

Monitoring Urban Expansion by Coupling Multi-Temporal Active Remote Sensing and Landscape Analysis: Changes in the Metropolitan Area of Cordoba (Argentina) from 2010 to 2021

Flavio Marzioletti ^{1,*}, Paolo Gamba ², Antonietta Sorriso ² and Maria Laura Carranza ¹

¹ EnvixLab, Department of Biosciences and Territory, Molise University, Contrada Fonte Lappone snc, 86090 Pesche, Italy; carranza@unimol.it

² Department of Electrical, Biomedical and Computer Engineering, University of Pavia, Via Ferrata, 5, 27100 Pavia, Italy; paolo.gamba@unipv.it (P.G.); antonietta.sorriso@unipv.it (A.S.)

* Correspondence: flavio.marzioletti@unimol.it; Tel.: +39-3291543594

Table S1. The Cosmo-SkyMed image dataset used in this work along with the acquisition date (month, day, year).

Date	Time Step
14 July 2010	T ₀
15 February 2012	T ₁
28 July 2012	T ₁
04 January 2013	T ₁
27 July 2013	T ₁
06 January 2018	T ₂
14 August 2018	T ₂
21 January 2019	T ₂
12 August 2019	T ₂
05 December 2020	T ₃
08 August 2021	T ₃
03 October 2021	T ₃

Table S2. Parameter setting of UEXT algorithm along with the range values, the tuning step intervals and the best values identified after accuracy assessment of urban extraction maps in T₀, T₁, T₂, T₃.

UEXT Parameter	Value Range	Step Interval	Best Values
Seed threshold	-3 - 3	1	-2 for T ₀ , T ₁ , T ₂ 1 for T ₃
Urban threshold	600 – 2000	100	1000 for T ₀ , T ₁ , T ₂ 800 for T ₃
Minimum size settlements	10 – 100	5	20 for T ₀ , T ₁ , T ₂ 15 for T ₃
Size hole filling	10 – 100	5	20 for T ₀ , T ₁ , T ₂ 15 for T ₃

Table S3. Accuracy assessment between WSF and visual inspection of coeval Google Earth images in the four time steps (T_0 , T_1 , T_2 , T_3). Accuracy values (mean \pm standard deviation) of overall accuracy in percentage (OA), Cohen's Kappa metric (K), user accuracy of Urban class in percentage (Urb. UA), producer accuracy of Urban class in percentage (Urb. PA), user accuracy of Not Urban class in percentage (N. Urb. UA), producer accuracy of Not Urban class in percentage (N. Urb. PA) are reported.

OA (%)	K	Urb. UA (%)	Urb. PA (%)	N. Urb. UA (%)	N. Urb. PA (%)
<i>T₀: WSF-2015 vs. Google Earth Images (20 January 2010, 28 January 2010)</i>					
91.86 \pm 5.33	0.80 \pm 0.16	84.11 \pm 17.73	88.64 \pm 6.46	94.96 \pm 1.05	93.37 \pm 5.53
<i>T₁: WSF-2015 vs. Google Earth Images (17 September 2013, 06 October 2013)</i>					
88.76 \pm 0.68	0.74 \pm 0.04	95.74 \pm 1.77	72.11 \pm 5.22	85.95 \pm 0.65	98.22 \pm 0.33
<i>T₂: WSF-2019 vs. Google Earth Images (14 August 2019)</i>					
91.53 \pm 0.34	0.81 \pm 0.01	98.22 \pm 1.11	78.01 \pm 2.53	88.72 \pm 1.33	99.20 \pm 0.55
<i>T₃: WSF-2019 vs. Google Earth Images (05 October 2021)</i>					
92.49 \pm 1.23	0.83 \pm 0.01	97.45 \pm 0.84	80.73 \pm 0.33	90.34 \pm 2.22	98.86 \pm 0.44

Table S4. Correspondences between Urban intensity classes used in this research and Urban Atlas class produced by Copernicus Land Monitoring Service.

Urban Intensity Class	Urban Atlas Class	Description	Code
Very Low	Isolated structures	Isolated artificially structures with a residential component, such as (small) individual farm houses and related buildings.	11300
	Discontinuous very low density urban fabric	Areas with very low degree of soil sealing (average degree \leq 10%). Vegetated areas with residential buildings, roads and other artificially surfaced areas.	11240
Low	Discontinuous low density urban fabric	Areas with low degree of soil sealing (10% < average degree \leq 30%). It includes residential buildings, roads and other artificially surfaced areas. The vegetated areas are predominant.	11230
Medium	Discontinuous medium density urban fabric	Areas with medium degree of soil sealing (30% < average degree \leq 50%). It includes residential buildings, roads and other artificially surfaced areas. The vegetated areas are slightly predominant.	11220
High	Discontinuous dense urban fabric	Areas with high degree of soil sealing containing a fraction of non-sealed areas (50 % < average degree \leq 80%). Predominant residential usage (e.g. single family house, high rise dwelling, city center or suburb), and the non-sealed areas might be private gardens or common green areas.	11210
	Continuous urban fabric	Areas with very high degree of soil sealing (average degree > 80%). It includes: single family houses, high rise dwellings, city center or suburb.	11100

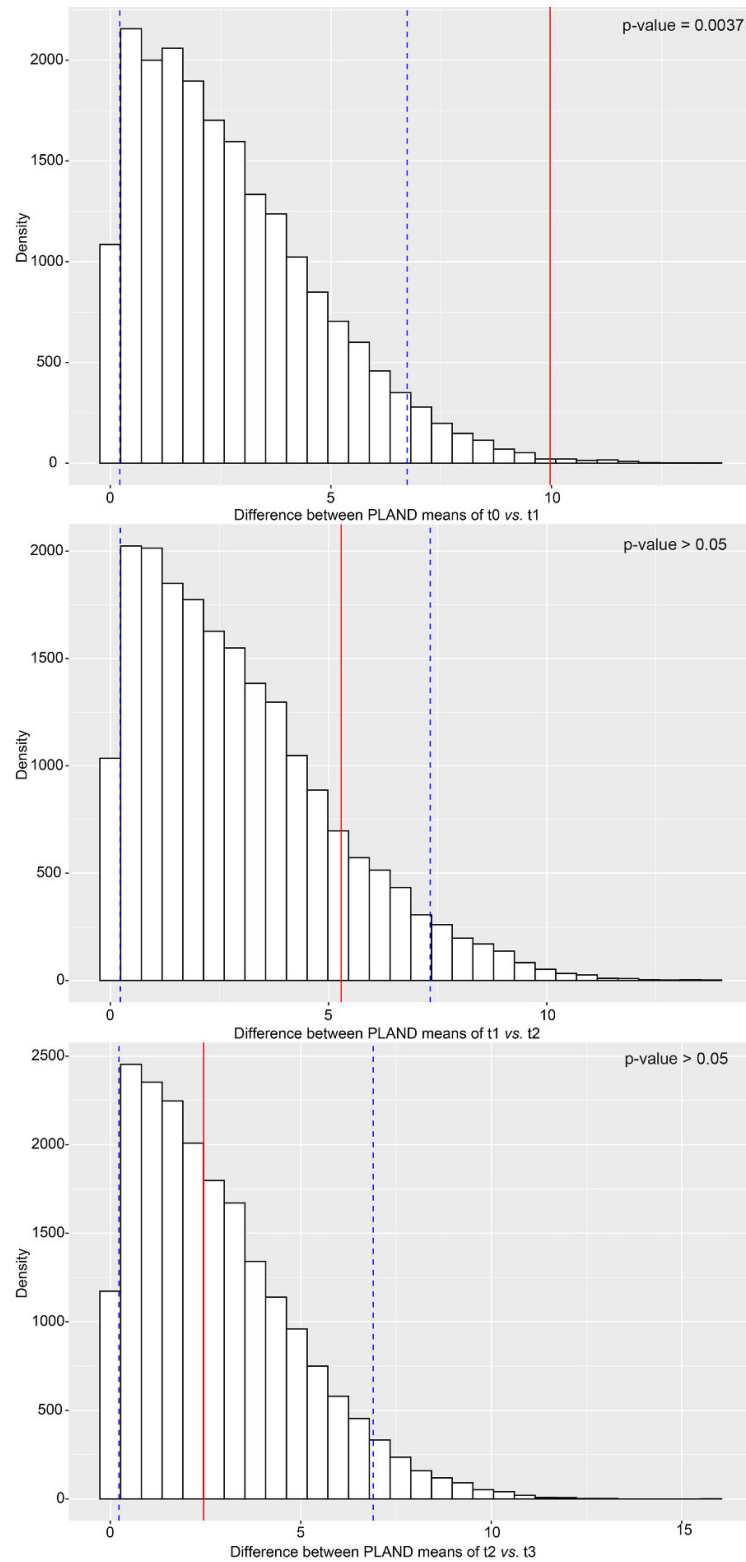


Figure S1. Bootstrapping test and the p-value values calculated on the difference of PLAND means between two subsequential time steps. The red line indicates the value of real mean difference, the blue dotted lines indicate the lower and upper confidence intervals.

