

## **Supplementary Information**

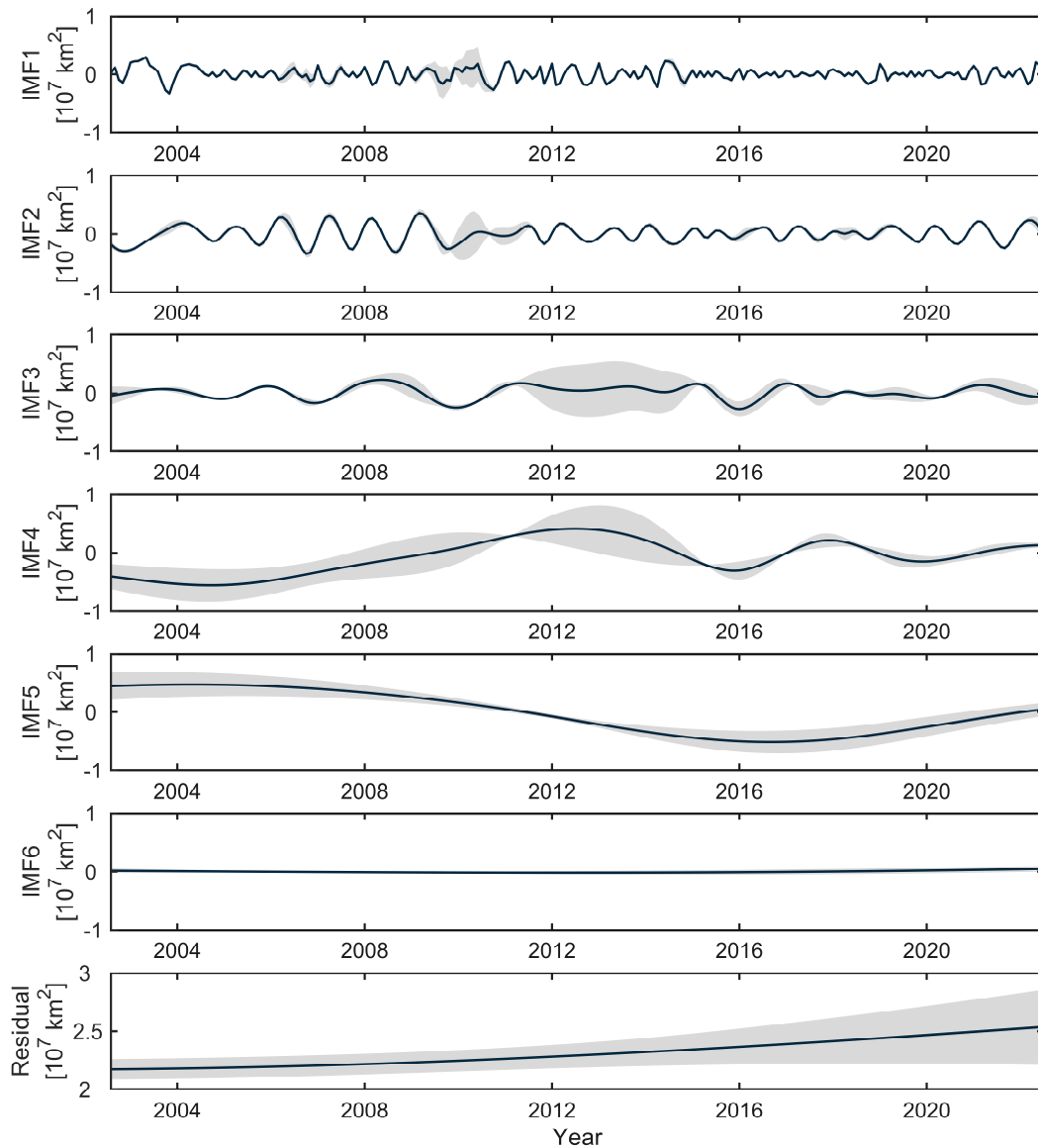
### **Ocean's largest chlorophyll-rich tongue is extending westward (2002-2022)**

Shuaixing Peng<sup>#</sup>, Xiaolong Yu<sup>#</sup>, Zhongping Lee, Hongyang Lin, Xin Liu, Minhan Dai,  
Shaoling Shang<sup>\*</sup>

