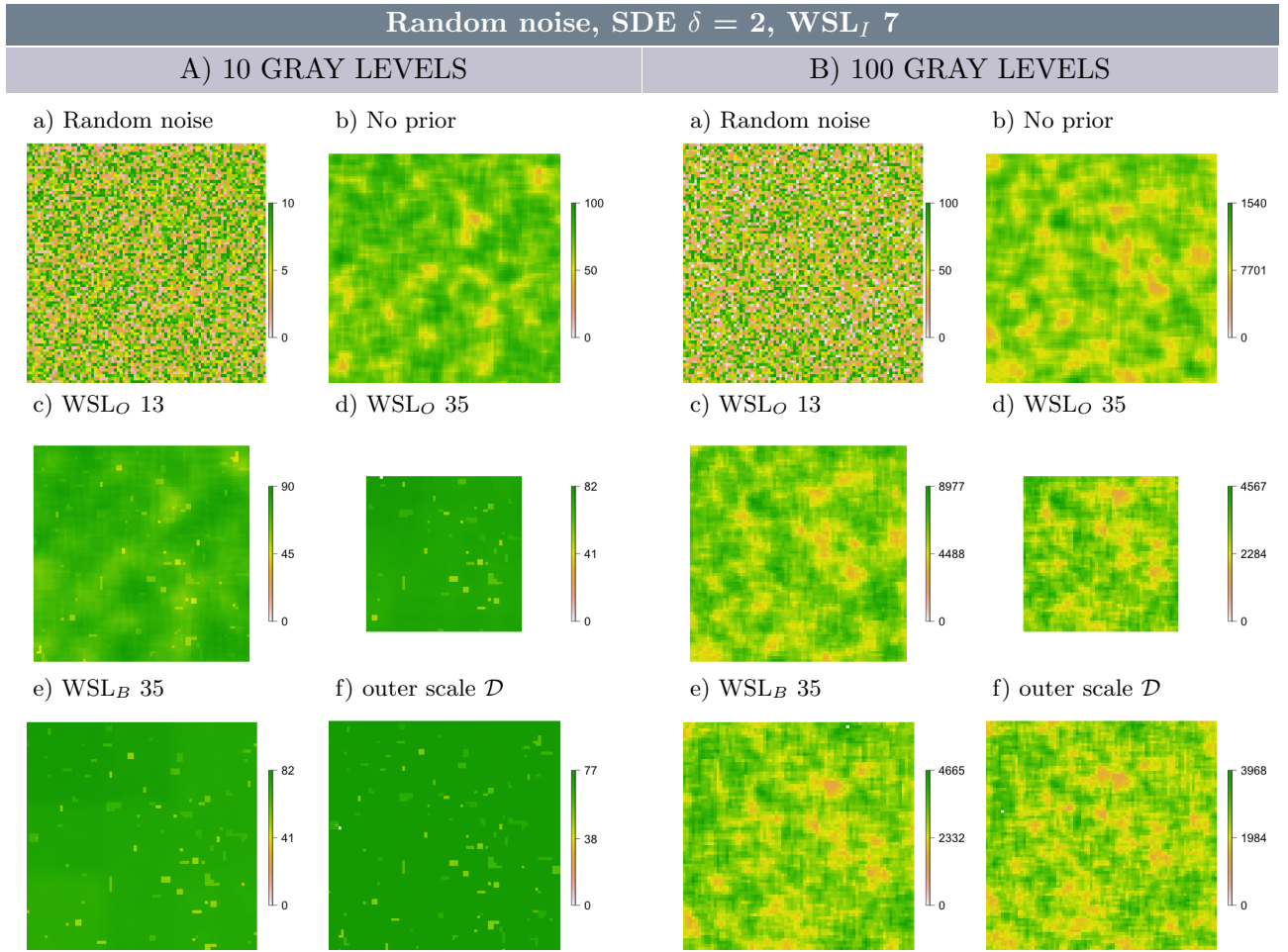


Figure S27: Random noise, structural diversity entropy (SDE),  $\delta = 2$ , WSL<sub>I</sub> 7.

