

Supporting Information for

Intensifying phosphorus limitation accelerates the decline in the CO₂

fertilization effect on terrestrial gross primary production

Zhuo Zhang¹, Chengjin Chu¹, Wenjie Dong², Li Dan³, Yaping Chen¹, Jing Peng^{1,2*}

¹ School of Ecology, State Key Laboratory of Biocontrol, Sun Yat-sen University,
Shenzhen, China,

² Southern Marine Science and Engineering Guangdong Laboratory (Zhuhai), and
School of Atmospheric Sciences, Sun Yat-sen University, Zhuhai, China,

³ Laboratory of Regional Climate-Environment for Temperate East Asia, Institute of
Atmospheric Physics, Chinese Academy of Sciences, Beijing, China,

*Correspondence to: Jing Peng (pengj275@mail.sysu.edu.cn)

Contents of this file:

Figures S1 to S10

Tables S1

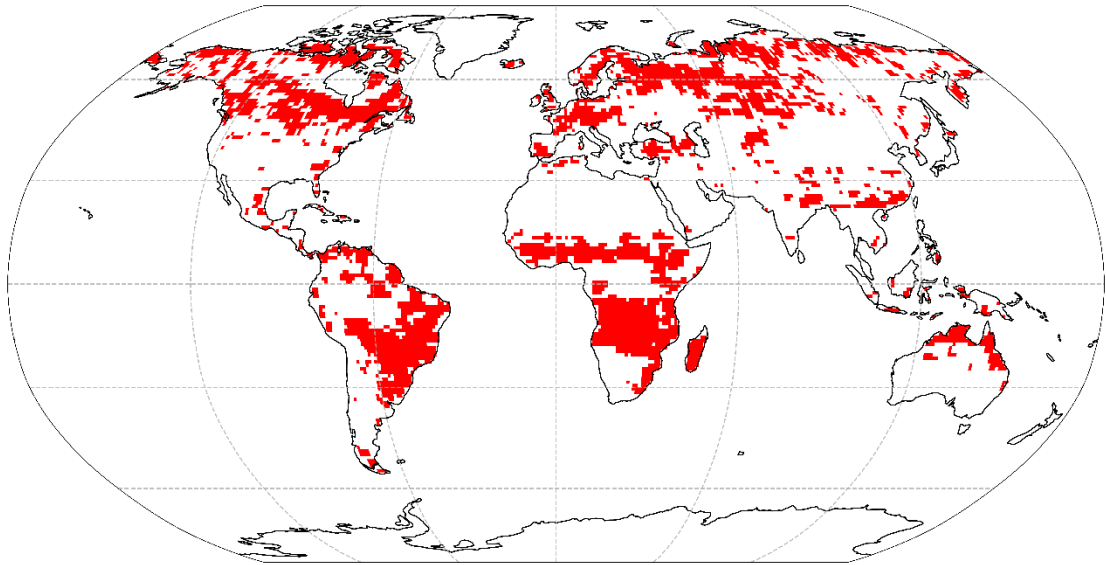


Figure S1. Spatial distribution of IPL regions during 1982–2015 (based on CABLE C–N and C–N–P simulations). Red shading indicates regions with intensifying phosphorus limitation.

