Supplement to

Persistent eutrophication and hypoxia in the coastal ocean

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Figures in the Supplement

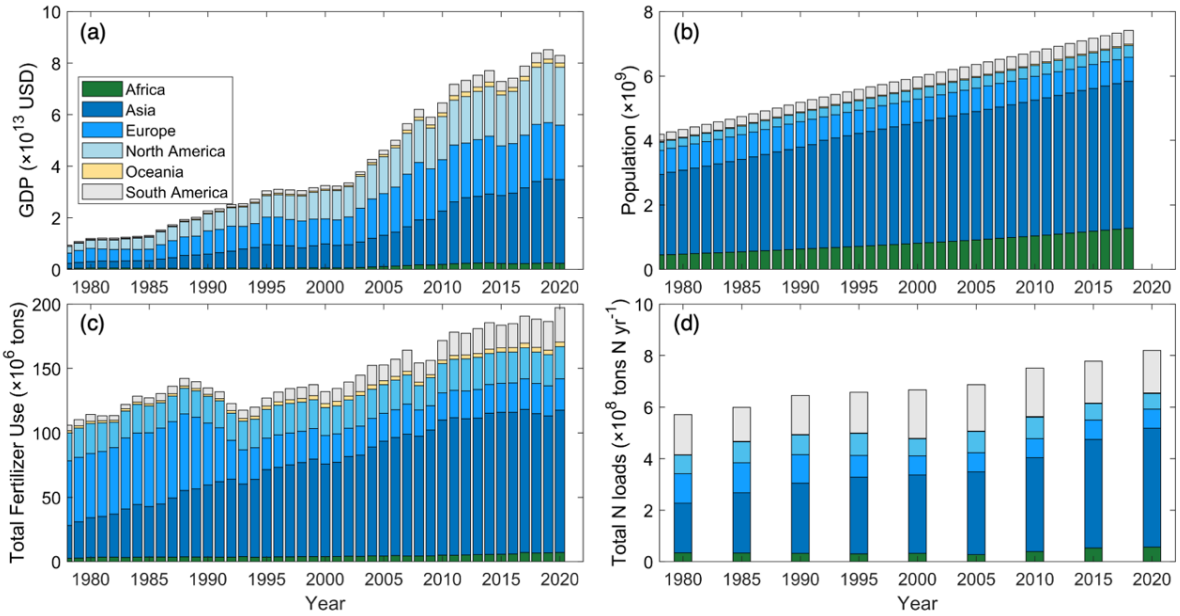

Figure S1. Long-term variations in (a) human population, (b) GDP, (c) total fertilizer use and (d) total N loads in six continents over the past four decades. Data of human population, GDP and total fertilizer use are from FAOSTAT (https://www.fao.org/faostat/en/#data/, access date: October 17, 2022). Data of total N loads are from Beusen et al. (2022).