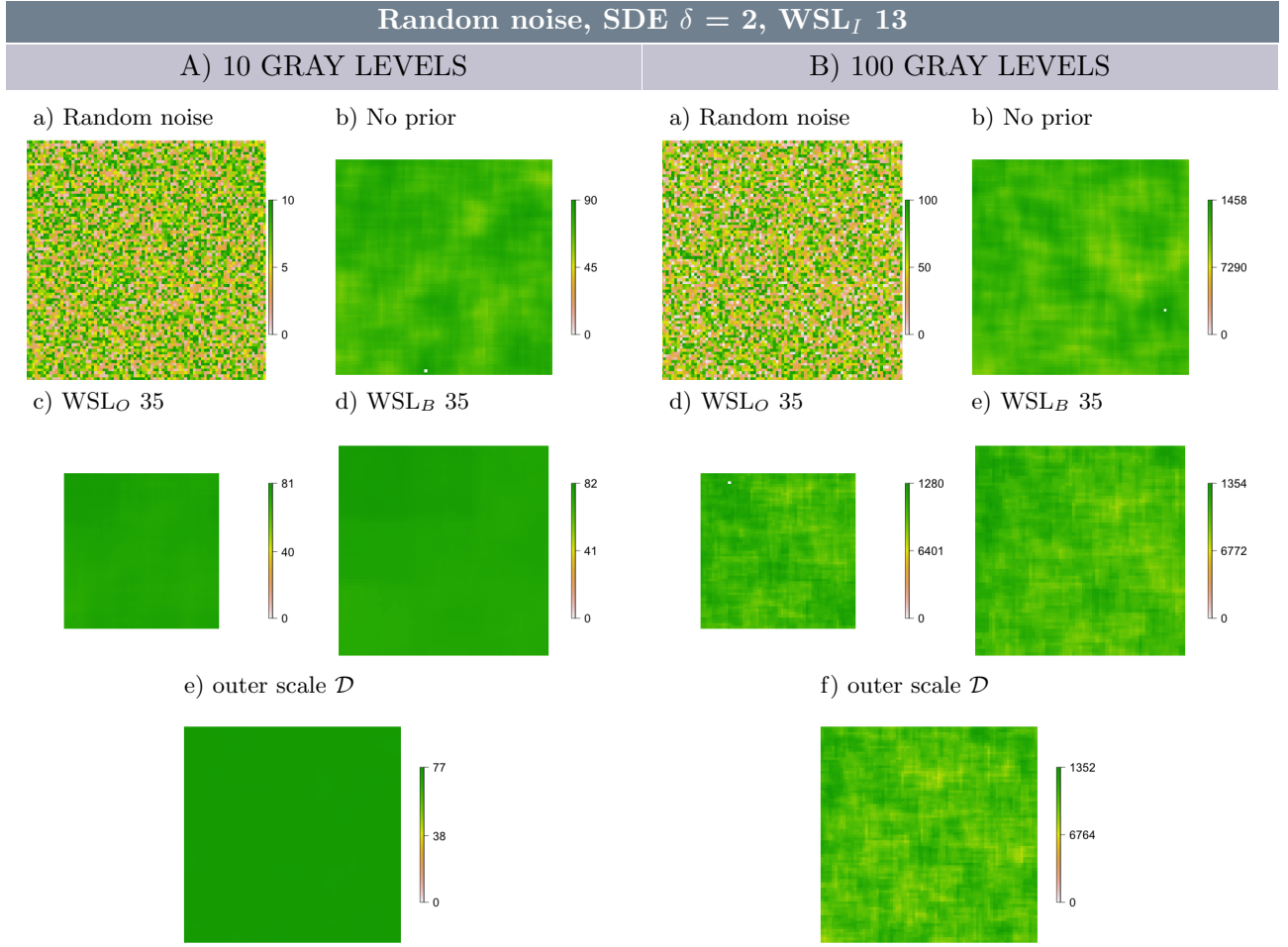


Figure S28: Random noise, structural diversity entropy (SDE),  $\delta = 2$ , WSL<sub>I</sub> 13.