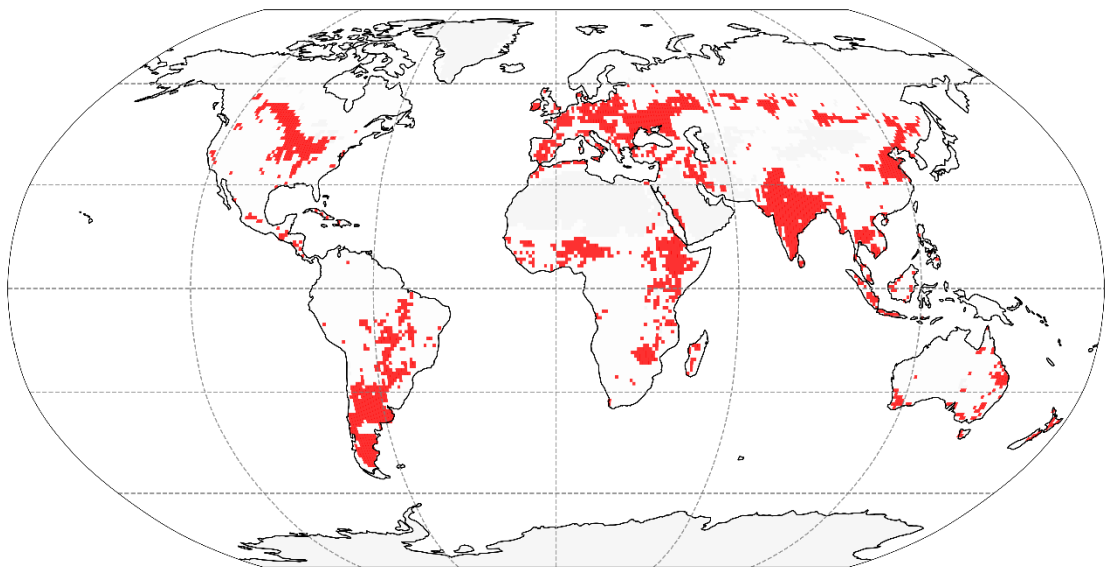


Figure S2. Land cover change mask for 1982–2015 (based on LUH2v2h dataset). Red pixels represent areas excluded from analysis due to land-use change.

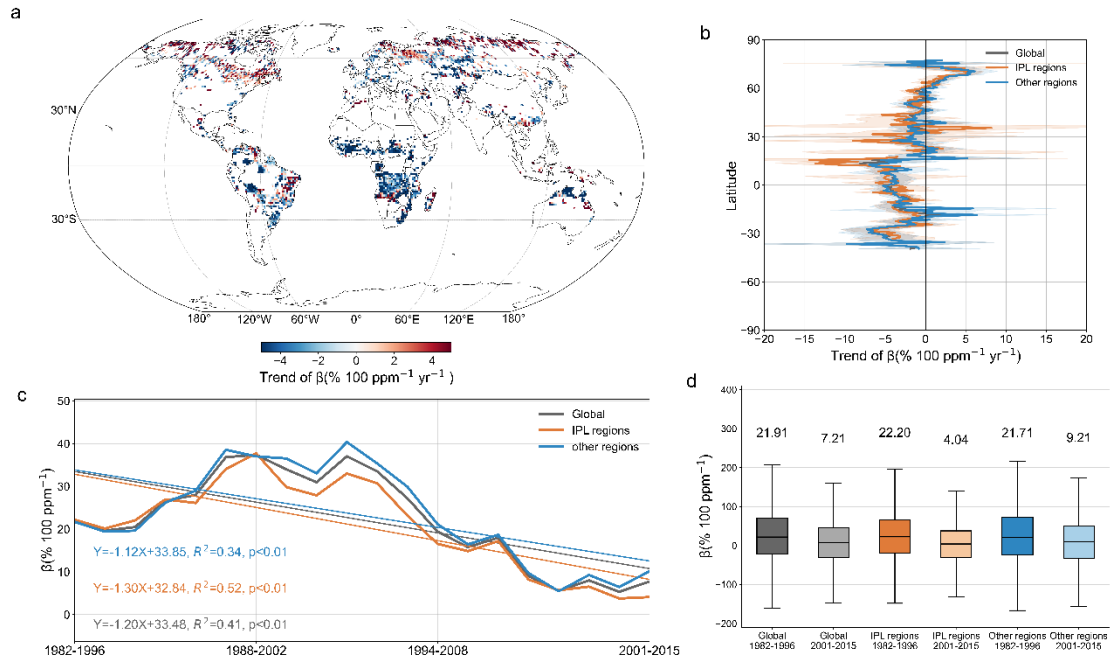


Figure S3. Accelerated decline of CO₂ sensitivity (β) in regions with intensifying phosphorus limitation during 1982–2015 (rEC-LUE GPP dataset). (a) Spatial pattern of β trends across intensifying phosphorus-limitation (IPL) regions. (b) Latitudinal profiles of β trends for the globe, IPL regions, and regions without intensifying phosphorus limitation (other regions); shaded bands denote the 95% confidence intervals. (c) Temporal time-series of β for the globe, IPL regions, and other regions. (d) Box-plot comparisons of β between two sub-periods across the globe and IPL regions. Boxes show the interquartile range (IQR), solid horizontal lines mark median values, and median β values for each period are annotated above each box.