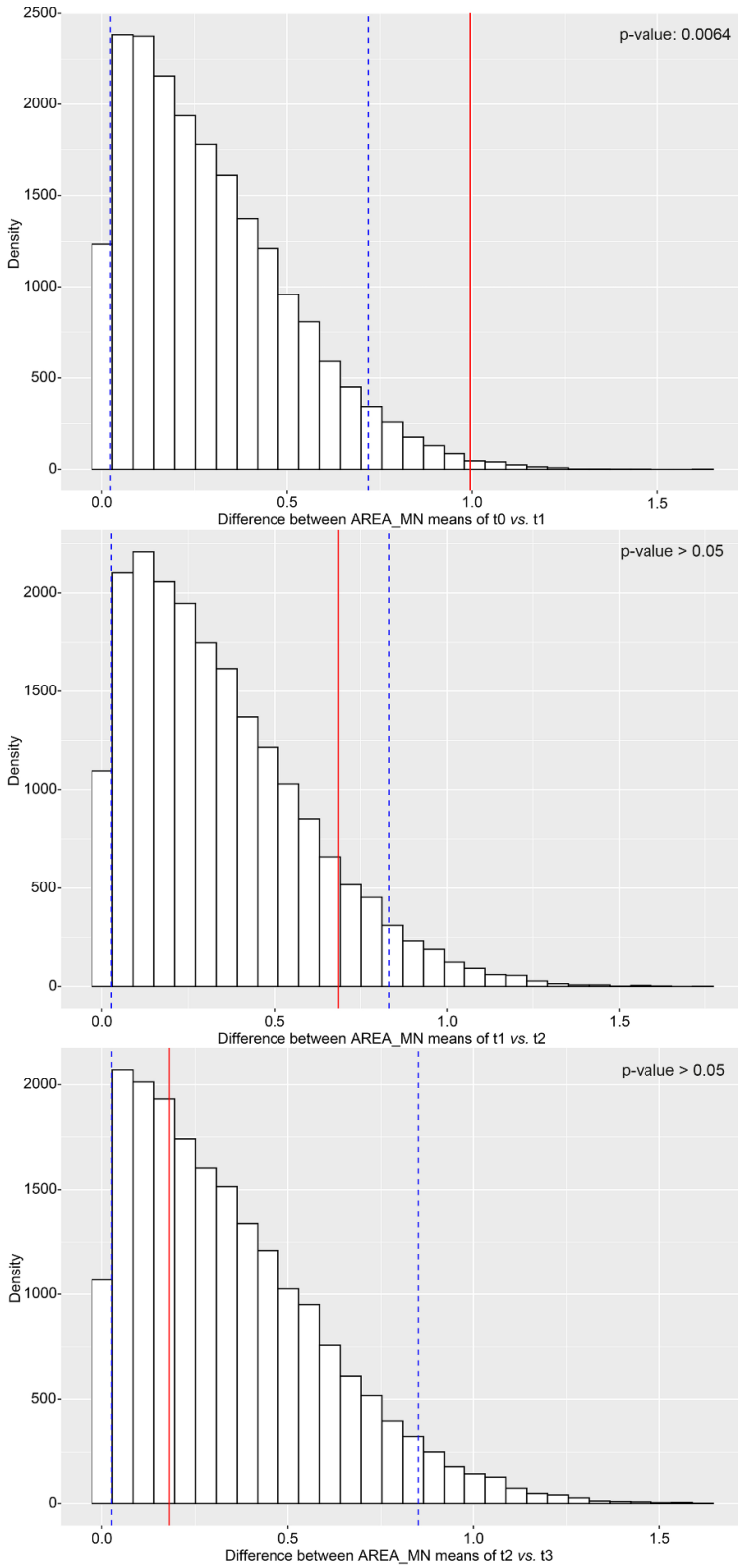


Figure S2. Bootstrapping test and the p-value values calculated on the difference of AREA_MN means between two subsequential time steps. The red line indicates the value of real mean difference, the blue dotted lines indicate the lower and upper confidence intervals.

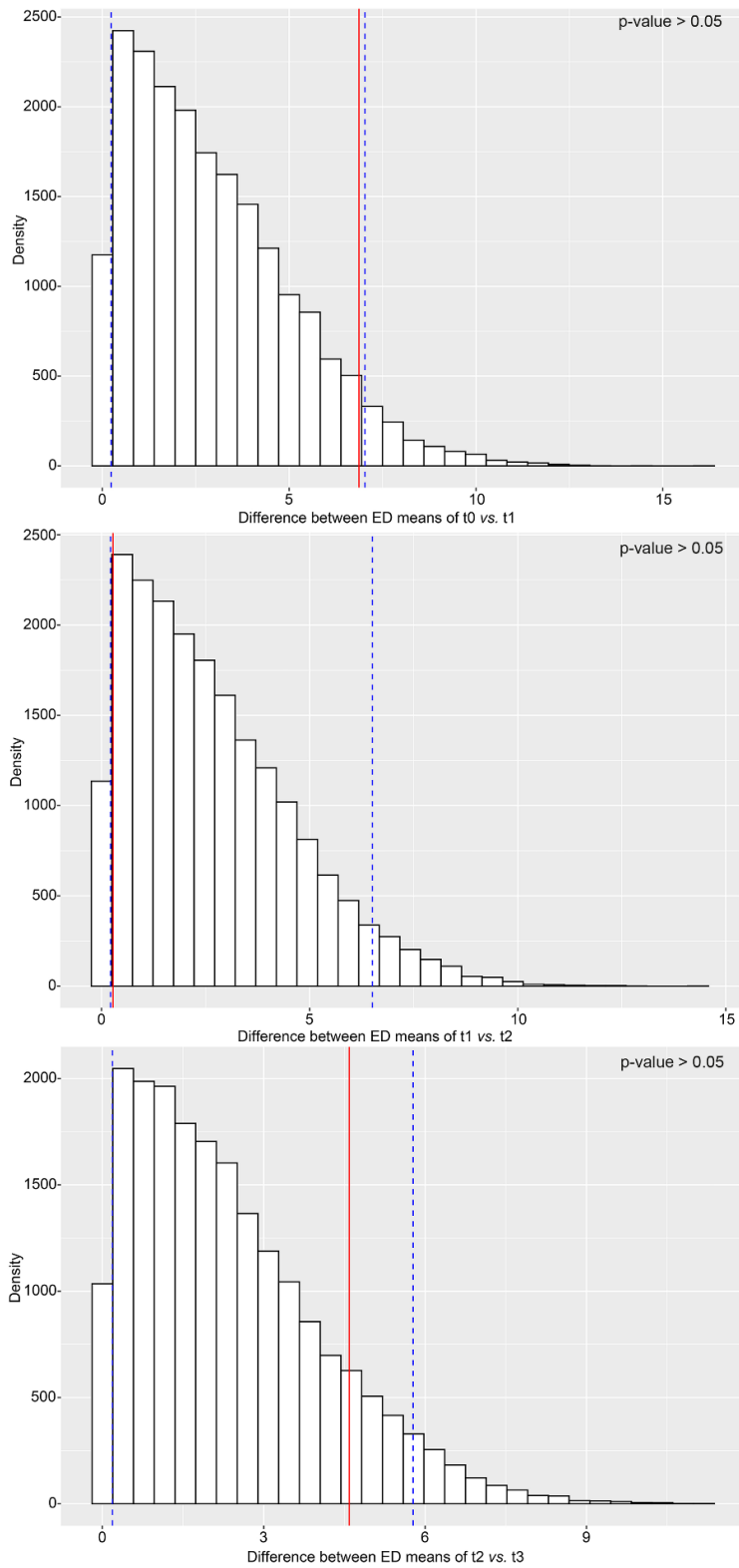


Figure S3. Bootstrapping test and the p-value values calculated on the difference of ED means between two subsequential time steps. The red line indicates the value of real mean difference, the blue dotted lines indicate the lower and upper confidence intervals.

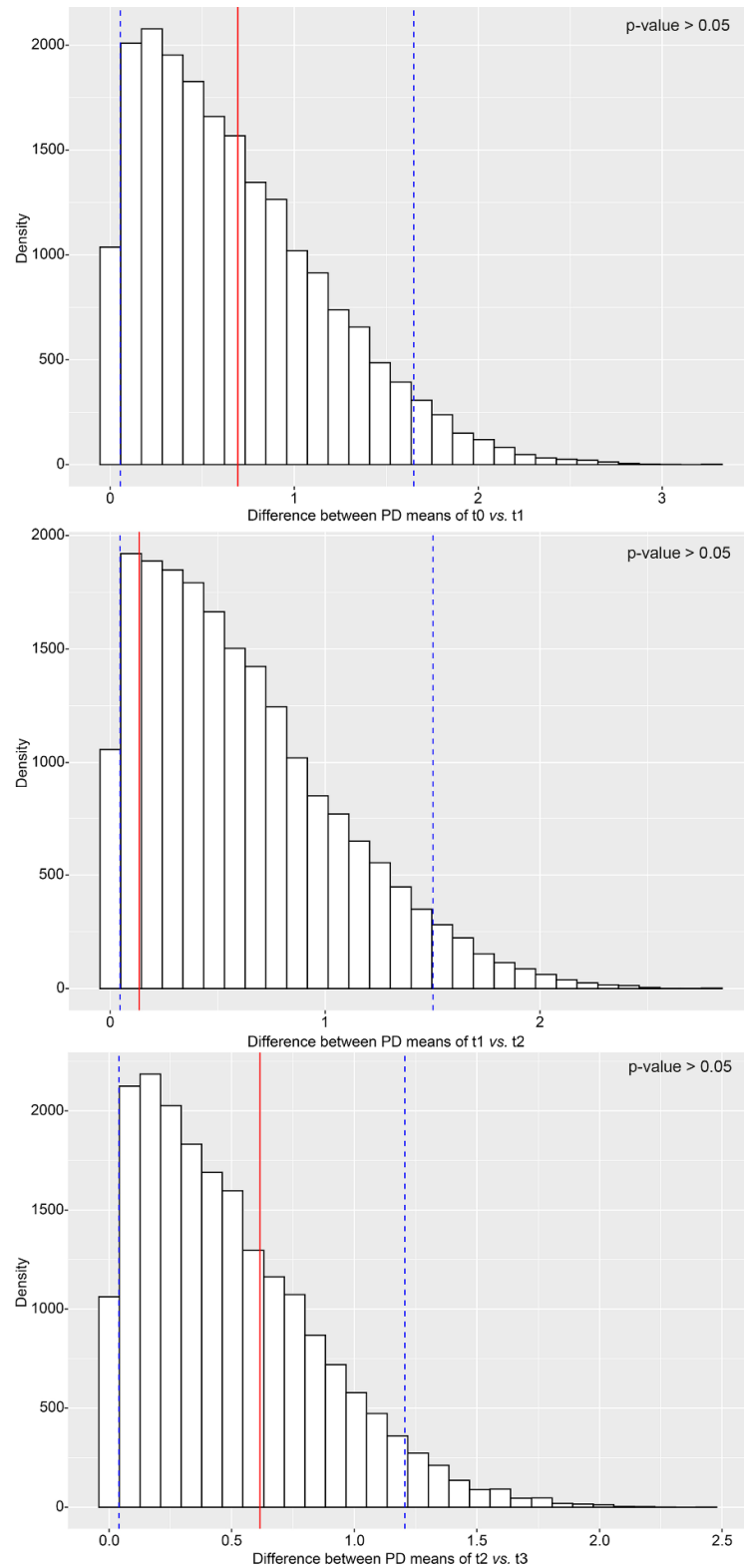


Figure S4. Bootstrapping test and the p-value values calculated on the difference of PD means between two subsequential time steps. The red line indicates the value of real mean difference, the blue dotted lines indicate the lower and upper confidence intervals.