### S7.3 Structural diversity in simulated linear gradient data

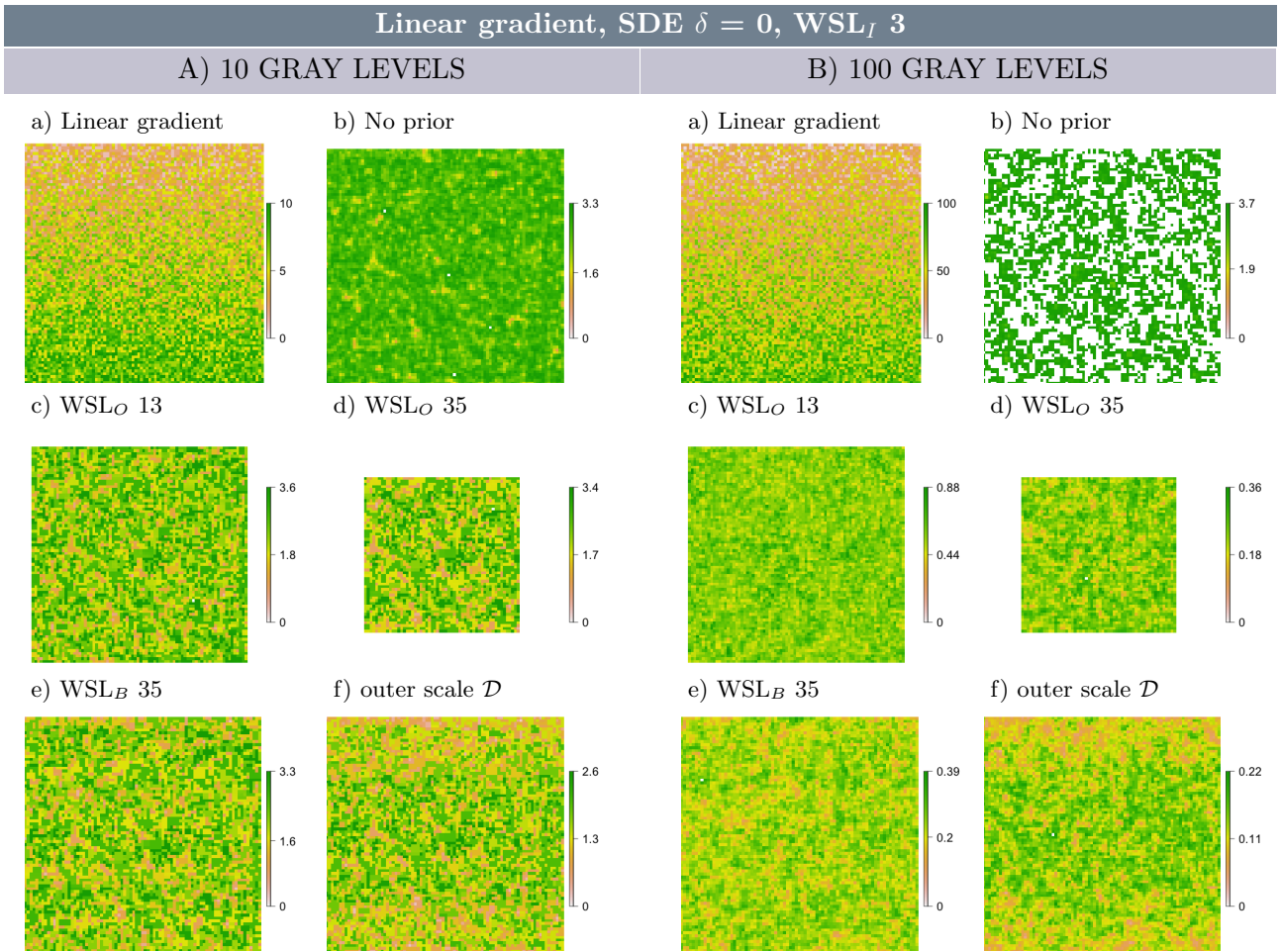


Figure S29: Linear gradient, structural diversity entropy (SDE),  $\delta = 0$ ,  $WSL_I$  3.

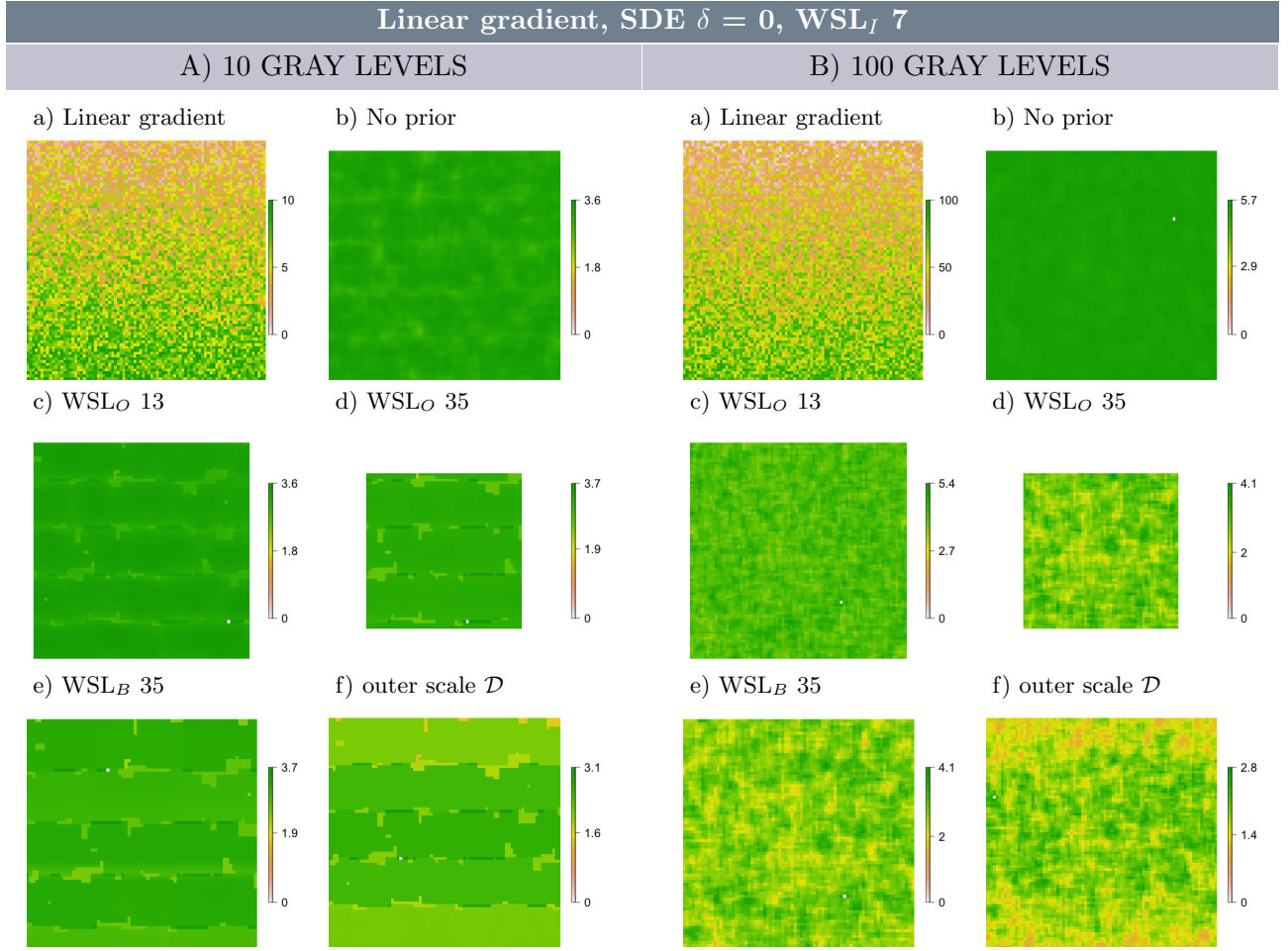


Figure S30: Linear gradient, structural diversity entropy (SDE),  $\delta = 0$ , WSL<sub>I</sub> 7.