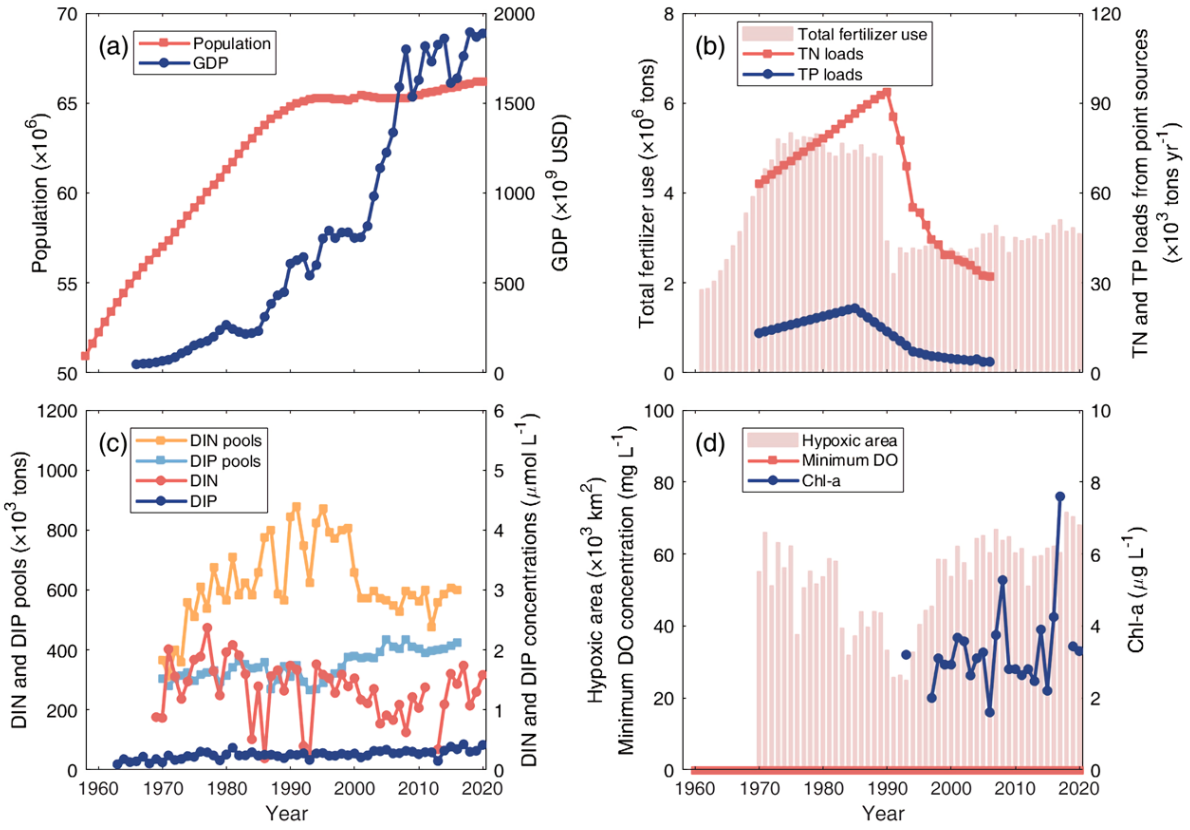

Figure S2. Variations in (a) total population and GDP of the main countries in the basin of Baltic Sea basin (Denmark, Finland, Poland, Sweden, Estonia, Latvia, Lithuania) (b) agriculture use of inorganic (chemical or mineral) fertilizers by these countries, total nutrient loads from the direct point sources (c) dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP) annual average surface concentration at station BY15 (57.33 N, 20.05 E) in the Baltic Proper, annual average DIN and DIP pools in the Baltic Proper (d) total area of the hypoxic zone in the Baltic Proper, summer average surface Chl-*a* concentrations at station BY15 and the minimum dissolved oxygen (DO) in the entire Baltic Sea. Population and GDP data in (a) were collected from United Nations - World Population Prospects (https://population.un.org/wpp/) and the World Bank (https://databank.worldbank.org/) respectively; total fertilizer use data in (b) are from FAOSTAT (https://www.fao.org/faostat/en/#data/); total nutrient loads from the direct point sources in (b) are from Rodriguez et al. (2012); DIN and DIP data in (c) and Chl-*a*, minimum DO are from SMHI SHARK web (https://sharkweb.smhi.se/hamta-data/); DIN and DIP pools data in (c) and the total areas of hypoxic zone in (d) are from Savchuk (2018, 2022).