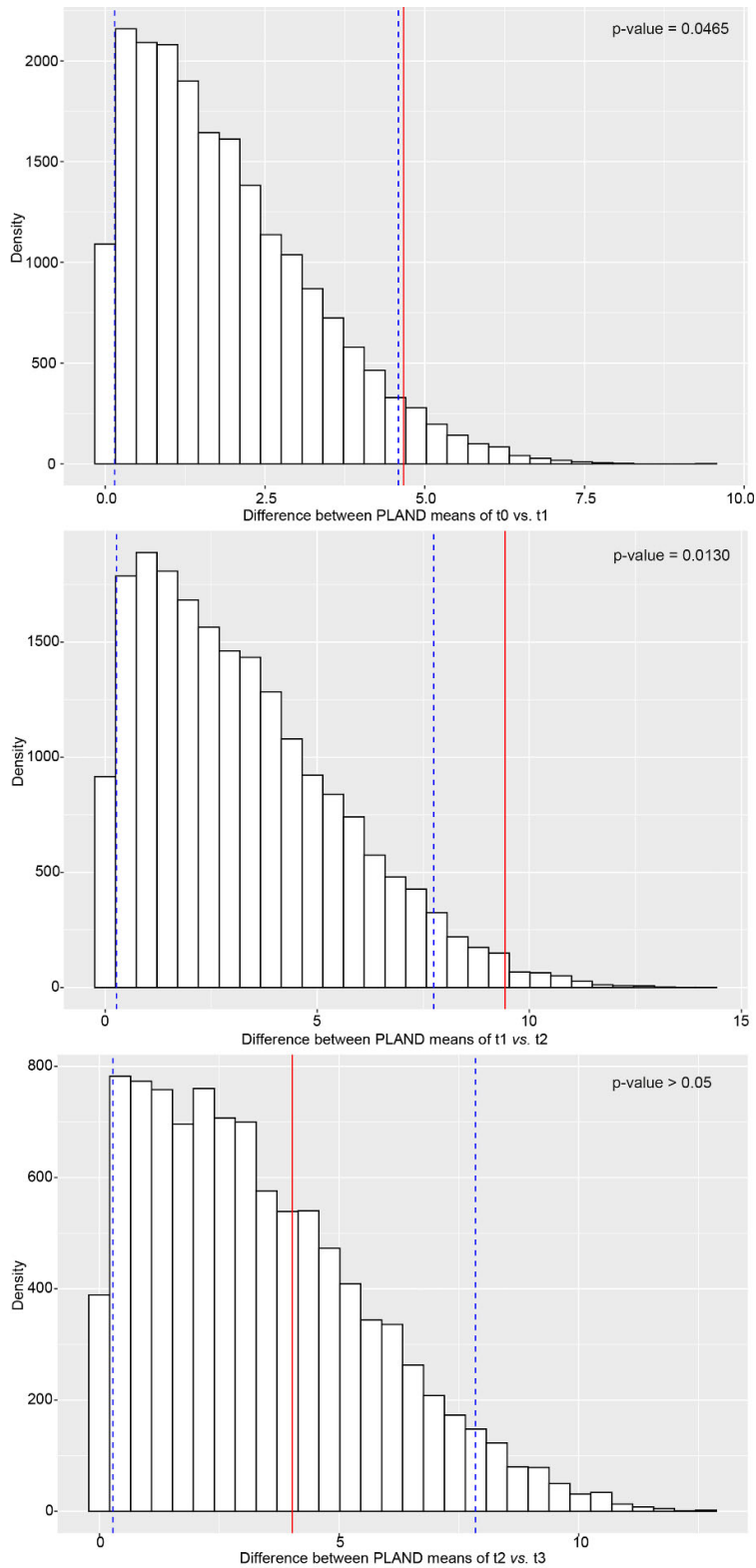


Figure S5. Bootstrapping test and the p-value values of Very Low class calculated on the difference of PLAND means between two subsequential time steps. The red line indicates the value of real mean difference, the blue dotted lines indicate the lower and upper confidence intervals.

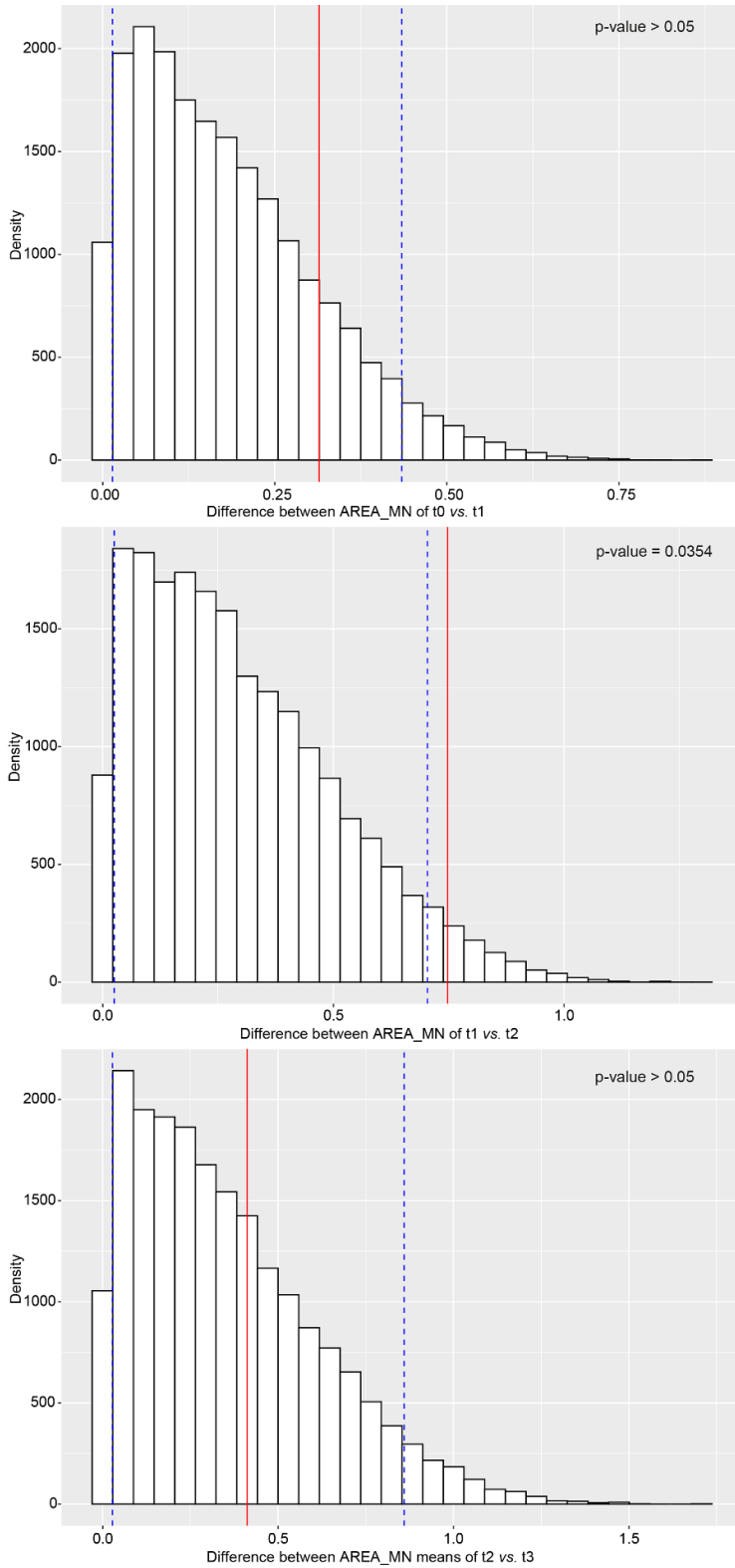


Figure S6 Bootstrapping test and the p-value values of Very Low class calculated on the difference of AREA_MN means between two subsequential time steps. The red line indicates the value of real mean difference, the blue dotted lines indicate the lower and upper confidence intervals.

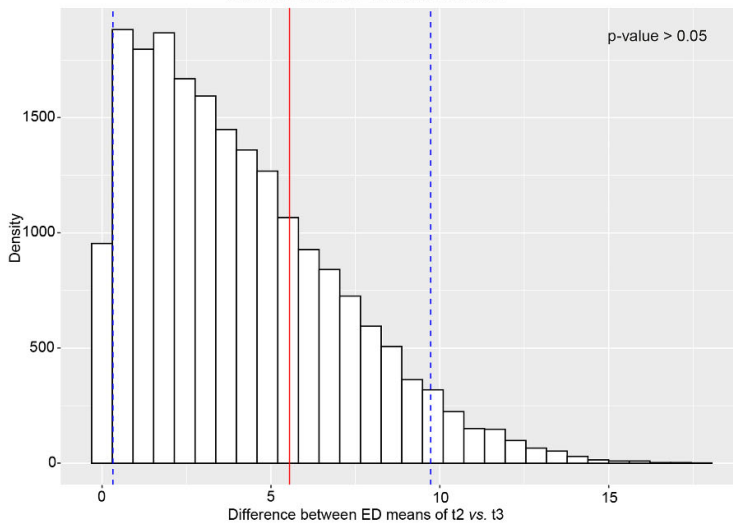
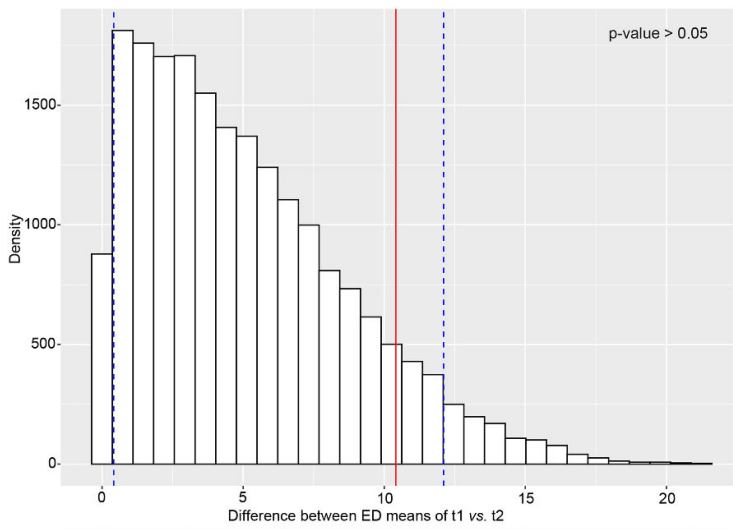
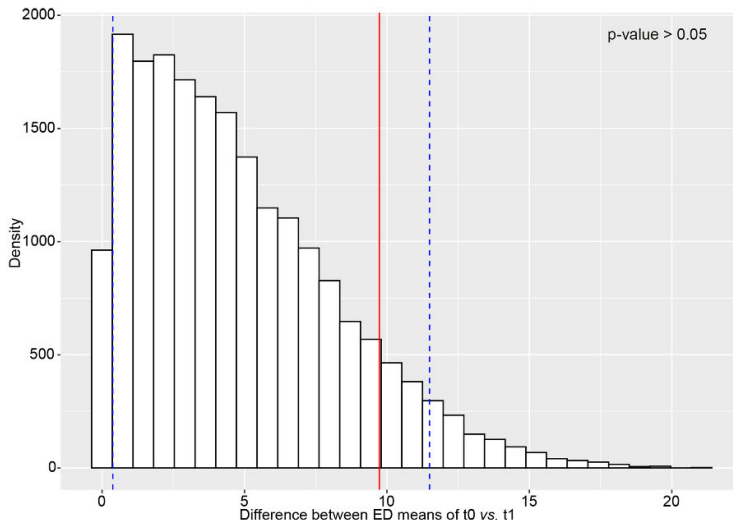


Figure S7. Bootstrapping test and the p-value values of Very Low class calculated on the difference of ED means between two subsequent time steps. The red line indicates the value of real mean difference, the blue dotted lines indicate the lower and upper confidence intervals.