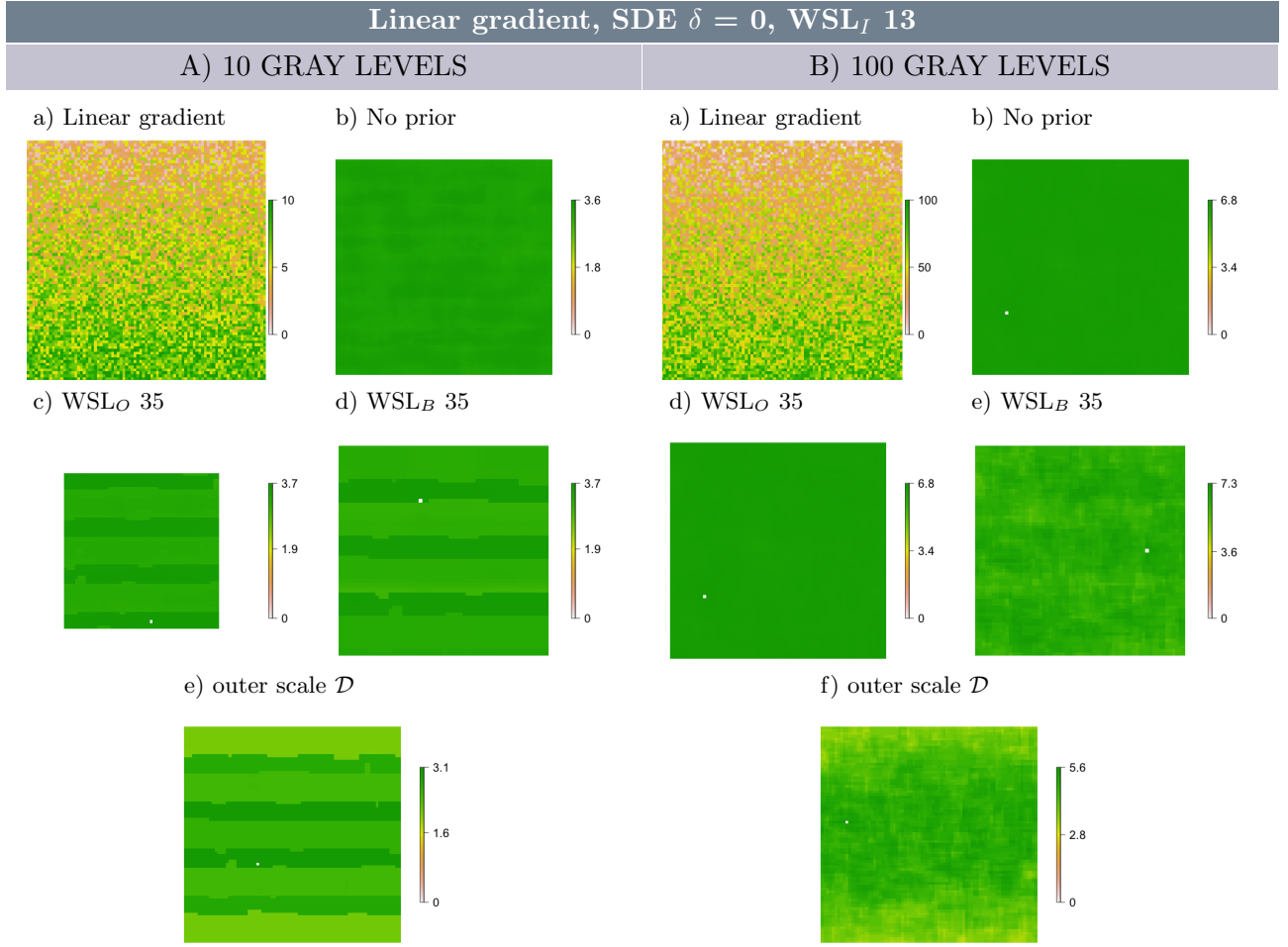


Figure S31: Linear gradient, structural diversity entropy (SDE),  $\delta = 0$ ,  $WSL_I$  13.