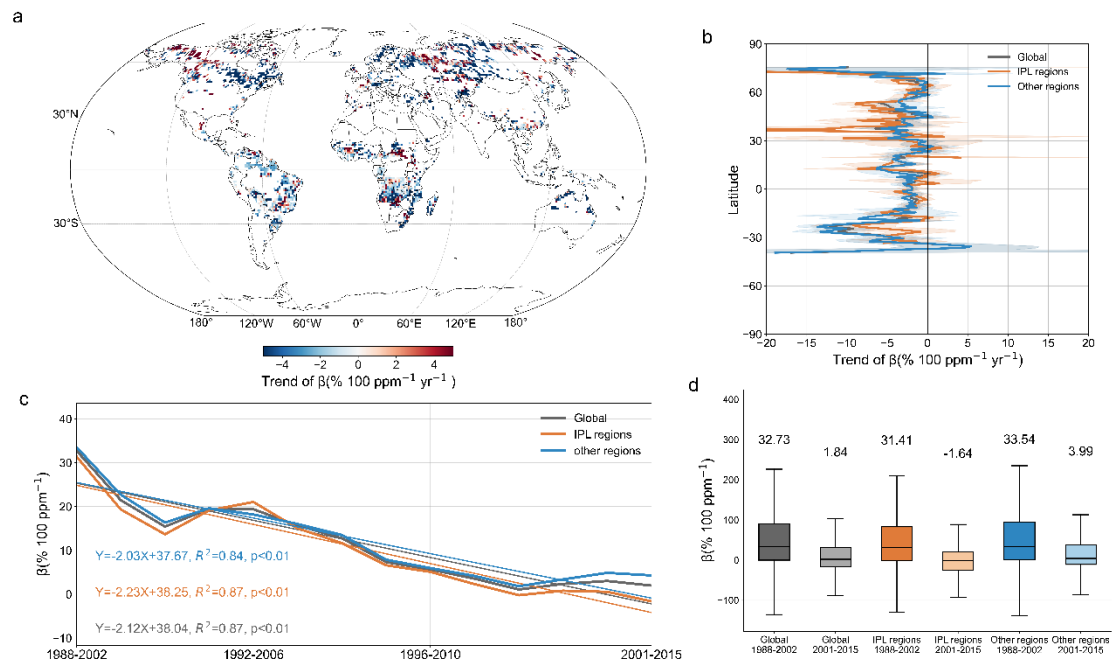


Figure S4. Accelerated decline of CO₂ sensitivity (β) in regions with intensifying phosphorus limitation during 1982–2015 (VODCA2 GPP dataset). (a) Spatial pattern of β trends across intensifying phosphorus-limitation (IPL) regions. (b) Latitudinal profiles of β trends for the globe, IPL regions, and regions without intensifying phosphorus limitation (other regions); shaded bands denote the 95% confidence intervals. (c) Temporal time-series of β for the globe, IPL regions, and other regions. (d) Box-plot comparisons of β between two sub-periods across the globe and IPL regions. Boxes show the interquartile range (IQR), solid horizontal lines mark median values, and median β values for each period are annotated above each box.