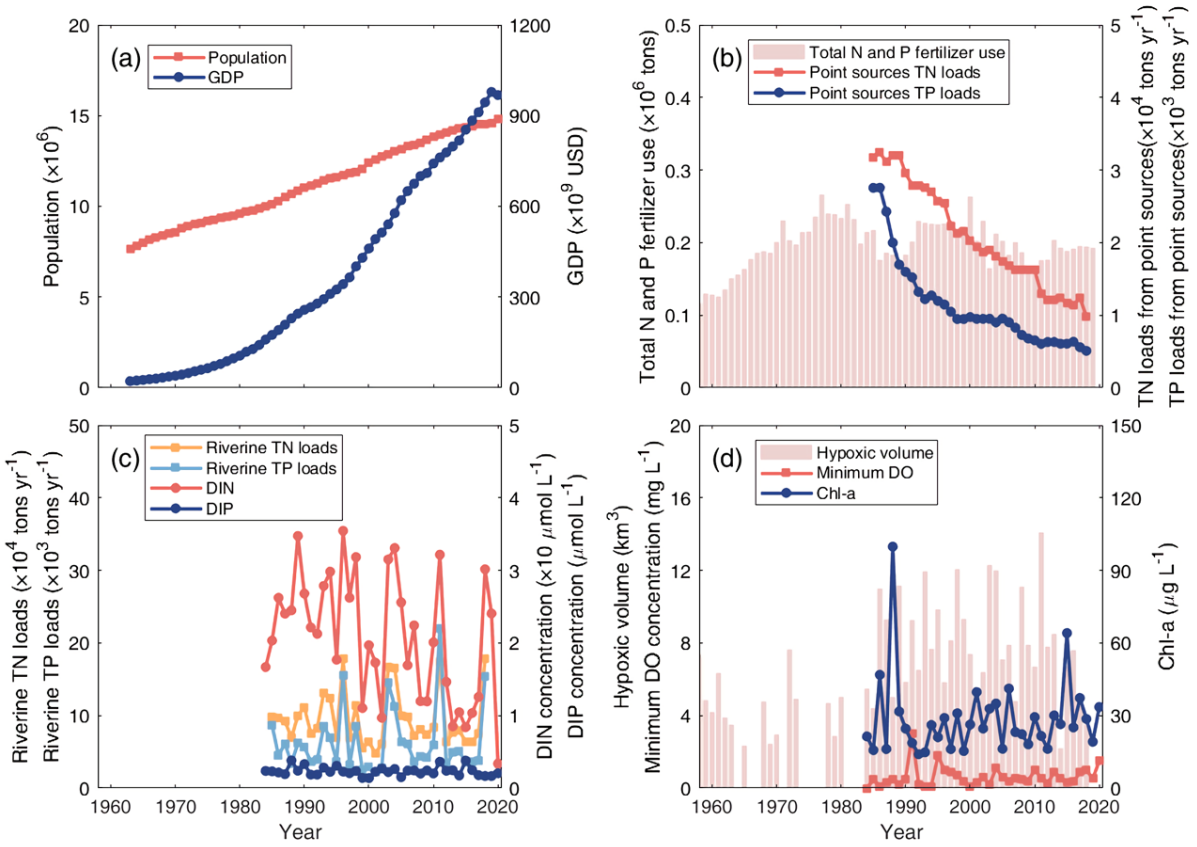

Figure S3. Variations in (a) population and total GDP of Maryland State and Virginia State, (b) fertilizer-derived nitrogen and phosphorus inputs to the Chesapeake Bay watershed, total nitrogen (TN) and total phosphorus (TP) loads from below-gage point sources (c) annual average surface concentrations of DIN and DIP at long-term monitoring station Horseshoe Point CB4.1W (38.81498°N, 76.46272°W), riverine TN and TP loads (d) summer hypoxia volume (data from a July cruise were always used when available), summer average surface Chl-*a* concentrations and the minimum DO at CB4.1W. Population and GDP data in (a) were collected from Macrotrends Data Download (https://www.macrotrends.net/states/us-states-by-population) and Bureau of Economic Analysis U.S. Department of Commerce (https://apps.bea.gov/itable/iTable.cfm?ReqID=70&step=1&acrdn=1) respectively; Fertilizer-derived N and P inputs in (b) are from Sabo et al. (2022); Sekellick (2017); TN and TP loads from below-gage point sources and river in (b) and (c) are from Murphy et al. (2022); DIN, DIP concentrations in (c), Chl-*a* concentrations and the minimum DO in (d) are from Eyes on the Bay (https://eyesonthebay.dnr.maryland.gov/); summer hypoxia volume are from Hagy Iii et al. (2004); Scavia et al. (2021).

