Water Quality Trends in Hempstead Bay, NY from 1968 – 2017:

A Historical Data Analysis and Report for Long Island's South Shore Estuary Reserve Western Bays

Prepared by *Steve M. Raciti*[1], *Antonios E. Marsellos*[1] and *James P. Browne*[2] on behalf of

Hofstra University's National Center for Suburban Studies[1]
&
Town of Hempstead Department of Conservation and Waterways[2]

with support and advisement from

The Long Island Regional Planning Council (LIRPC),
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Executive Summary

This report focuses on water quality within Hempstead Bay, which is sometimes referred to as the South Shore Estuary Reserve (SSER) Western Bays. This report is a continuation and expansion of the work began in the *Town of Hempstead Water Quality Report: 1975 – 2012*, which sought to digitize and gather the long-term record of water quality monitoring in the study area. It expands upon the past report by bringing the data up to the near present (through summer of 2017), adding contextual data about changes in the watershed environment that could influence water quality, and additional temporal analyses.

Increasing urban and suburban development has been strongly associated with increased nitrogen loading to surface water and groundwater on Long Island. The United Nations Environment Programme (2019) characterizes nitrogen pollution as one of the most important issues facing our planet with the cost of N pollution to society estimated at approximately $210 billion per year in the United States alone (Sobota et al. 2015). Key sources of nitrogen pollution that have been identified in Hempstead Bay include effluent from wastewater treatment plants, urban and suburban development and associated stormwater runoff, atmospheric nitrogen deposition, soil and sediment loss, and groundwater inputs of nutrients that originate from septic systems or the use of fertilizers (Fisher et al. 2017).

The data analyses represented in this report are part of a project to re-establish continuous monitoring for nutrients and other water quality parameters in Hempstead Bay, its contributing tributaries, and its watershed. Our research team has gathered all readily available historical water quality data in the study area for which we could find consistent, long-term data records. Our primary aim was to evaluate change over time, so we did not include intermittent or short-term data collection efforts in these analyses. Much of the data summarized in this report originates from the Hempstead Bay Study, which began with a single year of monitoring in 1968, followed by 42-years of continuous data collection from 1974-2017. The report contains:

- Temporal analyses of water quality parameters in Hempstead Bay (i.e. the SSER Western Bays) from 1968-2017
- Graphs and descriptions of temporal trends over time
- Interpretation of potential drivers of water quality changes where possible
- Temporal analyses of land use and demographic changes in the watershed for time periods where data are available to provide greater context for observed water quality trends
- An appendix with graphs and figures that provide material that will help support further research and analysis

To put the findings of the water quality data into greater context, we used temporal and spatial datasets to explore changes in human population, urban and suburban development, and impervious surface cover in Nassau County and the Town of Hempstead. Growing urban and suburban development typically leads to increased nitrogen loading to surface waters, thus one of the questions we sought to answer in this report is whether we could use population and land cover changes to better understand the historical water quality trends in Hempstead Bay.

We were unable to observe any clear temporal relationships between observed changes in the watershed (in terms of human population and intensity of development) and changes in water quality indicators for the period from 1975 to 2017. While Nassau County and the Town of Hempstead both experienced exponential increases in population growth from the early 1900s through 1960, population density in the region peaked around 1970, shortly before the beginning of the continuous 42-year record of water quality data represented in this report.

Changes in population and intensity of development have been relatively small over the 1975-2017 time period, with a small loss of population in the 1980s, a modest rebound in the 1990s, and then relatively stable population size in the 2000s. Based on these trends, and the dominance of wastewater treatment plant (WWTP) effluent as a source of anthropogenic nitrogen inputs to Hempstead Bay, it is unsurprising that no clear relationships were found between watershed-level changes and water quality indicators.

We examined general spatial patterns in Hempstead Bay and found that indicators of nutrient pollution increased from East Bay to Middle Bay to West Bay. As one moves westward towards the New York City border and Jamaica Bay, nutrient indicators such as nitrate, nitrite, ammonia, and orthophosphate all generally increase. This increasing trend is likely due to a combination of nonpoint sources from dense urban development and point sources (mainly wastewater treatment plant discharges) whose magnitude and influence increase from east to west.

The Town of Hempstead, Department of Conservation and Waterways, began monitoring the condition of its bays in 1968 with a one-year study focused primarily on the effects of treated sewage discharge on the quality of bay water. These data from 1968 provide information about water quality in Hempstead Bay prior to the start of the main monitoring data presented in this report (1975 and onward). A comparison of data from 1968 and 1975 onward suggest that some improvements in water quality may have occurred over this seven-year time period in relation to potential pathogenic bacteria. Total coliform counts (an indicator of potentially pathogenic bacteria) were considerably reduced between 1968 and 1975, while nitrate levels were relatively stable across this time period.

Looking over the entire timespan, median annual nitrate concentrations remained near 1968 levels until the late 1970s, then increased during the early 1980s, after which nitrate concentrations steadily declined through 2017 (see *Nitrate* section of this report). The cause of the rise and fall in nitrate concentrations from the 1970s through the near present requires further exploration but may be related to changes in WWTP effluent. The timing of peak annual nitrate concentrations among water sampling stations, and subsequent declines, correspond with the peak and decline in WWTP effluent volume. We caution that this correlation is not necessarily causation and that the volume of effluent and concentration of nitrogen within that effluent may not be directly proportional over this time period. Total coliform counts, while reduced compared to 1968, generally remained near 1975 levels until the early-1990s. Total coliform counts and fecal coliform counts both declined steadily from the early 1990s until the near present (see *Total Coliform Bacteria* and *Fecal Coliform Bacteria* sections of this report). Further investigation is warranted, but the early 1990's declines may, in part, reflect increasing acceptance of pooper-scooper laws around this time period. A continued drop in coliform counts in the 2000's, particularly noticeable in East Bay, may be the result of the Town of Hempstead's purchase and operation of two pump-out boats and the implementation of an additional stormwater medallion program targeting pet waste. Interestingly, nitrite (NO_2^-) concentrations generally increased over the 1975 to 2017 time frame, but this nitrogen-containing compound only comprises a small fraction of total nitrogen in Hempstead Bay and its residence time is typically short-lived. The cause of this change in nitrite concentrations is not yet clear. While many water quality challenges remain, these data provide evidence of a potential improvement in pathogen indicators between 1968 and 1975 and additional improvements in both nutrient and pathogen indicators in recent decades.

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INTRODUCTION

About this Document

This data analysis and report are part of a project to monitor nutrients and other water quality parameters in Hempstead Bay, its contributing tributaries, and its watershed. Hempstead Bay is part of the South Shore Estuary Reserve (SSER) within Nassau County and its bays are sometimes referred to as the SSER Western Bays. The overarching goal of this project is to provide a framework for monitoring, analysis, and reporting of water quality within the surface waters of Nassau County's South Shore and its major tributaries. To achieve this goal, Hofstra University proposes a partnership with the Town of Hempstead Department of Conservation and Waterways (TOH C&W) to continue, and expand upon, the water quality monitoring that the TOH C&W laboratory has conducted in the South Shore of Long Island in Nassau County, New York.

The TOH's monitoring program, whose earliest sites have been monitored since 1968, went mostly offline in the summer of 2017. This has left an irretrievable gap in our record of water quality at a time of major change to the region, but fortunately, this monitoring work has been re-established via a collaborative partnership between TOH C&W, Hofstra University, and the Long Island Regional Planning Council (LIRPC) with the support of the Long Island Nitrogen Action Plan (LINAP) and the New York State Department of Environmental Conservation.

Past and present monitoring data are needed to provide a baseline against which to evaluate changes to nutrient loadings that are expected in the next decade as a result of large-scale green and gray infrastructure upgrades in the region. This includes an immediate need for sampling around the South Shore Water Reclamation Facility (SSWRF; formerly known as the Bay Park Sewage Treatment Plant) before major upgrades are completed.

Suez, the company that has a twenty-year contract to run the wastewater treatment plant (WWTP), plans to bring Biological Nutrient Removal (BNR) processes online in its secondary treatment systems during summer 2020. A Sidestream Centrate Treatment project will further reduce nutrient loads in effluent and should be completed near the end of 2021 or early 2022. Together these upgrades are expected to reduce nutrient loads in effluent by approximately 50% in the short term and possibly near 70% once a new blower building is completed on the site.

The Long Beach Water Pollution Control Plant, a smaller WWTP facility in the region, will be converted to a pump station near the end of 2022, so its sewage can be rerouted to the SSWRF and benefit from the upgraded treatment operations at that site. Finally, the long-term plan is to reroute effluent from the SSWRF to the Atlantic Ocean through a connection to the Cedar Creek Water Pollution Control Plant ocean outfall, which discharges treated effluent approximately three miles offshore. This effort is called the Bay Park Conveyance Project (https://www.bayparkconveyance.org/). Nassau County anticipates that this project will be completed by the end of 2022. These upgrades are expected to greatly alter water quality in Hempstead Bay and its tributaries.

As part of our ongoing monitoring efforts, our research team has gathered all readily available historical water quality data in the study area for which we could find consistent, long-term data records. Our primary aim was to evaluate change over time, so we did not include intermittent or short-term data collection efforts in these analyses. This effort involved several phases, including i) gathering all readily available water quality data, ii) data conversion to a common format and quality control procedures to detect errors, inconsistencies, and other potential problems, iii) centralization of all data sources within a common database, iv) analysis of temporal trends, v) generation of a report that includes a summary of major trends over time.

The resulting report contains

- Background information about the study area and the history of long-term monitoring by the Town of Hempstead Department of Conservation and Waterways and its collaborators
- Temporal analyses of water quality parameters in Hempstead Bay (i.e. the SSER Western Bays) from 1975-2017, including nutrients, dissolved oxygen, and pathogen indicator data
- Temporal analyses of land use, land cover, and demographic changes in the watershed for time periods where data are available. This information provides greater context for observed water quality trends, which are often related to changes in population size, impervious surface cover, and other factors.
- Graphs and descriptions of temporal trends over time
- Interpretation of likely drivers of water quality changes where possible
- A brief written summary of the overall trends over time and their relationship to potential drivers in the watershed.
- An appendix with graphs and figures that provide material that will help support further research and analysis

This report is a continuation and expansion of the work began in the *Town of Hempstead Water Quality Report: 1975 – 2012*, which sought to digitize and gather the long-term record of water quality monitoring in the study area. This report expands upon that past report by bringing the data up to the near present (through summer of 2017), adding contextual data about changes in the watershed environment that could influence water quality, and additional temporal analyses.

ORGANIZATIONAL MISSIONS

Hofstra University

Hofstra University, located in Hempstead, NY, boasts a vibrant College of Liberal Arts and Sciences, Schools of Engineering and Applied Science, Business, Communications, and Health Professions. The medical school and law school add depth and breadth to educational offerings and campus experiences. STEM majors at Hofstra can select from mathematics, the natural sciences, computer science and engineering; natural sciences programs include astronomy, biology, chemistry, environmental studies, geology, mathematics, physics, psychology, and sustainability. The University's primary focus on education is complemented by a faculty who are actively engaged in cutting-edge research and supported with state-of-the-art facilities that emphasize modern, flexible teaching and research spaces.

At Hofstra, we feel that research is a critical part of undergraduate STEM education. Students are actively encouraged to engage with faculty in mentored laboratory and field research projects and are provided support to present their research at academic and professional conferences. For example, students majoring in biology can select from several areas of specialization, including urban ecology, marine and freshwater biology, cell and molecular biology. These students have studied endangered coastal plants, marsh restoration, and the environmental microbiology of vineyards and sand dunes. Earth Science students have mapped the bedrock geology of New York City and investigated groundwater flooding and soil contamination in the suburbs of Long Island utilizing virtual simulation and prediction algorithms. Chemistry students have studied how to break down industrial waste, bacterial resistance to antibiotics, and the eco-toxic impact of herbicides in rainwater. Such hands-on experience with advanced instrumentation and field research allows Hofstra students to move beyond a traditional content-focused curriculum, fostering the development of successful STEM professionals with the experience and skills to solve 21st century problems.

Hofstra sees fostering partnerships beyond disciplinary boundaries as a major part of its mission, including promoting new cross-campus collaborations as well as exciting connections between the University, the surrounding community, and our partners in industry and research. For example, a new $6 million Collaboratorium brings faculty in biology, geology, and sustainability studies together to share and develop cutting edge research and teaching. Hofstra faculty have a proven track record of working together on projects aiming to improve local ecology and safeguard the environment, including researching the history and function of coastal ecosystems on Long Island; studying local public health issues and their relationships to sustainability; improving hazardous weather warnings in times of hurricanes and tornadoes; and a project funded by the National Science Foundation to develop new interdisciplinary curricula focusing on anthropogenic impacts to the functioning of Earth systems. Moreover, Long Island has long been the home of technological innovation and Hofstra has been an important source of STEM professionals working in Nassau County in ecological management, biotechnology, health sciences, hydrology, engineering, sustainability, and environmental consulting.

Town of Hempstead Department of Conservation and Waterways

The Town of Hempstead's outstanding Department of Conservation and Waterways (TOH C&W) oversees 20,000 acres of wetlands and 180 miles of coastal waterways. Comprising much of our South Shore, these waters remain a tremendous asset to our nature and marine enthusiasts. The four marinas operated by the Department of Conservation and Waterways can accommodate some 600 pleasure craft and a number of party boats. In addition, the Department maintains more than 400 aids to navigation, while its Bay Constables enforce all applicable navigation and conservation laws, enhancing safety for those who utilize the Town's waterways for recreational boating and fishing.

The Town maintains the 50-acre Marine Nature Study Area in Oceanside. This outdoor laboratory provides tours of a tidal salt marsh conducted by trained biologists and wildlife personnel. Many school groups, naturalist organizations and members of the general public take advantage of this tremendous educational resource. The Lido Beach Passive Nature Area (LBPNA) is a 40-acre site located along Lido Boulevard in Lido Beach that supports a wide variety of grasses, vegetation and marine life. The LBPNA includes interpretive displays, a circular trail, a walkout to the bay, and benches for visitors to relax.

The Town's shellfish management program is a shared jurisdiction of the department's law enforcement and science divisions. The science division manages the town's shellfish hatchery and seeding program, which adds millions of clams and oysters to the Town of Hempstead bays annually.

In addition, the TOH C&W chemists have traditionally provided water quality analyses of bay waters sampled from 39 sites in the Town of Hempstead estuary. The findings of this research support biological modeling and the thriving clam industry in Town waters. To provide these analyses, the Town's chemists are using state-of-the-art instrumentation and techniques such as: inductively coupled plasma spectrometry, gas chromatography, atomic absorption spectrometry, etc., in order to keep pace with changes in the required New York State Health

Department standards and proficiencies. Unfortunately, budget cuts will end this sampling soon if other sources of funding are not secured.

The department maintains a biological staff whose disciplines range widely from endangered, injured and stranded species; entomology, botany, geology, ornithology, marsh, estuarine and beach processes, clam grow-out and seeding, to computer design and applications, including the field of geographic information systems and time series analysis. The department also oversees real-time and near-real-time systems and data collections, emergency weather detection and dissemination, tide and meteorological gauging.

STUDY AREA DESCRIPTION AND BACKGROUND INFORMATION

Hempstead Bay

The south shore of Long Island, New York, is characterized by a series of shallow estuaries that are separated from the Atlantic Ocean by a series of sandy barrier beach islands. Starting from the east, these include Shinnecock Bay, Moriches Bay, and the South Shore Estuary that together comprise the South Shore Estuary reserve. Jamaica Bay is the last and most westward of the south shore estuaries and the Hudson River Estuary lies just west of Long Island. The South Shore Estuary is often subdivided for administrative reasons into Great South Bay, South Oyster Bay, and Hempstead Bay, but are contiguous water bodies. This report focuses on the water quality results within Hempstead Bay (Figure 2) that comprises the western 19,500 acres of the South Shore Estuary. This wetland contains approximately 7,000 acres of tidal salt marsh, the most extensive single concentration within New York State. It is populated by a diversity of estuarine creatures. Large numbers of waterfowl, wading birds, shore birds and other species nest and raise their young here. Additional species of birds and seals spend the winter in Hempstead Bay as well as neighboring estuaries. Many local residents and visitors spend their free time fishing, crabbing and clamming in our waters and we retain an active group of commercial clammers and crabbers. We are committed to the understanding and maintenance of the diverse community of species in our part of the estuary.

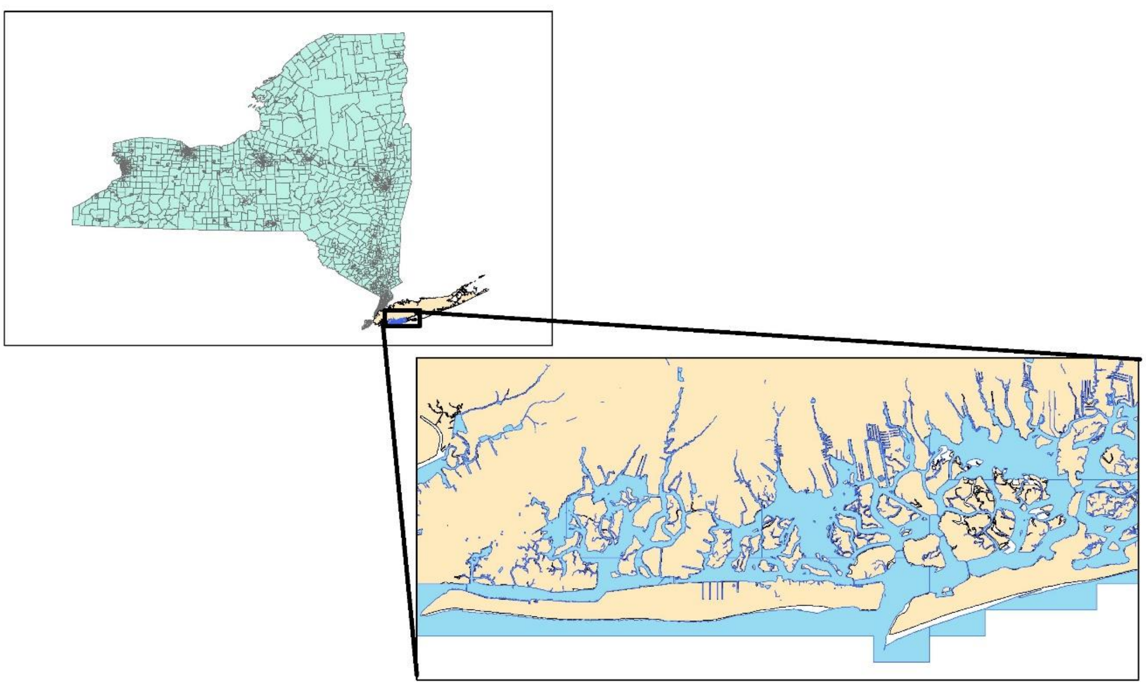


Figure 1. A map of New York State and Long Island, NY showing the location of Hempstead Bay (inset).

The Watershed of Hempstead Bay and the Town of Hempstead Department of Conservation and Waterways

Hempstead Township, through its Department of Conservation and Waterways, manages Hempstead Bay (i.e. the Western Bays) within the South Shore Estuary Reserve. Densely populated urban areas surround these bays. Hempstead Township has a population of approximately 760,000, The City of Long Beach just south of the estuary has approximately 33,000, and approximately 550,000 live within the watersheds that lead to the bays monitored in this study. The bays occur behind barrier beaches (Long Beach Island and Jones Beach Island) and contain over 6,000 acres of salt marsh and over 12,000 acres of channels and flats.

The West Bay is the smallest of the Hempstead Bays and approximately 38% of the surface area is covered with *Spartina* marsh. Urban and suburban development completely surrounds this bay, with the city of Long Beach to the south, the village of Island Park to the East and several other incorporated villages to the north and west. This bay is influenced by discharge from four wastewater treatment plants, potentially by ground water discharge, and Mill River. There is tidal input from the East Rockaway ocean inlet in the southwest. There are a small number of houses on approximately 1 acre plots in Lawrence that still use septic systems.

The Middle Bay is larger, extending from Island Park to the Meadowbrook State Parkway. While there are no large sources of treated water currently, this bay has thermal input from the E. F. Barrett power plant located in Island Park. In addition, there are indications that Middle Bay receives nutrients from the West Bay. Less than 33% of the surface area is covered by *Spartina* marsh and a significant amount of surface runoff enters this bay from the north. The edges are somewhat less developed than West Bay, with undeveloped parts of census-designated place Lido Beach to the south and a vegetated border to the East created by the Meadowbrook. Tidal flushing is provided by Jones Inlet in the southeast. The properties surrounding Middle Bay are sewered except for approximately 500 households and 50 businesses in the hamlet of Point Lookout, which is located at the east end of Long Beach Barrier Island (US Census ACS 2017, Point Lookout Chamber of Commerce 2020).

East Bay is the largest of the bays extending from the Meadowbrook to the Oyster Bay town line. The neighborhoods draining into the bays once had individual septic systems, but most were sewered during the late 1960s as part of Nassau County's Cedar Creek Wastewater Treatment Plant construction. A small number of homes in the East Bay area still use septic systems, but Nassau County plans to connect these homes to the sewage system in the coming years. The Cedar Creek Treatment Plant was designed with an ocean outfall. The Jones Beach treatment plant was the only seasonally treated effluent water source found in this area and now discharges treated sewage into the ocean through a connection to the Cedar Creek outfall. Several creeks and many storm water systems discharge into the northern edge of East Bay. The northern edge is also the only part of this bay with high-density suburban development along its edge. The Meadowbrook, Wantagh State Parkway, and Jones Beach State Park provide large tracts of varied vegetation and wildlife habitat along the East Bay.

Known Impairments, Sources of Impairment, and Challenges to Restoring Water Quality in Hempstead Bay

Known impairments to water quality in Hempstead Bay include excess nutrient pollution and associated eutrophication; pathogens and associated dangers to public health; and loss of aquatic vegetation that helps capture nutrients, stabilize dunes and provide protection from storms (Fisher et al. 2017). New York State lists parts of Hempstead Bay and its tributaries in its list of water body segments with impairments requiring a TMDL or other strategy for mitigation (NYS DEC 303(d) List of Impaired Waters 2016). The suspected sources of these impairments include urban and stormwater runoff, municipal wastewater treatment plants, and atmospheric nitrogen deposition either directly to water bodies or indirectly via runoff from watersheds. Ground water poses an additional source of potential nutrient inputs with residence times that likely vary from weeks to decades (Fisher et al. 2017).

Eutrophication is a major cause for concern in Long Island's waters due to excess nutrients, particularly nitrogen and phosphorous. High nutrient inputs to coastal waters have been associated with the loss of eelgrass beds and salt marshes, low dissolved oxygen concentrations, toxic algal blooms, macroalgal blooms, and harm to shellfisheries (Fisher et al. 2017). Key sources of nutrient pollution that have been identified in the study area include the wastewater treatment plants that directly discharge their treated effluent into Hempstead Bay, urban and suburban development and associated stormwater runoff, atmospheric nitrogen deposition, soil and sediment loss, and groundwater inputs of nutrients that originate from septic systems or the use of fertilizers (Fisher et al. 2017). We enumerate some of the causes and consequences of excess nutrient pollution (particularly nitrogen) in the list of impairments below.

Wastewater Treatment Plants (WWTPs) and runoff from urban and suburban development are major sources of excess nutrients to Hempstead Bay. WWTPs are the largest point sources (i.e. single identifiable discharge locations) and may contribute 80% or more of the anthropogenic nitrogen inputs to Hempstead Bay (NYS DEC 2014). Increases in nonpoint (i.e. diffuse) sources of nitrogen have been associated with urban and suburban development on Long Island (e.g. Kinney and Valiela 2011 in Great South Bay) and in other locations around the United States and globally (Brabec et al. 2002, Schueler et al. 2009). The strong relationship between development and nitrogen loading is largely attributed to greater surface water runoff, increased erosion of nutrient-laden sediments, increased use of artificial fertilizers, higher rates of atmospheric nitrogen deposition, and lower infiltration of stormwater into soils (and therefore less associated nutrient removal by ecosystems). One of the questions we sought to answer in this report is whether such relationships are apparent within the historical water quality records for Hempstead Bay, which was already heavily developed before the start of our continuous data records (i.e. before 1975) and contains high nitrogen loads associated with WWTPs.

We hypothesized that development-related increases to nonpoint source nitrogen loads might be difficult to detect due to high pre-existing development in the watershed in 1975 and large inputs from WWTPs. Planned upgrades to the WWTP infrastructure in the area could greatly reduce these effluent inputs. The largest WWTP in the region (the South Shore Water Reclamation Facility) is in the process of implementing Biological Nutrient Removal (BNR), which would considerably lower nitrogen levels in effluent (Fred Treffeisen, Senior Technical Manager at SUEZ, personal communication). Long-term planning is also underway to reroute the South Shore Water Reclamation Facility's effluent from its current outfall in Hempstead Bay to an ocean outfall by way of the Cedar Creek Water Pollution Control Plant in Wantagh, NY. When the latter plan is implemented, nitrogen inputs would be even more greatly reduced. What remains unclear is the extent to which nonpoint sources of nitrogen would continue to impair Hempstead Bay and its tributaries because these nonpoint sources, including runoff, atmospheric nitrogen deposition, and groundwater inputs have not been well-characterized.

Atmospheric N Deposition is another source of nonpoint source nutrient to Long Island's waters. Recent estimates of atmospheric nitrogen deposition to Long Island's major coastal water bodies range from 33% in the

SSER Eastern Bays (Gobler et al. 2016) to 56% in Peconic Bay (Lloyd 2014) when direct-to-water and indirect watershed inputs are combined. In Hempstead Bay, the large WWTP loads dwarf nonpoint sources such as atmospheric nitrogen deposition, but once these WWTP loads have been addressed, atmospheric nitrogen deposition is expected to increase in relative importance.

Estimates of the magnitude of atmospheric nitrogen deposition to urban and suburban areas (such as Hempstead Bay's watershed) are highly uncertain, in large part because these loads are typically calculated using data from national-scale atmospheric monitoring networks. The monitoring sites within these networks are sparsely distributed (just one site on Long Island), almost always located in rural locations, and are designed to capture continental-scale patterns of background N deposition by avoiding local sources. These sites were never designed to capture local-scale patterns in N deposition, particularly in areas with large sources of urban, suburban, or agricultural emissions sources (Rao et al. 2014, Wetherbee et al. 2019).

A report by Swanson et al. (2013) estimated that total imported nitrogen to the Hempstead Bay watershed's land area was approximately 790,000 kg/y and that atmospheric nitrogen deposition accounted for approximately one quarter of this imported nitrogen. But it is unknown what proportion of this imported nitrogen ends up in surface waters. Furthermore, the estimated rate of nitrogen deposition used in that study (5 kg N/yr) is unexpectedly low. That loading rate is approximately half the value used to make similar calculations for Great South Bay, which has a much less densely developed watershed and is much further from New York City and other major urban point and nonpoint sources of atmospheric nitrogen deposition (Kinney and Valiela 2008, 2011). This value would also need to be applied to the surface area of Hempstead Bay to account for direct-to-water inputs of atmospheric nitrogen deposition. The current monitoring program in Hempstead Bay and its watershed includes measurements of atmospheric nitrogen deposition to address these large uncertainties (see *Current Monitoring Program* section).

Groundwater inputs of nitrogen to Hempstead Bay are difficult to quantify, but likely account for a considerable portion of nonpoint source nitrogen loads (i.e. those not related to WWTPs). A report by Swanson et al. (2013) used a range of sources to estimate total nitrogen inputs from groundwater to be approximately 12% of total nitrogen loads into Hempstead Bay second only to WWTP inputs. Sources of nitrogen to groundwater include onside wastewater treatment systems, leaking sewage pipe infrastructure, and leaching of fertilizers from lawns, gardens, and agriculture. The latter source (agriculture) likely represents a negligible contribution for Hempstead Bay, given the densely developed nature of the watershed. Scientists at the U.S. Geological Survey, in cooperation with NYS DEC, have been working to better model groundwater flow, so that we might improve our understanding of the magnitude of groundwater nutrient inputs and the lag time between when these nutrients enter groundwater and eventually enter surface waters, such as Hempstead Bay and its tributaries (Fisher et al. 2018).