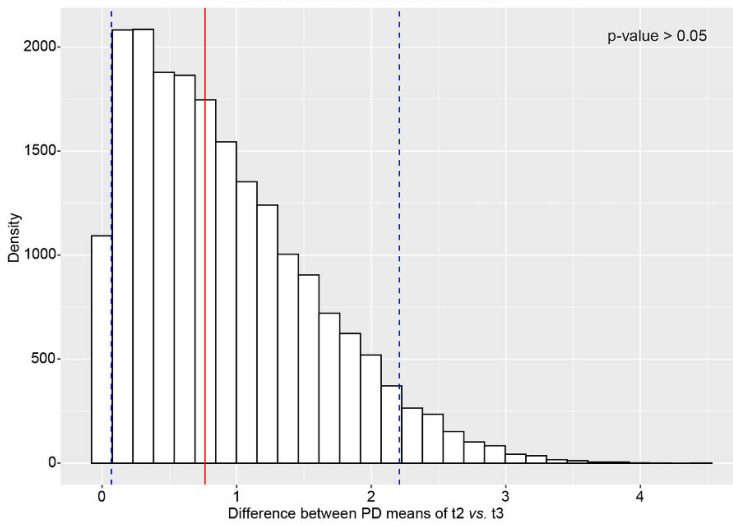
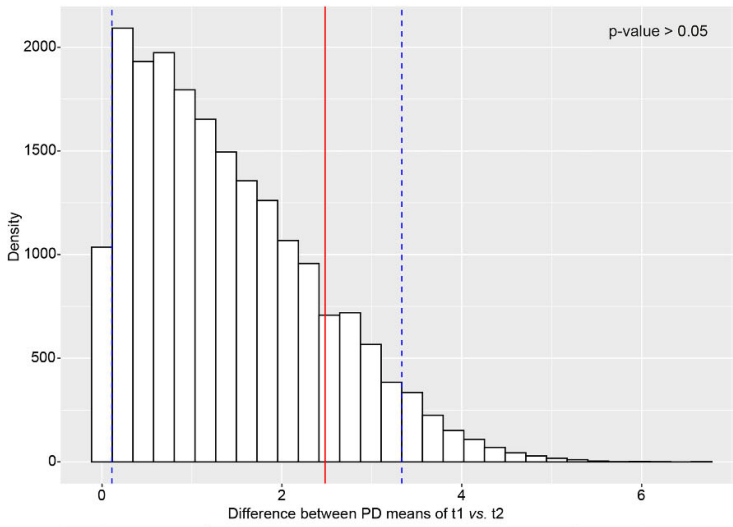
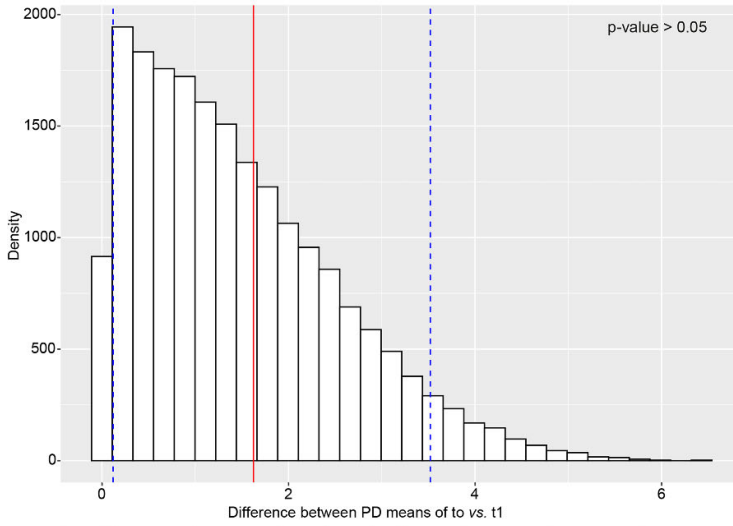


Figure S8. Bootstrapping test and the p-value values of Very Low class calculated on the difference of PD means between two subsequent time steps. The red line indicates the value of real mean difference, the blue dotted lines indicate the lower and upper confidence intervals.

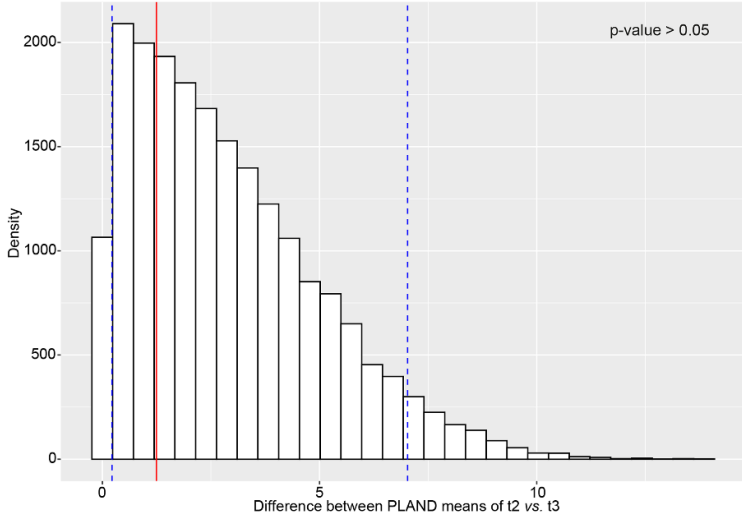
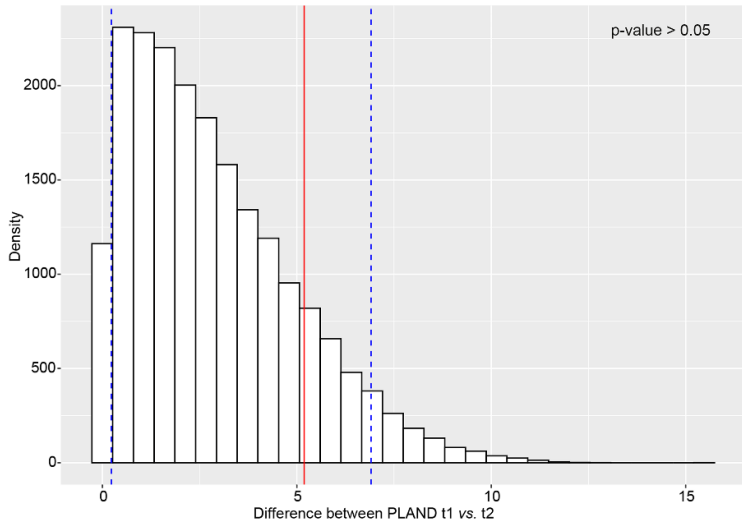
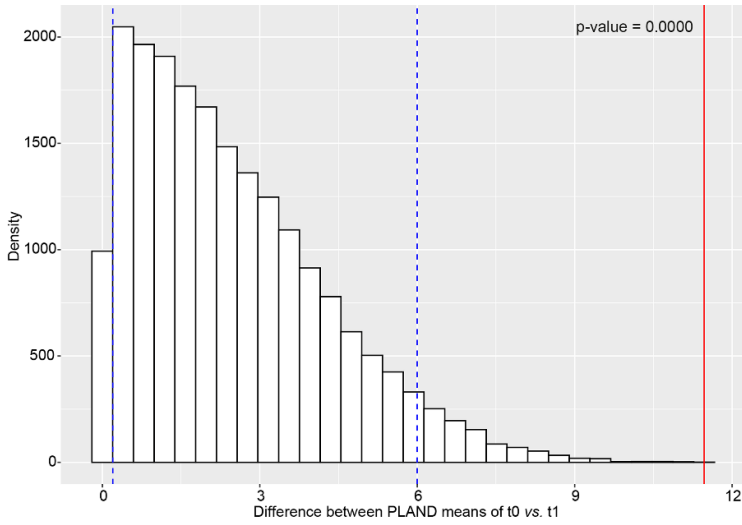


Figure S9. Bootstrapping test and the p-value values of Low class calculated on the difference of PLAND means between two subsequential time steps. The red line indicates the value of real mean difference, the blue dotted lines indicate the lower and upper confidence intervals.