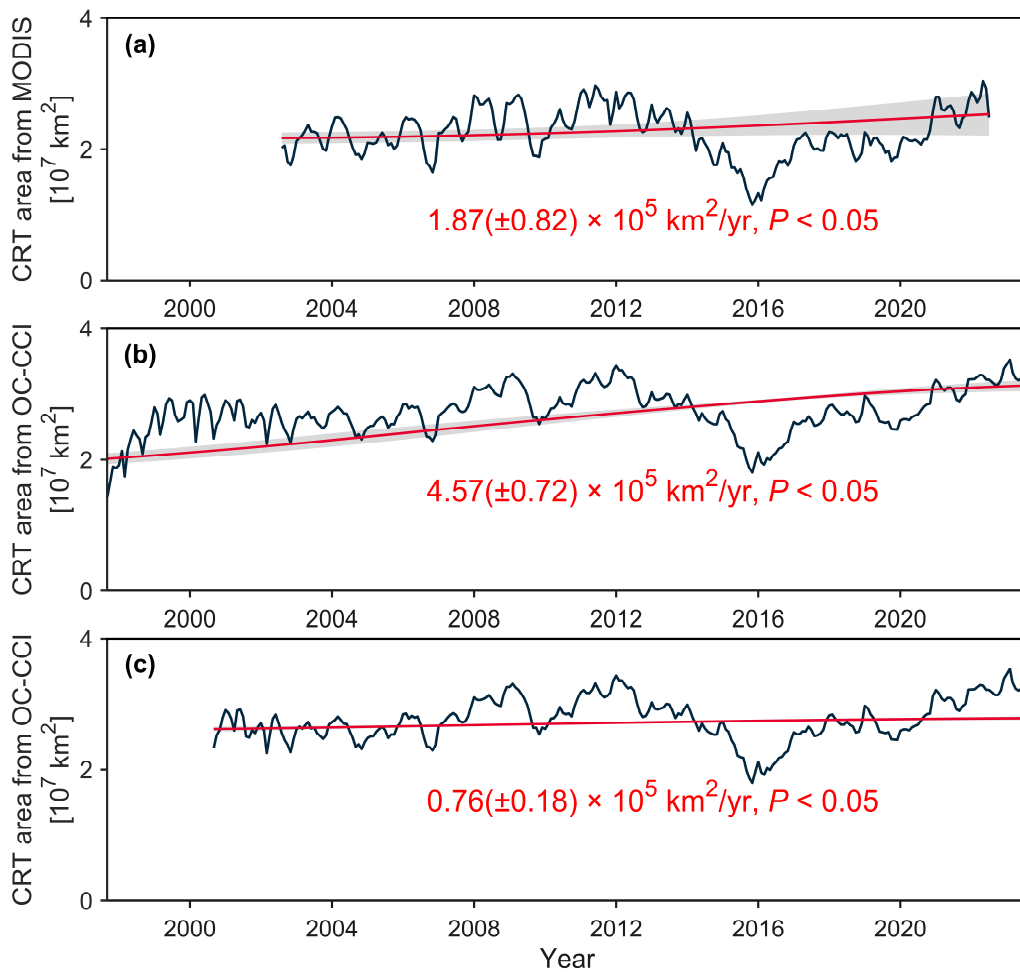
State Key Laboratory of Marine Environmental Science, College of Ocean and Earth  
Sciences, Xiamen University, Xiamen, Fujian 361102, China