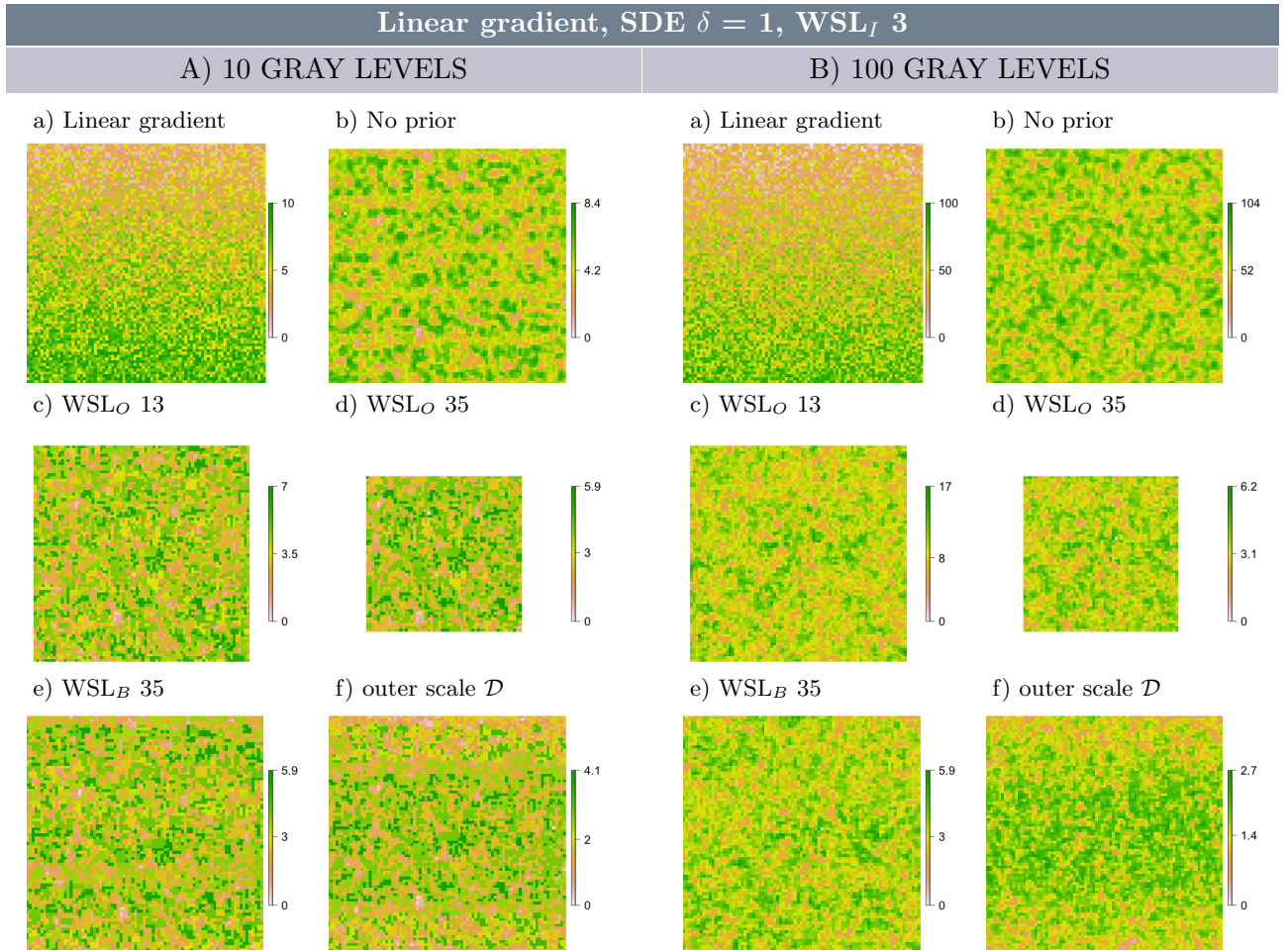


Figure S32: Linear gradient, structural diversity entropy (SDE),  $\delta = 1$ , WSL<sub>I</sub> 3.

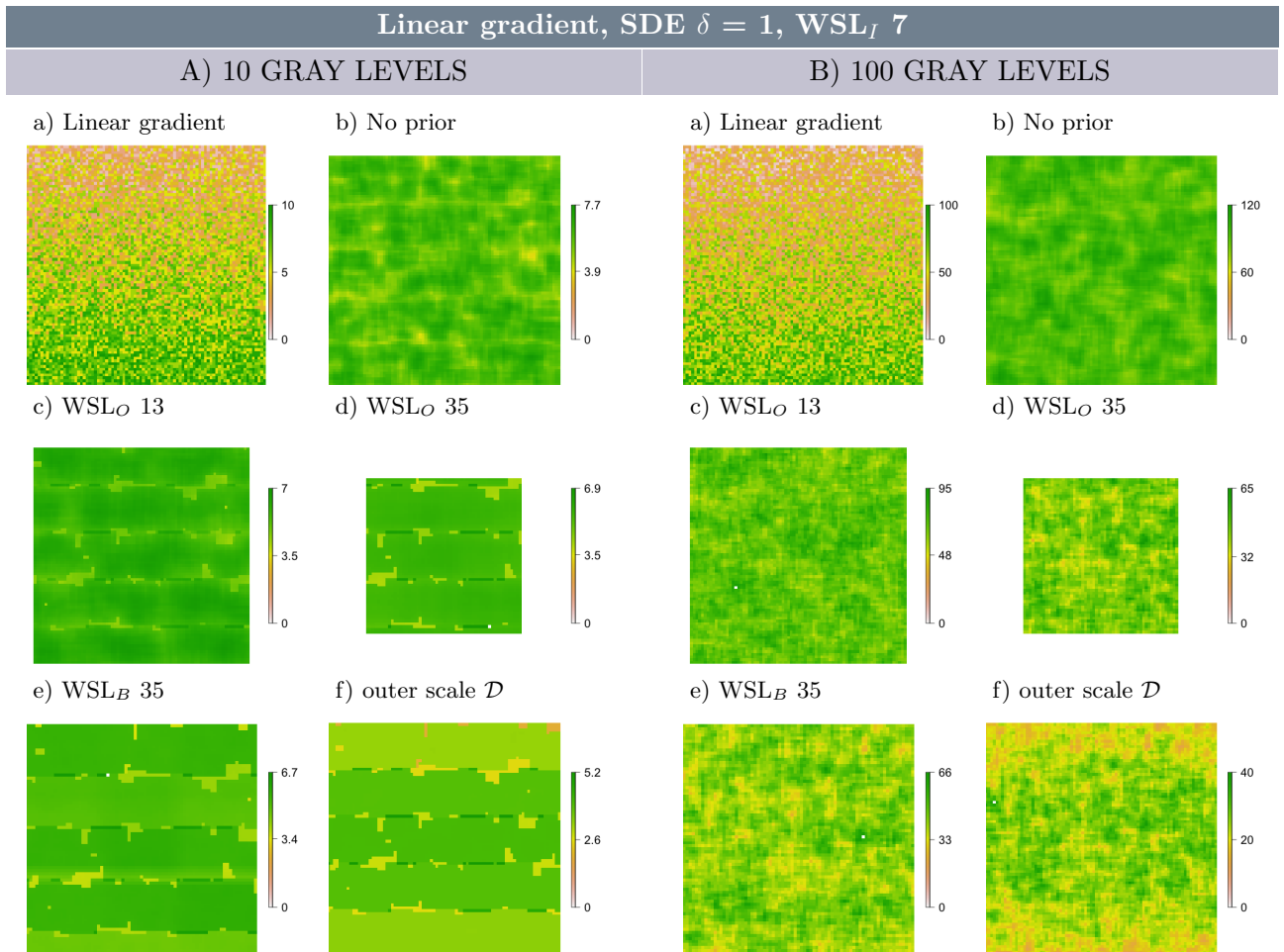


Figure S33: Linear gradient, structural diversity entropy (SDE),  $\delta = 1$ , WSL<sub>I</sub> 7.