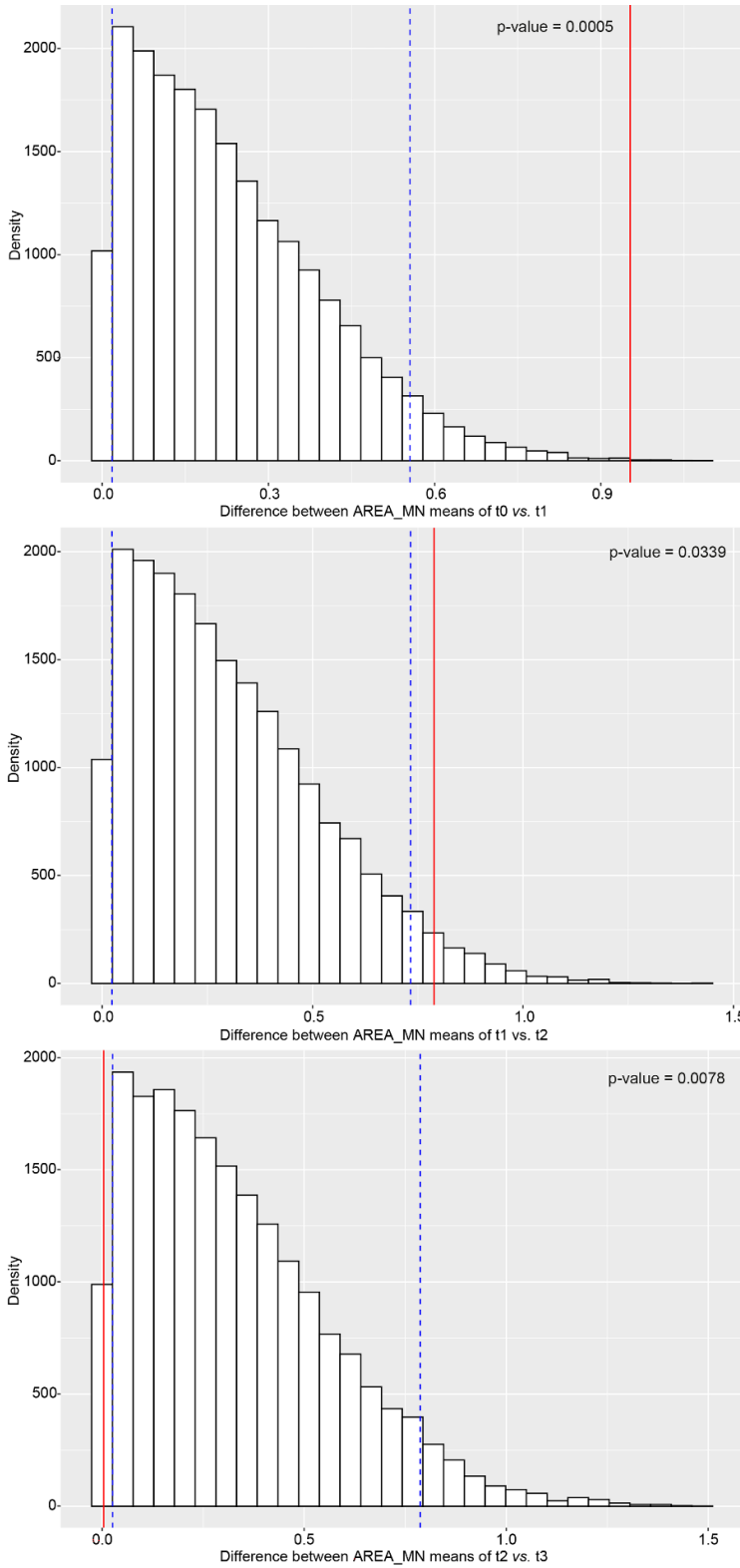


Figure S10. Bootstrapping test and the p-value values of Low class calculated on the difference of AREA_MN means between two subsequential time steps. The red line indicates the value of real mean difference, the blue dotted lines indicate the lower and upper confidence intervals.

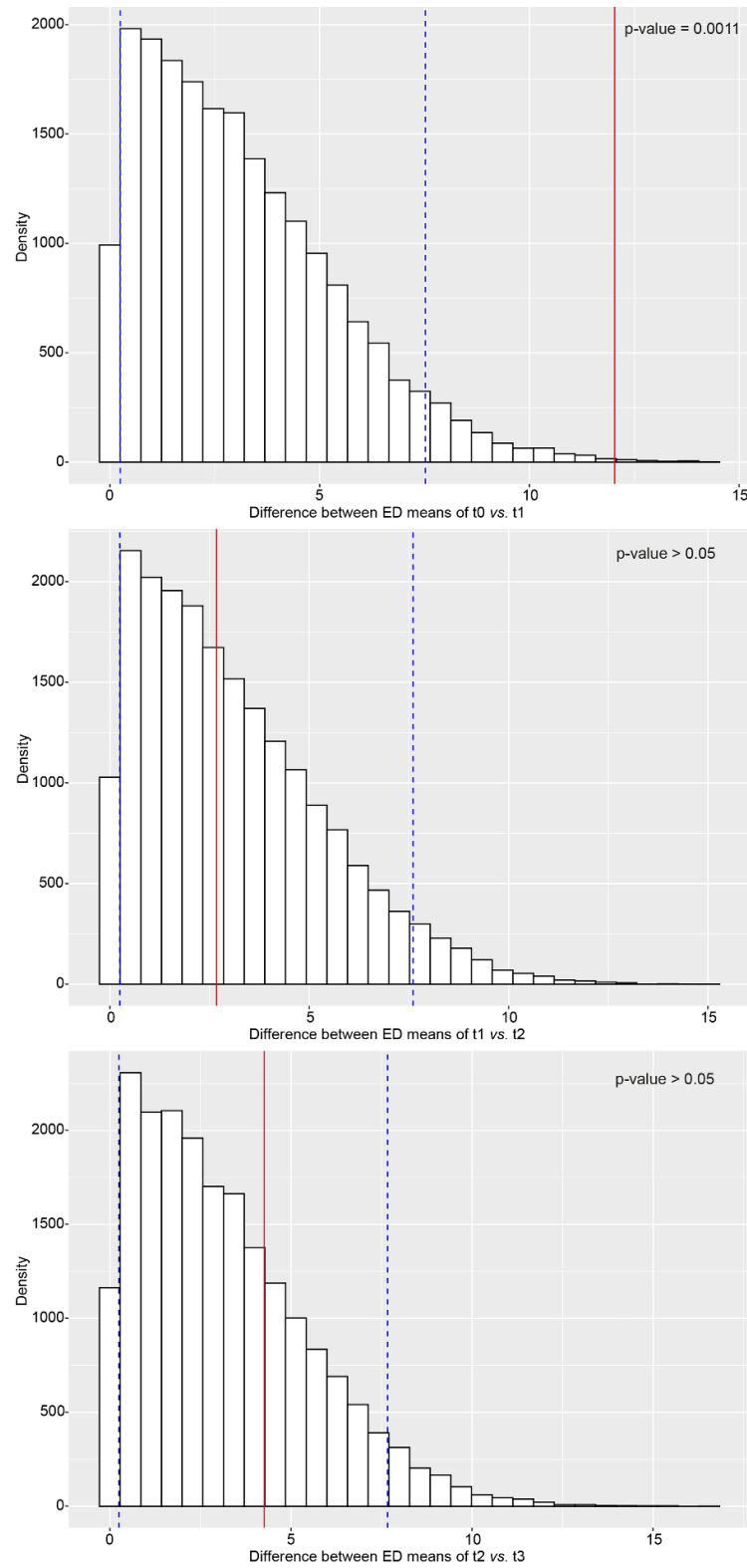


Figure S11. Bootstrapping test and the p-value values of Low class calculated on the difference of ED means between two subsequent time steps. The red line indicates the value of real mean difference, the blue dotted lines indicate the lower and upper confidence intervals.

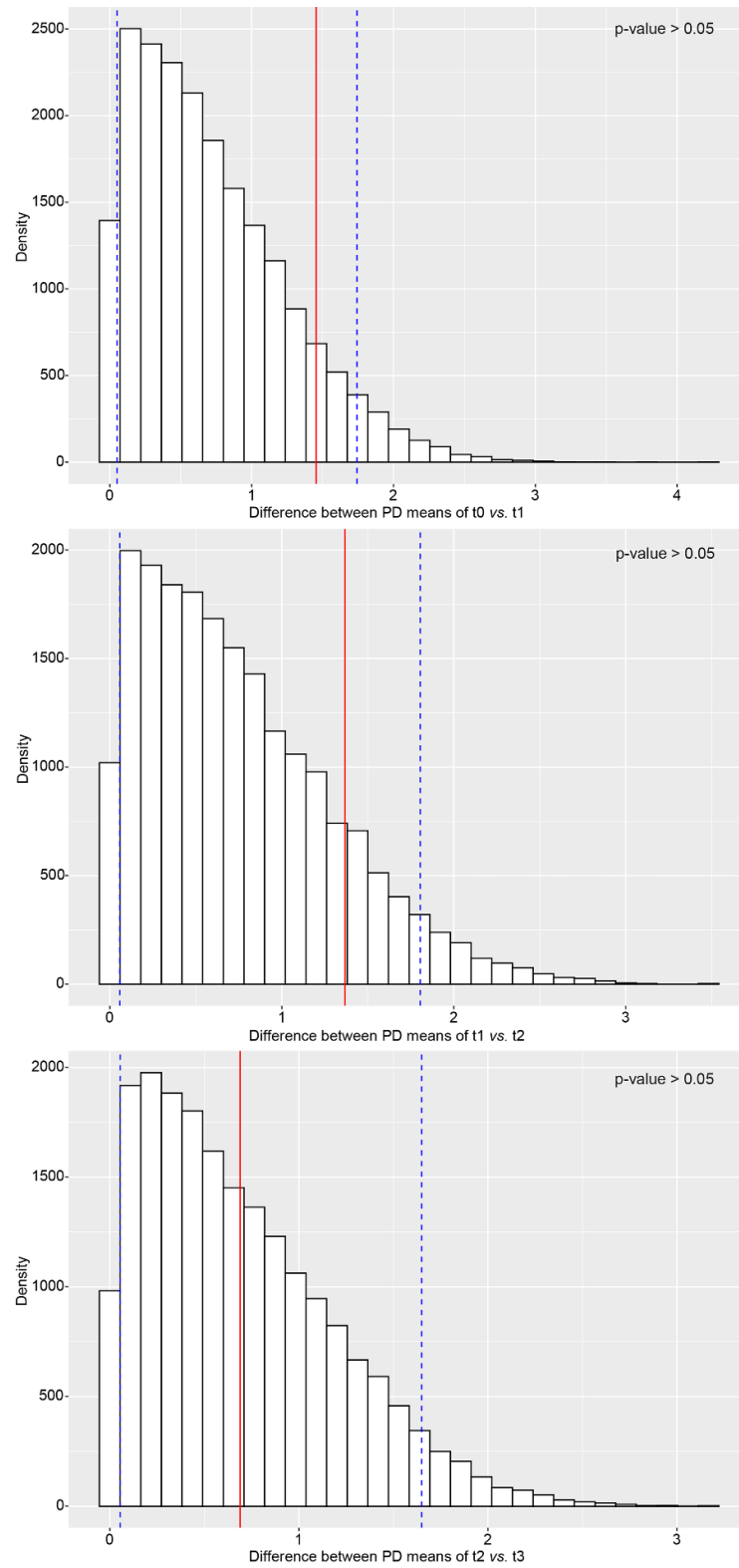


Figure S12. Bootstrapping test and the p-value values of Low class calculated on the difference of PD means between two subsequential time steps. The red line indicates the value of real mean difference, the blue dotted lines indicate the lower and upper confidence intervals.