Pathogens are major source of impairment to Hempstead Bay that have led to either long-term or periodic restrictions on shellfishing, use of swimming and bathing beaches, and other commercial and recreational uses of parts of this water body. Water-borne pathogens are bacteria and viruses whose origins are often in untreated wastewater and/or wildlife (e.g. Canada Geese and marine mammals). Thus, in some cases, nutrient pollution (e.g. from wastewater) and pathogens are intrinsically linked. The risk to people from pathogens is typically estimated using counts of total coliform and/or fecal coliform colonies measured from incubations of diluted water samples on microbial plates (US EPA 1989). These measurements are simple and repeatable, but do not distinguish between pathogenic bacteria and non-pathogenic bacteria within these broad classes. Still, these measurements represent a first line of defense and are the basis for legal determinations of which commercial and recreational activities may take place within a water body. These data also provide evidence needed for predictive models, which can forewarn about periods of time when pathogenic bacteria may be elevated, such as after major rainfall events. Advanced monitoring methods are being developed that may better differentiate among pathogenic and non-pathogenic bacteria.

The loss of salt marshes and other aquatic vegetation is cause for concern in the study area. Salt marshes are coastal wetlands that are flooded and drained (fully or partially depending on elevation) by the tides. Hempstead Bay (i.e. the SSER Western Bays) contains approximately 6,000 acres of salt marshes, which are critical for supporting fish and wildlife, water filtration, nutrient uptake, and storm protection via their ability to stabilize sediments. These salt marshes are threatened by many factors, including shoreline development, changes to sedimentation rates, storms, sea level rise, and perhaps most importantly for Hempstead Bay, nutrient over-enrichment of coastal waters (Edinger et al. 2014). Analyses based on remote sensing data demonstrate the rapid loss of salt marshes in recent decades around Long Island, particularly on Long Island's south shore (Edinger et al. 2014).

It has long been understood that salt marshes have a high capacity for nutrient capture and removal (e.g. Valiela et al. 1976), however, it is only recent decades that research has demonstrated that excessive nutrient inputs may actually cause harm to the salt marshes themselves (Turner et al. 2009, Maher 2018). In the presence of high nutrient loads, aboveground vegetation may increase in density and height, but at the expense of root and rhizome production. This can lead to destabilization of sediments at marsh edges, leading to weakened resistance to normal wave action and greater susceptibility to damage during storm events (Turner et al. 2009, Deegan et al. 2012, Edinger et al. 2014, Maher 2018). Marsh vegetation has the ability to dissipate wave energy and reduce wave height (e.g. Anderson and Smith 2014), which suggests that nutrient over-enrichment has weakened Long Island's natural defenses against storms and decreased the future capacity of these ecosystems to absorb excess nutrients.

SOURCES OF WATER QUALITY INFORMATION USED IN THIS REPORT

The main datasets analyzed in this report come from the Town of Hempstead Department of Conservation and Waterway's long-term monitoring efforts in Hempstead Bay (1968 and 1975 – 2017). In the following pages we outline the history of TOH C&W's monitoring efforts and the connection to Hofstra University scientists, who remain partners in the current monitoring activities and co-authors on this report.

Our research team has gathered all readily available historical water quality data in the study area for which we could find consistent, long-term data records. Our primary aim was to evaluate change over time, so we did not include intermittent or short-term data collection efforts in these analyses, which excluded most other datasets from consideration. The report contains:

- Temporal analyses of water quality parameters in Hempstead Bay (i.e. the SSER Western Bays) from 1975-2017
- Graphs and descriptions of temporal trends over time
- Interpretation of likely drivers of water quality changes where possible
- Temporal analyses of land use, land cover, and demographic changes in the watershed for time periods where data are available. This information provides greater context for observed water quality trends, which are often related to changes in population size, impervious surface cover, and other factors.
- An appendix with graphs and figures that provide material that will help support further research and analysis

Brief History of the Town of Hempstead Department of Conservation and Waterways

The Town of Hempstead Department of Conservation and Waterways (TOH C&W) was established for the purpose of implementing the policies that are intended to conserve and maintain the Town of Hempstead's wetlands and waterways for the benefit of the residents of the town and to exclusively administer the wetlands management plan of the Town of Hempstead (§53 of Town Code). The Department of Conservation and Waterways, under the general supervision of the Commissioner, is charged with the administration and enforcement of all local laws and Town Board resolutions pertaining to the preservation, conservation, management and maintenance of the town wetlands and waterways. These duties include leasing of underwater and marginal lands; structures in waterways; erosion protection; marinas, piers, moorings and docks; shellfishing, operation of boats and seaplanes, dredging and other designated uses of the wetlands and waterways; and such other matters as may from time to time be referred to the Department (§53-3 of Town Code).

The Conservation Division also conducts ecological and investigative studies to understand the factors influencing populations of marine life in the waterways, chemical and biological characteristics of the waters, circulation patterns of Hempstead Bay estuary, qualitative analysis of bottom sediments, productivity and carrying capacity of marshlands within the bay area to determine approximate populations of wildlife which may be supported within the bay complex; to establish and maintain shellfish and wildlife sanctuaries and to improve the ecological balance within the wetlands for desirable species of marine life that can contribute to the recreational enjoyment and economy of the Town of Hempstead (§53-3C1 of Town Code).

Wastewater treatment plants discharge treated effluent into Hempstead Bay, a consideration that was noted in the 1968 report and a focus of this continuing study. Added to this is the need and intent to understand the effects from nonpoint sources. These water quality efforts are in conjunction with the Department's other goals, including the successful management of local wildlife, fish, shellfish, marshlands, and other natural resources within the Town of Hempstead.

Long-term Monitoring History by TOH C&W

The Town of Hempstead Department of Conservation and Waterways initiated a pilot water sampling program in 1968 (Udell 1969), and then initiated regular Bay Study (i.e. Hempstead Bay) sampling in the mid-1970s. A report on this program was published using funding from the New York State Department of State, Environmental Protection Fund (NYS DOS EPF) in 2013 (TOH C&W 2013). This sampling protocol was continued until funding was discontinued and the TOH C&W Water Quality Laboratory was closed in June 2017 pending future support.

Monitoring efforts prior to this time period included monthly one-meter depth water sampling for nitrate, nitrite, ammonia, orthophosphate, dissolved oxygen (DO), salinity, temperature, chlorophyll a, and silica in Hempstead Bay. Additional sampling protocols were developed and expanded during the 1990s and into the early 2000s. These protocols included the establishment of vertical profile stations, which are locations with deep water at which a subset of water quality parameters is collected using sensors that are dropped from the surface to full water depth. Tributary sampling was piloted using YSI water quality instruments in the major waterways that contribute to Hempstead Bay. This work was later expanded to include nutrient, chemical and bacterial measurements. Most of these activities were discontinued after June of 2017. See Figure 2 for past and ongoing monitoring locations in Hempstead Bay and its tributaries.

Tidal data recording was also initiated at 6 locations within Hempstead Bay during the 1970s using nitrogen gas pressure recorders (Bristol Inc), and transitioned to electronic data collection by USGS (TOH C&W, Freeport Village, and NYS DEC funding) and Stony Brook SoMAS (NYS DOS EPF and TOH C&W funded), with the addition of water quality and weather parameters at the USGS station at Point Lookout with matching funds from TOH C&W. USGS later added an additional station at Hog Island Channel under NYS DEC local match that includes nitrate and other water quality parameters, with calibration support from TOH C&W.

Trend studies and sediment characteristic studies of the salt marshes and bays were performed in collaboration with researchers from various organizations, including USGS, Stony Brook Ecology and Evolution, Stony Brook SoMAS, Hofstra University Geology and Sustainability, CUNY Baruch College, Adelphi University Environmental Studies, and others. Research on wildlife in the estuary and associated barrier beaches is continuing in cooperation with NYS DEC Division of Fish, Wildlife, and Marine Resources (DFWMR), US Fish and Wildlife Service, Audubon New York, Hofstra University, Adelphi University, and many others. Citizen science efforts have been organized by Operation SPLASH that include beach plantings, marsh clean-ups, some water quality sampling funded by the Long Island Sound Study, and volunteer assistance with shell bagging in support of the TOH C&W oyster reestablishment efforts. Local secondary schools have also participated in estuarine research work and volunteer assistance, notably Long Beach High School. The Town of Hempstead also maintains estuarine educational facilities at the Oceanside Marine Nature Study Area since 1970 and the more recent Lido Nature Preserve, Levy Preserve.

The datasets provided by this program are considered essential to the continued evaluation and monitoring of this section of the South Shore Estuary Reserve and allows us to implement outcomes 6-1 & 6-3 of the SSER Comprehensive Management Plan (SSERC 2001, Fisher et al. 2018). This management plan (SSER CMP) is currently the regional management plan of record in which the Town of Hempstead is a participant. Data from the Town's programs have typically been available upon request to TOH C&W.

Partnership between Hofstra University and TOH C&W: Past and Present

Hofstra University was founded as a branch of New York University in 1935, and subsequently granted an independent charter as Hofstra College and accreditation in 1940. Hofstra has been a partner with the Town of Hempstead, Department of Conservation and Waterways since the Department's inception and assisted with early water quality studies. This association has continued, with Hofstra alumnae on the Department's staff and continued scientific collaboration with Hofstra researchers.

The marine laboratory associated with the Town of Hempstead's (TOH's) water quality monitoring program started in a trailer in a partnership with Hofstra University in the 1960s. In 1968, a permanent laboratory facility was constructed, formalizing the effort that would result in 50 years of water quality monitoring by TOH in this area. During this time the program has introduced new instruments and expanded beyond the original monthly sampling of the estuary at one-meter depth to include: i) in situ measurements of water quality parameters across vertical depth profiles using YSI SONDEs, ii) monthly sampling of tributaries of Hempstead Bay, and iii) the use of continuous water quality monitoring devices at strategic locations within Hempstead Bay. The study area (Figure 3) for monitoring activities includes the Town of Hempstead and parts of Nassau County outside the Town borders, but largely within the South Shore Estuary Reserve (SSER) watershed (SSERC 2001, Fisher et al. 2018).

The current monitoring program includes a new network to sample atmospheric deposition of inorganic nitrogen species, which are an important but understudied portion of nitrogen inputs to urban and suburban watersheds (Rao et al. 2014). The oldest monitoring efforts (started at the outset of the Hempstead Bay Study), consist of one-meter depth water sampling that are being continued for nitrate, nitrite, ammonia, orthophosphates, dissolved oxygen (DO), salinity, temperature, chlorophyll a, and silica. The tributary monitoring program is continuing with a subset of past stations in the tributaries of Hempstead Bay. The stations will be monitored for the same nutrient parameters listed above for the Hempstead Bay Study and the same parameters measured in vertical profiles using YSI SONDEs. Finally, Hofstra University is leading efforts to monitor the atmospheric deposition of nitrogen at stations throughout the southern half of Nassau County (TOH and portions of the Town of Oyster Bay) in order to quantify nitrogen inputs from atmospheric deposition. Based on data from other urbanized areas, atmospheric nitrogen deposition is expected to be higher than predicted by national-scale monitoring networks, which purposely locate measurement sites far from urban and suburban areas and their respective sources of atmospheric nitrogen (Rao et al. 2014).

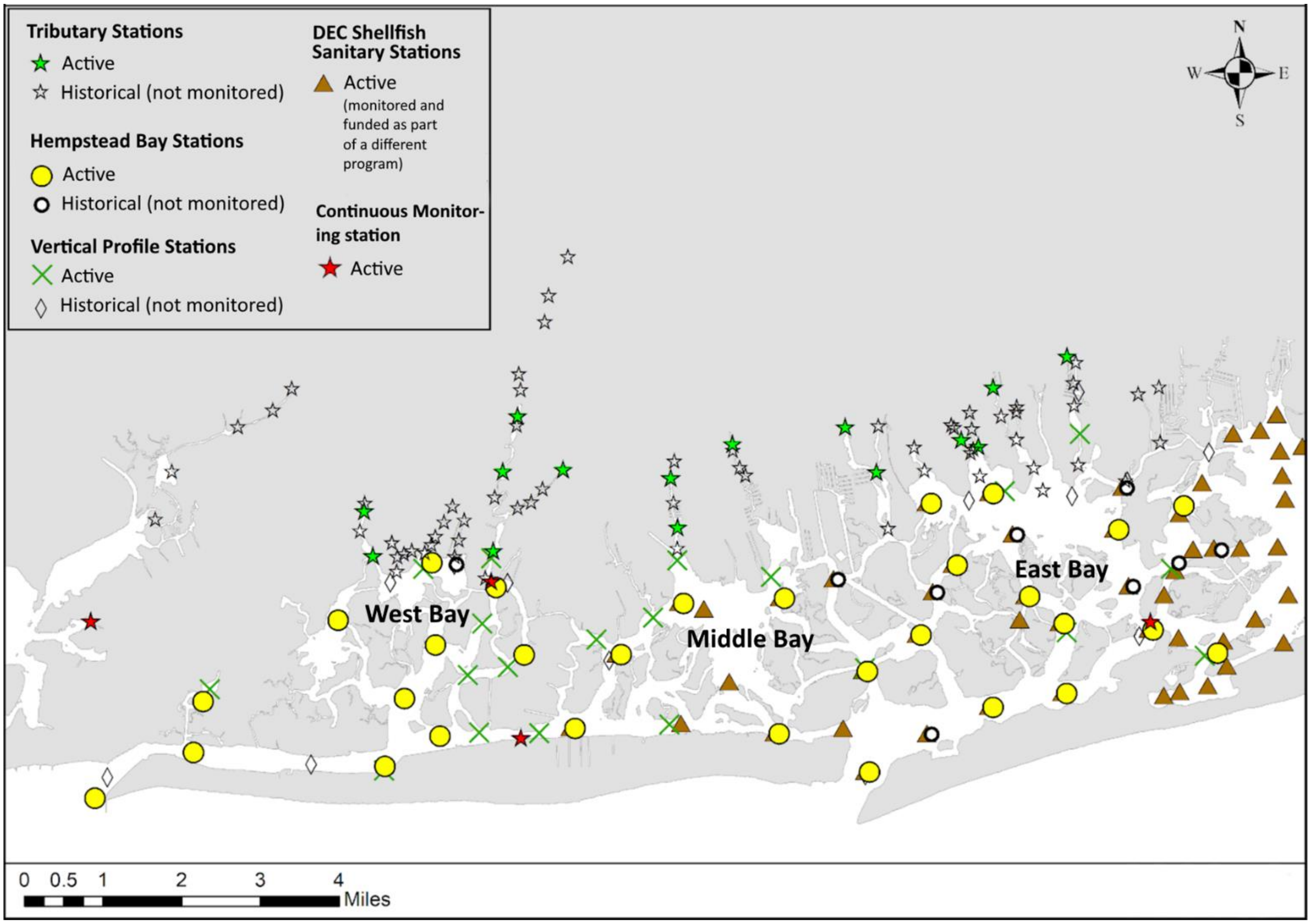


Figure 2. Map of current and historical water sampling stations. Hempstead Bay sampling stations, tributary sampling stations, and vertical profile sampling stations are sampled once per month for a wide range of water quality parameters. Three continuous monitoring stations, one each within the West Bay, Middle Bay, and East Bay sections of Hempstead Bay, measure a subset of water quality parameters *in situ* at 12-minute intervals. TOH C&W also operates a continuous monitoring station in Jamaica Bay (western side of the map). DEC Shellfish Sanitary Stations often overlap in location with the Hempstead Bay monitoring stations and are included in the maps and tables above as a helpful reference to additional water quality data that are being collected by TOH C&W.

Current Monitoring Program

The current monitoring program represents a partnership between TOH C&W and Hofstra University, in collaboration with the LIRPC and other entities, to continue many of the efforts carried out under TOH's past monitoring programs while also adding measurements of atmospheric nitrogen deposition. The monitoring program includes: i) monthly one-meter depth water sampling for nitrate, nitrite, ammonia, orthophosphate, dissolved oxygen (DO), salinity, temperature, chlorophyll a, and silica in Hempstead Bay and its tributaries; ii) monthly vertical profiles from the surface to maximum depth using YSI SONDEs to collect salinity, DO, temperature, fluorometric chlorophyll, turbidity, and pH at deep water locations throughout Hempstead Bay; iii) continuous water quality monitoring using in-situ instruments located in each of the three bays (West Bay, Middle Bay, and East Bay) within Hempstead Bay to provide a record of salinity, DO, temperature, fluorometric chlorophyll, turbidity, and tidal depth at 12 minute intervals, and iv) an atmospheric nitrogen deposition monitoring network within the southern half of Nassau County. The study area for these activities includes Hempstead Bay, its major tributaries, and a network of atmospheric deposition monitoring stations located largely within the Nassau County portion of the South Shore Estuary Reserve (SSER) watershed (Figure 3). These monitoring data are needed to provide a baseline against which to evaluate changes to nutrient loadings that are expected in the next decade as a result of large-scale infrastructure upgrades in the region, particularly those related to the South Shore Water Reclamation Facility (formerly known as the Bay Park Sewage Treatment Plant) before major upgrades are completed.

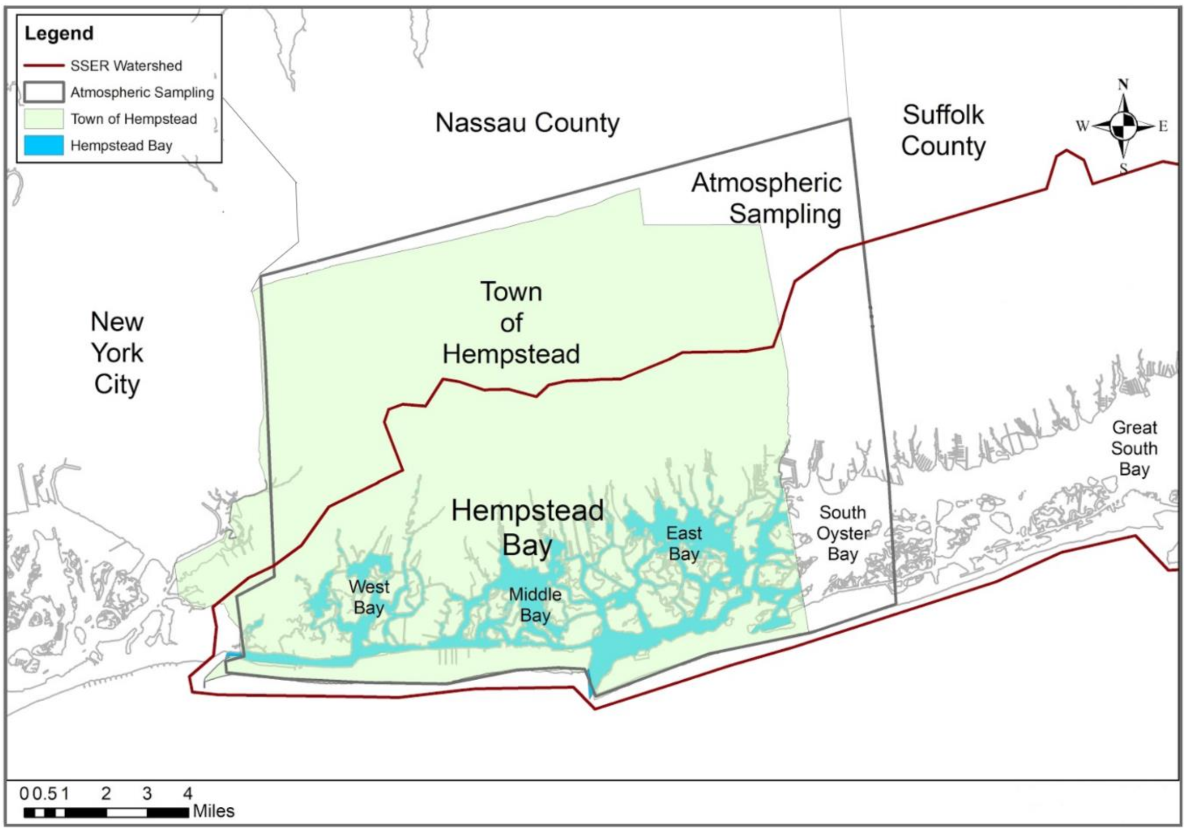
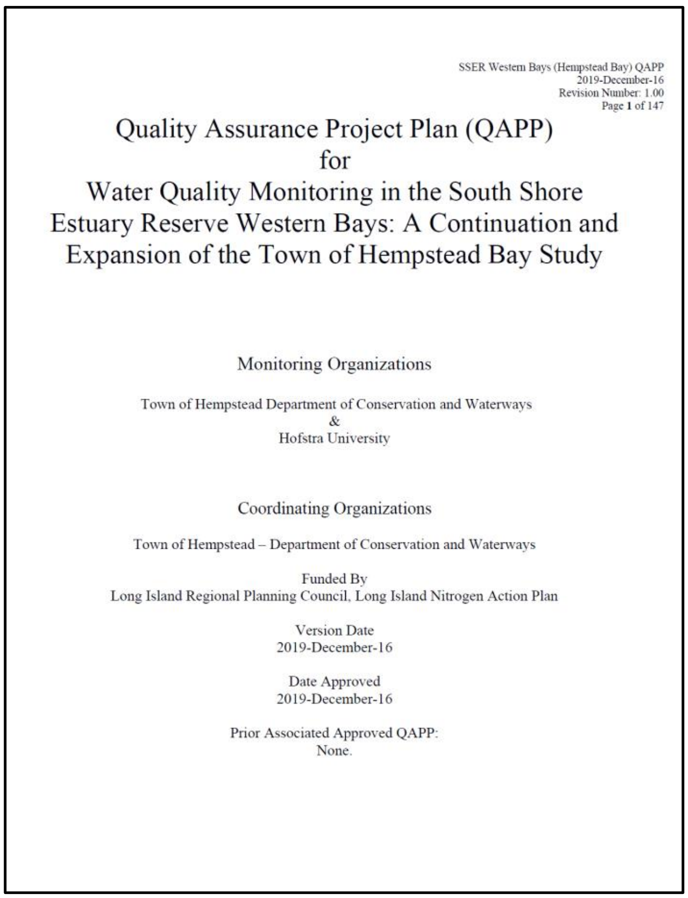


Figure 3. The study area covered under current monitoring efforts includes i) water quality monitoring in the tributaries and coastal waters of the South Shore Estuary Reserve (SSER) within Nassau County (red outline) and ii) land areas inside and just outside this boundary (dark gray line) to help us characterize sources of atmospheric nitrogen deposition as part of recently begun (not historical) monitoring efforts.

SAMPLING METHODS AND LIST OF WATER QUALITY PARAMETERS

Methods used to Measure the Parameters in this Report on Historical Water Quality Data

All sample collection and laboratory analysis were performed in accordance with the contemporaneous edition of Standard Methods for the Examination of Water & Wastewater or with Environmental Protection Agency (EPA) approved variations, recommended by the manufacturers of the instrumentation. Samples were obtained monthly throughout the bays starting in 1975 at 28 separate stations. Water quality parameters sampled at this time included: water temperature (°C), salinity (parts per thousand - ppt), chlorophyll 'a' (mg/m3), nitrate (μM), nitrite (μM), ammonia (μM), particulate organic matter (mgC/m3), dissolved oxygen (mg/L), Secchi depth (m), orthophosphates (μM), coliforms (MPN), and fecal coliforms (MPN). Sampling currently occurs at 36 stations and now includes urea (μM), silicate (μM), and total chlorophyll in place of particulate organic matter and Biological Oxygen Demand (BOD).



SSER Western Bays (Hempstead Bay) QAPP
2019-December-16
Revision Number: 1.00
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Quality Assurance Project Plan (QAPP)
for
Water Quality Monitoring in the South Shore Estuary Reserve Western Bays: A Continuation and Expansion of the Town of Hempstead Bay Study

Monitoring Organizations

Town of Hempstead Department of Conservation and Waterways
&
Hofstra University

Coordinating Organizations

Town of Hempstead – Department of Conservation and Waterways

Funded By
Long Island Regional Planning Council, Long Island Nitrogen Action Plan

Version Date
2019-December-16

Date Approved
2019-December-16

Prior Associated Approved QAPP:
None.

For a detailed examination of the current methods used to measure these parameters, please see the document “Quality Assurance Project Plan (QAPP) for Water Quality Monitoring in the South Shore Estuary Reserve Western Bays: A Continuation and Expansion of the Town of Hempstead Bay Study” (Browne and Raciti 2019).

List of Water Quality Parameters Examined in this Report

A list of the parameters measured and used in this report are below. The time period (in parentheses) represents the range of time that these data were collected within Hempstead Bay. Tributary measurements of these parameters are only available for more recent time periods and are therefore not part of this report, which focuses on long-term trends.

Dissolved Oxygen (1975 - 2017)

Dissolved oxygen concentration is one of the most universal indicators of overall water quality and is critical for respiration by aquatic life. It is measured in milligrams of oxygen per liter of water (mg/L). Adequate dissolved oxygen is necessary for good water quality. NYS DEC's Technical & Operational Guidance Series documents suggest that daily average oxygen concentrations below 4.8 mg/L represent a chronic low oxygen condition and that concentrations below 3.0 mg/L for any length of time represent an acute low oxygen condition within saline surface waters (https://www.dec.ny.gov/docs/water_pdf/togs116.pdf).

Particulate Organic Matter (1975 - 2001)

Particulate organic matter is material of plant or animal origin that is suspended in water. Particulate organic matter is an important food resource for many filter feeding organisms, but very high concentrations indicate potential water pollution problems, such as excessive erosion and transport of sediments or soil due to runoff and/or disturbance.

Orthophosphate (1975 - 2017)

Orthophosphate is the dissolved inorganic form of phosphate found in aquatic systems. Most of the phosphate is incorporated into organic compounds or bound into plant and animal tissues. Orthophosphate values indicate the portion of phosphate that is available to plants and animals. Phosphate becomes insoluble and is lost to sediments in ecosystems with very low productivity.

Ammonia (1975 - 2017)

Ammonia is a simple inorganic nitrogen compound that is typically excreted by marine invertebrates and fishes. It is also the main form of nitrogen produced by anthropogenic sources like treated wastewater and inexpensive fertilizers. Ammonia is readily utilized by many forms of algae, is absorbed directly by the leaves of saltmarsh cordgrass (*Spartina alterniflora*) and converted to nitrite by bacteria. Because it is readily utilized, ammonia normally does not last long (has a short half-life) in oxic conditions. However, ammonia can also be toxic to fishes and aquatic organisms if concentrations become too high. Ammonia exists in equilibrium with ammonium ions (NH_4^+) and most measurements of ammonia (including our measurements) are really combined measurements of ammonium ions and ammonia. While ammonia is toxic, it only dominates when pH is relatively high (i.e. under basic conditions). Under neutral or acidic conditions, non-toxic ammonium ions typically dominate over ammonia at a ratio of 100:1 or greater. Temperature influences the ratio of ammonia to ammonium with higher temperatures favoring ammonium at any given pH.

Nitrite (1975 - 2017)

Nitrite (NO_2^-) is formed when bacteria oxidize ammonia. Although it is less toxic than ammonia, elevated levels of nitrite are still a threat to aquatic life, especially fishes. In open waters, nitrite is usually oxidized to nitrate in a short time.