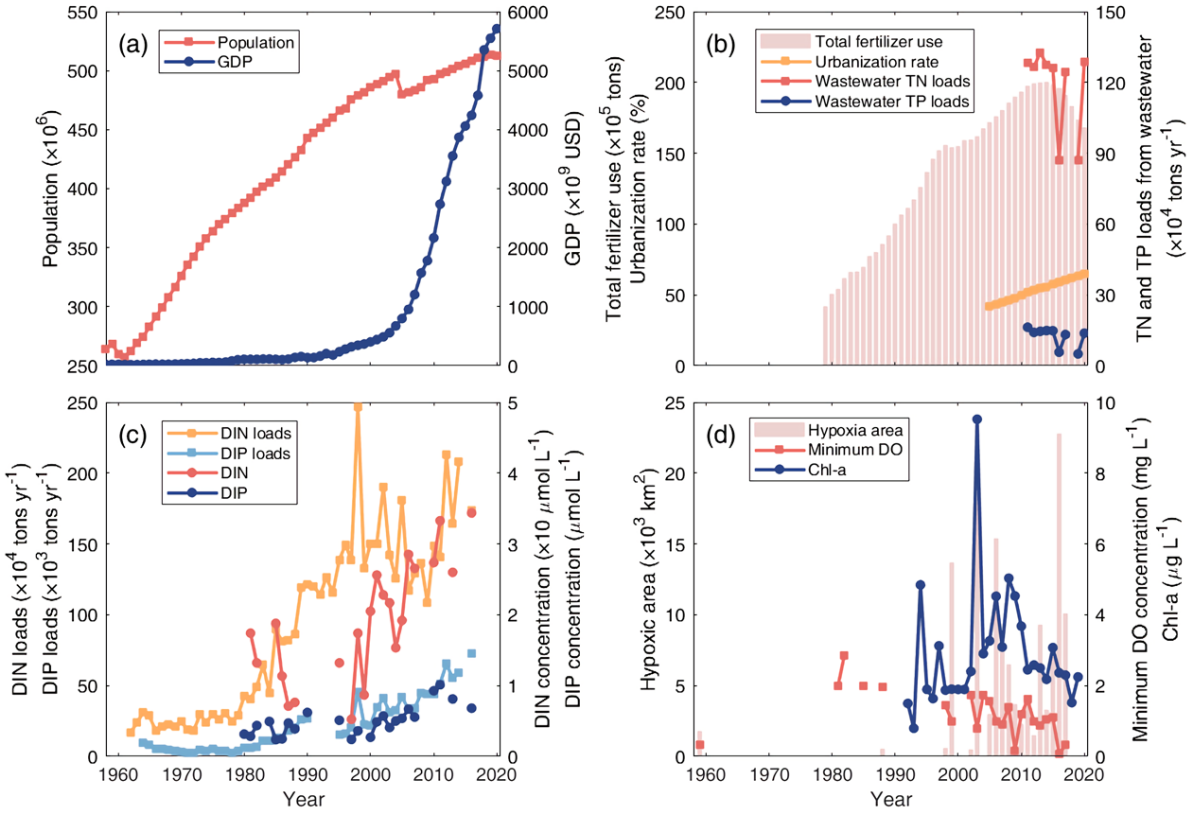

Figure S4. Variations in (a) total population and GDP (b) total fertilizer use, urbanization rate and total nutrient loads of wastewater for provinces (Qinghai, Tibet, Sichuan, Yunnan, Chongqing, Hubei, Hunan, Jiangxi, Anhui, Jiangsu, Shanghai) along the Changjiang mainstream (c) annual average surface concentrations of DIN and DIP in the Changjiang Estuary (mainly spanning between 30.5-32ºN and 122-123.5ºE), and the loads of DIN and DIP in the Datong station located at the lower reach of the Changjiang River, (d) hypoxia area, DO minimum and Chl-*a* concentration off the Changjiang estuary (mainly spanning between 30.5-32ºN and 122-123.5ºE). Data in (a) and (b) are summarized from the National Bureau of Statistics and China Statistical Yearbook (access data: August 16, 2022, *in Chinese*), respectively. Nutrient concentration and loads data in (c) are collected from previously published literatures (Dai et al., 2011; Ding et al., 2019; Wang et al., 2018; Wang et al., 2015; Wang et al., 2021). Data of DO and hypoxia area in (d) are also previously published observational results (Chen et al., 2020; Chen et al., 2014; Chen et al., 2017; Chen, 1988; Chi et al., 2020; Chi et al., 2017; Jiang, 2009; Li et al., 2002; Li et al., 2011; Liblik et al., 2020; Limeburner, 1983; Liu et al., 2012; Luo et al., 2018; Ni et al., 2016; Ren, 1992; Shi et al., 2006a; Shi et al., 2006b; Tian et al., 1993; Wang and Wang, 2007; Wei et al., 2007; Zhu et al., 2016; Zhu et al., 2011; Zhu, 2007). Chl-*a* data in (d) are the mean value in Summer (Jane-August). Data from 1992-2010 are collected from Wang et al. (2015) and data from 2011-2019 are derived from the remote sensing satellite image. Satellite Chl-*a* data from 2011-2019 were collected from the Climate Change Initiative-European Space Agency project (http://www.esa-oceancolour-cci.org/). These files are monthly composites of merged sensors with a 4km spatial resolution (Sea-Viewing Wide Field-of-View Sensor (SeaWiFS), Moderate-resolution

Imaging Spectroradiometer (MODIS), Medium-resolution Imaging Spectrometer (MERIS), Ocean and Land Color Instrument (OLCI), and Visible infrared Imaging Radiometer sensor (VIIRS)).