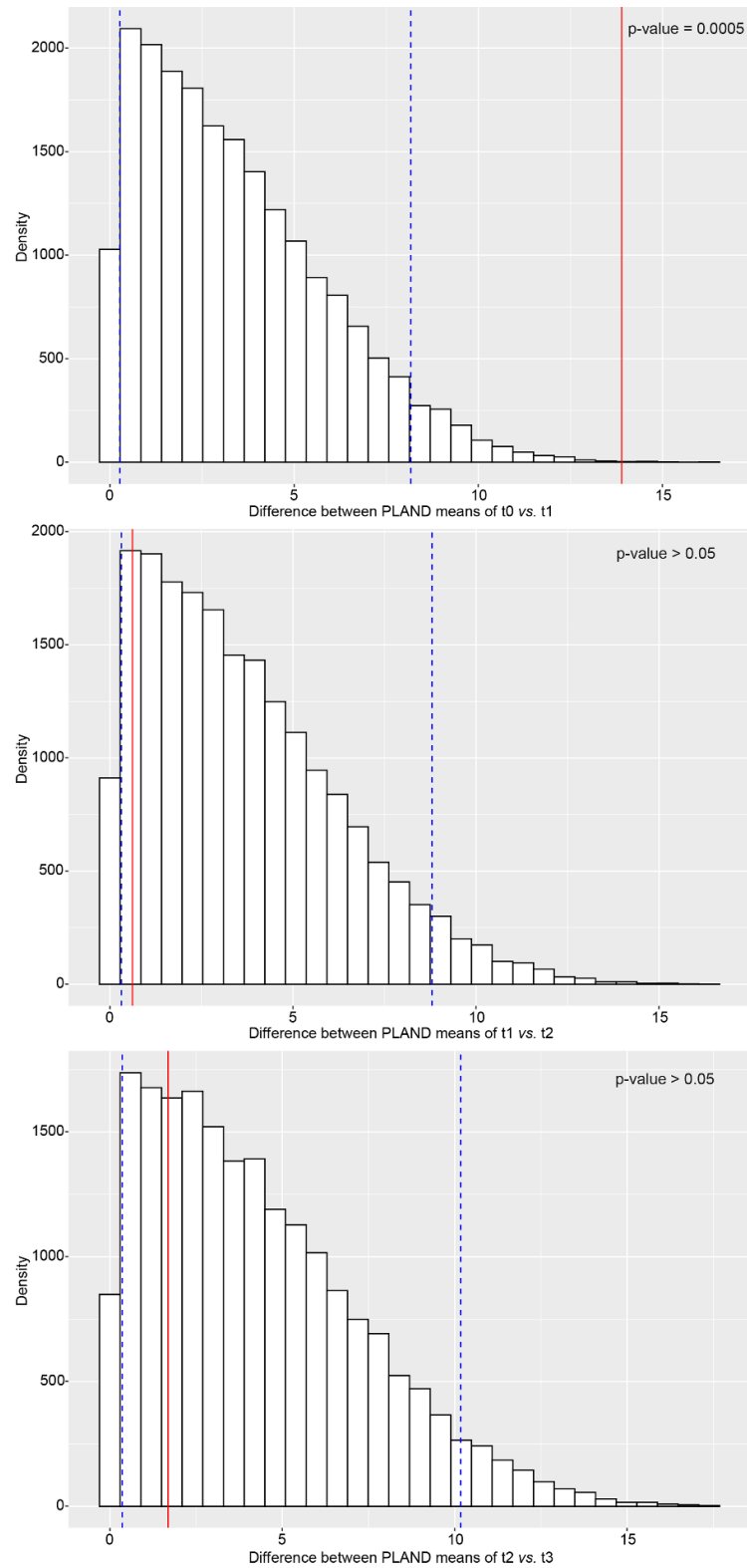


Figure S13. Bootstrapping test and the p-value values of Medium class calculated on the difference of PLAND means between two subsequential time steps. The red line indicates the value of real mean difference, the blue dotted lines indicate the lower and upper confidence intervals.

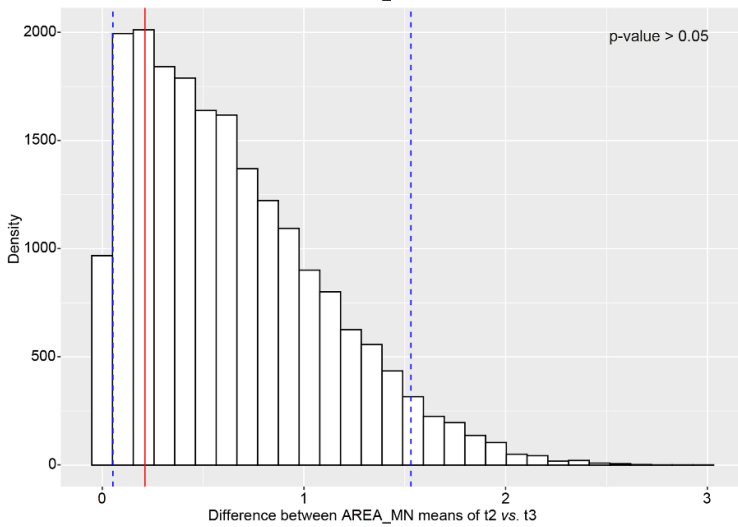
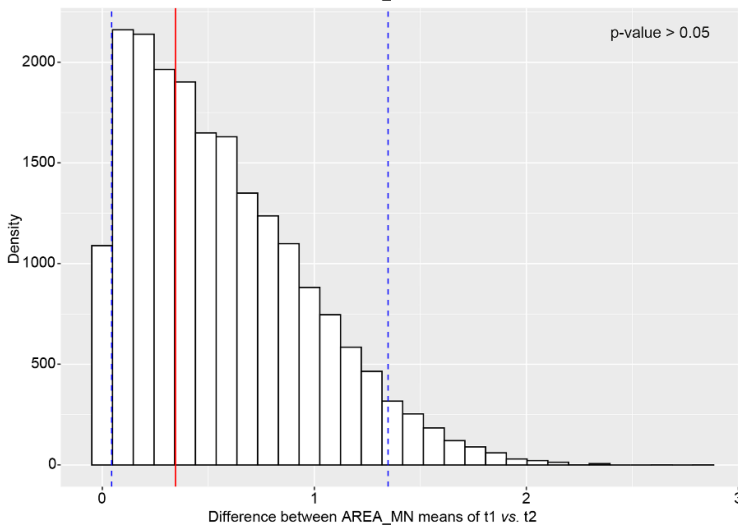
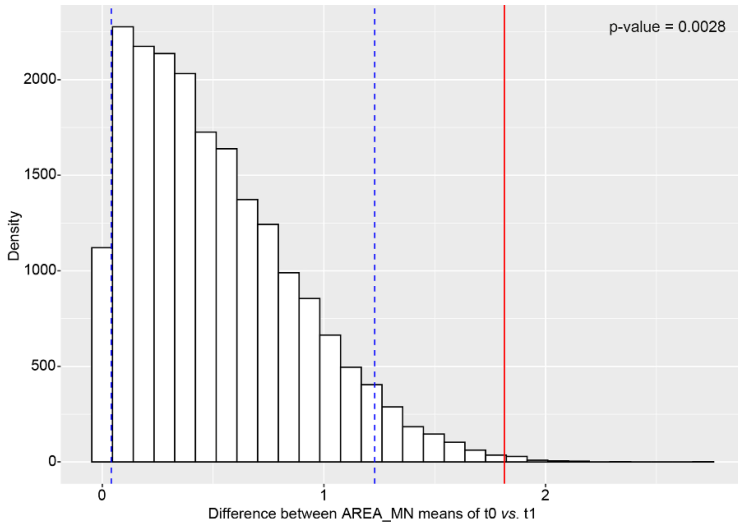


Figure S14. Bootstrapping test and the p-value values of Medium class calculated on the difference of AREA_MN means between two subsequential time steps. The red line indicates the value of real mean difference, the blue dotted lines indicate the lower and upper confidence intervals.

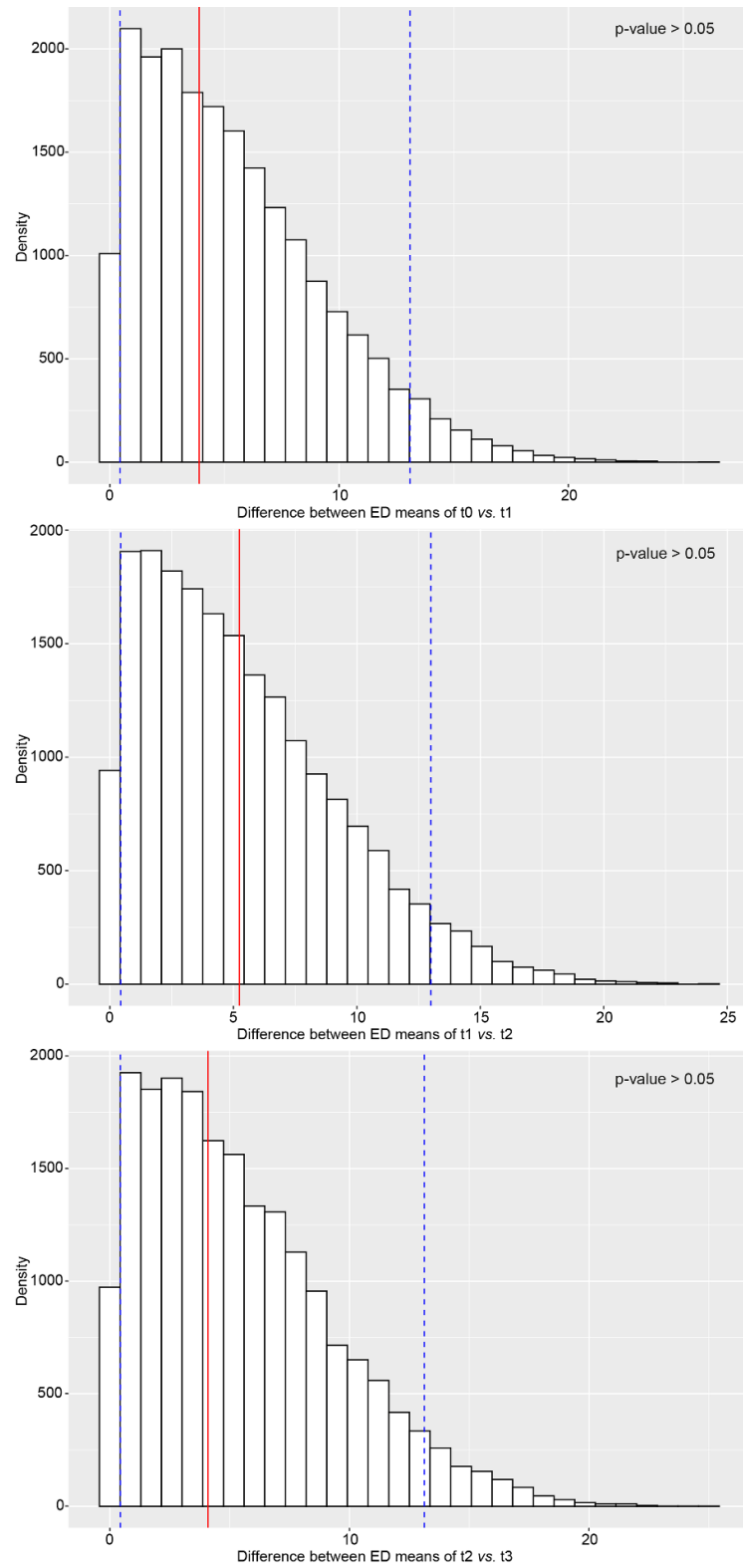


Figure S15. Bootstrapping test and the p-value values of Medium class calculated on the difference of ED means between two subsequent time steps. The red line indicates the value of real mean difference, the blue dotted lines indicate the lower and upper confidence intervals.