Nitrate (1968, 1975 - 2017)

In the next stage of the nitrogen cycle, bacteria oxidize nitrite (NO_2-) to nitrate (NO_3^-). Nitrate is a nutrient for plants and is necessary for supporting marine life. However, high concentrations can cause excessive unconsumed growth of algae and other plants. This growth can lead to accelerated eutrophication and loss of dissolved oxygen.

Dissolved Inorganic Nitrogen (1975 - 2017)

Dissolved inorganic nitrogen is the sum of ammonia, nitrite and nitrate. This parameter is often used in studies instead of its components. It is an important parameter because nitrogen is usually the limiting factor of ecosystem productivity in marine systems.

Chlorophyll 'a' (1968, 1975 - 2017)

Chlorophyll 'a' is the primary green pigment that allows plants to capture energy from sunlight and produce organic compounds and is the predominant type of chlorophyll found in algae. High levels of chlorophyll 'a' may indicate nutrient loading because excess nutrients fuel the growth of algae. Areas with lower algal levels have clearer water and fewer harmful blooms, but insufficient levels (or the wrong species) of phytoplankton can negatively impact filter feeding species and other herbivores. Ideal levels of chlorophyll 'a' indicate that there is enough algae to fuel the food web, but not so much that hypoxic conditions are prevalent.

Total Coliform (1975 - 2017)

Some coliform bacteria are not directly an indication of contamination by raw fecal matter, so these readings are taken in combination with fecal coliform to judge the likelihood of such contamination and potential presence of organisms that can affect human health. Counts are measured as most probable number (MPN) per 100ml.

Fecal Coliform (1968, 1975 - 2017)

The presence of fecal coliform bacteria in aquatic environments indicates that the water has been contaminated with the fecal material of humans or other warm-blooded animals. The source water may also have been contaminated by pathogens, disease-producing bacteria or viruses, which can exist in fecal material. The presence of fecal coliform(s) is an indicator of potential health risks, most notably waterborne gastroenteritis.

Secchi depth (1975 - 2017)

The clarity of water is estimated using a Secchi disc. High Secchi depth, associated with clear low-productivity water, is typically when the disk is visible to depths of 2 m or more. Low Secchi depth of 1 m or less, is indicative of turbid or light limiting conditions. Low Secchi readings are often associated with degraded waters because transparency decreases as suspended sediments or algal abundance increases. Clear water can indicate a healthy bay, though high Secchi readings are also found in with waters devoid of marine life.

Silicate (2007 - 2017)

Silicates are important primarily for the production of protective structures on many plants. It can be a limiting nutrient for diatoms, a useful group of algae, and the production of their external frustules (i.e. their silicate "shells").

Urea (2007 - 2017)

Urea is a simple organic nitrogen compound. Elevated levels often indicate untreated waste from anthropogenic sources or excretion from mammals. Some fertilizers are urea based and may contribute to elevated urea levels.

Fluorometric Chlorophyll (2007 - 2017)

Fluorometric chlorophyll readings are now being collected in conjunction with chlorophyll 'a' using a YSI 6600 SONDE. This parameter measures algae by using different biological chemistry than the chlorophyll "a" test.

Salinity (1975 - 2017)

Salinity is a measure of the salt concentration of water. It is usually expressed in parts per thousand (ppt). Many estuarine organisms, notably the eastern oyster (*Crassostrea virginica*), survive better at lower salinity (22.5-28 ppt), while many predators and parasites of estuarine species prefer salinity closer to the 32 ppt that is typical of the ocean. Increased salinity may have a potential negative influence on the estuary.

Water Temperature (1975 - 2017)

Fluctuations in water temperature influence where bay grasses grow and when fish, crabs and oysters feed, reproduce and migrate. Warmer water holds less dissolved oxygen and can lead to hypoxic events.

Representative Stations in West Bay, Middle Bay, and East Bay

The analysis of water quality parameters in this report includes summary data for *all of Hempstead Bay* and also for *representative stations* within each of its major embayments, West Bay, Middle Bay, and East Bay (Figure 4). The representative stations varied in tandem for each of the parameters studied.

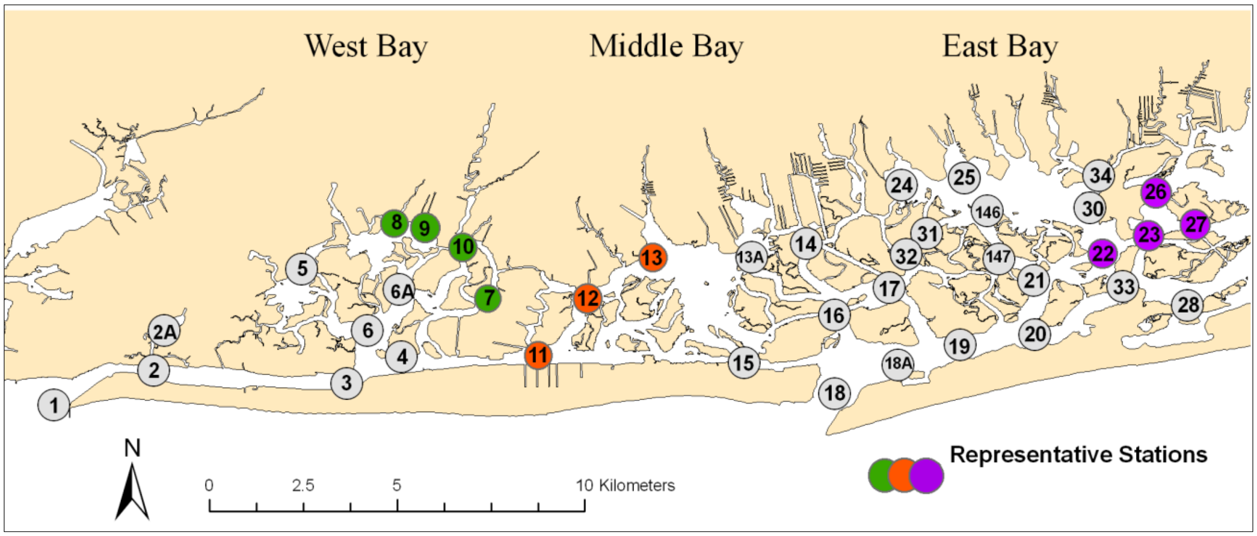

Figure 4. Locations of stations used to collect water quality data during the length of the study. West, Middle, and East Bay are identified. Stations in green, red, or purple indicate representative stations in each embayment. The remaining stations are indicated in gray.

CHANGES IN THE LONG ISLAND LANDSCAPE OVER TIME

Changes in Population and Impervious Cover in Nassau County and the Town of Hempstead

Increasing urban and suburban development has been strongly associated with increased nitrogen loading to surface waters on Long Island (e.g. Kinney and Valiela 2011 in Great South Bay) and in other locations around the United States and globally (Brabec et al. 2002, Schueler et al. 2009). This strong relationship between development and nitrogen loading is largely attributed to greater surface water runoff, increased erosion of nutrient-laden sediments, increased use of artificial fertilizers, higher rates of atmospheric nitrogen deposition, and lower infiltration of stormwater into soils (and therefore less associated nutrient removal by ecosystems). One of the questions we sought to answer in this report is whether we could use population and land cover changes to better understand the historical water quality trends in Hempstead Bay.

The Town of Hempstead covers most of the Hempstead Bay's watershed with additional areas contained within Nassau County, NY. Both the County and the Town have experienced large increase in population growth since 1900. The changes in land use, land cover, and human activities over this time period have caused impairments to Hempstead Bay's surface waters. The 42-year record of water quality data represented in this report begins in 1975, shortly after peak population density for the region (circa 1970, Figure 5). Changes in population over time have been relatively small over this time period, with a small decrease in the 1980s, a modest rebound in the 1990s, and relatively stable population in the 2000s. Based on these data, it is unsurprising that no detectable relationships were found between population changes and water quality over the study period.

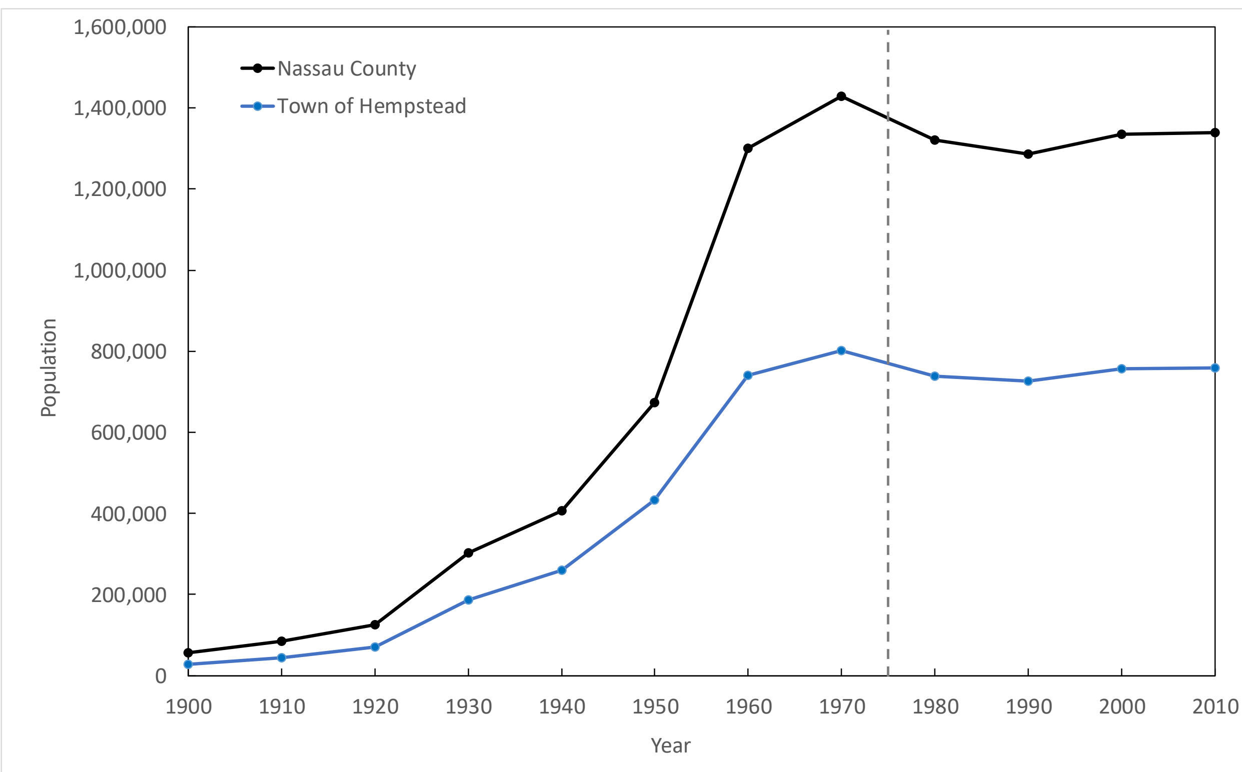

Figure 5. Changes in population size for Nassau County (black line) and the Town of Hempstead (blue line) from 1900 to 2020 (based on US Census data). The dashed line represents the start of the historical data record covered in this report.

The impervious cover model, first proposed by Schueler in 1994 and revised fifteen years later (Schueler et al. 2009), describes the relationship between the proportion of a watershed that is covered in impervious surface and likely stream water quality (Figure 6). The model (and its revised version) serves as a useful reference for how we might compare a highly urbanized watershed to one that still largely contains natural land covers. Based on this model, Hempstead Bay tributaries would generally fall into the “nonsupporting” category, indicating that they may no longer represent their original hydrology, habitat quality, water quality, or biological diversity. The average impervious surface cover in the watershed is approximately 50% (Figure 7).

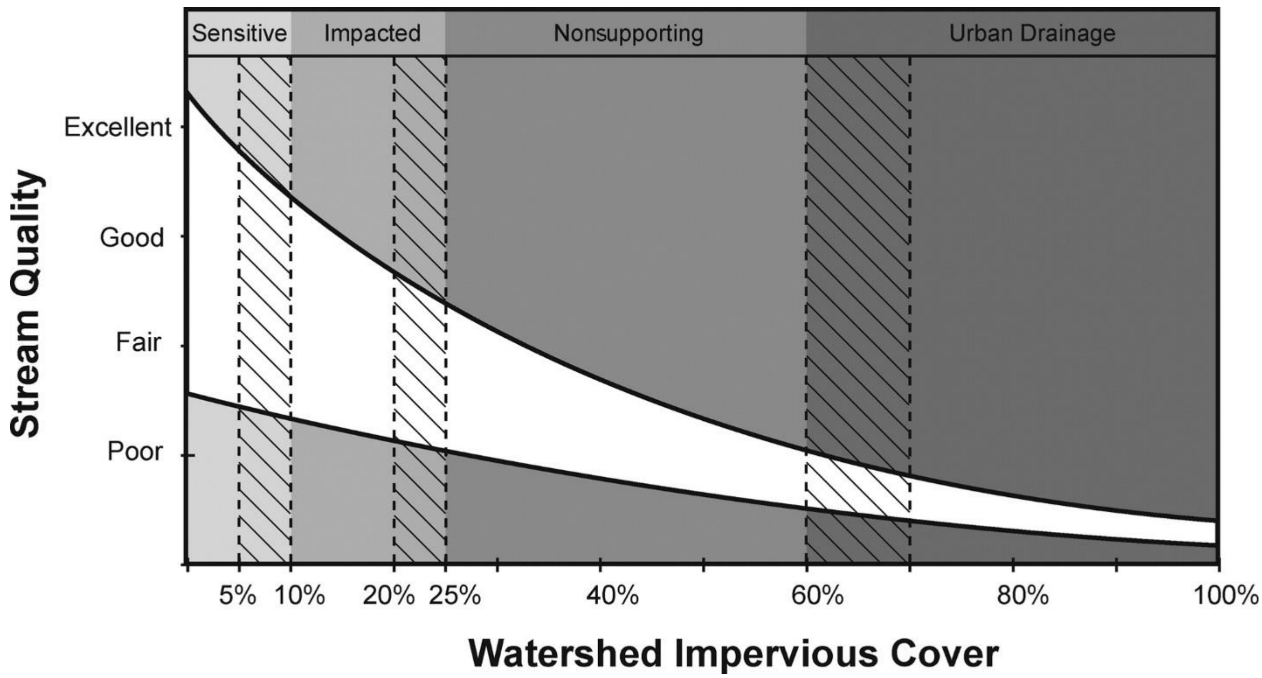

Figure 6. Reformulated impervious cover conceptual model (Schueler et al. 2009).

Population density in Nassau County and the Town of Hempstead remains below peak levels, but there is still evidence of modest urban and suburban development within the study area (Figure 8). Based on the National Land Cover Database (NLCD) Land Cover Change Index, approximately 1.3% of the study area experienced land cover change between 2001 to 2016. Most of this change was classified as “urban change”, indicating changes within already developed areas, but there was also some evidence of forest loss (“forest theme change”) over a small proportion of the land area. A major caveat regarding these data is that they are derived from 30m resolution NLCD imagery, which may underestimate land use and land cover changes within urban and suburban areas and bias estimates of vegetation and impervious cover (Smith et al. 2010, Raciti et al. 2012).

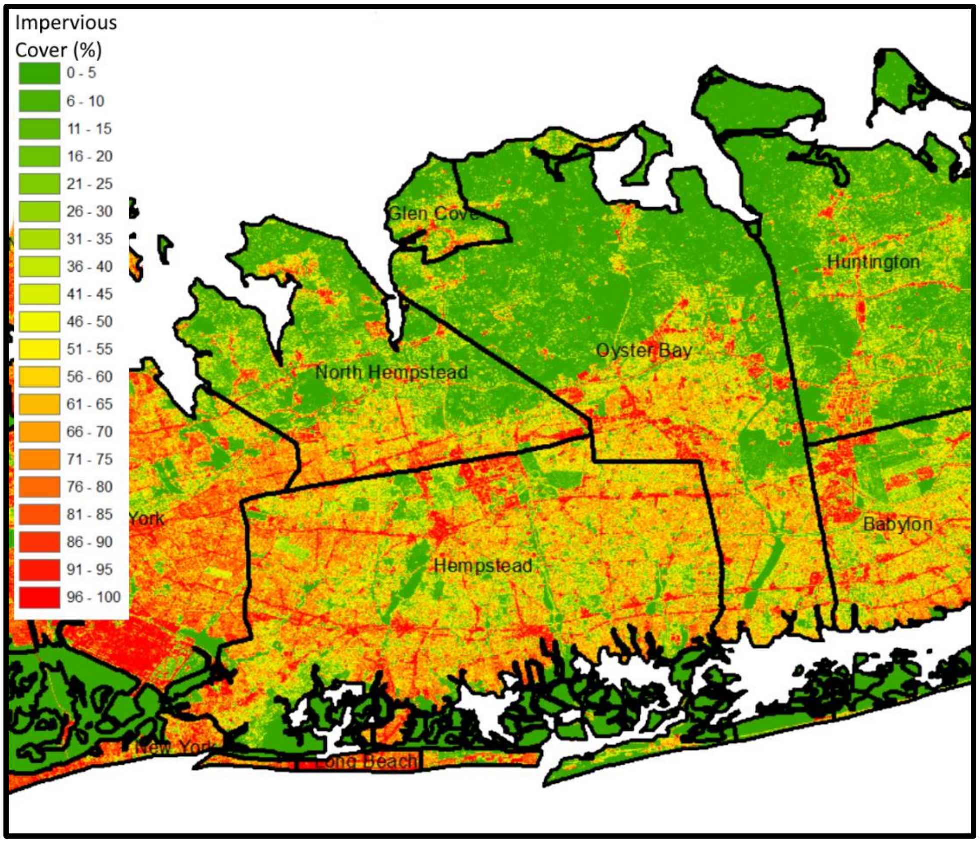

Figure 7. Map of impervious surface cover in the study area and surrounding region (based on data from the 2011 National Land Cover Database).

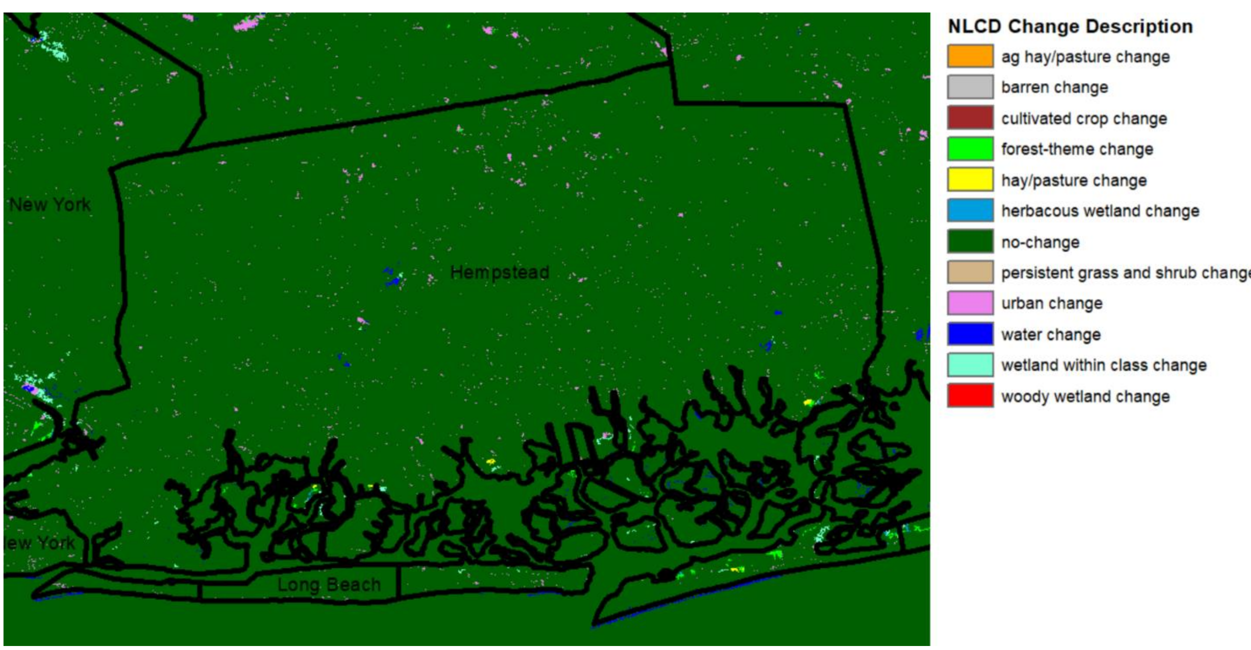

Figure 8. Map of 2001 to 2016 land cover change (based on the 2001-2016 National Land Cover Database).

Changes to Wastewater Infrastructure in the Nassau County portion of the South Shore Estuary Reserve

We hypothesized, and confirmed through time series analysis, that development-related increases to nonpoint source nitrogen loads were not detectable. This is likely due to a combination of high pre-existing development (Figure 7) and peak population density (Figure 5) in the watershed prior to 1975 and large inputs from WWTPs that likely overshadowed the small changes observed in land use and land cover (Figure 8). WWTPs may contribute more than 80% of the anthropogenic nitrogen inputs to Hempstead Bay (NYS DEC 2014).

Planned upgrades to the WWTP infrastructure in the area could greatly reduce these effluent inputs. The largest WWTP in the region (the South Shore Water Reclamation Facility) is in the process of implementing Biological Nutrient Removal (BNR), which should be online in summer 2020, and Sidestream Centrate Treatment which should be completed near the end of 2021 or early 2022. These technologies will considerably lower nitrogen levels in effluent. The Long Beach Water Pollution Control Plant is a smaller facility, which will be converted to a pump station near the end of 2022, so its sewage can be rerouted to the SSWRF and benefit from the upgraded treatment operations at that site. Finally, the long-term plan is to reroute effluent from the SSWRF to the Atlantic Ocean through a connection to the Cedar Creek Water Pollution Control Plant ocean outfall, which discharges treated effluent approximately three miles offshore. Nassau County anticipates that this project will be completed by the end of 2022.

A report by Swanson et al. (2013) outlines some of the early records of wastewater management in the Hempstead Bay (i.e. Western Bays) watershed. According to that report, communities recognized a need for wastewater treatment at least as early as the 1920s, but it wasn't until the 1950s that a large proportion of the region was connected to sewer systems and associated WWTPs. Prior to this time period, sewage for the most part was discharged via cesspools and septic systems. For at least the past five decades, the majority of sewage effluent discharged into Hempstead Bay has originated from the South Shore Water Reclamation Facility at approximately 50 MGD, compared to 5 MGD for the Long Beach WWTP, and smaller discharges from other WWTPs.

<u>Key time periods in the history of wastewater treatment in the study area</u>

- 1951: The Long Beach WWTP was constructed as a secondary treatment facility, meaning that it used procedures that would substantially degrade the biological content of sewage that is largely derived of human waste, food waste, and soaps/detergents. The disinfected effluent was discharged to Reynolds Channel within Hempstead Bay at a rate of 6.4 MGD (Dvirka and Bartilucci, 2009). Recent discharge rates are closer to 5 MGD.
- 1952: The South Shore Water Reclamation Facility (originally called the Bay Park sewage treatment facility) was completed in 1952 as a secondary treatment facility with an initial discharge of 8.8 MGD, but today it discharges about 50 MGD.
- 1976: On June 2, two sewage sludge storage tanks on Pearsalls Hassock exploded as a consequence of unauthorized personnel playing with fireworks near the tanks, leading to the release of one million gallons of sewage sludge into East Rockaway Channel. Nassau County dredged the area around the tanks over the next month to remove much of the sludge along with enormous quantities of sand and mud.
- 1984: Annual daily averaged discharge from the South Shore Water Reclamation Facility reached a peak flow of 69.6 MGD. It then declined considerably, averaging ~55 MGD from 1989-2010.

- 2019-2021: Biological Nutrient Removal (BNR) is in being implemented at the South Shore Water Reclamation Facility, which should reduce the nitrogen loads released in sewage effluent.
- Future: Relocation of the Bay Park effluent outfall from Hempstead Bay to the ocean via the Cedar Creek WWTP, which will remove the largest point source of nitrogen pollution from Hempstead Bay.

CHANGES IN WATER QUALITY OVER TIME

Nitrate (NO_3^-)

Nitrate is a nutrient for plants and is necessary for supporting marine life. However, high concentrations can cause excessive unconsumed growth of algae and other aquatic vegetation. This growth can lead to accelerated eutrophication and loss of dissolved oxygen in the water column and surface sediments.

Concentrations of nitrate in Hempstead Bay rose considerably across all seasons in the late 1970s, peaked in the early 1980s, and then generally fell over time (Figure 9). Looking at median annual nitrate concentrations beginning in the 1980s, we see a clear downward linear trend (R^2 = 0.61, Figure 10). This pattern appears to demonstrate improvements (i.e. decreases) in nitrate loading over time, but the end of our time series (2017) contains a sudden increase in nitrate concentrations during the spring of that year, so caution is advised in extrapolating these results to the present day.

The cause of the rise, and then eventual fall, in nitrate concentrations from the 1970s through the present requires further exploration but may be related to changes in WWTP effluent. A report by Swanson et al. (2013) suggests that annual daily averaged discharge from the South Shore Water Reclamation Facility (SSWRF; formerly known as the Bay Park Sewage Treatment Plant) reached a peak flow of 69.6 MGD (million gallons per day) in 1984, and then declined considerably, averaging ~55 MGD from 1989-2010. The timing of peak annual nitrate concentrations at our water sampling stations (1984), and subsequent declines in nitrate concentrations at those sites, correspond with the peak and decline in WWTP effluent volume. We caution that this correlation is not necessarily causation and that the volume of effluent and concentration of nitrogen within that effluent may not be directly proportional over this time period.

Seasonal trends are evident in the data, which indicate higher nitrate levels in the winter months, which is likely due to decreased biological uptake during the coldest months of the year (Figures 11 and 12). Large-scale spatial patterns are also evidence. Nitrate concentrations increase as one moves from East Bay towards West Bay (i.e. towards New York City, Figure 11).

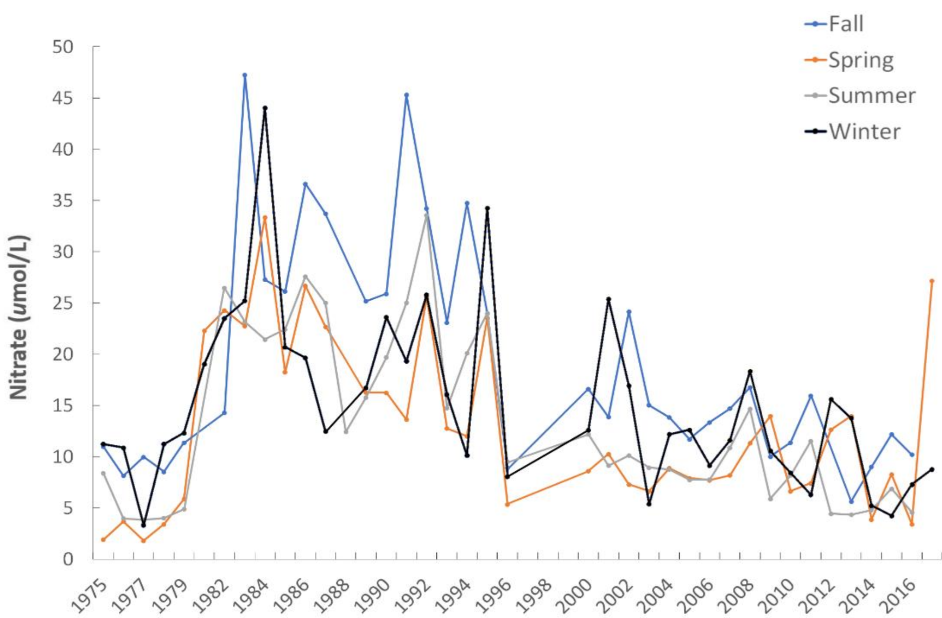

Figure 9. Median nitrate concentrations by season from 1975 – 2017 (µmoles/L).