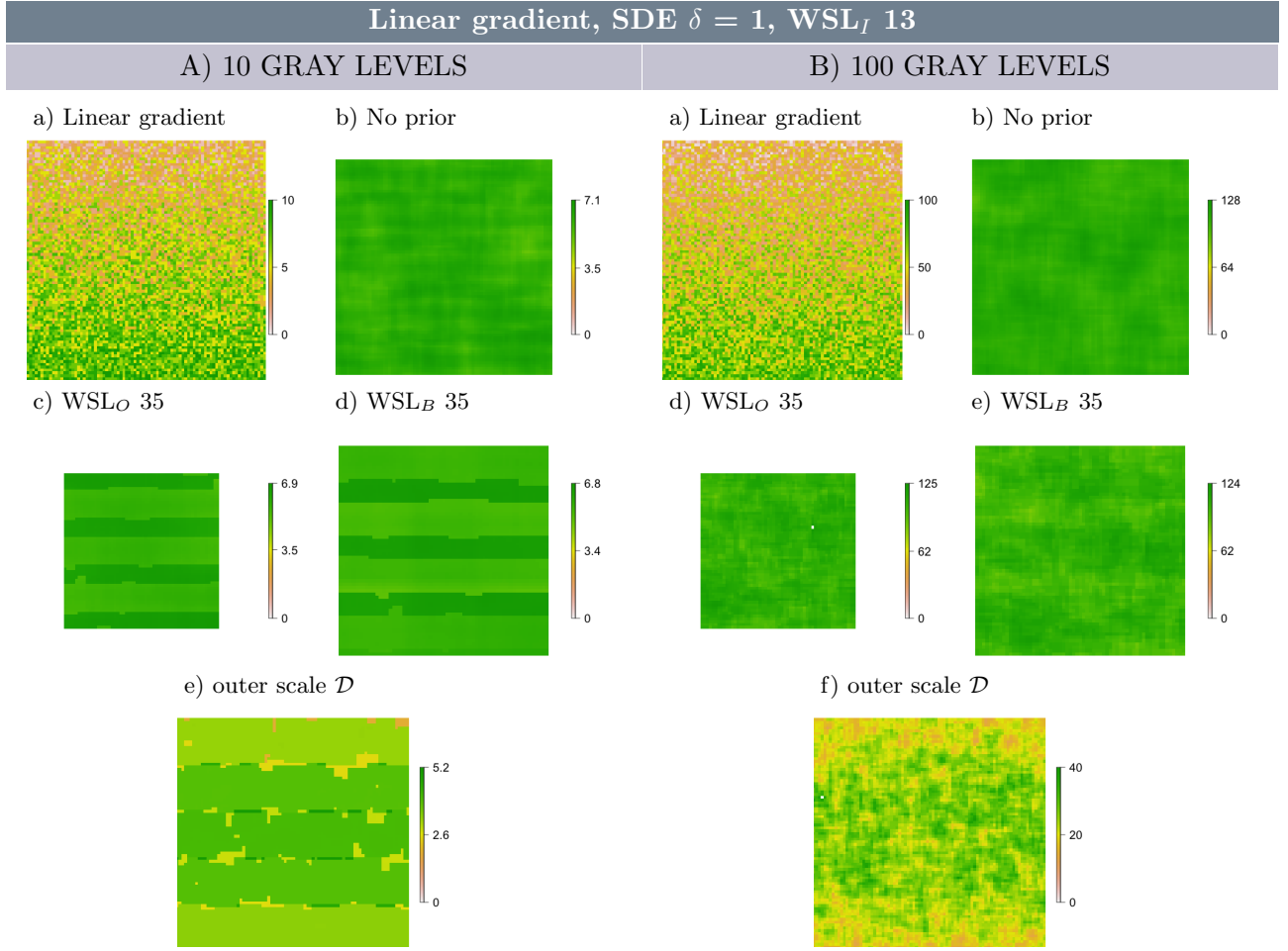


Figure S34: Linear gradient, structural diversity entropy (SDE),  $\delta = 1$ , WSL<sub>I</sub> 13.