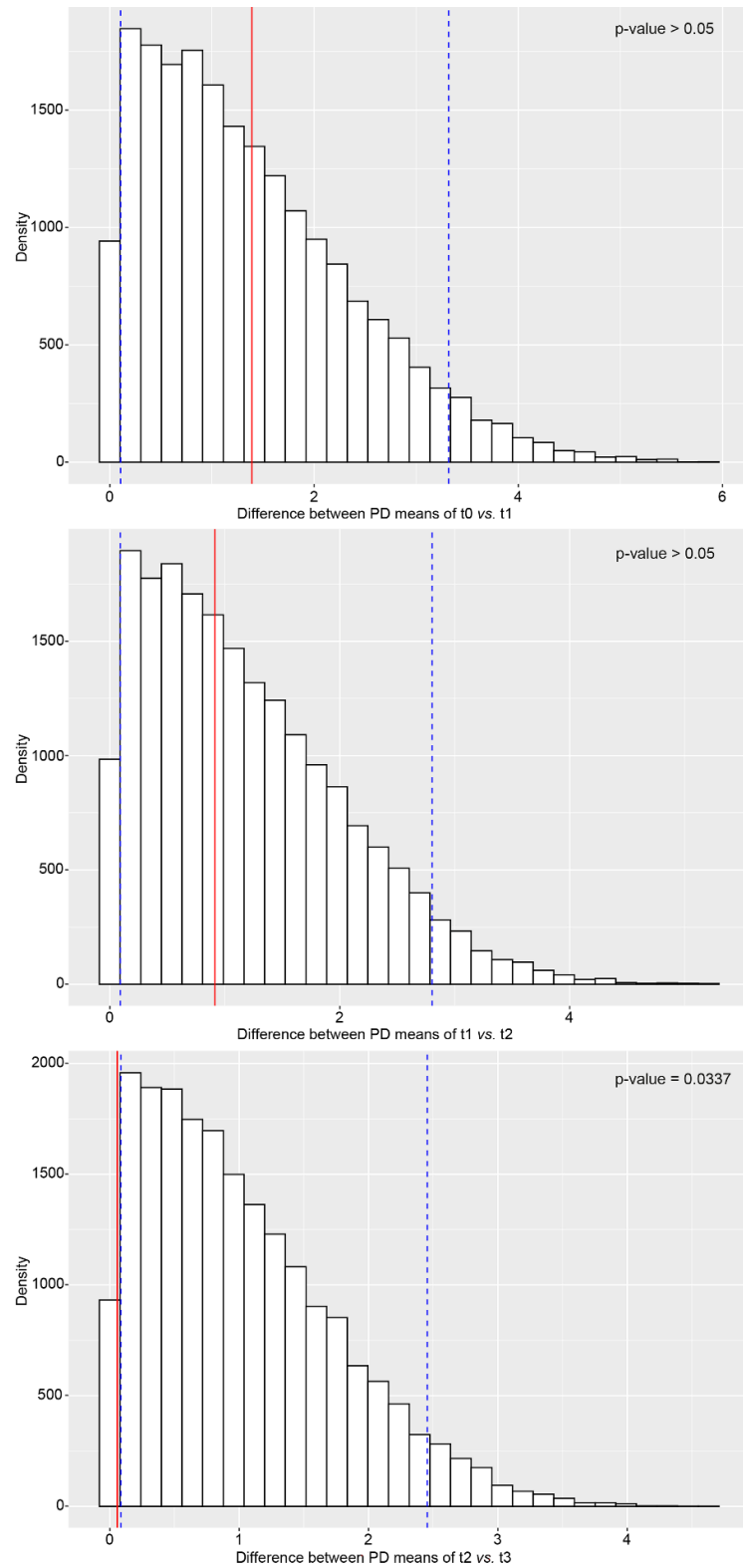


Figure S16. Bootstrapping test and the p-value values of Medium class calculated on the difference of PD means between two subsequent time steps. The red line indicates the value of real mean difference, the blue dotted lines indicate the lower and upper confidence intervals.

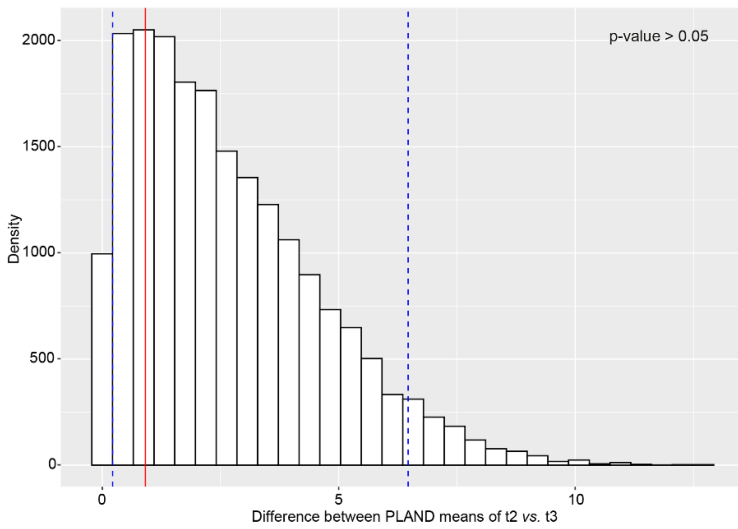
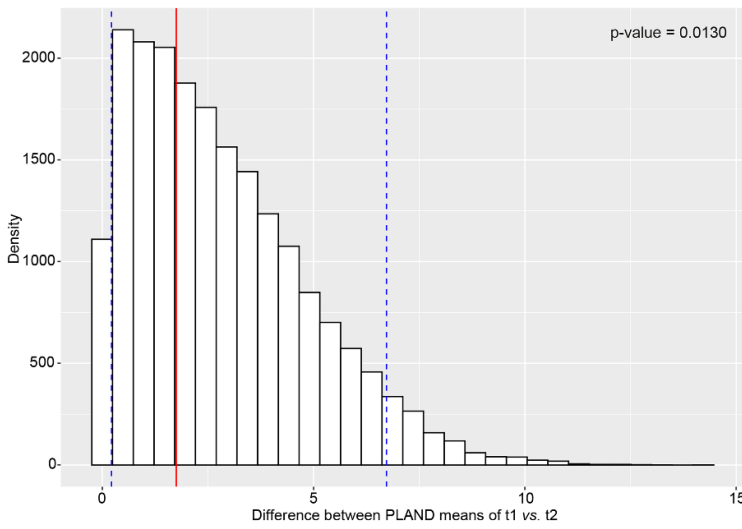
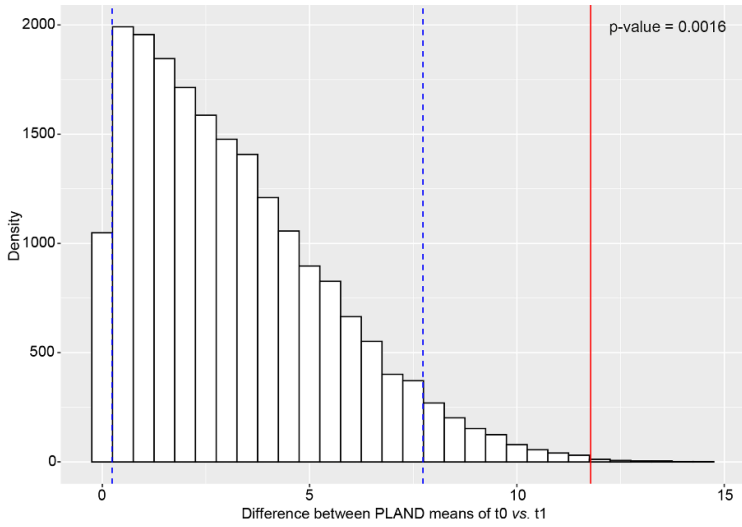


Figure S17. Bootstrapping test and the p-value values of High class calculated on the difference of PLAND means between two subsequent time steps. The red line indicates the value of real mean difference, the blue dotted lines indicate the lower and upper confidence intervals.