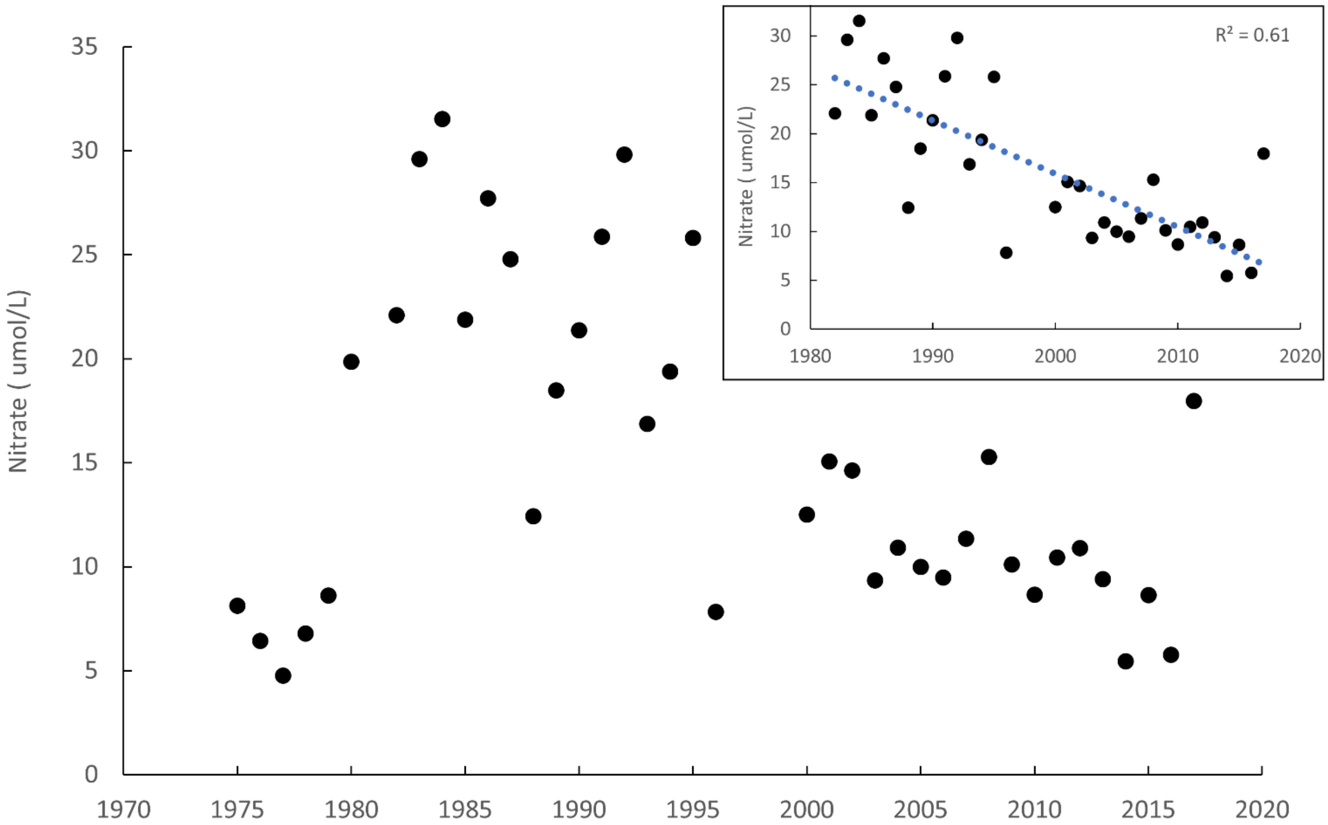

Figure 10. Median annual nitrate concentrations by year from 1975 – 2017. The inset graph highlights the declining trend in median annual nitrate concentrations from 1984 to 2017.

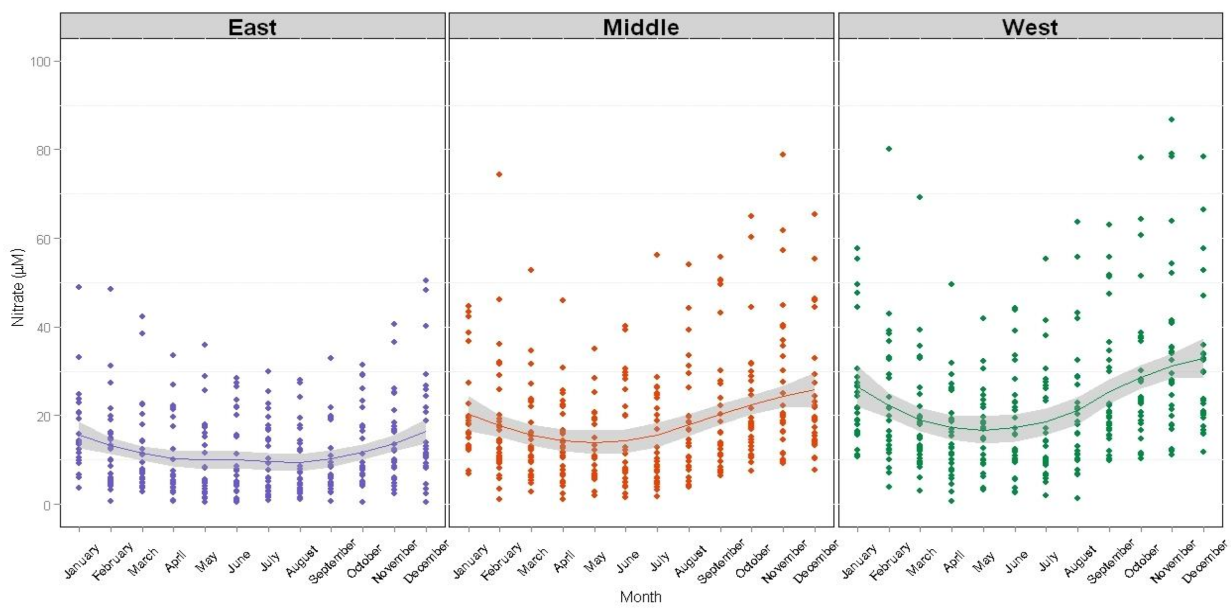

Figure 11. Monthly nitrate concentrations, 1975-2011, for East, Middle and West bay, with LOESS curves and 95% confidence regions.

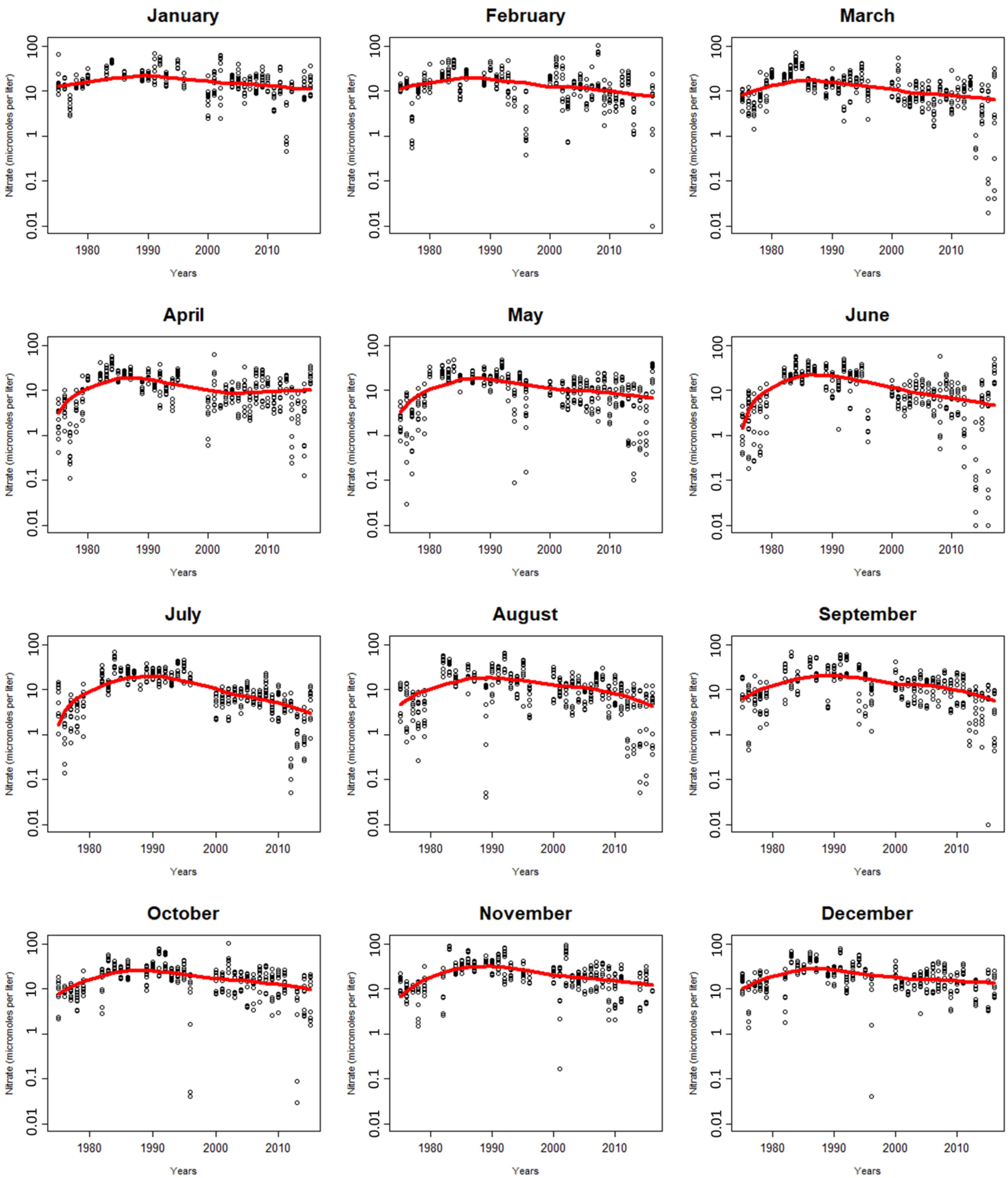

Figure 12. Annual trends in measured nitrate concentrations in Hempstead Bay reported for each month of the year.

Ammonia (NH_3)

Ammonia is a simple inorganic nitrogen compound that is typically excreted by marine invertebrates and fishes. It is also the main form of nitrogen produced by anthropogenic sources like treated wastewater and inexpensive artificial fertilizers. Ammonia is readily utilized by many forms of algae, is absorbed directly by the leaves of saltmarsh cordgrass (*Spartina alterniflora*), and converted to nitrite by bacteria. Because it is readily utilized, ammonia normally does not last long (has a short half-life) in oxic conditions. However, ammonia can also be toxic to fish and aquatic organisms, even in low concentrations.

There was no evidence of a consistent trend in ammonia concentrations over time at the seasonal (Figures 13 and 15) or annual level (Figure 14 and Figure 16). Overall concentrations of ammonia increased predictably from East Bay moving towards West Bay (Figure 15).

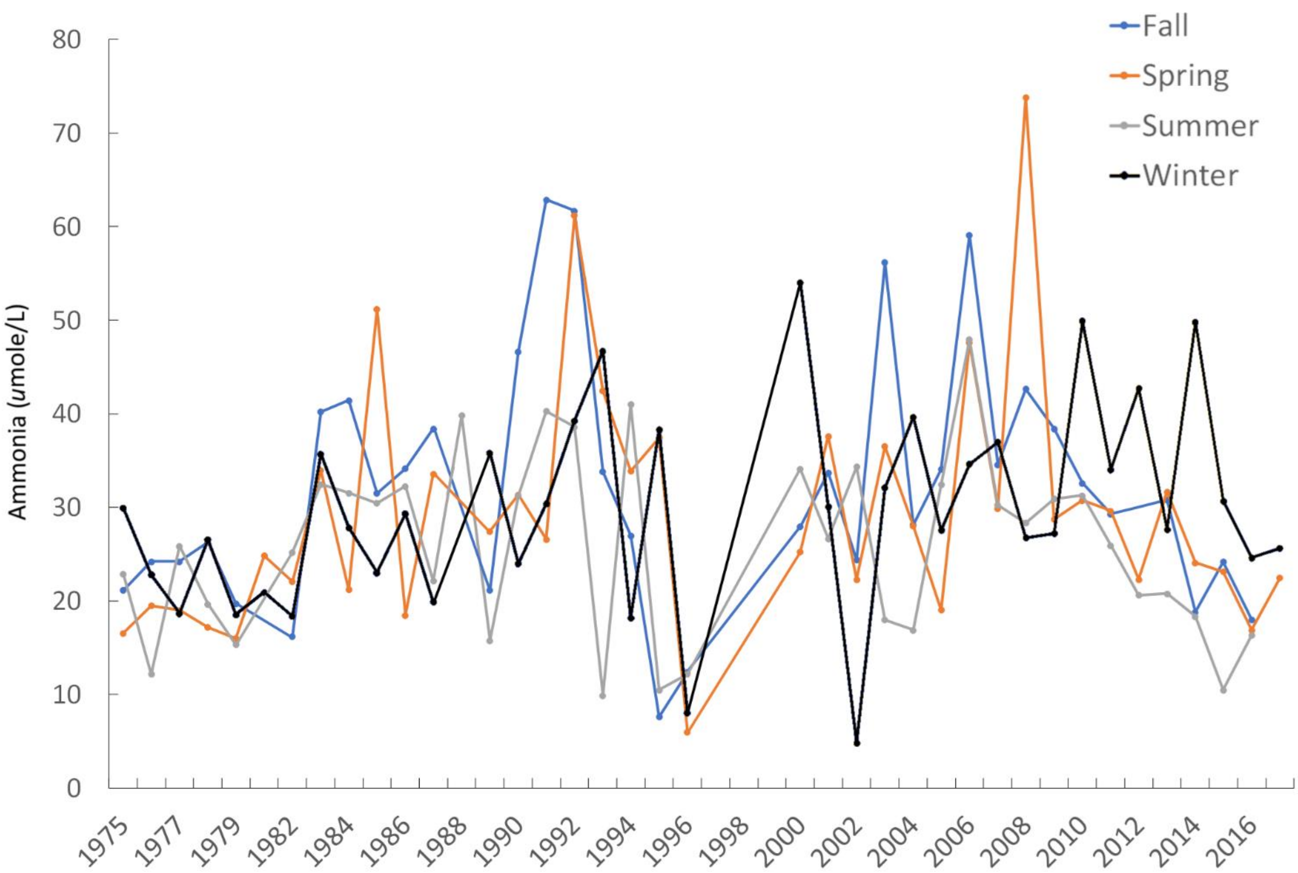

Figure 13. Median ammonia concentrations by season from 1975 – 2017.

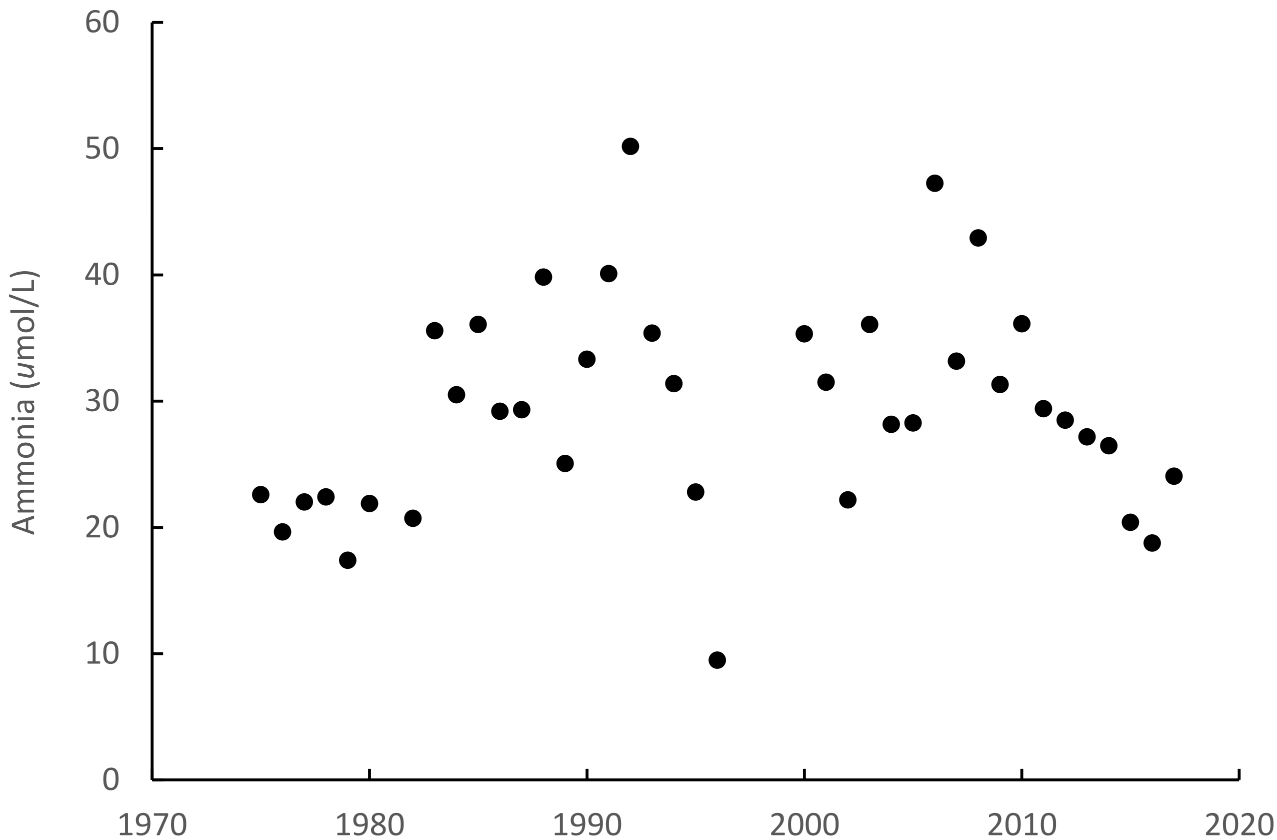

Figure 14. Median annual ammonia concentrations by year from 1975 – 2017.

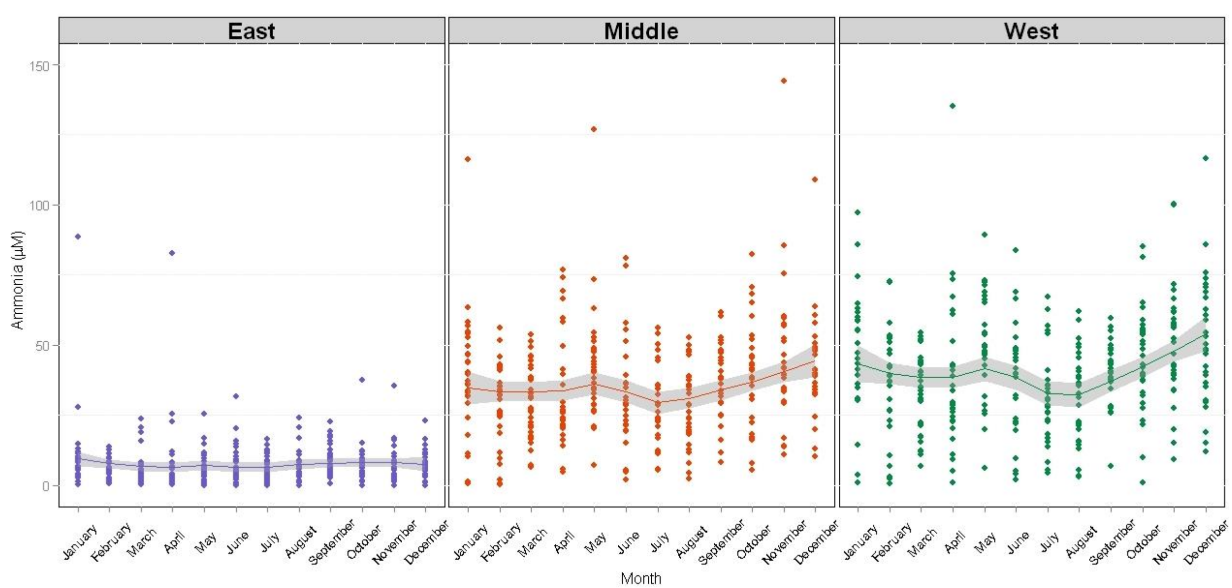

Figure 15. Monthly ammonia concentrations for East, Middle and West Bay from 1975-2011, with LOESS curves and 95% confidence regions.

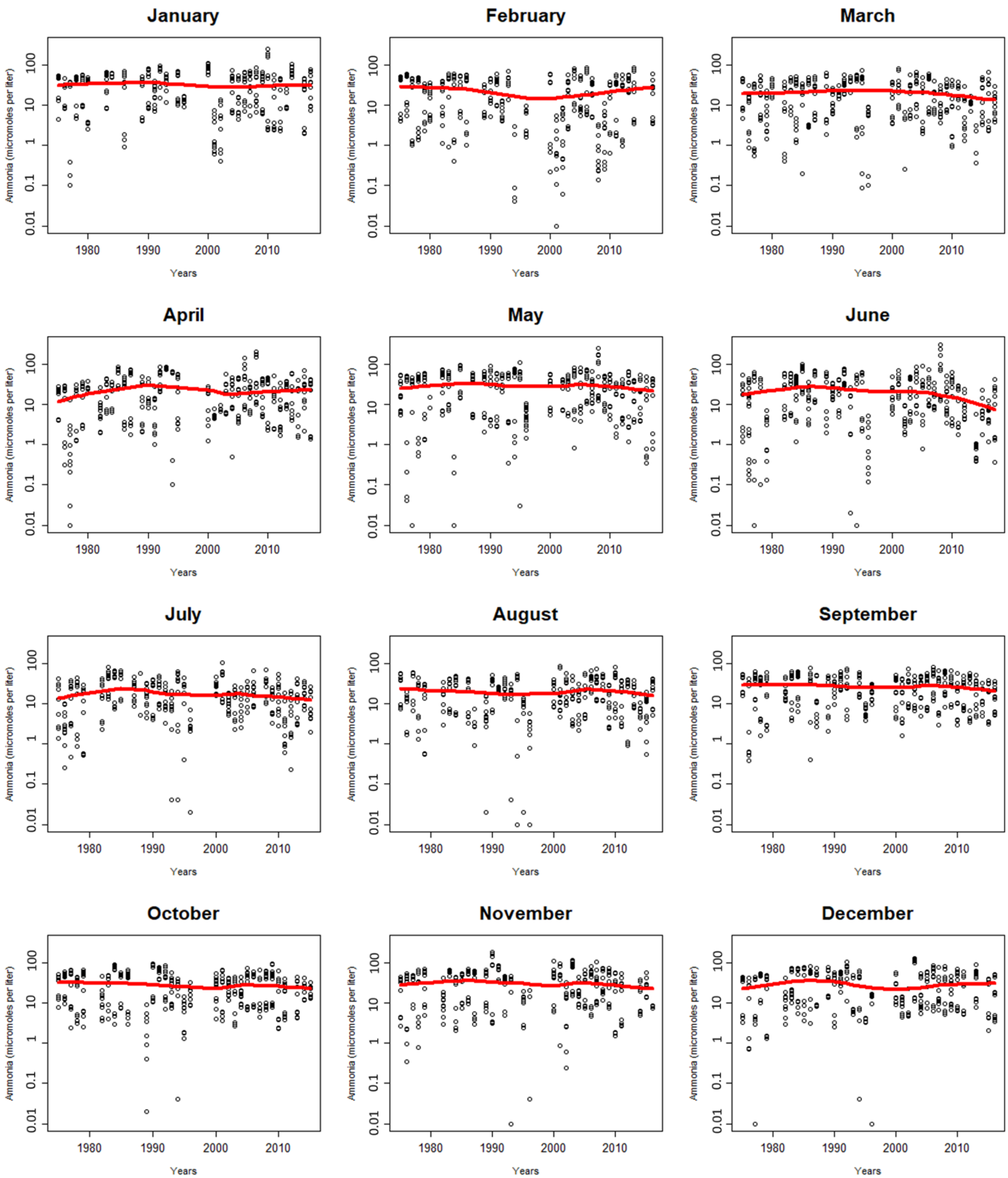

Figure 16. Annual trends in measured ammonia concentrations in Hempstead Bay reported for each month of the year.

Nitrite (NO_2^-)

Nitrite (NO_2^-) is formed when bacteria oxidize ammonia. Although it is less toxic than ammonia, elevated levels of nitrite are still a threat to aquatic life, especially fishes. In open waters, nitrite is usually oxidized to nitrate in a short time.

Overall, there was a positive (i.e. rising) trend in nitrite concentrations over time on an annual basis (R^2 = 0.62, Figures 17 and 18). Median concentrations in the spring of 2001 were anomalously high (Figure 17). The cause should be further investigated. Seasonal patterns are evident with peaks in nitrite concentration occurring in late summer within Middle Bay and West Bay. The expected pattern of increasing nitrite as one travels from east to west also holds for this component of the nitrogen budget and likely reflects greater sources of nitrogen enrichment in areas closer to both New York City and major point sources of effluent from WWTPs.

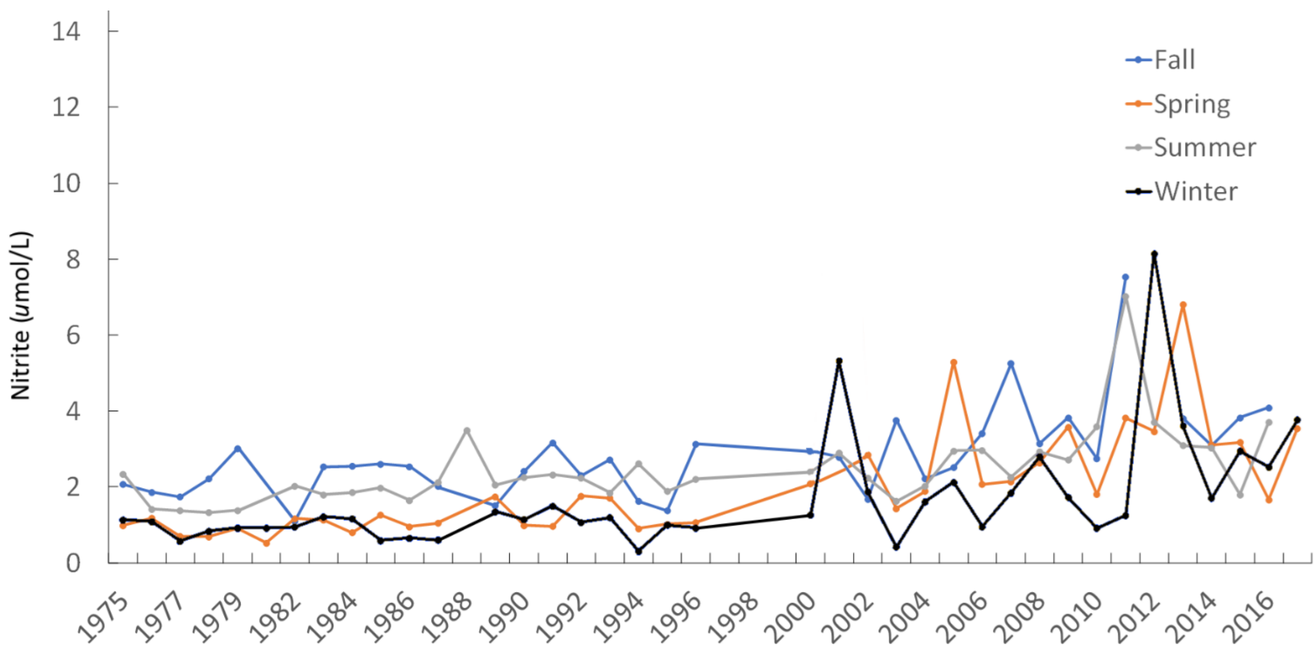

Figure 17. Median annual nitrite concentrations from 1975 – 2017 in Hempstead Bay by season.