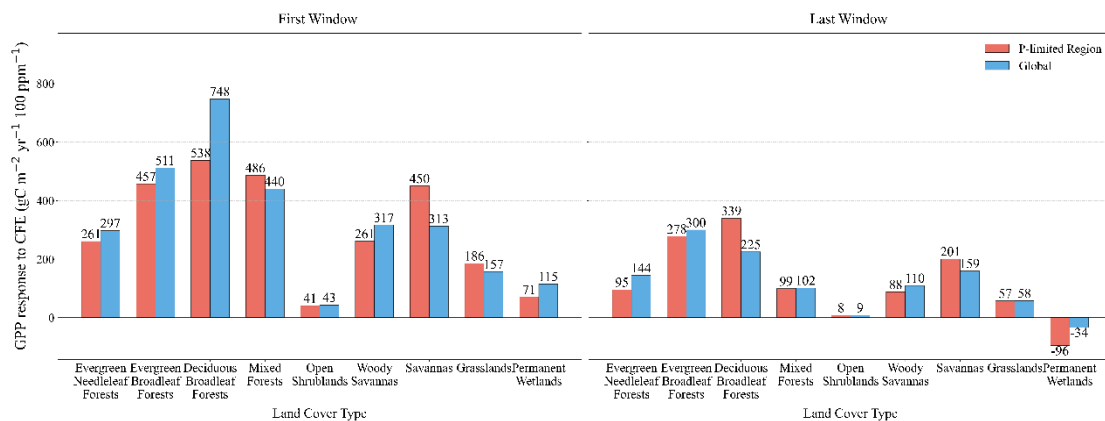


Figure S5. Comparison of absolute changes in the CO₂ fertilization effect across different vegetation types between global and phosphorus-intensifying regions across two sub-periods.

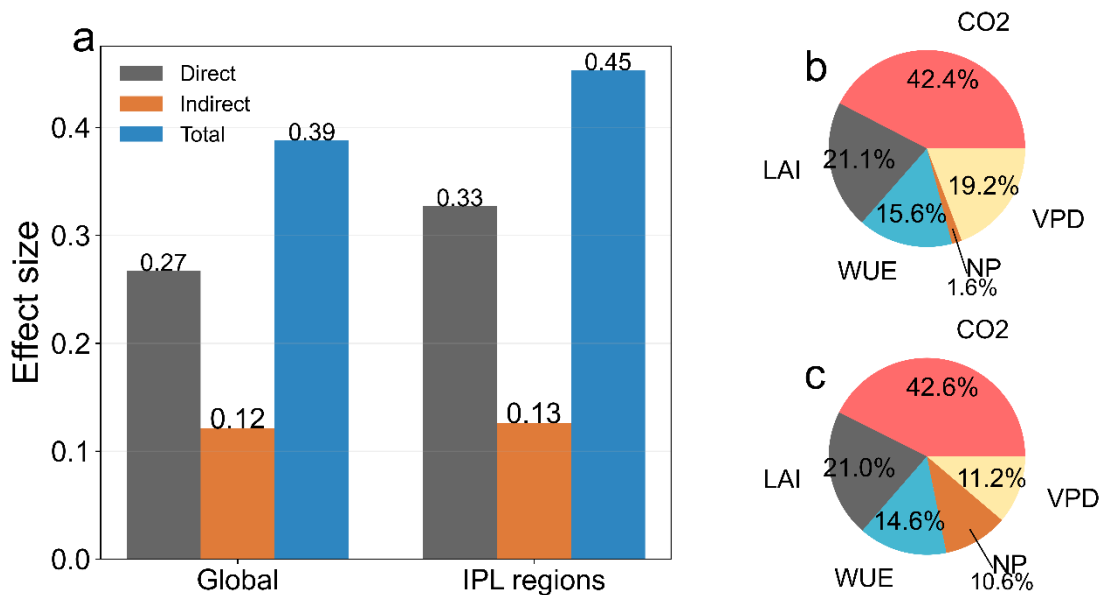


Figure S6. Direct, indirect, and total effects of CO₂ on GPP and relative contributions of key drivers to GPP in global and IPL regions. (a) Direct, indirect, and total effects of CO₂ on GPP; (b) Relative contributions of each driver to GPP at the global scale; (c) Relative contributions of each driver to GPP in IPL regions. Variables include: CO₂ (atmospheric CO₂ concentration), LAI (leaf area index), WUE (water-use efficiency), NP (leaf N:P ratio), and VPD (vapor pressure deficit).