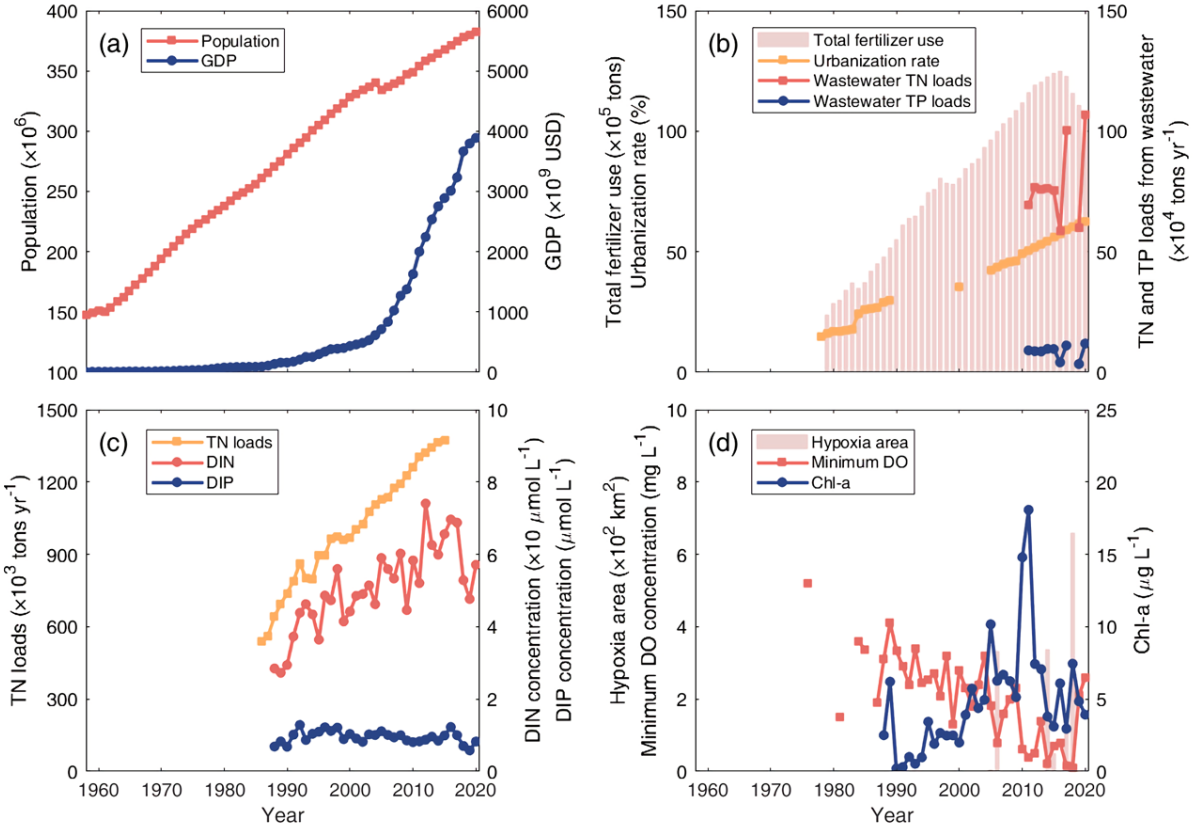

Figure S5. Variations in (a) total population and GDP, (b) total fertilizer use, urbanization rate and total nutrient loads of wastewater for the provinces (Yunnan, Guizhou, Guangxi, Guangdong, Hunan, Jiangxi, Hong Kong, Macau) along the Pearl River mainstream, (c) annual average surface concentrations of DIN and DIP in the northwestern Hong Kong waters and total nitrogen loads due to fertilizer use (assumed 70% of fertilizer N use goes into rivers) in the Pearl River Basin, and (d) hypoxia area and DO minimum off the Pearl River estuary (mainly spanning between 21.6-22.4°N and 113.2-114.2°E), and (d) Chl-*a* concentrations in the northwestern Hong Kong waters. Data in (a) and (b) are summarized from the National Bureau of Statistics and China Statistical Yearbook (access data: August 16, 2022, *in Chinese*), respectively. However, data on the population and GDP of Hong Kong and Macao were obtained from the World Bank (https://databank.worldbank.org/), while data on fertilizer use and wastewater discharge were not available. Nutrient concentration data in (c) were collected from four stations (DM5, NM5, NM6, NM8) located in the northwestern Hong Kong waters from the Environmental Protection Department (EPD) of Hong Kong (https://cd.epic.epd.gov.hk/EPICRIVER/marine/; Qian et al. (2022b)), and total nitrogen loads data are collected from Cui et al. (2020). Data of DO and hypoxia area data in (d) are the observational results from previously published literatures (EPD; Hu et al. (2021); Li et al. (2018); Qian et al. (2018); Su et al. (2017); Yin et al. (2004); Zhao et al. (2020); Zhao et al. (2021)). The Chl-*a* data shown are the mean values in summer (June-August) are collected from the same station by the EPD.