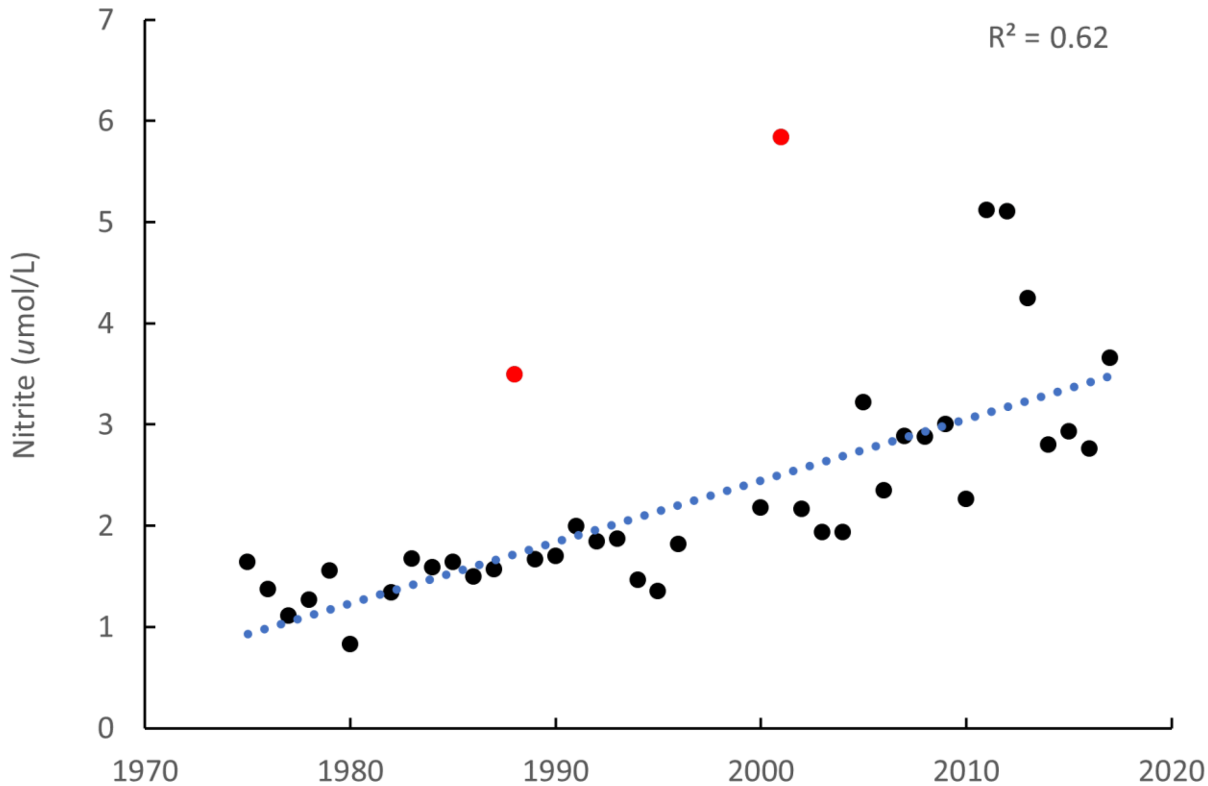

Figure 18. Median annual nitrite concentrations from 1975 – 2017. Red points represent outliers that were not included in the best-fit regression line displayed on the chart.

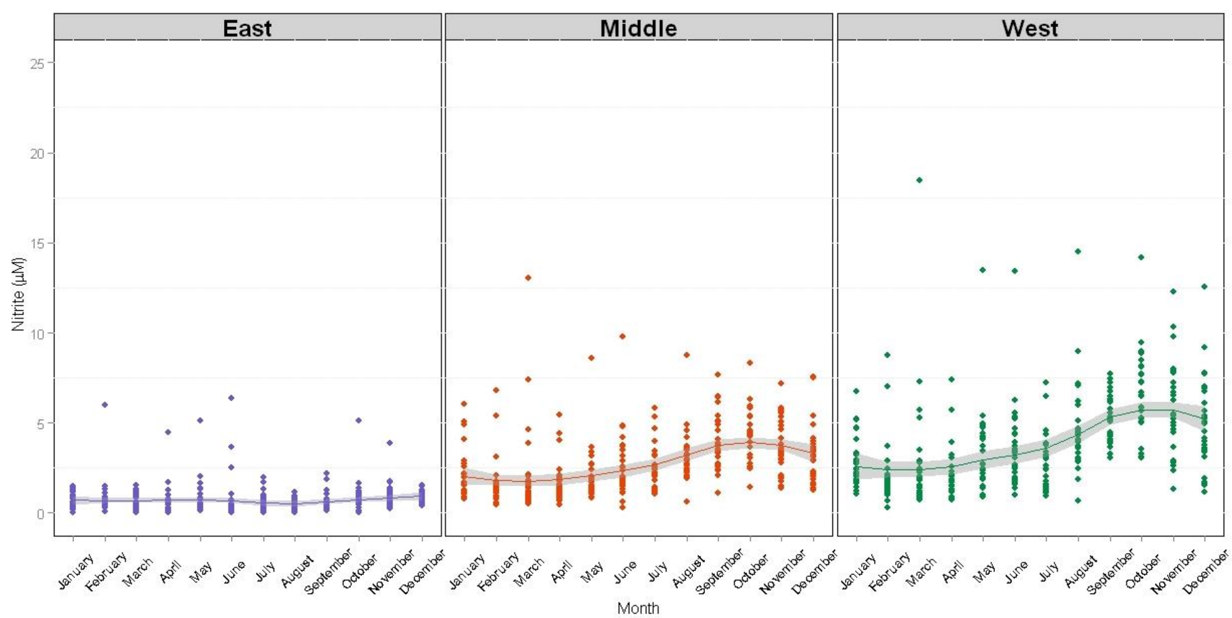

Figure 19. Monthly nitrite concentrations for East, Middle and West Bay from 1975-2011, with LOESS curves and 95% confidence regions.

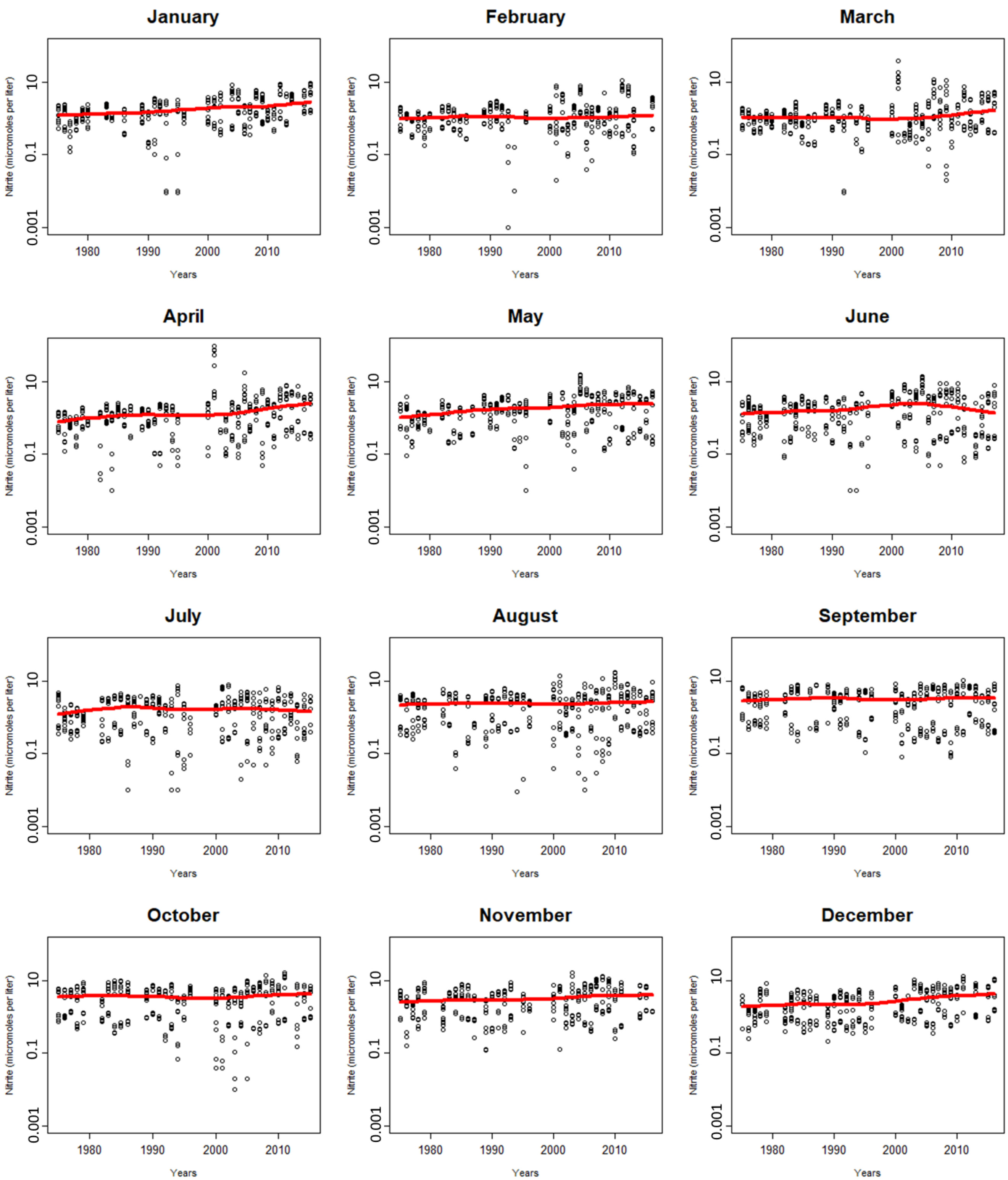

Figure 20. Annual trends in measured nitrite concentrations in Hempstead Bay reported for each month of the year.

Orthophosphate (PO_4^{3-})

Orthophosphate is the dissolved inorganic form of phosphate found in aquatic systems. Phosphorous is often a limiting nutrient for growth. Most phosphate is incorporated into rock, organic compounds or bound in plant and animal tissues. Orthophosphate values indicate the portion of phosphate that is available to plants and then animals. Phosphate becomes insoluble and is lost to sediments in ecosystems with very low productivity.

Between 1975 and 2017 phosphate values were relatively steady, with the exception of high median values in 1987 and 1988. While one could interpret the pattern from 1993 to 2017 as linear decline (R^2 = 0.36, Figure 22), the long-term trend over the entire time series is generally flat, even when the outlier years of 1987 and 1988 are removed from consideration. Orthophosphate levels in East Bay showed little seasonal variation while values in Middle and West bay showed seasonal variation with levels highest between June and September (Fig 23). Orthophosphate levels were lowest in East Bay and highest in West Bay.

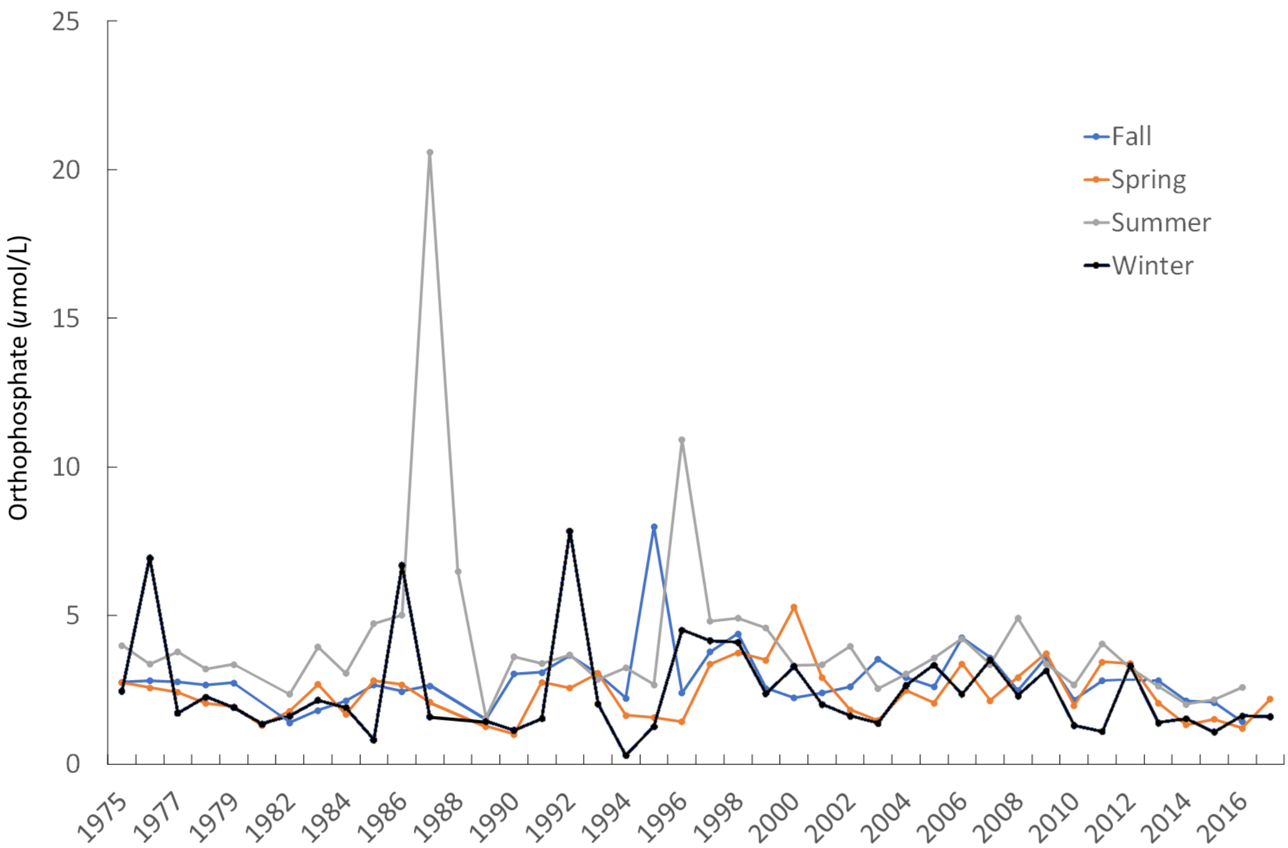

Figure 21. Median annual orthophosphate concentrations over time in Hempstead Bay by season from 1975 – 2017.

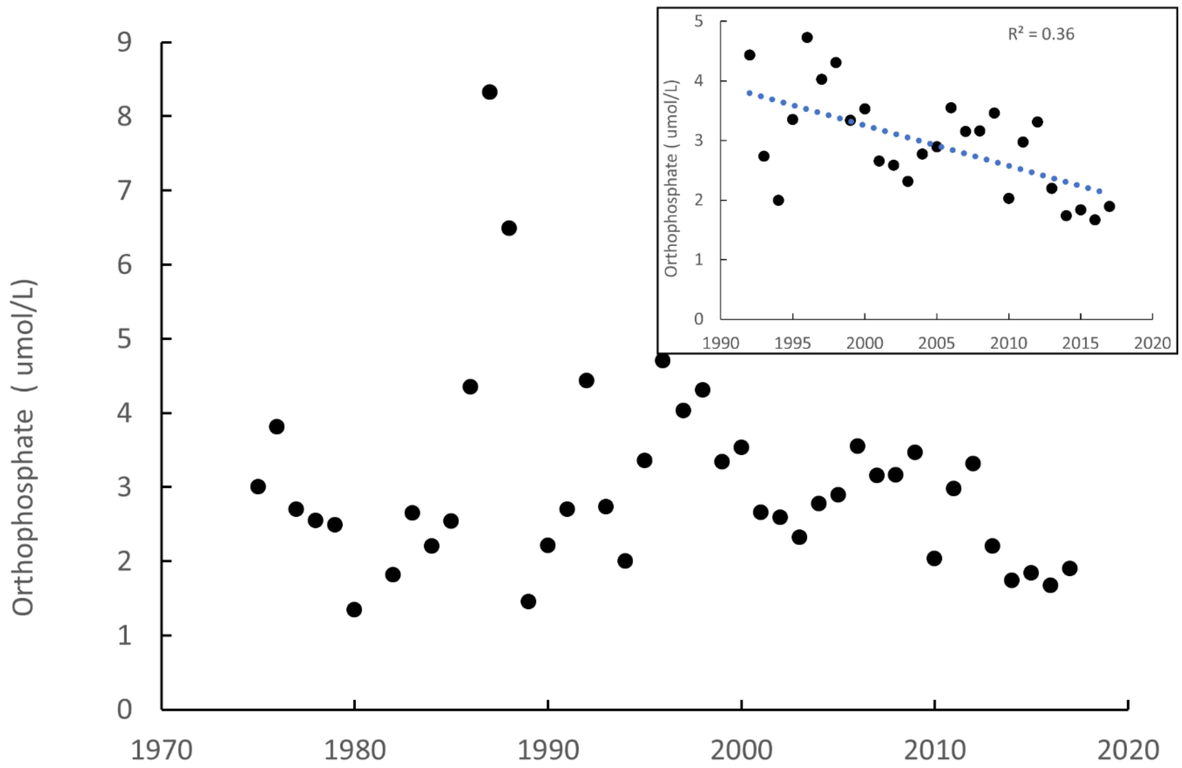

Figure 22. Median annual orthophosphate concentrations over time by year. The inset displays the trend from 1993 to 2017.

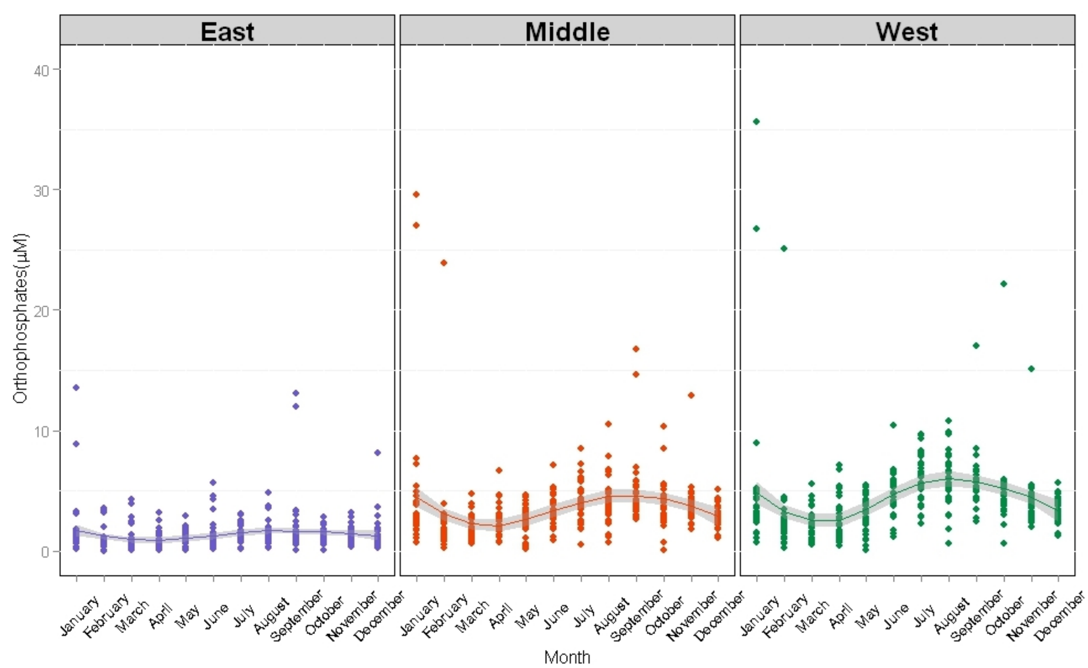

Figure 23. Monthly orthophosphate concentrations for East, Middle and West Bay from 1975-2011, with LOESS curves and 95% confidence regions.

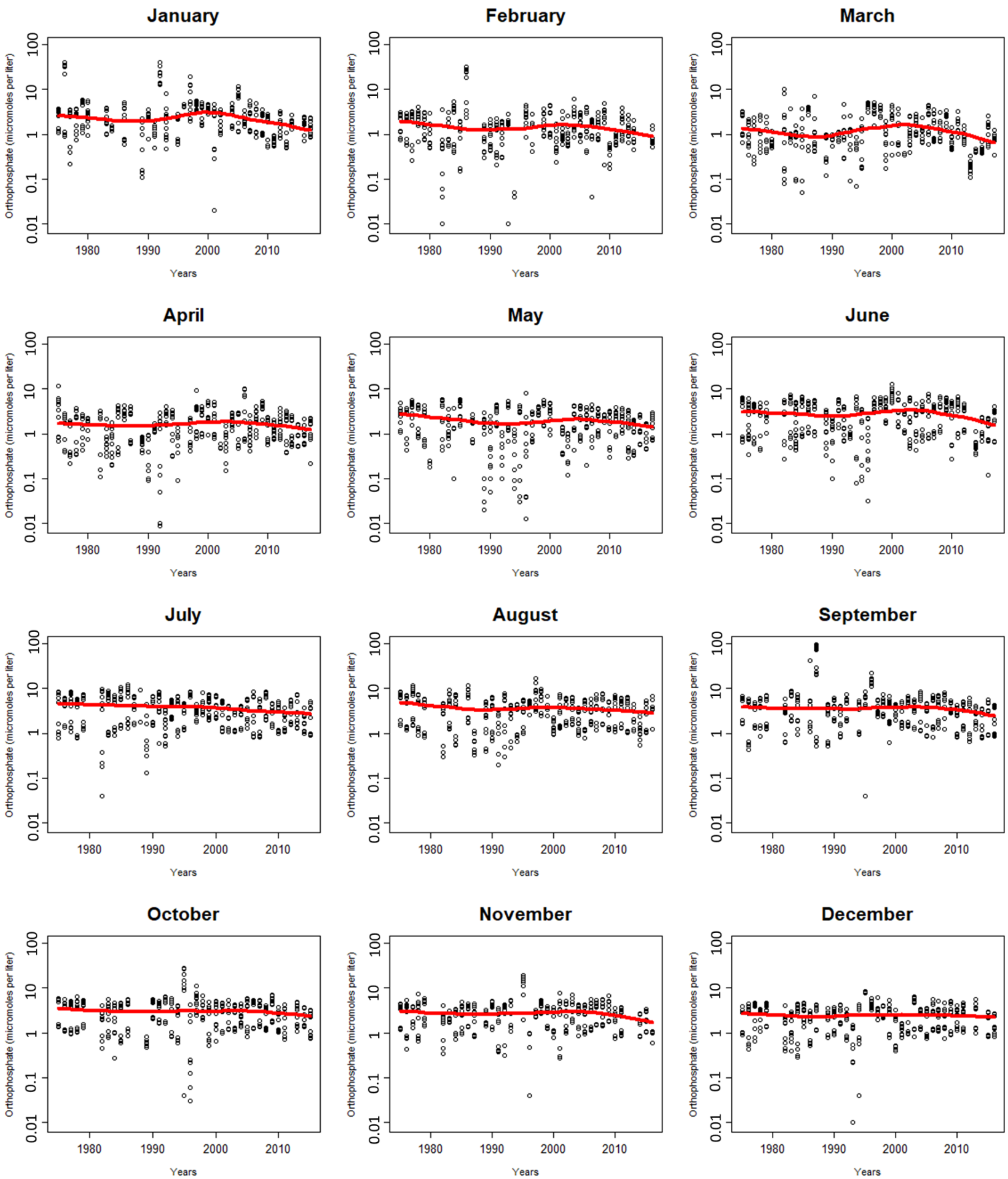

Figure 24. Annual trends in measured orthophosphate concentrations in Hempstead Bay reported for each month of the year.

Particulate Organic Matter

Particulate organic matter is material of plant or animal origin that is suspended in water. Particulate organic matter is an important food resource for many filter feeding organisms, but very high concentrations indicate potential water pollution problems, such as excessive erosion and transport of sediments or soil due to runoff and/or disturbance.

Particulate values significantly declined throughout the bay from 1975-2001 (R^2 = 0.74, Figures 25 and 26). Spatially, East Bay had lower particulate values than the West Bay though the difference was most prominent in the final years (1989-2001) of collection. From 1975-1988, particulate values at Station 4 near the South Shore Water Reclamation Facility outfall were considerably higher than the rest of the bay. Although values at Station 4 were still high in 1989-2001, the readings were lower as were the readings at all stations. Particulate values in the West Bay showed a slight seasonal trend with the highest readings occurring between March and June, possibly reflecting phytoplankton productivity (Figure 27).

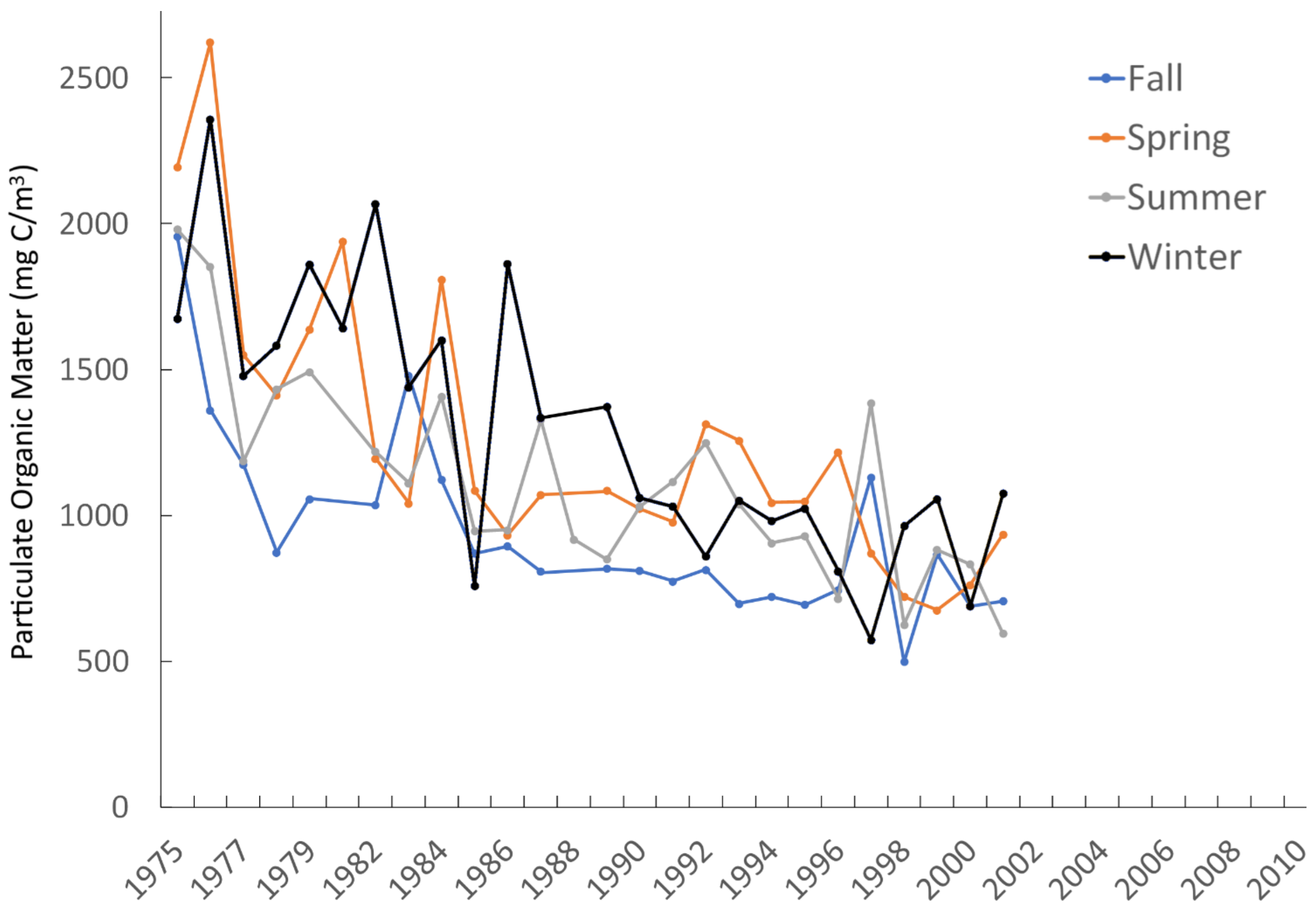

Figure 25. Median annual particulate organic matter concentrations over time in Hempstead Bay by season from 1975-2002.