<sup>#</sup>These two authors contributed equally

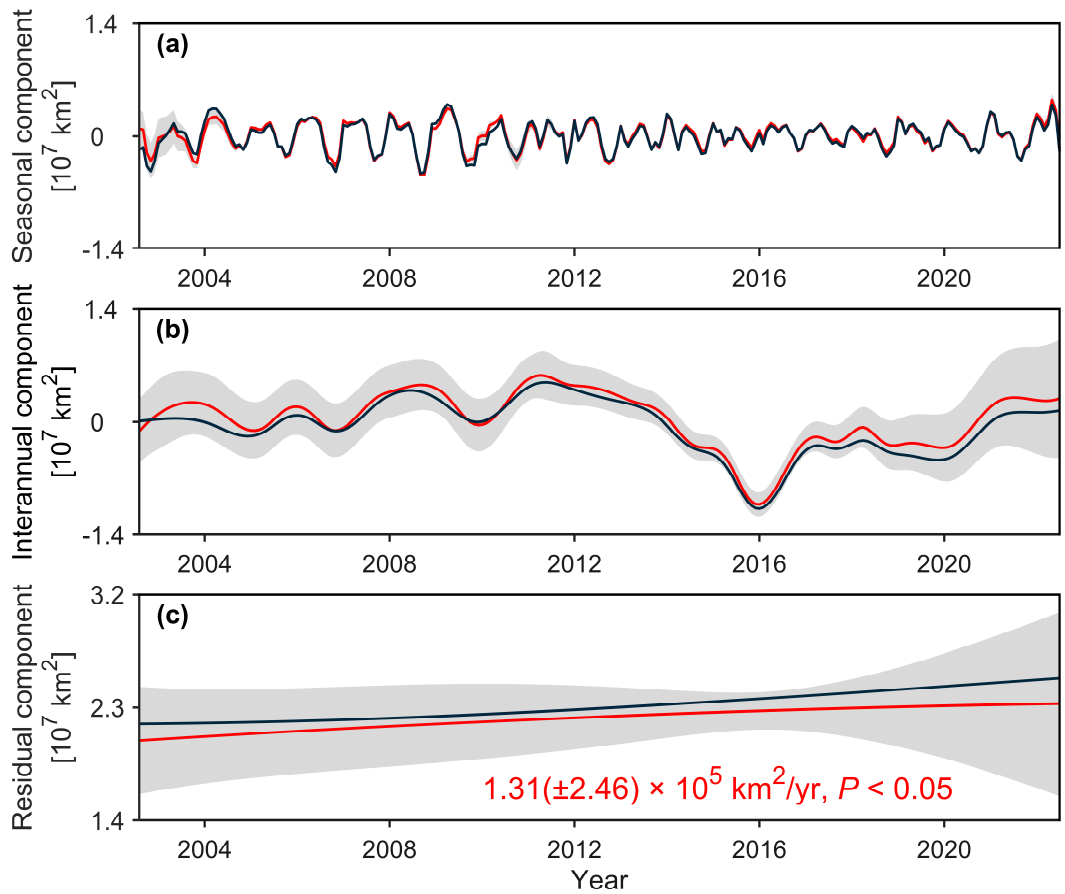
<sup>\*</sup>Correspondence to: slshang@xmu.edu.cn (S. S.)