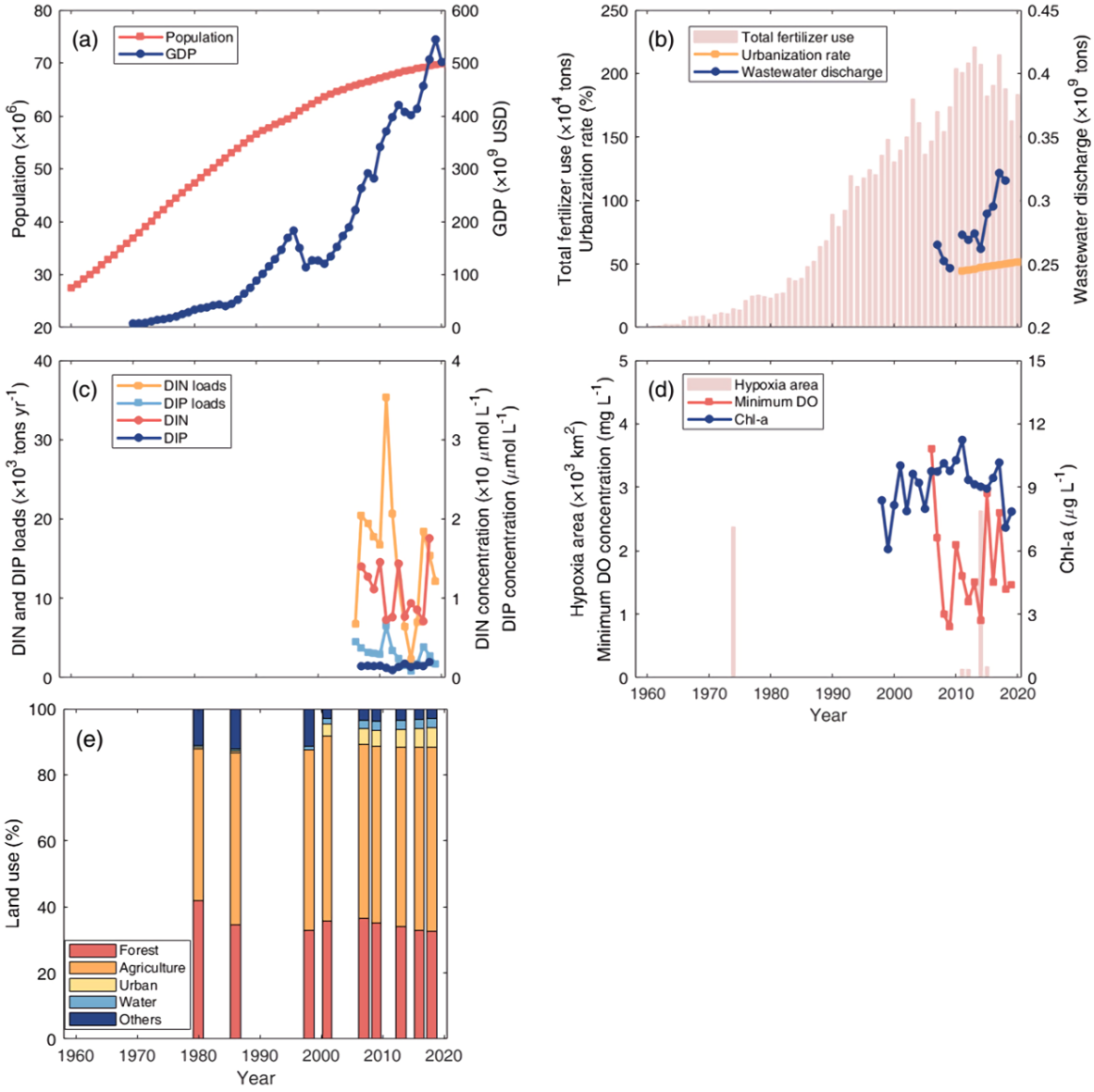

Figure S6. Variations in (a) total population and GDP of Thailand , (b) total fertilizer use and urbanization rate of Thailand, and wastewater discharge of the Chao Phraya River, which is the major tributary draining into the Upper Gulf of Thailand, (c) and total depth loading of DIN and DIP at SPCP station (Samut Prakan province-the Chao Phraya River station, which is located at 100.59 ºE and 13. 52 ºN) between 2006 - 2019 and average surface concentrations of DIN and DIP in the wet season (May – October) at station SPCP, (d) hypoxia area, DO minimum (station SPCP) and Chl-*a* concentrations in the Upper Gulf of Thailand (mainly spanning between 12.6-13.6ºN and 100-101.2ºE) and (e) the type of land use in Thailand. Data in (a) were collected from the World Bank's (2021) website (https://databank.worldbank.org/). Fertilizer use and urbanization rate data are from FAOSTAT (https://www.fao.org/faostat/en/#data/) and Statista (2022); wastewater discharge data are collected from Office of the National Water Resources (2019). Data of DIN and DIP concentrations and DO minimums are from unpublished data provided by Marine and Coastal Resources Research & Development Institute, Department of Marine and Coastal Resources,

Thailand. Data of hypoxia area are observational results from previously published literatures Tharnboopha and Lulitanond (1976); Morimoto et al. (2012); Buranapratheprat et al. (2021). The Chl-*a* data are the mean values in wet season derived from the remote sensing satellite images sourced from the Climate Change Initiative-European Space Agency project (http://www.esa-oceancolour-cci.org/). Data in (e) were collected from the Land Development Department (LDD), Ministry of Agriculture and Cooperatives (http://www1.ldd.go.th/WEB_OLP/index.html).