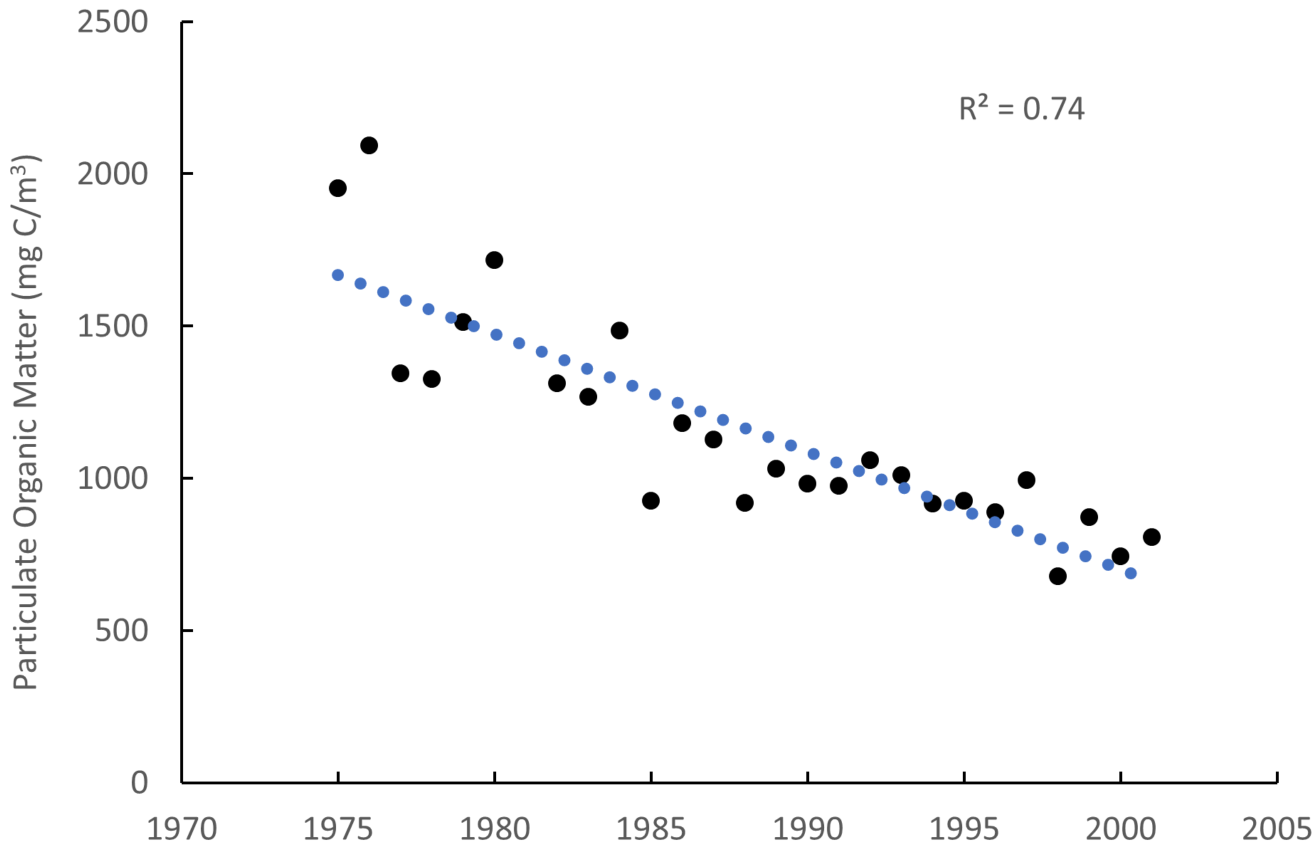

Figure 26. Median annual particulate organic matter concentrations over time by year.

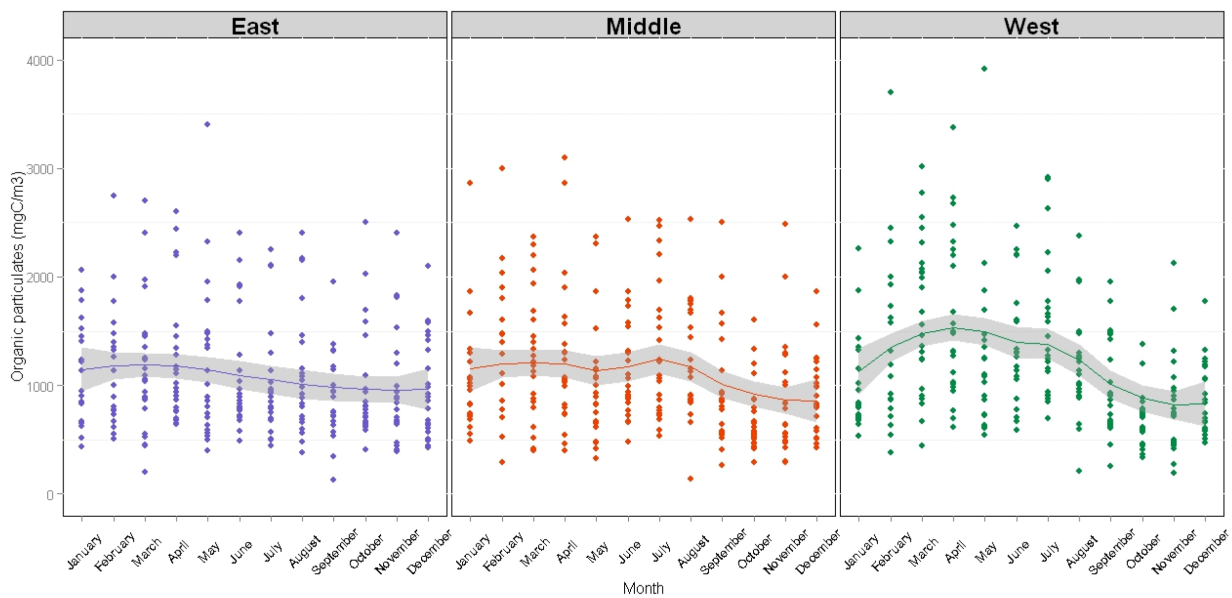

Figure 27. Monthly particulate organic matter concentrations for East, Middle and West Bay from 1975-2011, with LOESS curves and 95% confidence regions.

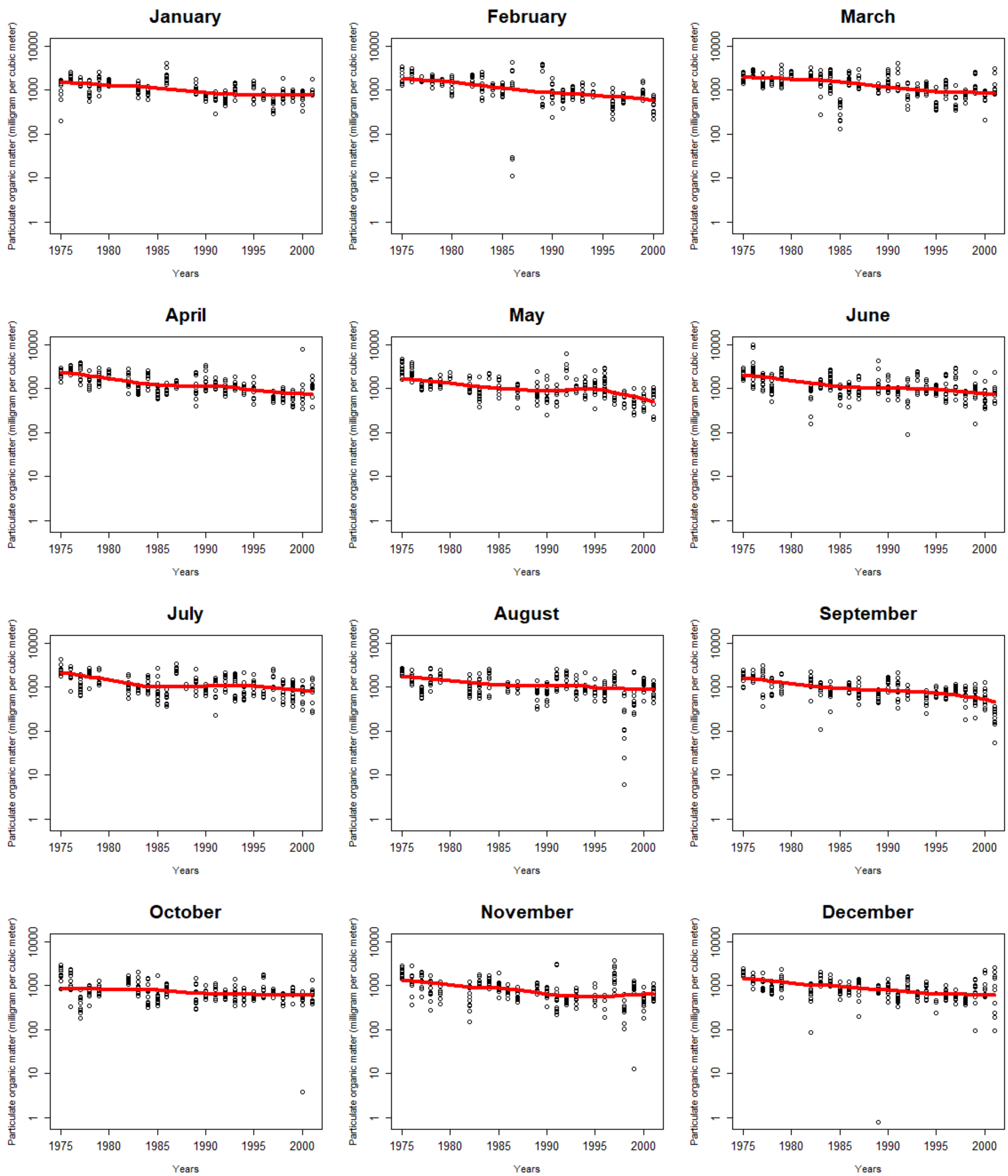

Figure 28. Annual trends in measured particulate organic matter concentrations in Hempstead Bay reported for each month of the year.

<u>Chlorophyll *a*</u>

Chlorophyll *a* is the primary green pigment that allows plants to capture energy from sunlight and produce organic compounds. It is the predominant type of chlorophyll found in algae. High levels of chlorophyll *a* indicate nutrient loading because excess nutrients fuel the growth of algae. Areas with lower algal levels have clearer water and fewer harmful blooms, but insufficient levels (or the wrong species) of phytoplankton can negatively impact filter feeding species and other herbivores. Ideal levels of chlorophyll 'a' indicate that there is enough algae to fuel the food web, but not so much that hypoxic conditions will develop.

There was no consistent trend towards either increasing or decreasing in Chlorophyll *a* measurements across the study period (Figures 29 and 30). Seasonally, Middle and West Bay Chlorophyll *a* values typically increased with warmer temperatures in early spring and then again in June and July (Fig. 31). Interannual examination of this seasonal trend throughout the years showed that the timing and magnitude of the chlorophyll 'a' spikes varied greatly (Fig. 29). For instance, in 2011, Chlorophyll *a* values peaked earlier in the year, while the peak occurred around July or August in many other years. Warmer spring and winter temperatures may have caused shifts in the timing of when chlorophyll values were the highest.

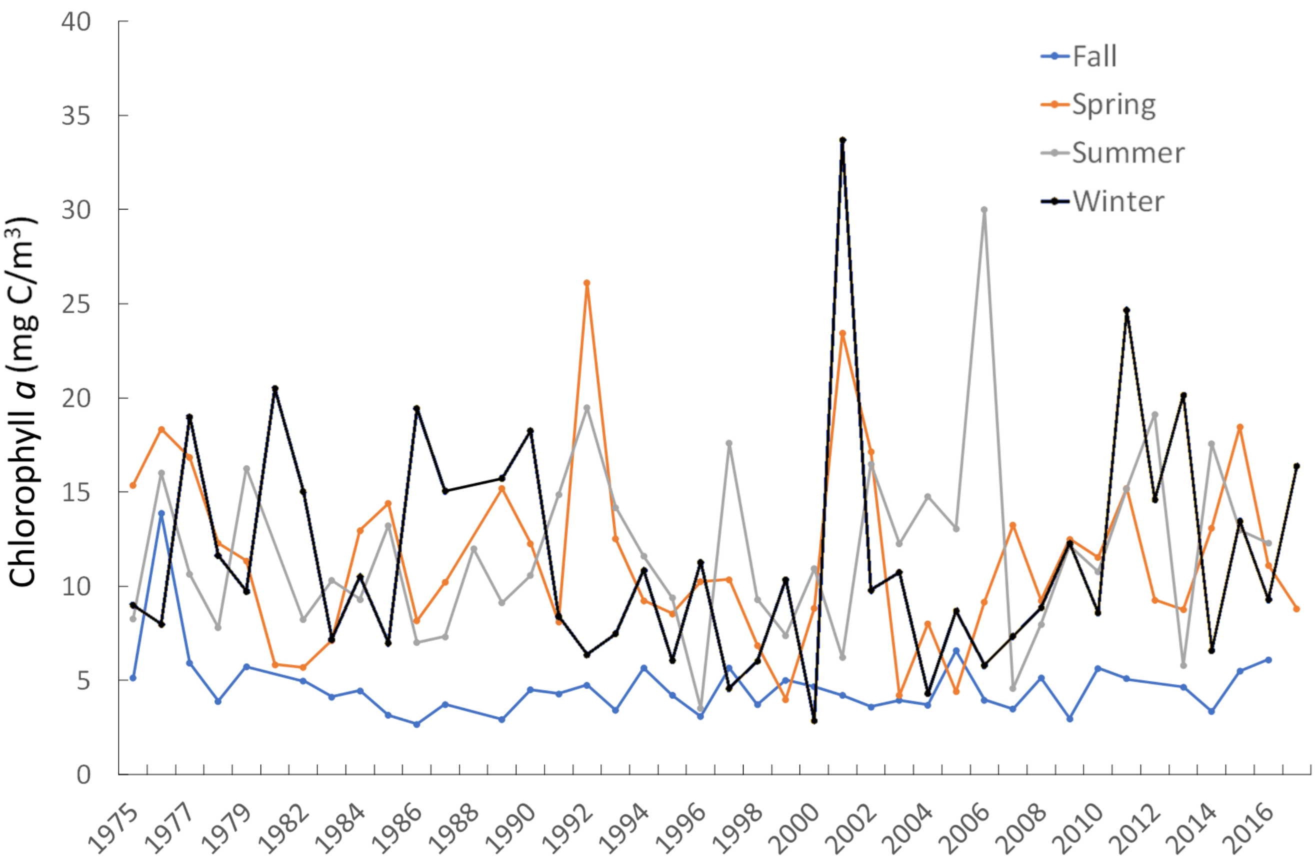

Figure 29. Median annual chlorophyll *a* concentration over time in Hempstead Bay by season from 1975-2017.

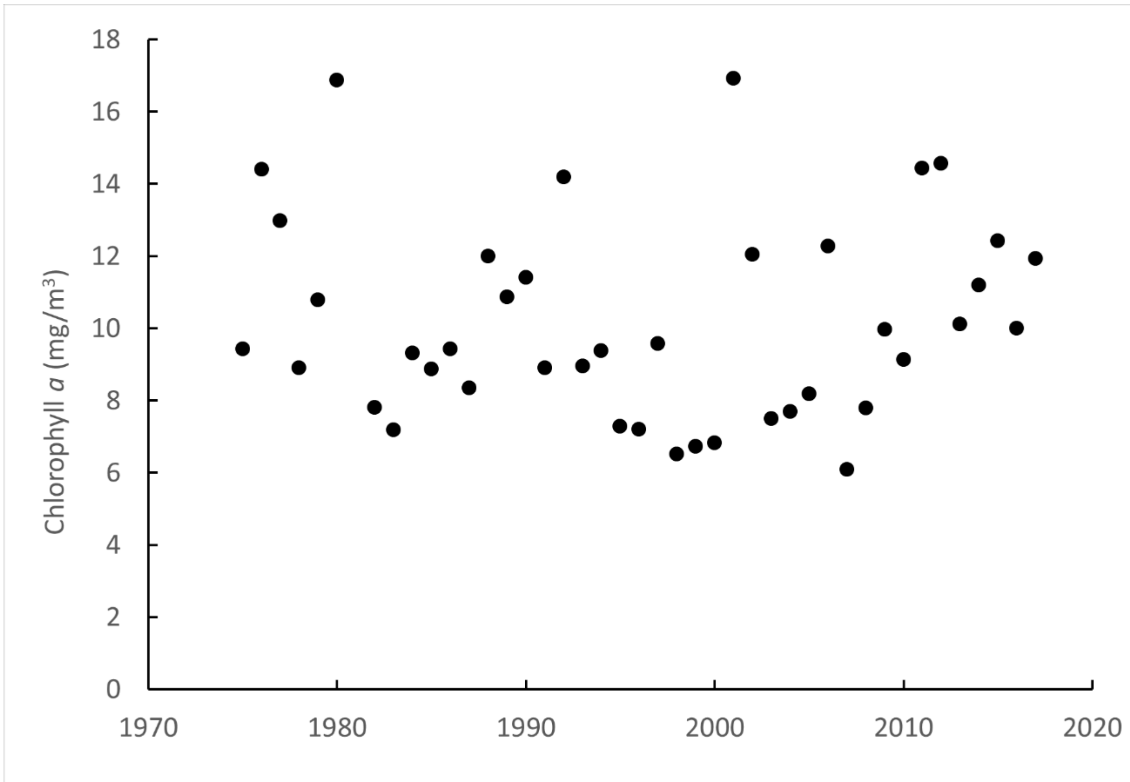

Figure 30. Median annual chlorophyll *a* concentration over time by year from 1975-2017.

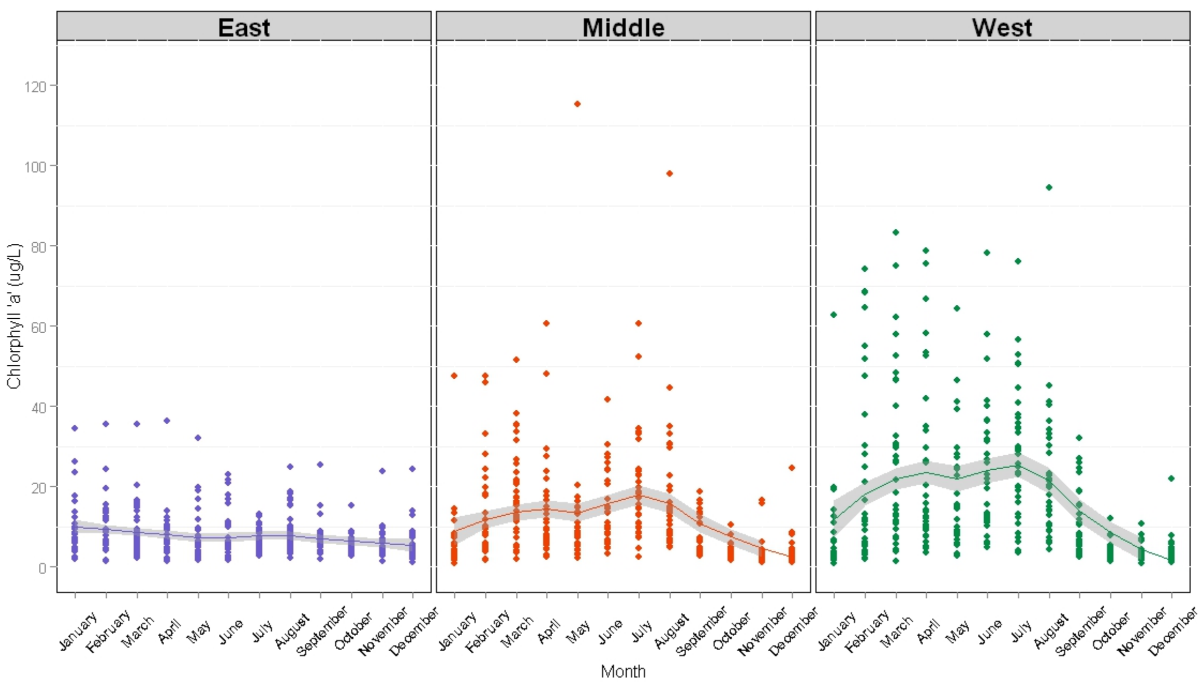

Figure 31. Chlorophyll *a* LOESS curves for each year and plotted separately for East, Middle, and West Bay, 1975-2011.

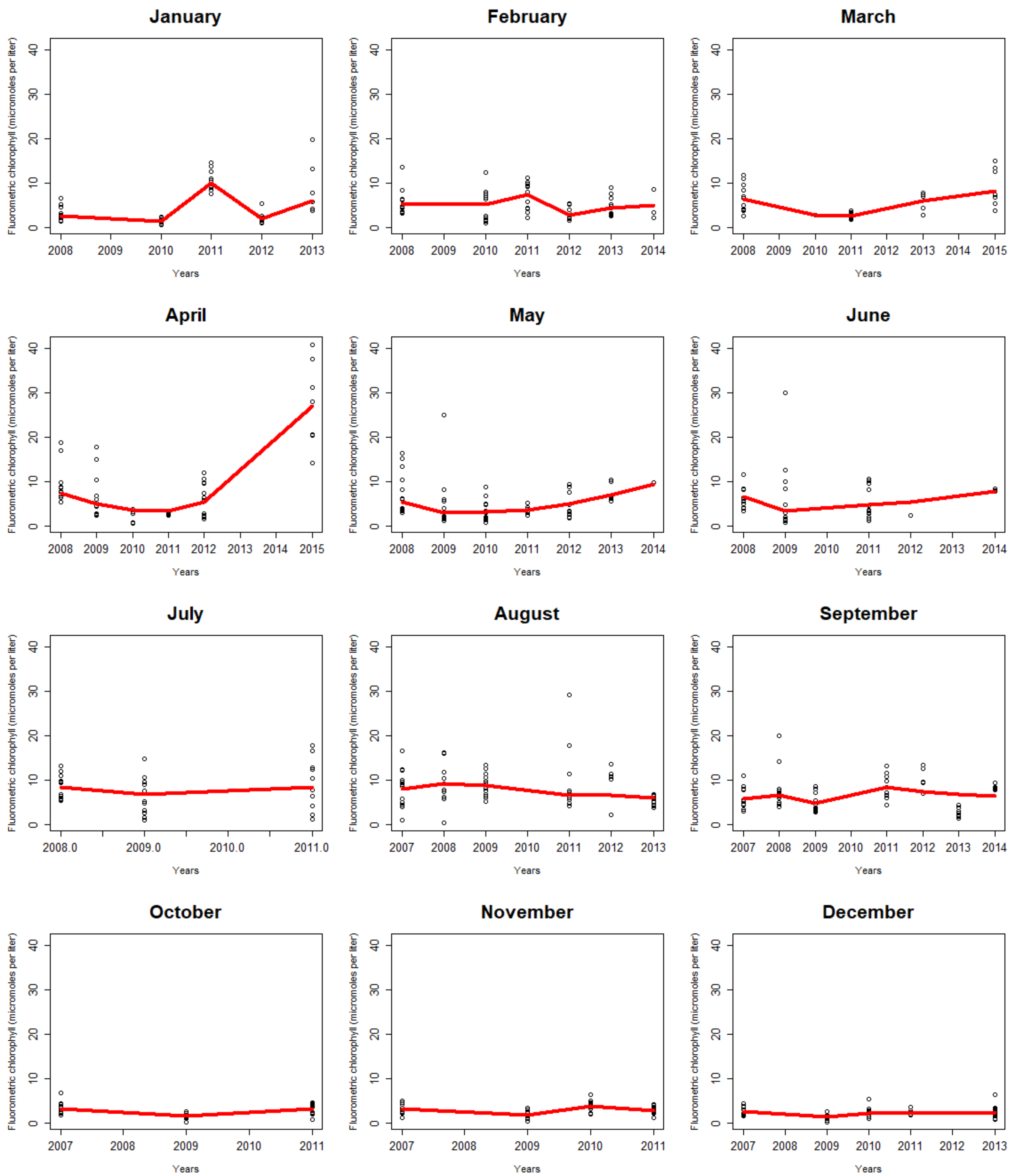

Figure 32. Annual trends in measured chlorophyll *a* concentrations in Hempstead Bay reported for each month of the year.

Dissolved Oxygen

Dissolved oxygen concentration is one of the most universal indicators of overall water quality and is critical for respiration by aquatic life. It is measured in milligrams of oxygen per liter of water (mg/L). Adequate dissolved oxygen is necessary for good water quality. NYS DEC's Technical & Operational Guidance Series documents suggest that daily average oxygen concentrations below 4.8 mg/L indicate a chronic low oxygen condition and that concentrations below 3.0 mg/L for any length of time indicate an acute low oxygen condition within saline surface waters (https://www.dec.ny.gov/docs/water_pdf/togs116.pdf).

There was no consistent annual trend (increasing or decreasing) over the study period (Figures 33 and 34). We observed expected seasonal trends with temperature (Figure 35), given that colder water can hold more dissolved oxygen before reaching saturation than warmer water. The June, July, August, and September months exhibited the lowest dissolved oxygen concentrations in surface waters (1m depth) with concentrations frequently dropping below 4 mg/L, sometimes dropping below 3 mg/L, but typically staying above 2 mg/L.

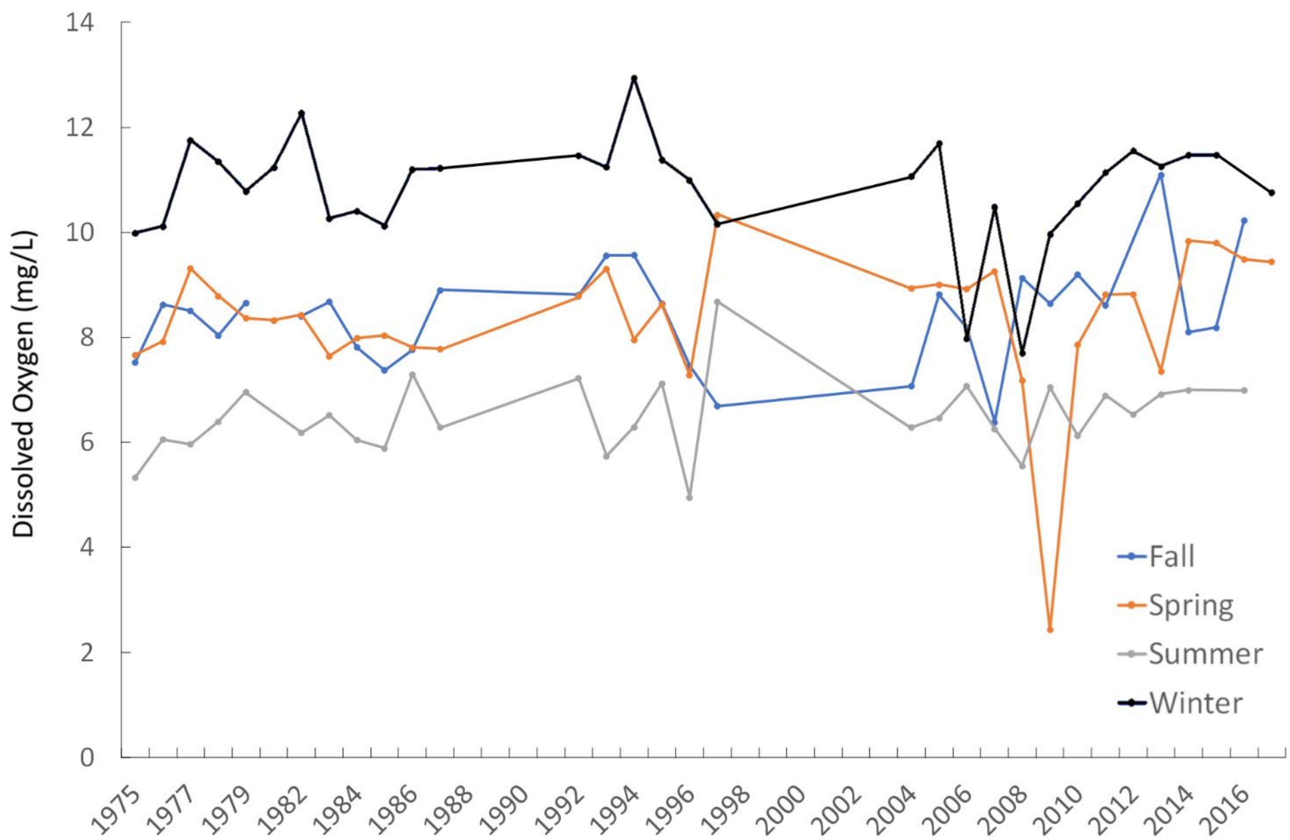

Figure 33. Median annual dissolved oxygen concentrations over time in Hempstead Bay by season from 1975-2017.