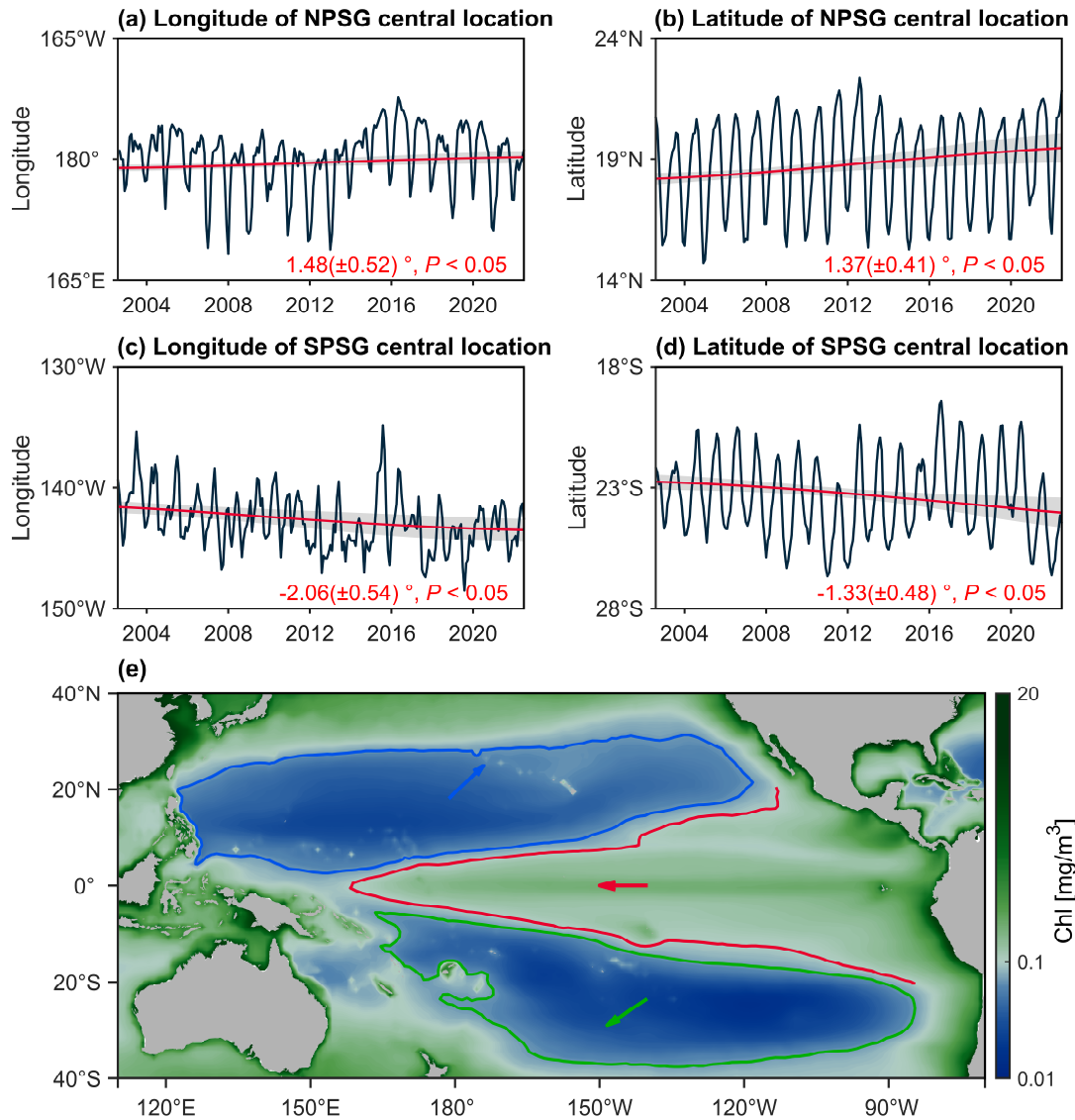
**Supplementary Figure 1 | The original Intrinsic Mode Functions (IMFs) generated from the empirical mode decomposition analysis of the 20-year time series of the chlorophyll-rich tongue area. The Mean (black lines) and standard deviation (gray shading) of each IMF were obtained from 5 different siftings corresponding to the S stoppage criterion from 2 to 6.**