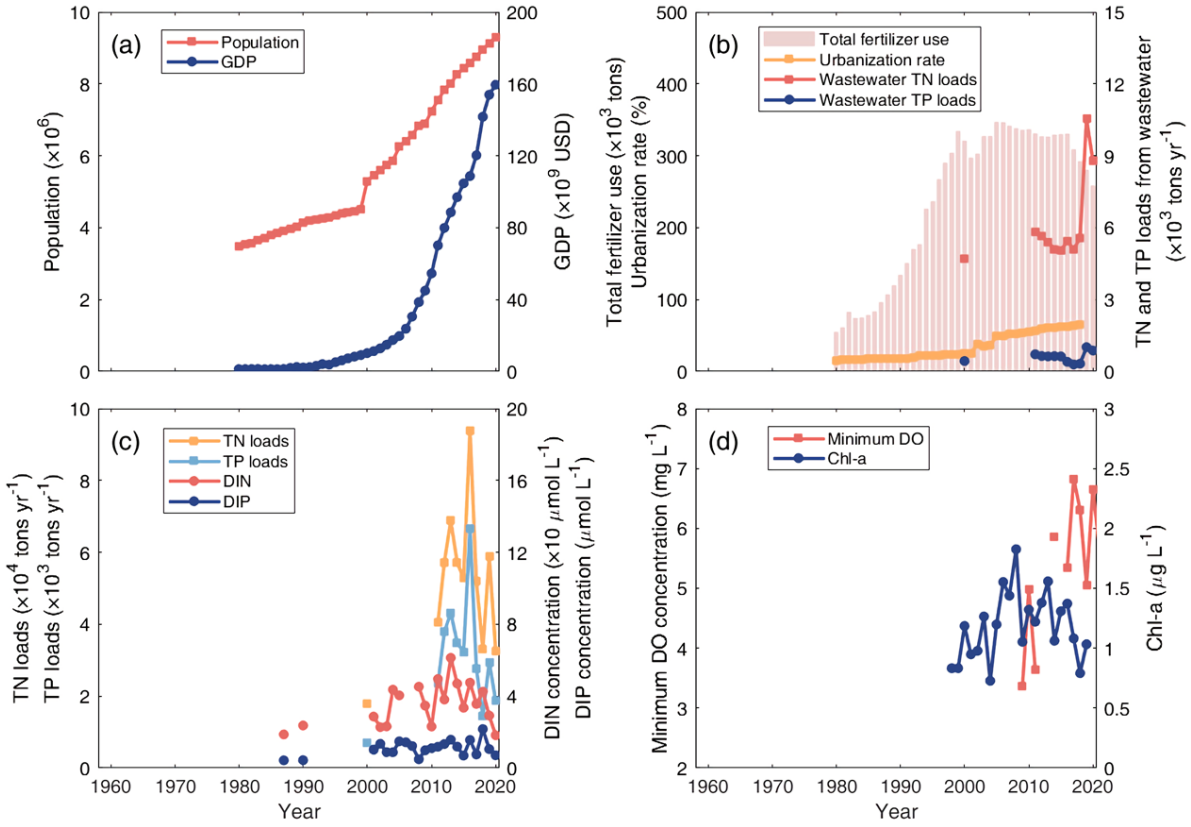

Figure S7. Variations in (a) total population and GDP in the Jiulong River-Xiamen Bay watershed, (b) total fertilizer use and urbanization rates in the Jiulong River -Xiamen Bay watershed, wastewater total N loads and total P loads to Xiamen Bay, (c) total N and total P loads of the Jiulong River, annual mean DIN and DIP concentrations at the outlet of the Jiulong River, (d) DO minimum and summer mean Chl-*a* concentrations in the Lower Jiulong River Estuary-Xiamen Bay. Note: Data representing the Jiulong River watershed are the sum of the Xinluo District of Longyan, Zhangping, Changtai, Hua'an, Pinghe, Nanjing, the Longwen District and the Xiangcheng District of Zhangzhou, Longhai. Final data are the sum of the Jiulong River watershed and Xiamen city. Population, GDP and fertilizer usage data of those cities/counties were collected from the Statistics Bureau of Fujian Province Yearbook. Urbanization rates are calculated as the ratio of the urban population to the total population. DIN and DIP concentrations are the annual mean values from Xiamen Bay (including the Western Harbor, Eastern Harbor and Tongan Bay). DIN and DIP data from 1987 are taken from Chen (1993); DIN and DIP data from 1990 are from Guo et al. (1998), DIN data from 2001-2005 are from Chen et al. (2013); DIP data from 2001-2007 are from the Xiamen Marine Environment Quality Report; DIN and DIP data from 2008-2020 are from the Fujian Provincial Environmental Monitor Center Station. Riverine N and P loads from 2000 are from the Xiamen Environmental Quality Bulletin (2000) and data from 2010-2020 are calculated from river N and P concentrations provided by the Fujian Provincial Environmental Monitor Center Station and the river discharges provided by the Bureau of Hydrology and Water Resources; Riverine N loads from 2003-2009 are estimated from riverine ammonium loads by the ratio of ammonium to total N loads from 2010-2020. Riverine P loads from 2003-2009 are estimated

from riverine N loads by the ratio of N loads to P loads from 2010-2020. Wastewater total N and P loads in 2000 are from the Xiamen Environmental Quality Bulletin (2000); data from 2017 are from the Second National Pollution Census; data from 2011-2020, except 2017, are estimated using Xiamen wastewater ammonium discharges and the ratio of wastewater ammonium discharges to N discharges and the ratio of wastewater N discharges to P discharges from Fujian Province originated from the Statistics Bureau of Fujian Province. The minimum DO concentrations from 2009-2011 are unpublished data provided by Weidong Zhai's lab, and the data from 2014-2020 are unpublished data provided by the Marine Monitoring and Information Service Center. The Chl-*a* data show the mean value in summer derived from the remote sensing satellite images.

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