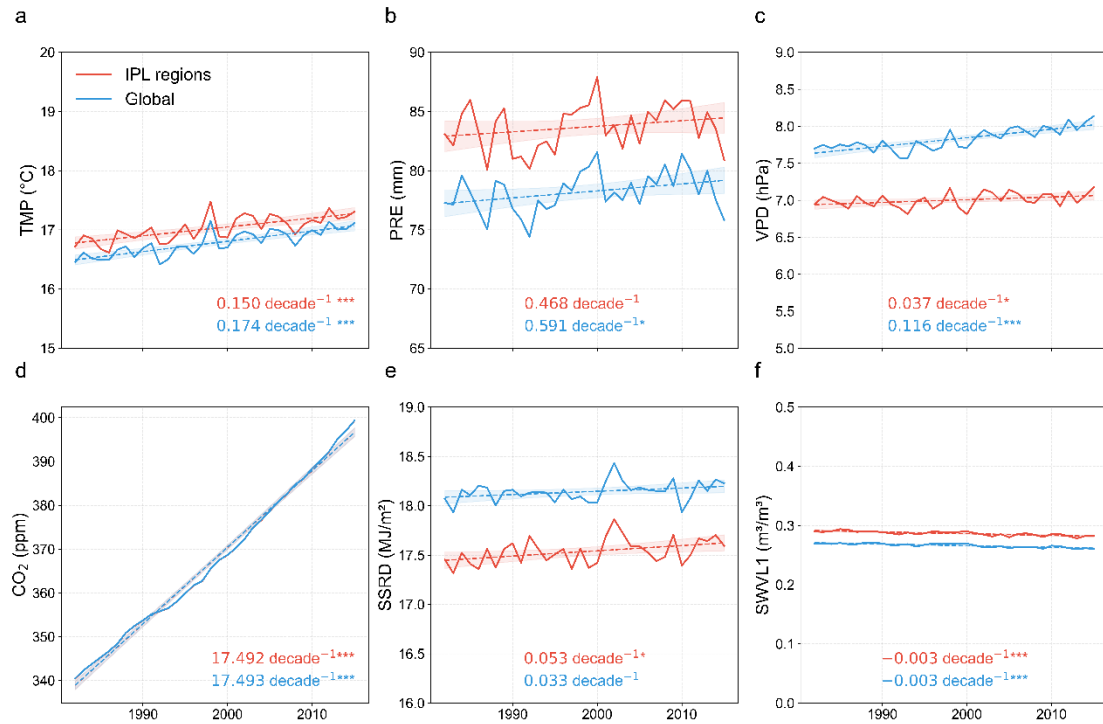


Figure S7. Temporal trends in environmental variables during 1982–2015 for global and IPL regions. Variables include temperature (TMP), precipitation (PRE), vapor pressure deficit (VPD), CO₂, solar radiation (SSRD), and soil water content (SWVL1). Dashed lines represent regression trends, and shaded bands represent the 95% confidence interval (*p < 0.05, **p < 0.01, ***p < 0.001).