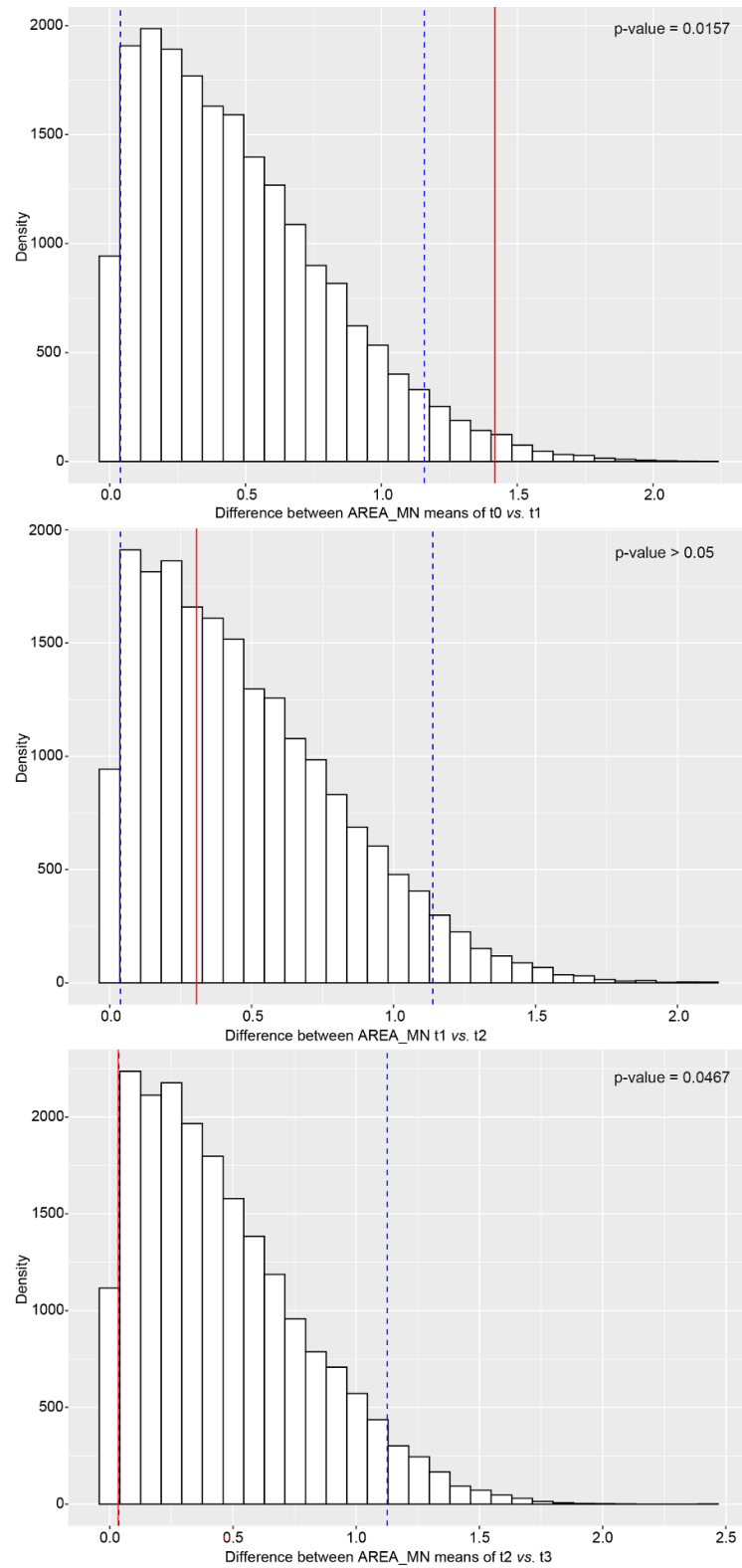


Figure S18. Bootstrapping test and the p-value values of High class calculated on the difference of AREA_MN means between two subsequential time steps. The red line indicates the value of real mean difference, the blue dotted lines indicate the lower and upper confidence intervals.

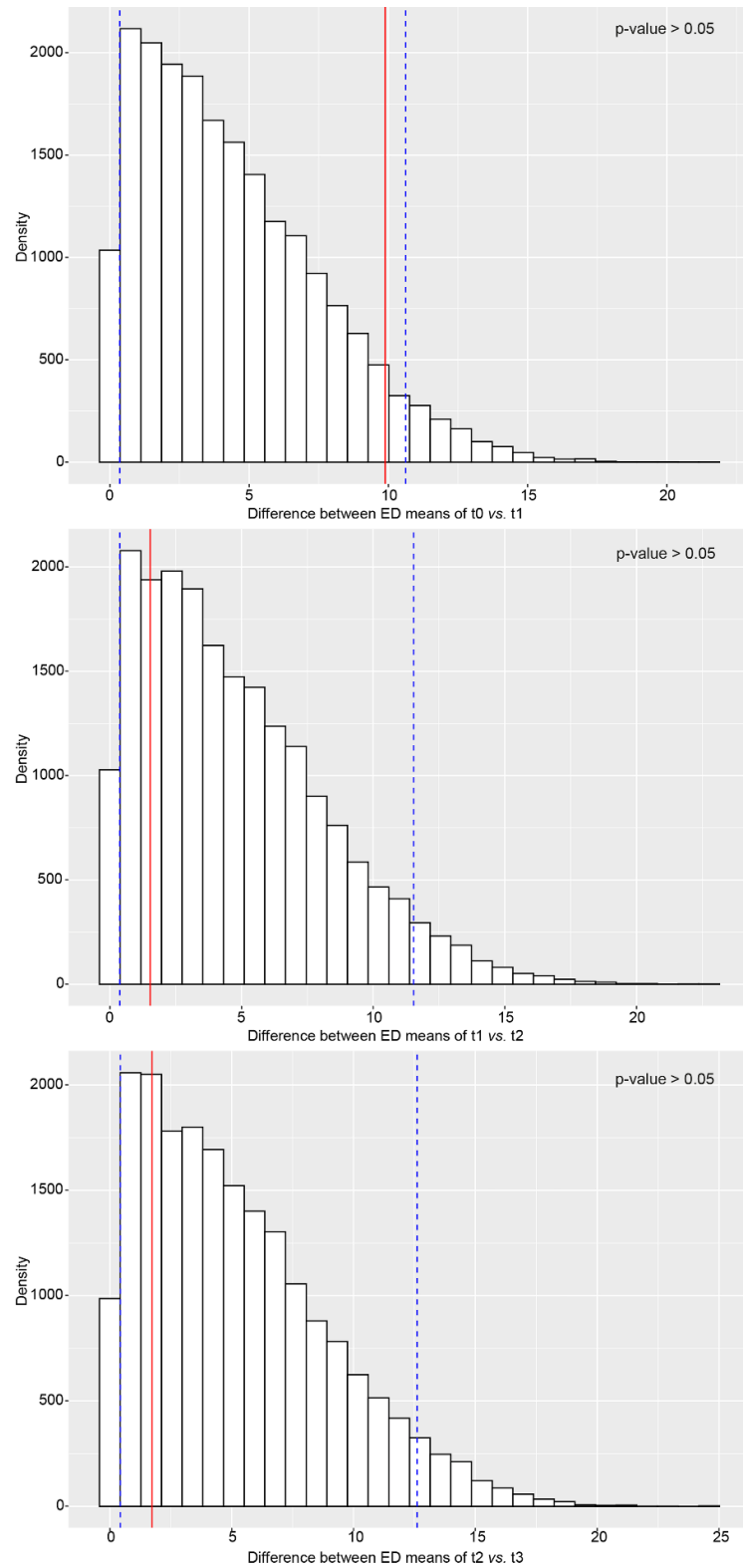


Figure S19. Bootstrapping test and the p-value values of High class calculated on the difference of ED means between two subsequential time steps. The red line indicates the value of real mean difference, the blue dotted lines indicate the lower and upper confidence intervals.

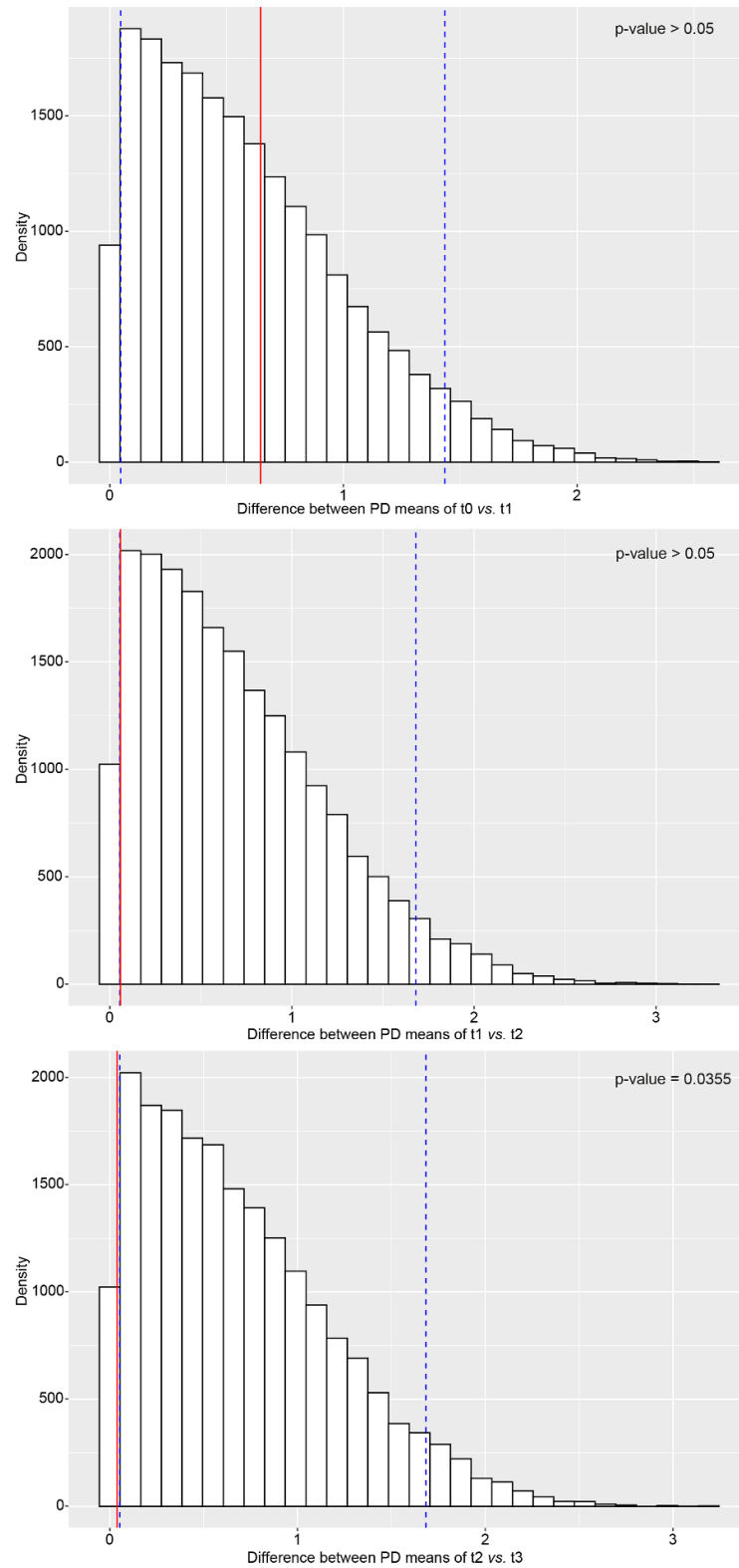


Figure S20. Bootstrapping test and the p-value values of High class calculated on the difference of PD means between two subsequential time steps. The red line indicates the value of real mean difference, the blue dotted lines indicate the lower and upper confidence intervals.