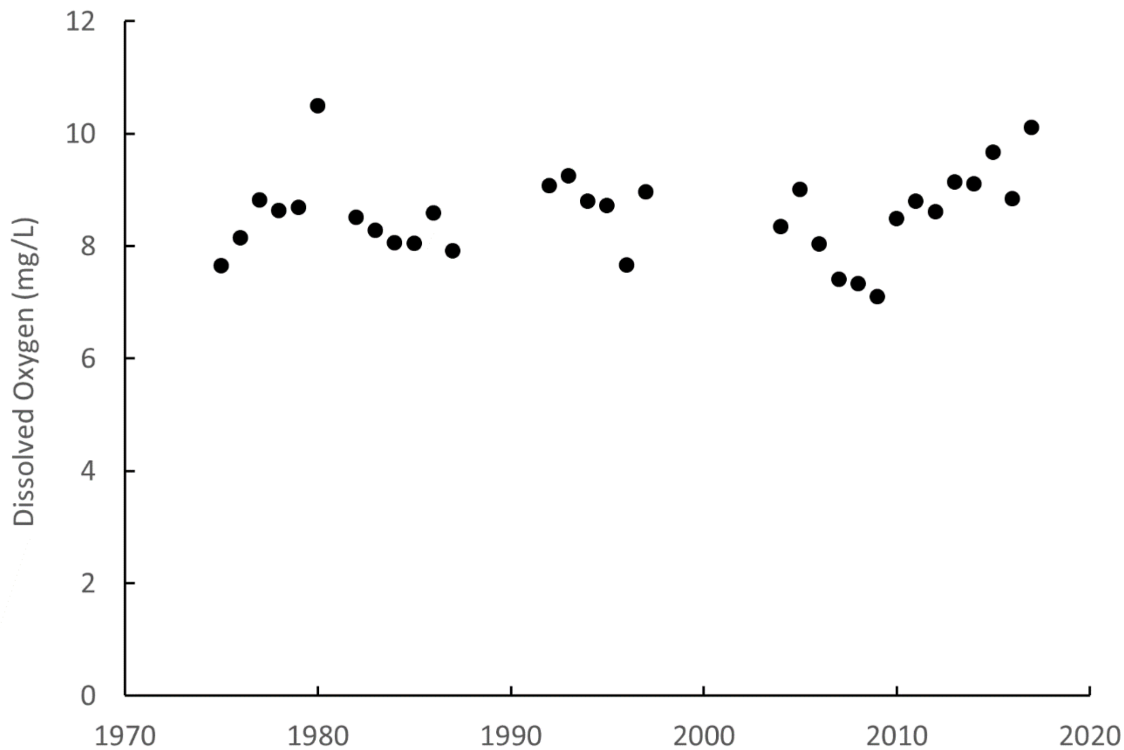

Figure 34. Median annual dissolved oxygen concentrations over time by year from 1975-2017.

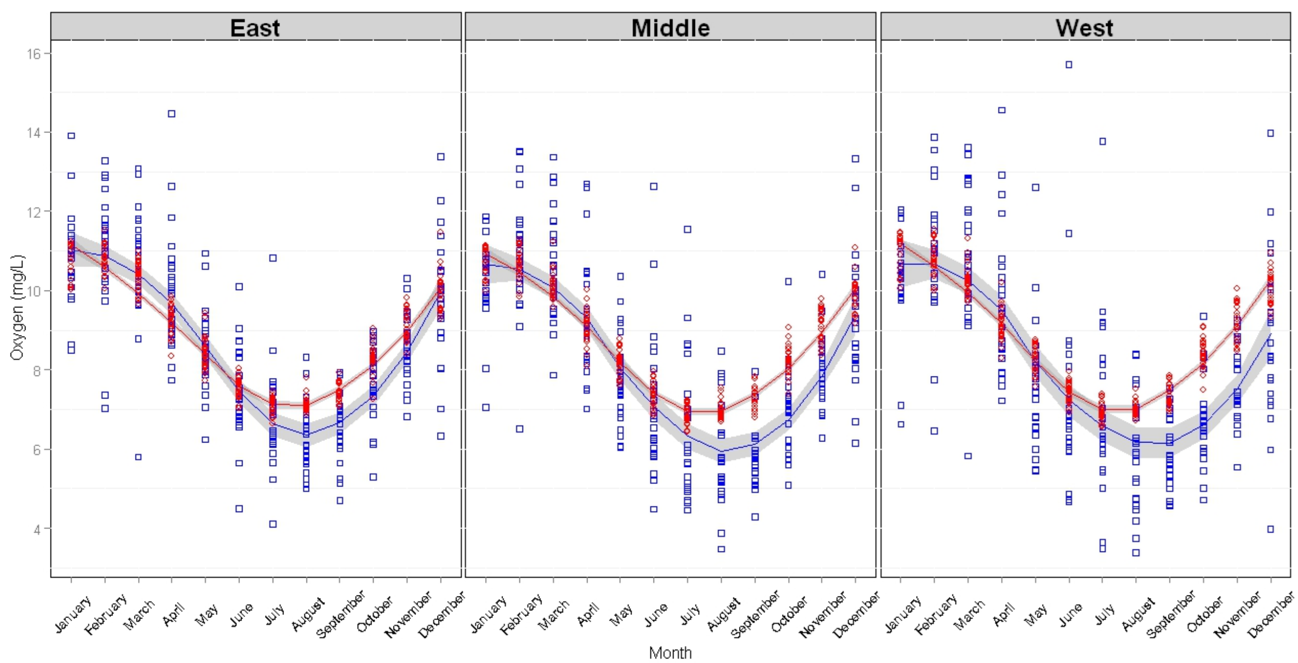

Figure 35. Dissolved oxygen LOESS curves (in blue) for each year and plotted separately for East, Middle, and West Bay, 1975-2011. The red curve, and faint red points, represent the calculated DO saturation point based on salinity and temperatures at a given station.

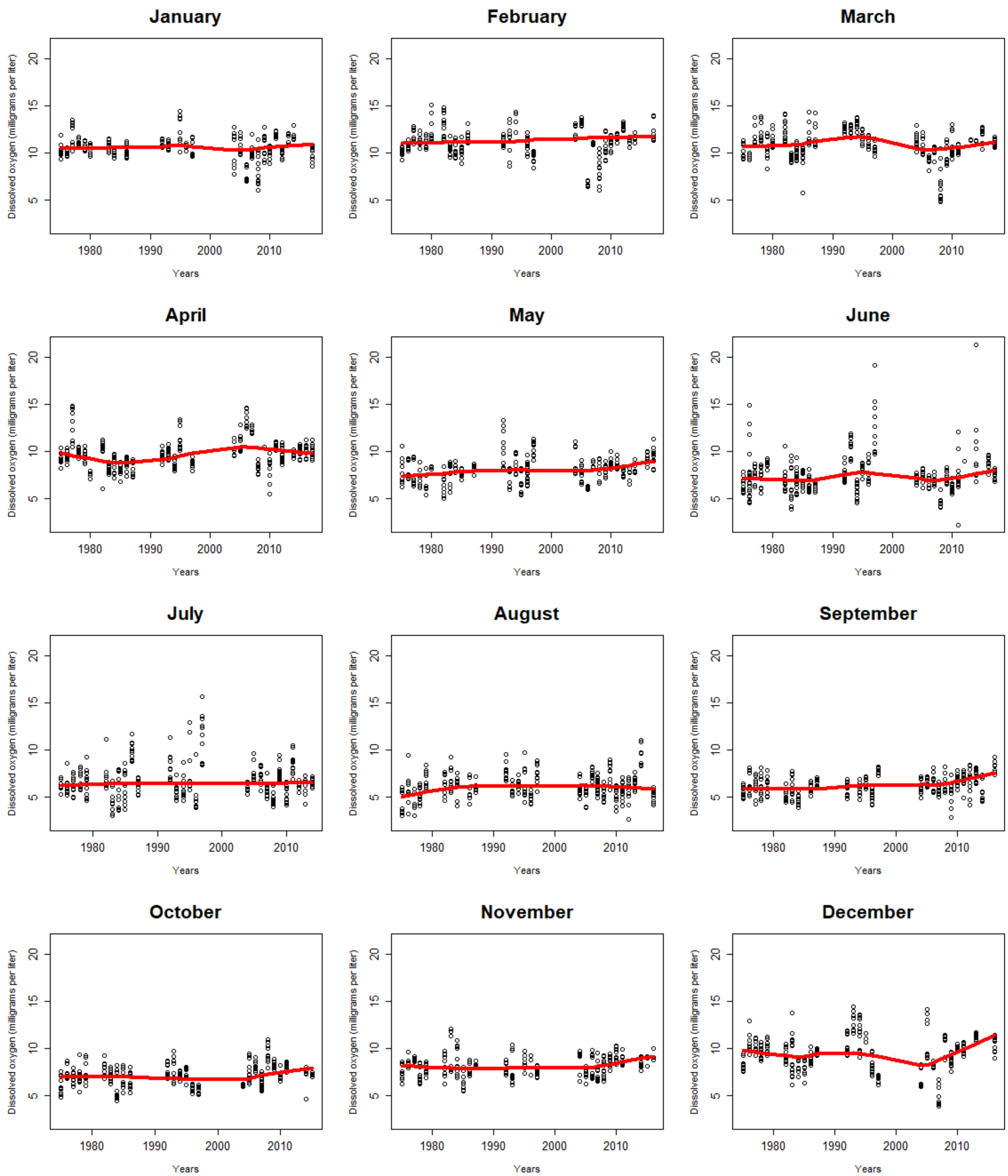

Figure 36. Annual trends in measured dissolved oxygen concentrations in Hempstead Bay reported for each month of the year.

Secchi Depth

The clarity of water is estimated using a Secchi disc. High Secchi depth, associated with clear low productivity water, is typically when the disk is visible to depths of 2 m or more. Low Secchi depth of 1 m or less, is indicative of turbid or light limiting conditions. Low Secchi readings are often associated with degraded waters because transparency decreases as suspended sediments or algal abundance increases. Clear water can indicate a healthy bay, though high Secchi readings are also found in with waters devoid of marine life.

There was no consistent annual trend (increasing or decreasing) over the study period (Figures 37 and 38). We observed weak seasonal trends associated with temperature and chlorophyll *a*, which is a proxy for algal abundance. Secchi values were highest and most stable in the East Bay. Middle and West Bay displayed more obvious seasonal trends in Secchi readings and were coincidental with chlorophyll 'a' fluctuations. Higher chlorophyll 'a' values were paired with lower Secchi readings and vice versa (Fig. 39). Chlorophyll "a" values may be used as a qualifier of Secchi values. Stations 2 and 2A had higher Secchi readings than the upper West Bay stations.

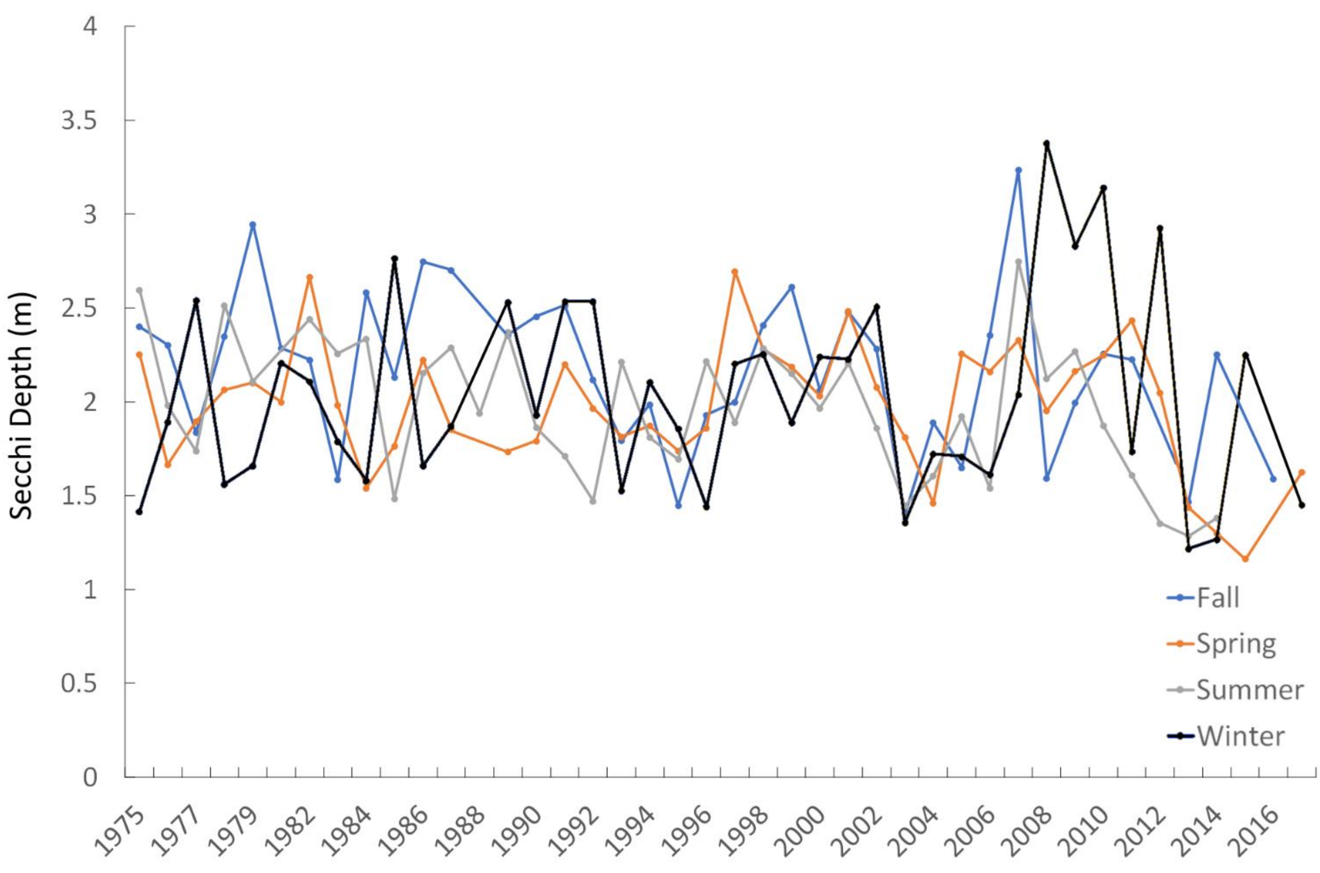

Figure 37. Median annual Secchi depth (m) over time in Hempstead Bay by season from 1975-2017.

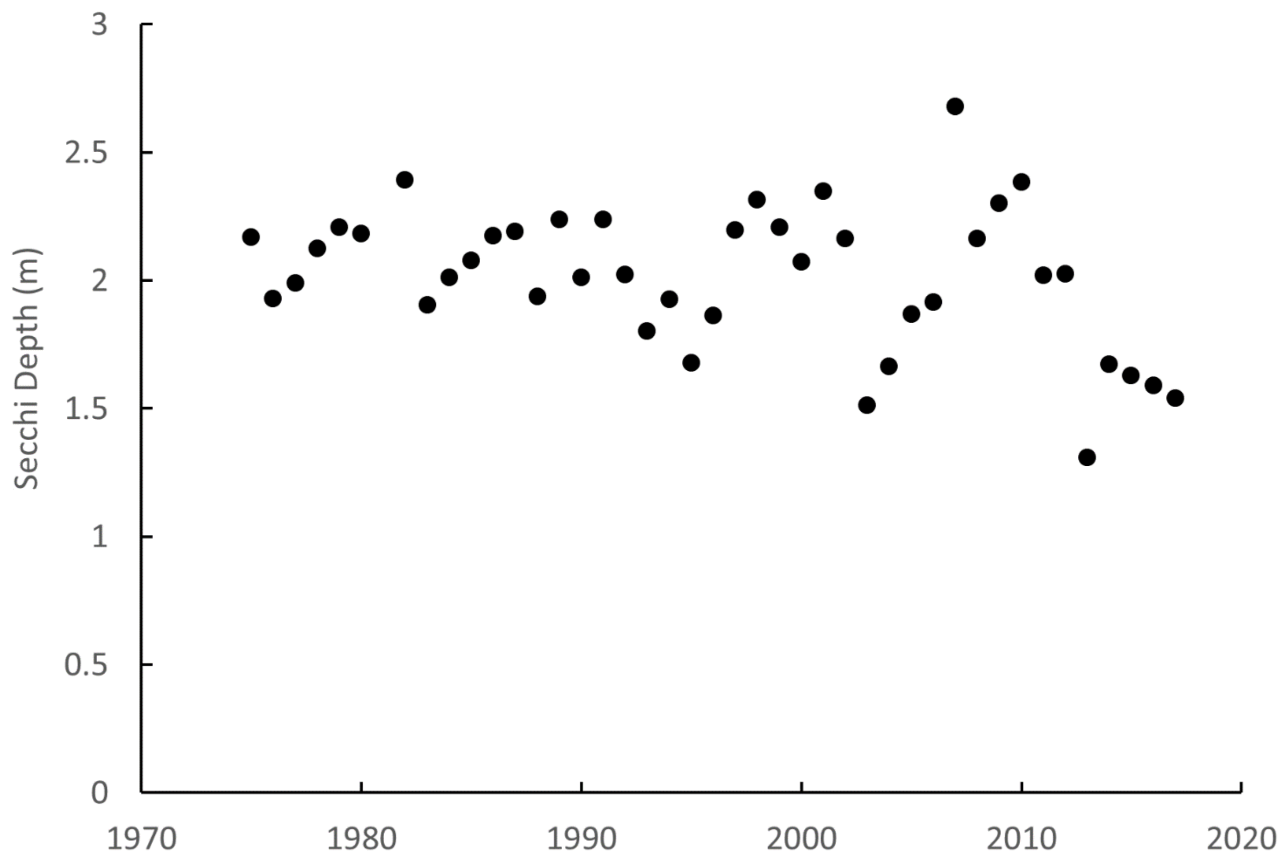

Figure 38. Median annual Secchi depth (m) over time by year from 1975-2017.

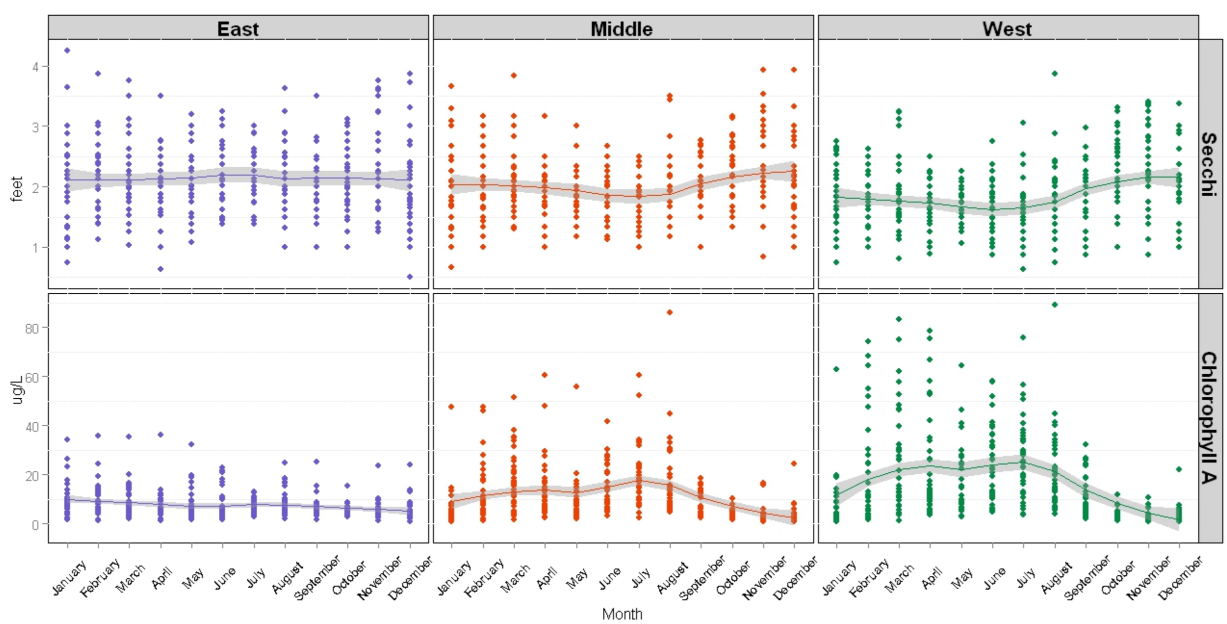

Figure 39. Secchi depth (ft) LOESS curves for each year and plotted separately for East, Middle, and West Bay, 1975-2011.

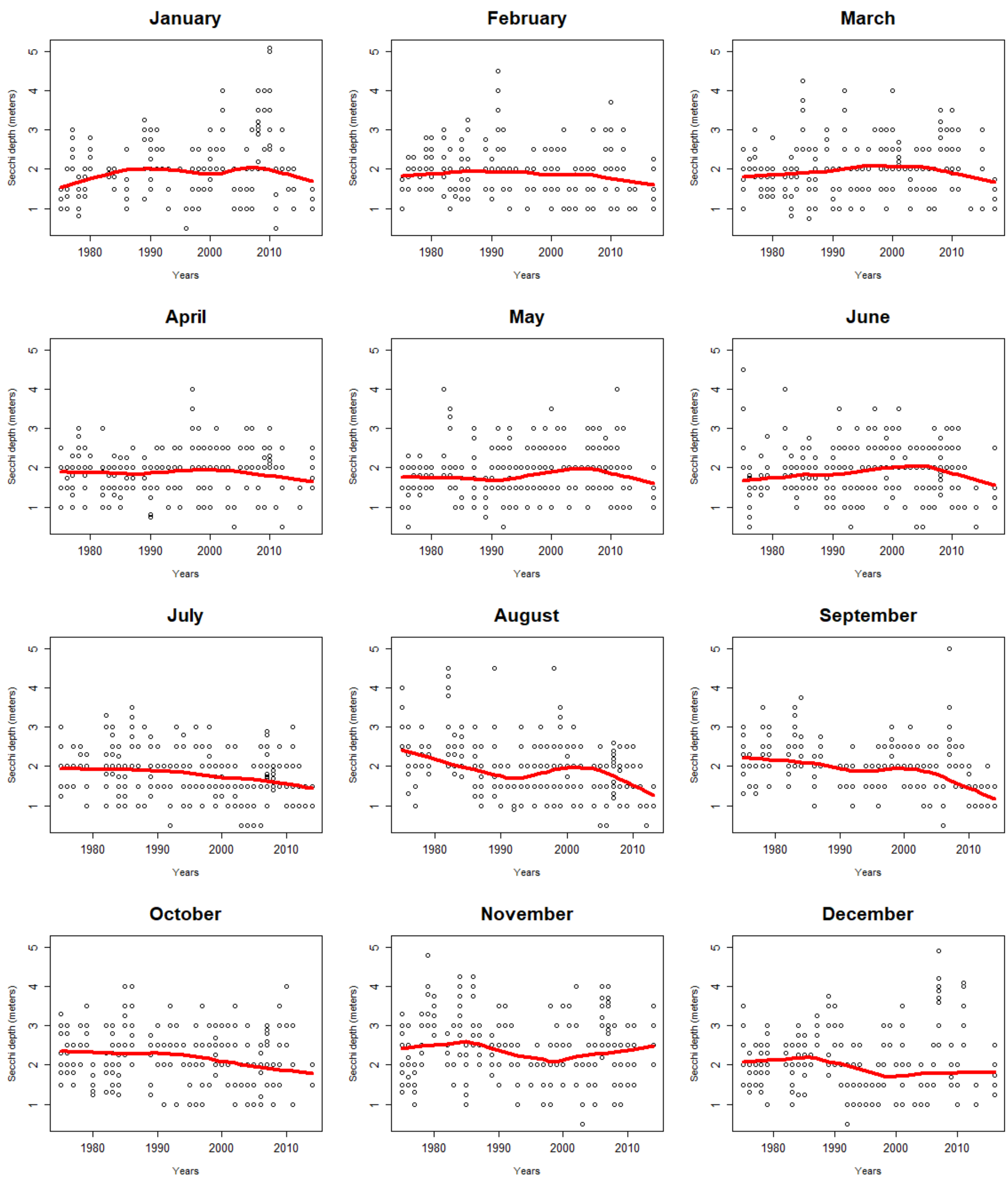

Figure 40. Annual trends in Secchi depth (m) in Hempstead Bay reported for each month of the year.

Total Coliform Bacteria

Most coliform bacteria are not directly an indication of contamination by raw fecal matter, so these readings are taken in combination with fecal coliform to better determine the likelihood of such contamination and potential presence of organisms that can affect human health. Counts are measured as most probable number (MPN) per 100ml.

We observed an overall decrease in total coliform counts across most of the study period beginning in the 1980s (Figures 41 and 42; $R^2 = 0.74$). Starting in the early 1990s, an additional decline is seen that may be related to the introduction and increasing acceptance of the pooper-scooper laws that were instituted in the 1980s. The reduction in the amount of dog waste in the streets was obvious at the time and is potentially reflected in the coliform data. A second abrupt drop in counts, particularly noticeable in East Bay, occurred in 2008 (Figure 43), and may be the result of the Town of Hempstead's (TOH) purchase and operation of two pump-out boats and the implementation of an additional stormwater medallion program targeting pet waste. The bay is a no-discharge zone, but some parts of the bay did not have ready access to on-shore pump-out facilities such as the TOH run facilities in Guy Lombardo Marina in Freeport and the East Marina in Point Lookout. The two TOH pump-out boats can travel to and service the boating public who may otherwise be tempted to release “black water” into the bay.