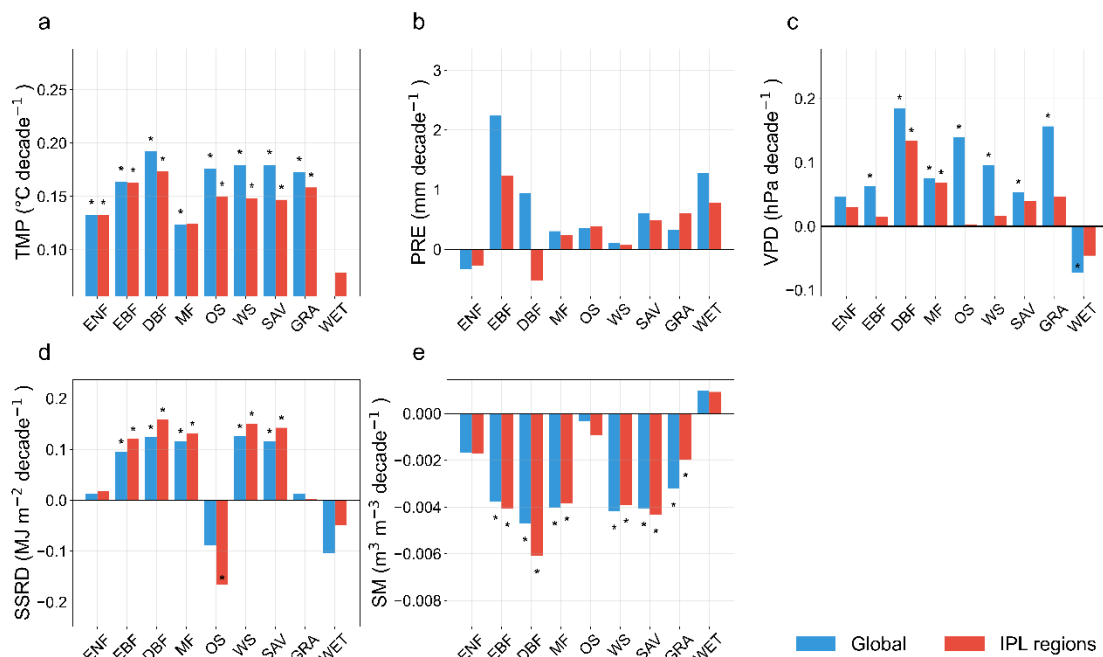


Figure S8. Temporal trends in environmental variables during 1982–2015 across different vegetation types in global and IPL regions. Environmental variables include temperature (TMP), precipitation (PRE), vapor pressure deficit (VPD), CO₂, solar radiation (SSRD), and soil water content (SWVL1). Vegetation types include evergreen broadleaf forest (EBF), evergreen needleleaf forest (ENF), deciduous broadleaf forest (DBF), mixed forest (MF), open shrublands (OS), woody savannas (WS), savannas (SAV), grasslands (GRA), and permanent wetlands (WET). Dashed lines represent regression trends, and shaded bands represent the 95% confidence interval (*p < 0.05).

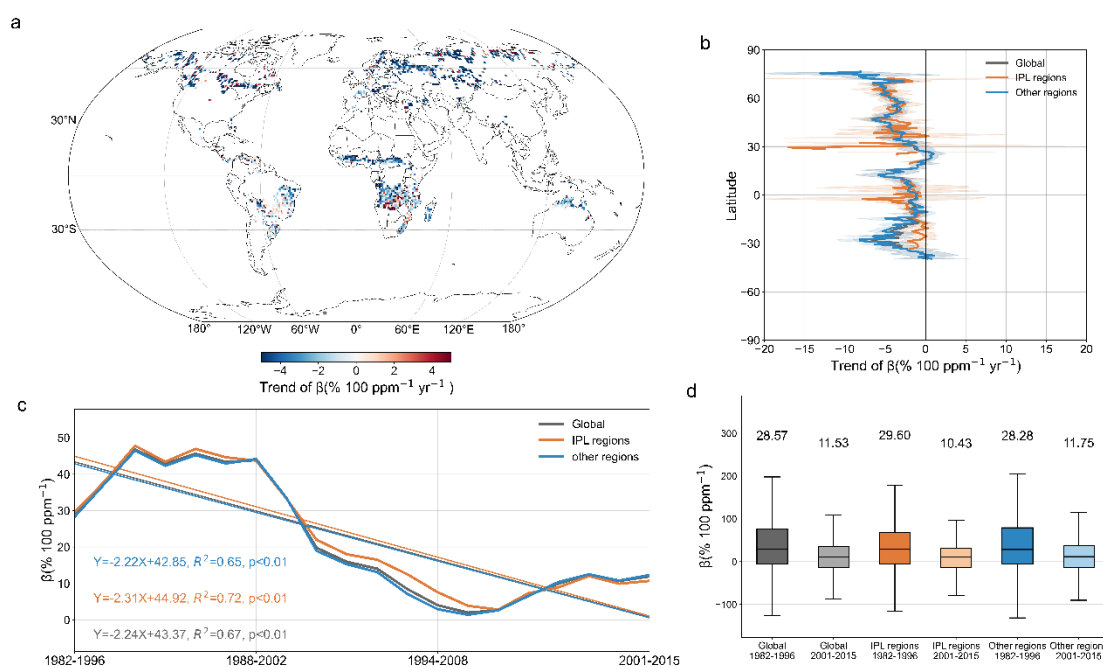


Figure S9. Accelerated decline of CO₂ sensitivity (β) in regions with intensifying phosphorus limitation during 1982–2015 (NIRv GPP dataset, 60th percentile threshold). (a) Spatial pattern of β trends across intensifying phosphorus-limitation (IPL) regions. (b) Latitudinal profiles of β trends for the globe, IPL regions, and regions without intensifying phosphorus limitation (other regions); shaded bands denote the 95% confidence intervals. (c) Temporal time-series of β for the globe, IPL regions, and other

regions. (d) Box-plot comparisons of β between two sub-periods across the globe and IPL regions. Boxes show the interquartile range (IQR), solid horizontal lines mark median values, and median β values for each period are annotated above each box. IPL regions were identified using the 60th percentile threshold.