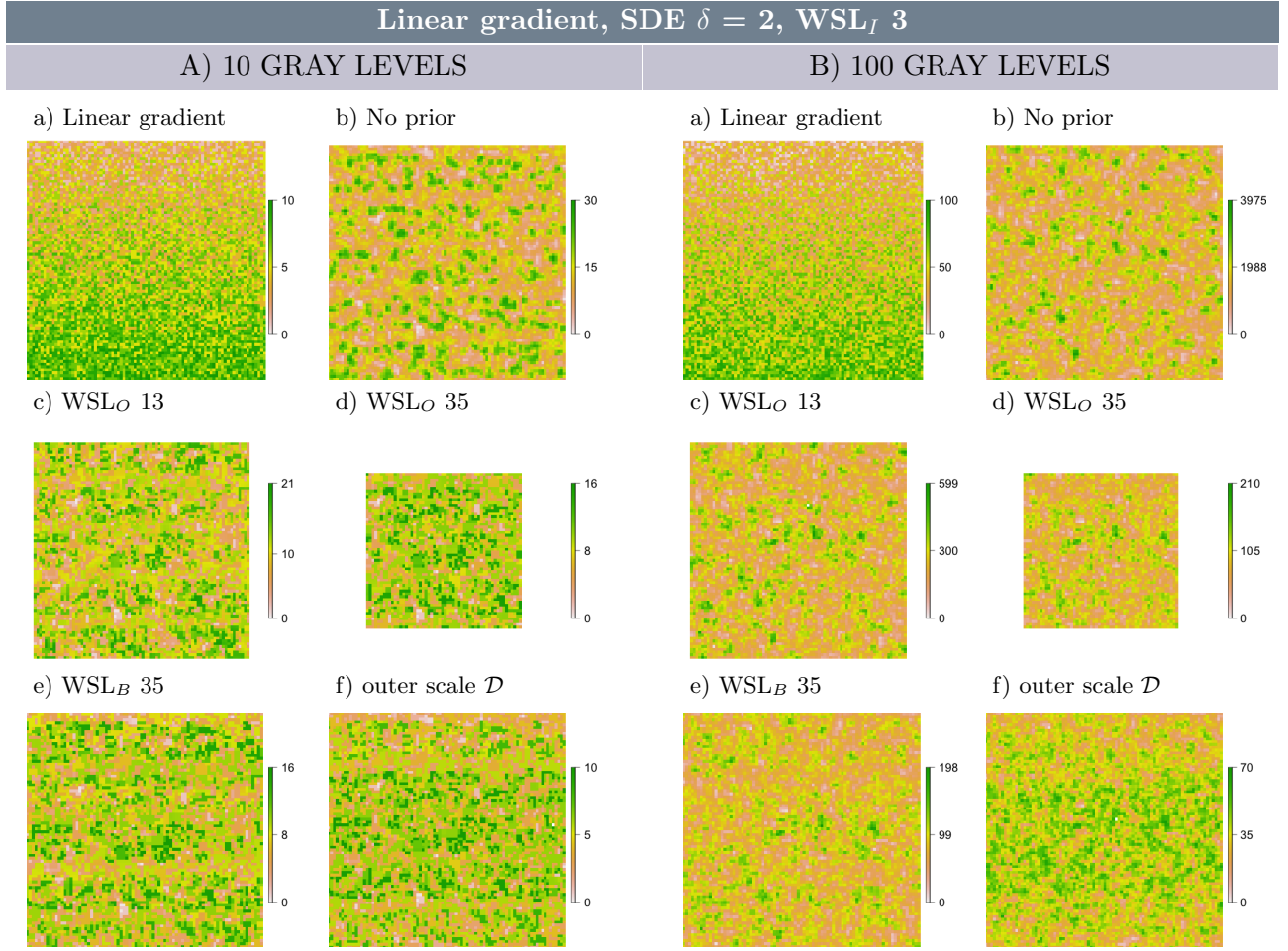


Figure S35: Linear gradient, structural diversity entropy (SDE),  $\delta = 2$ , WSL<sub>I</sub> 3.