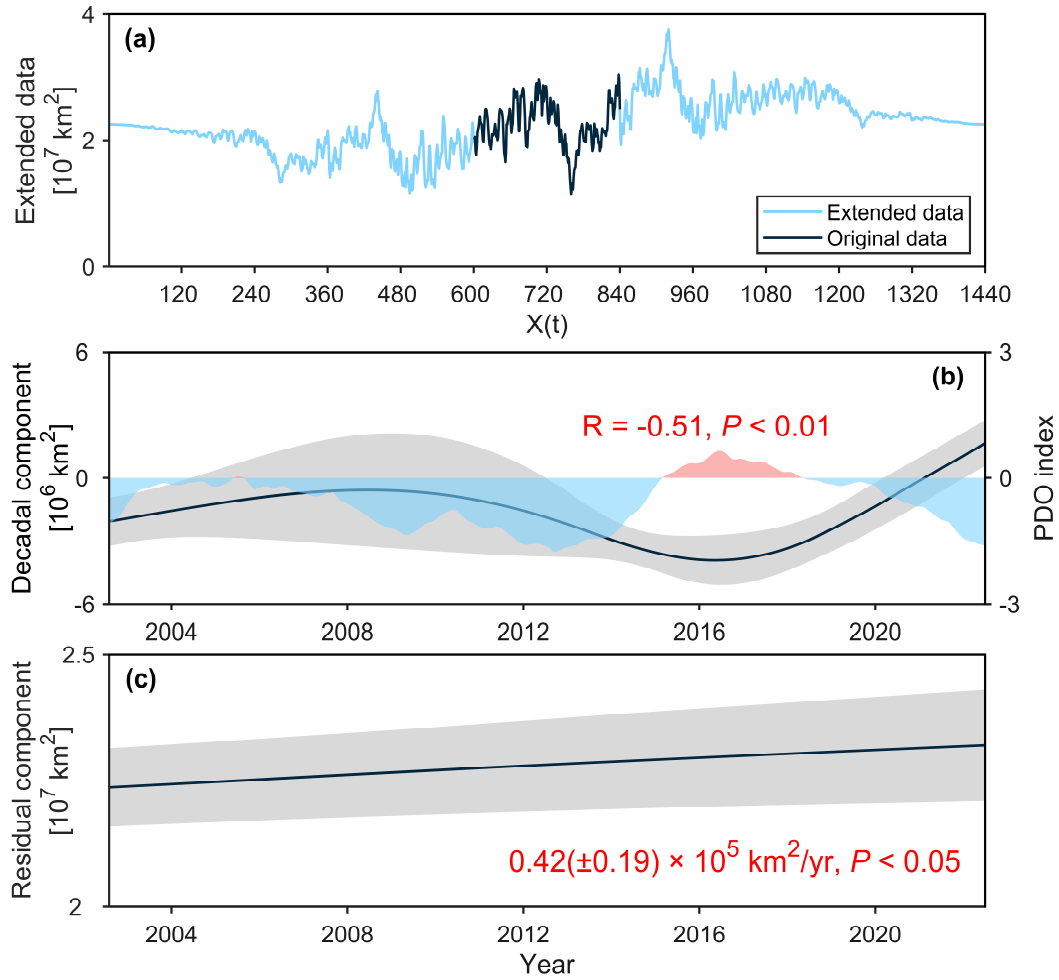
**Supplementary Figure 2 | The long-term trends of the chlorophyll-rich tongue (CRT) area observed from different satellite datasets.** (a) MODIS-aqua monthly Chl product from August 2002 to July 2022 (9 km spatial resolution), exhibiting an expansion of CRT at a rate of  $\sim 1.87 \times 10^5 \text{ km}^2/\text{yr}$ . (b) OC-CCI merged monthly Chl product from September 1997 to August 2023, at 4 km spatial resolution, exhibits a greater expansion rate at  $\sim 4.57 \times 10^5 \text{ km}^2/\text{yr}$ . (c) Same as (b), but excludes data between September 1997 and August 2000 to avoid the strong interannual influence, resulting in an expansion rate of  $\sim 0.76 \times 10^5 \text{ km}^2/\text{yr}$ .



**Supplementary Figure 3 | Decomposition of the monthly series of the chlorophyll-rich tongue area using ensemble empirical mode decomposition (EEMD).** The decomposed (a) seasonal, (b) interannual, and (c) residual trend components by EEMD are shown in the red curve compared with the empirical mode decomposition result in the black curve. The gray shading represents two standard deviations, or 95% confidence limit, of the EEMD results.



**Supplementary Figure 4 | The directional movements of the North and South Pacific Subtropic Gyre (NPSG and SPSG) centers over the past two decades.** The monthly variability of the NPSG central location is represented by **(a)** longitude and **(b)** latitude (See Methods). **(c-d)** same as **(a-b)**, but for SPSG. The center of NPSG and SPSG moved towards the northeast and southwest directions, respectively. **(e)** Demonstrations of the extent of NPSG (solid blue curve), SPSG (solid green curve), and chlorophyll-rich tongue (CRT) (solid red curve), with their movement directions over the past two decades delineated by the arrows in the corresponding colors. In the tropical Pacific, CRT tends to occupy more areas.



**Supplementary Figure 5 | Decomposition of the extended time series of the chlorophyll-rich tongue (CRT) area.** (a) The extended time series of the CRT area (blue line) from the original data (black line) (see Methods). The decomposed (b) interdecadal and (c) residual trend components via empirical mode decomposition analysis are shown only for the temporal span from August 2002 to July 2022. The red and blue colors in (b) represent the positive and negative values of the Pacific Decadal Oscillation (PDO) index, respectively. The gray shading represents the 95% confidence limit. The trend and p-values in (c) were computed for data from August 2002 to July 2022 only.