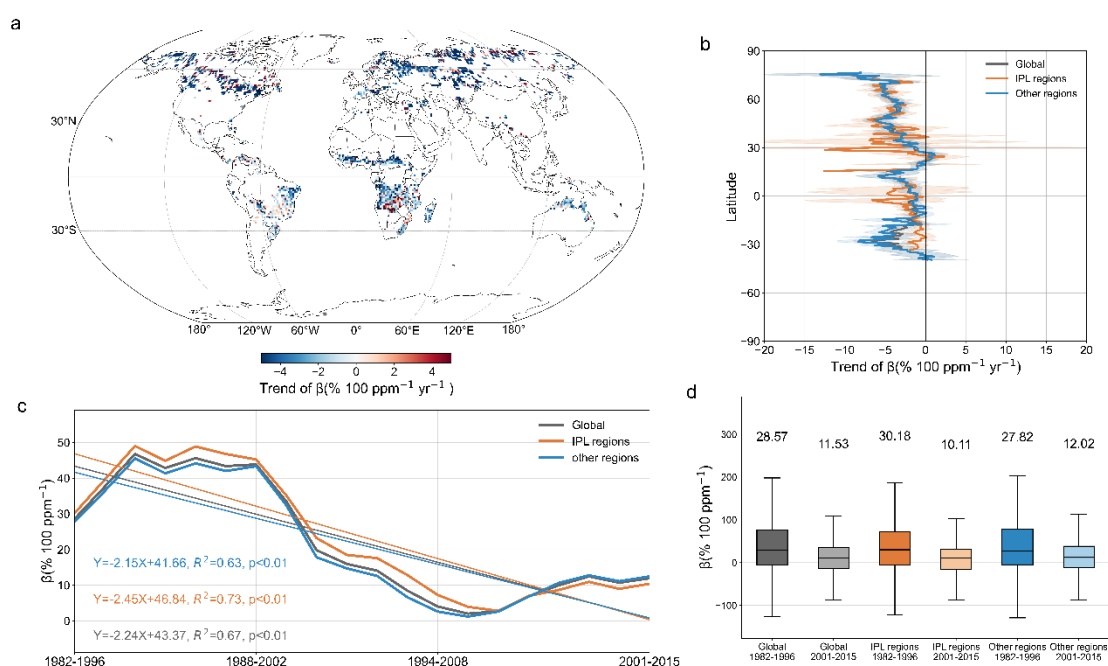


Figure S10. Accelerated decline of CO₂ sensitivity (β) in regions with intensifying phosphorus limitation during 1982–2015 (NIRv GPP dataset, 40th percentile threshold). (a) Spatial pattern of β trends across intensifying phosphorus-limitation (IPL) regions. (b) Latitudinal profiles of β trends for the globe, IPL regions, and regions without intensifying phosphorus limitation (other regions); shaded bands denote the 95% confidence intervals. (c) Temporal time-series of β for the globe, IPL regions, and other regions. (d) Box-plot comparisons of β between two sub-periods across the globe and IPL regions. Boxes show the interquartile range (IQR), solid horizontal lines mark median values, and median β values for each period are annotated above each box. IPL regions were identified using the 40th percentile threshold.

Table S1. Fraction of land area with significant β trends during 1982–2015 in global and IPL regions (NIRv GPP dataset).

Region	Proportion of significant increase(%)	Proportion of increase(%)	Proportion of significant decrease(%)	Proportion of decrease(%)
Global	9.25	24.19	50.09	75.81
IPL regions	9.79	23.97	50.78	76.03