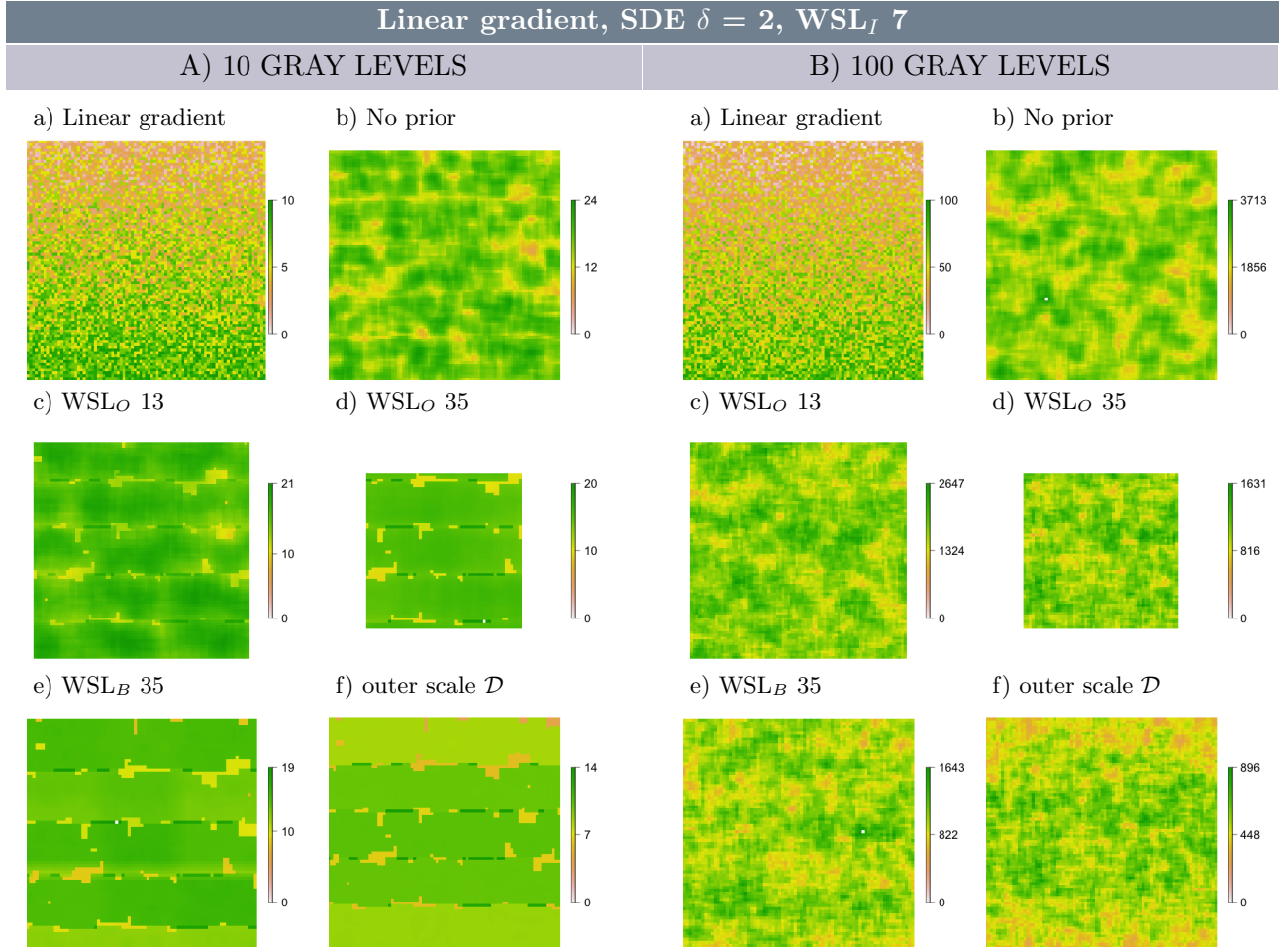


Figure S36: Linear gradient, structural diversity entropy (SDE),  $\delta = 2$ , WSL<sub>I</sub> 7.

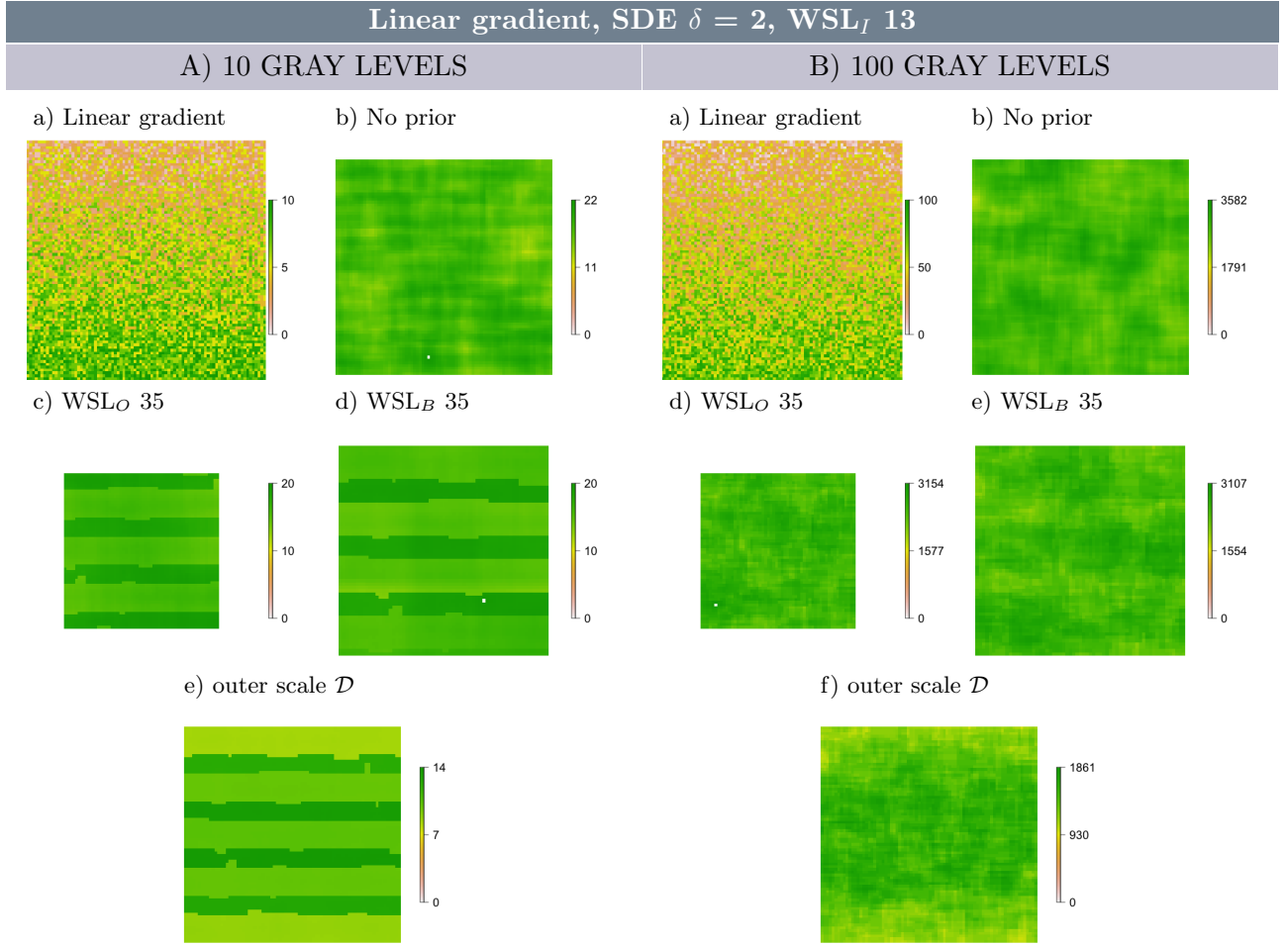


Figure S37: Linear gradient, structural diversity entropy (SDE),  $\delta = 2$ ,  $WSL_I$  13.

## References

Schuh, L., Santos, M.J., de Jong, R., Schaepman, M. & Furrer, R. (under review) Structural diversity entropy: a unified diversity measure to detect latent landscape features.