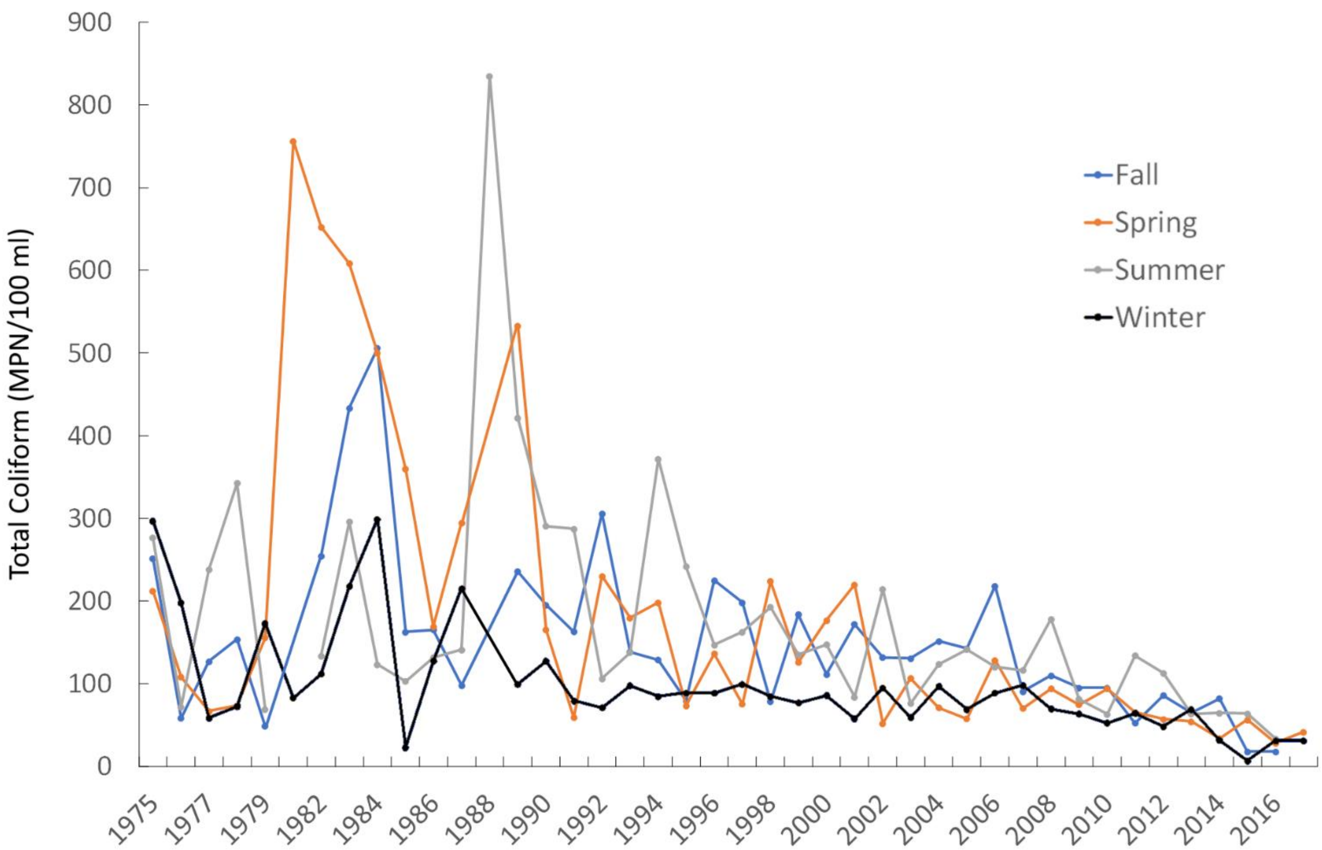

Figure 41. Median annual total coliform counts over time in Hempstead Bay by season from 1975-2017 (MPN per 100ml).

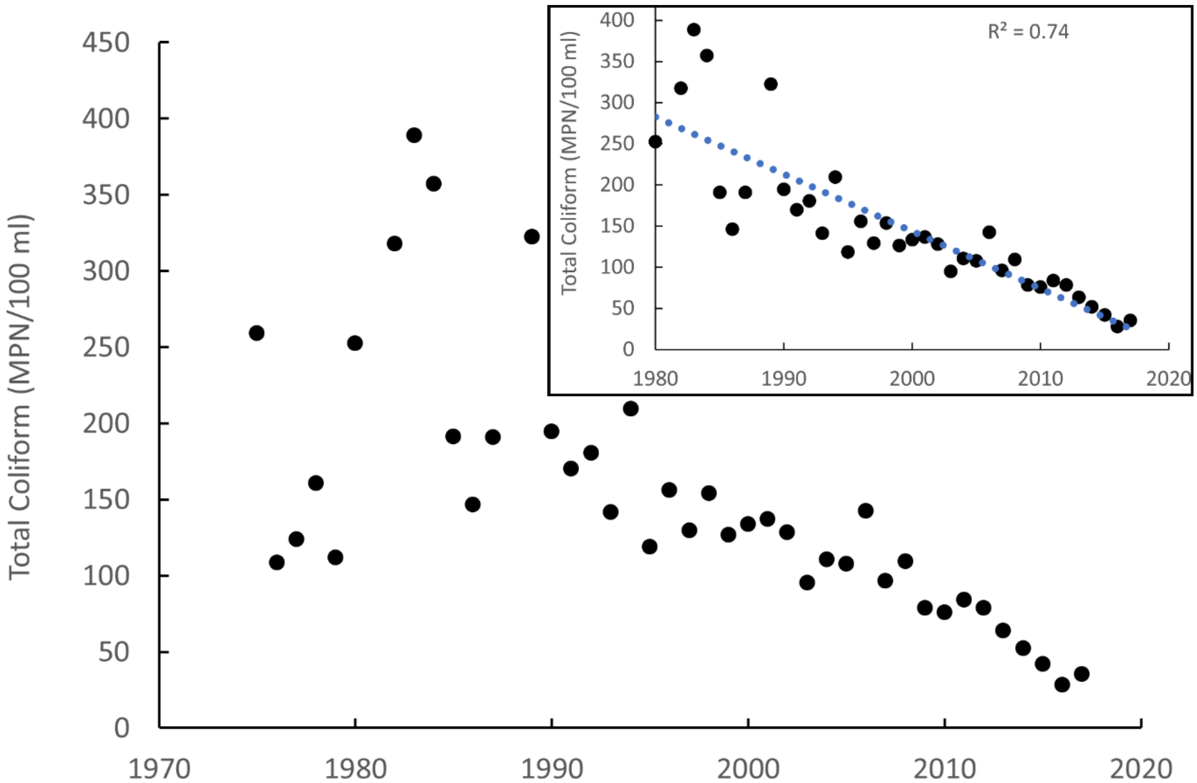

Figure 42. Median annual total coliform counts from 1975-2017. Inset graph displays the downward trend in this parameter from 1980 to 2017.

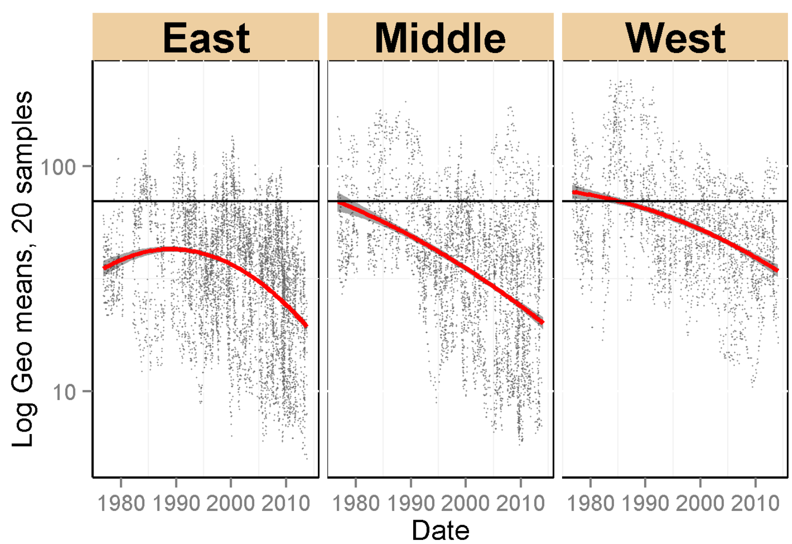

Figure 43. The 20-sample moving geometric means of Total Coliform (MPN/100 ml) data were plotted to log scale for each station over time. Generalized additive model (GAM) curves are included that show the trends in the geometric means for each bay.

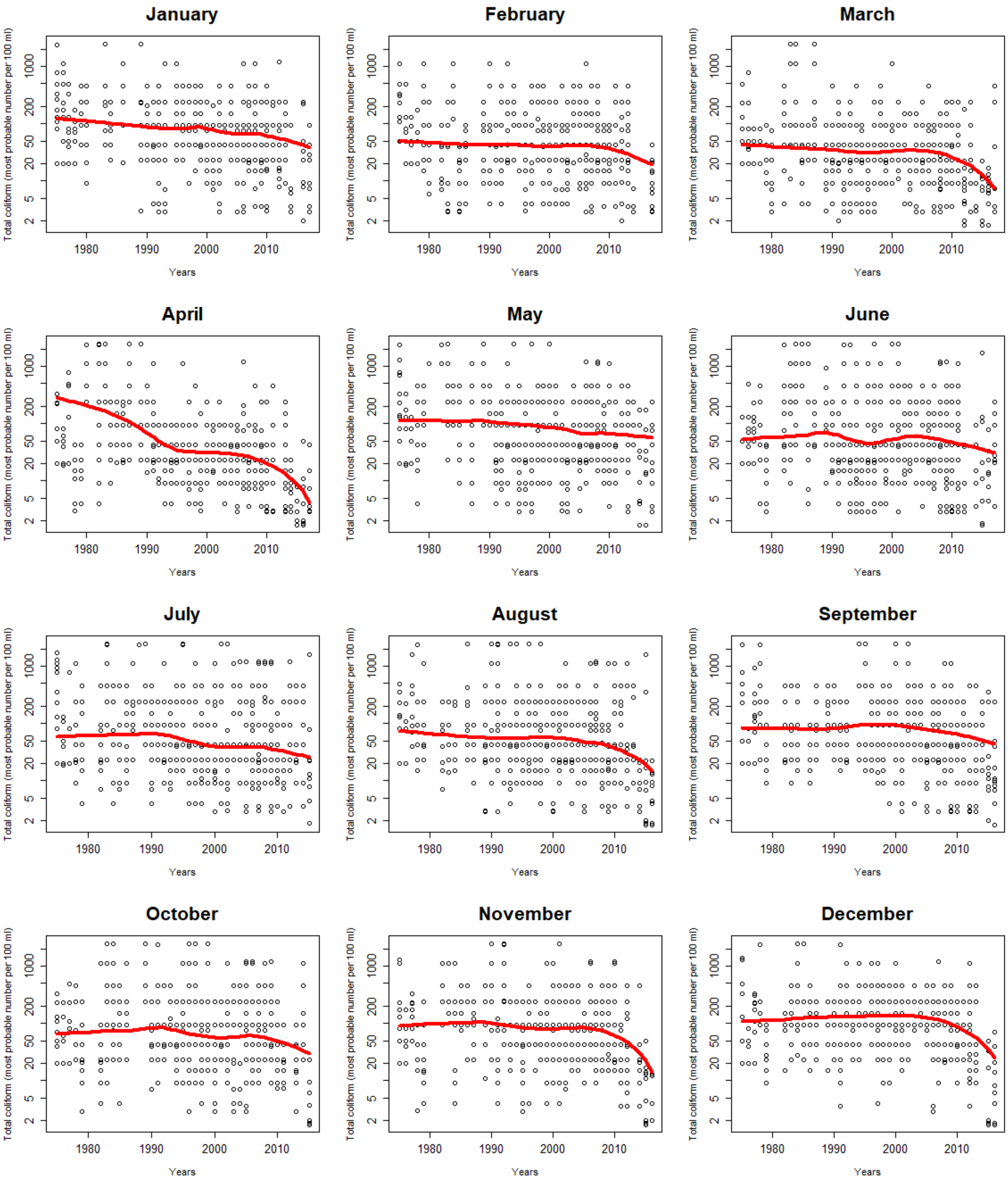

Figure 44. Annual trends in median total coliform in Hempstead Bay reported for each month of the year.

Fecal Coliform Bacteria

The presence of fecal coliform bacteria in aquatic environments indicates that the water has been contaminated with the fecal material of humans or other warm-blooded animals. The source water may also have been contaminated by pathogens, disease-producing bacteria or viruses, which can exist in fecal material. The presence of fecal coliform(s) is an indicator of potential health risks, most notably waterborne gastroenteritis.

Fecal coliform values fluctuated through time in Hempstead Bay, but there was a clear decline beginning in the early-1990s (Figures 45 and 46; $R^2 = 0.65$). No single location consistently reported higher fecal coliform values than the others. Station 2A, next to the Lawrence outfall, had levels similar to upper West Bay, although the nearby Station 2 reported lower values. The South Shore Water Reclamation Facility outfall in the lower West Bay produced mid-level results and is not a major source. Based on these results and the existence of sewering in locations near high readings, additional sampling is required to determine the precise sources that may include illicit discharge or wildlife. After calculating the geometric mean for each station for the recent decades, we determined that no stations exceeded the NYS DEC fecal coliform water standard of 200 MPN/100 ml for fishing.

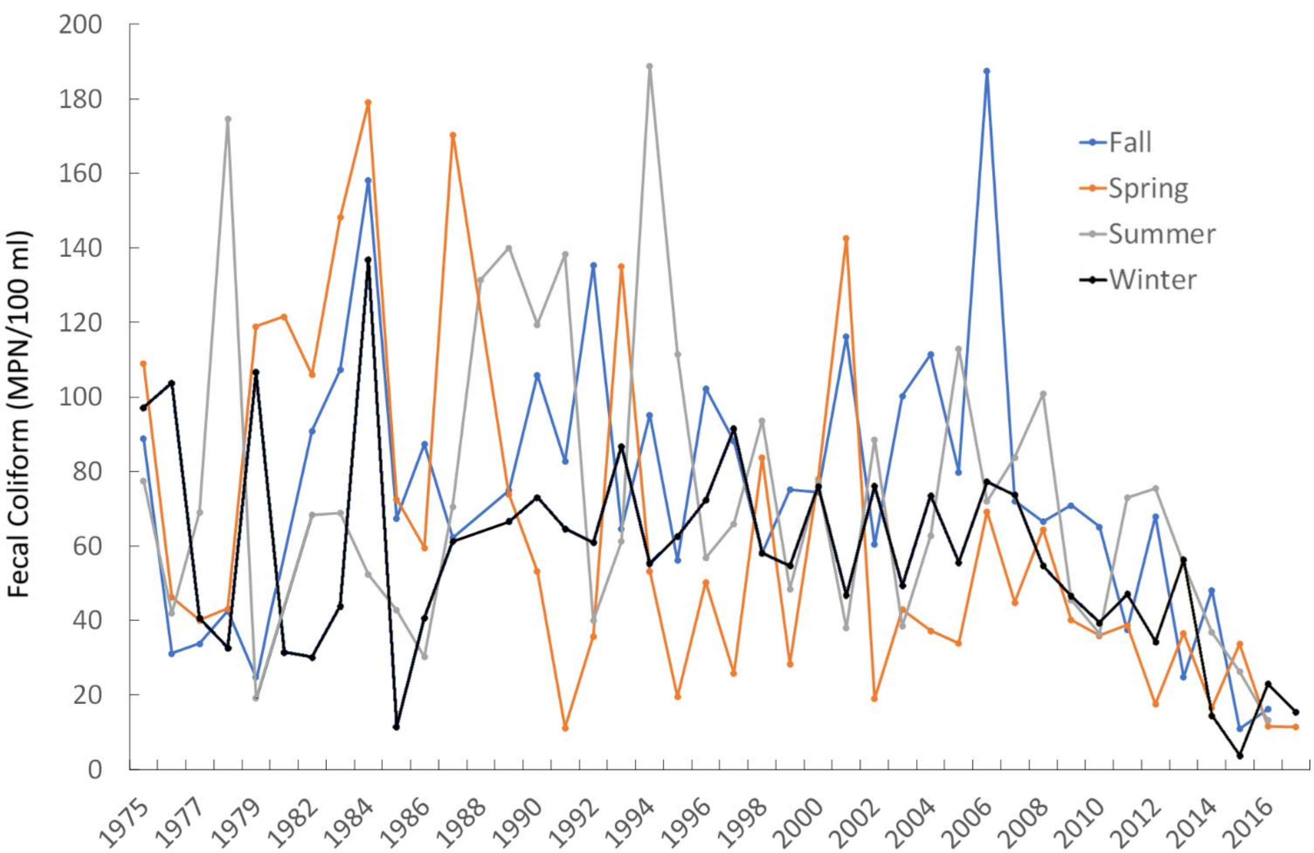

Figure 45 Median annual fecal coliform counts over time in Hempstead Bay by season from 1975-2017 (MPN per 100ml).

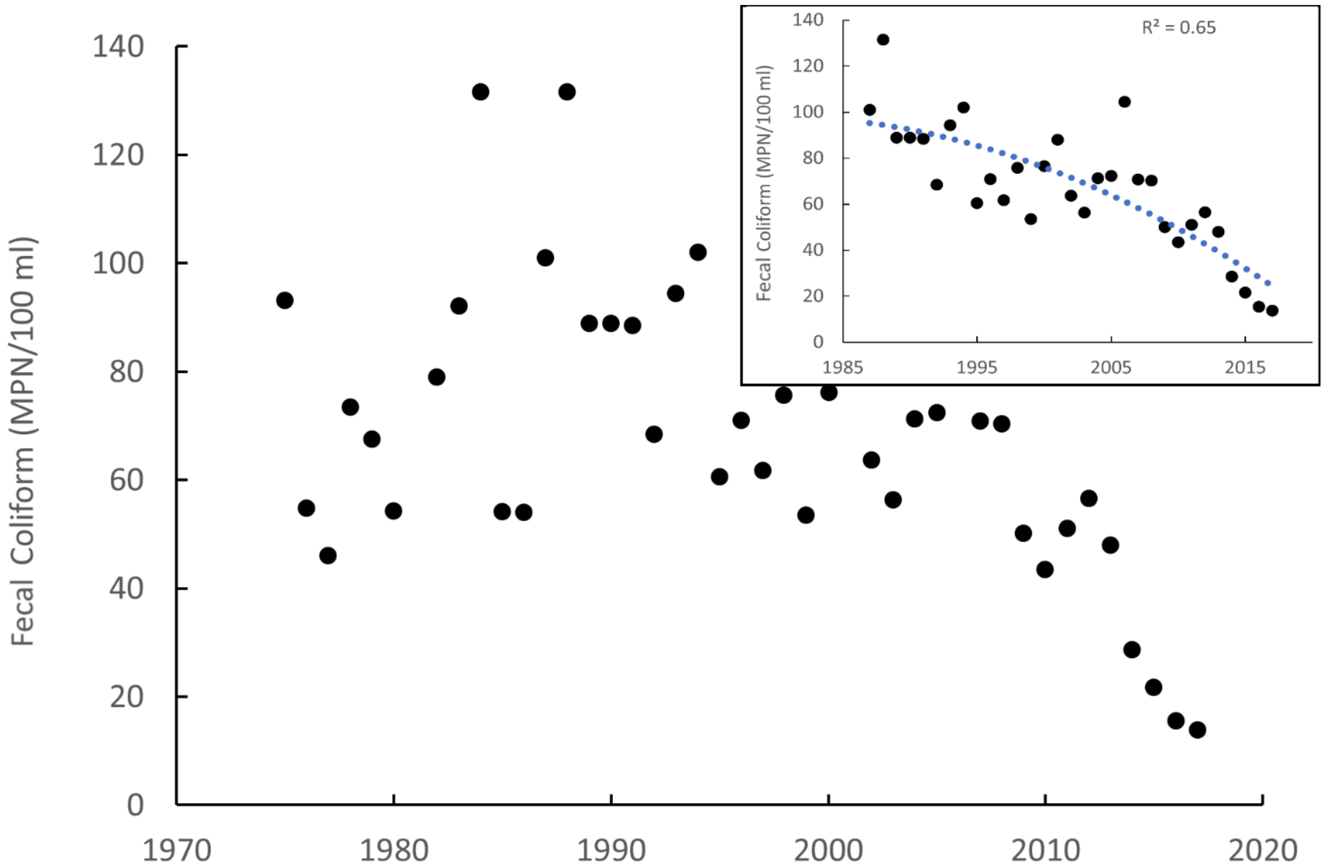

Figure 46. Median annual fecal coliform counts from 1975-2017. Inset graph displays the downward trend in this parameter from early 1990s to 2017.

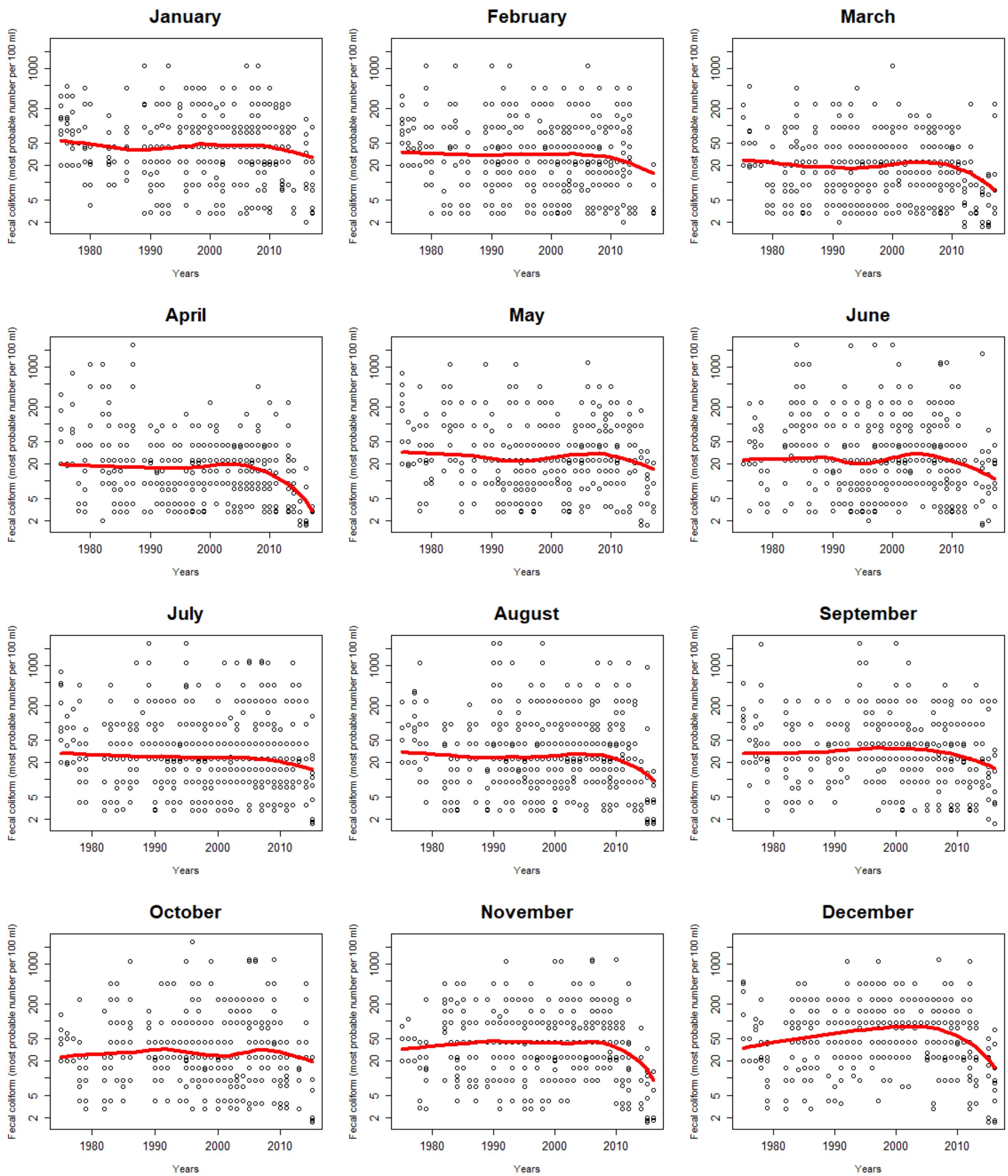

Figure 47. Annual trends in median fecal coliform in Hempstead Bay reported for each month of the year.

A Comparison of Water Quality Changes between 1968 and 1975 onward:

Nitrate and Fecal Coliform

The Town of Hempstead Department of Conservation and Waterways began monitoring the condition of its bays in 1968. This effort consisted of a one-year study focused primarily on the effects of treated sewage discharge on the quality of bay water. The results of this study were published as the "Water Quality Study, Hempstead Bay Estuary, 1968." In 1975, the Hempstead Bay monitoring program was initiated, which collected water samples at 28 stations throughout Hempstead Bay. The number of sampling stations eventually increased to 36 for more complete coverage.

The 1968 water quality study examined the water temperature, salinity, nitrate, total coliform counts, Chlorophyll *a*, and orthophosphate readings at 26 bay sampling stations. To understand how these parameters have changed between 1968 and the beginning of the monitoring program, we compared 1968 and 1975 data. Although the locations and numbering of the sampling stations used in the 1968 study differ from those used in this report, we compared parameter values at similarly located stations (1968 Stations: 19, 4, 5, 8, 14, 10, 3 and 1975: 3, 11, 6, 14, 17, 23, 12, respectively). These data help us extend our historical data record further back in time.

Nitrate concentrations were broadly similar in 1968 and in 1975 and the following several years. Spatially, the 1968 data indicate decreasing nitrate as one moves from West Bay to Middle Bay to East Bay, similar to the pattern seen in recent decades (see Nitrate section of this report). Total coliform values were higher in 1968 than in 1975 with averages of 830.3 and 442.4 MPN/100 ml, respectively (Fig. 49). Chlorophyll "a" values were similar in 1968 and 1975 with averages of 8.7 and 9.4 mg/m^3, respectively (Fig. 49).

The data from 1968 provide information about water quality in Hempstead Bay prior to the start of the monitoring data presented in this report (1975 and onward) and suggest that some improvements in water quality may have occurred over this seven year time period in relation to potential pathogenic bacteria as indicated by total coliform counts. Looking over the entire timespan, median annual nitrate concentrations remained near 1968 levels until the late 1970s, then increased during the early 1980s, after which nitrate concentrations steadily declined through 2017 (see Nitrate section of this report). Median annual total coliform counts generally remained near 1975 levels until the mid-2000s and then declined steadily over time until the near present (see Total Coliform section of this report). Overall, these data provide evidence of a potential improvement in bacteria counts between 1968 and 1975, but no improvement in most other indicators until more recent decades.

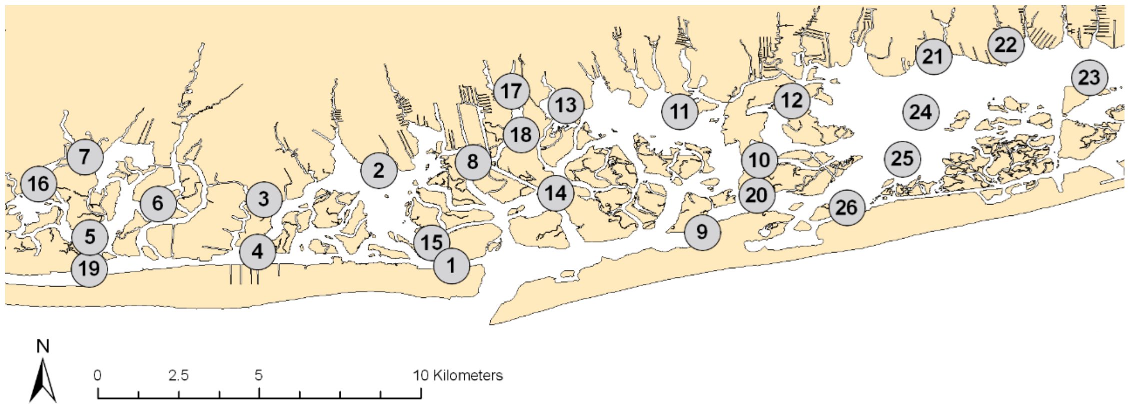

Figure 48. Locations of stations used to collect water quality data for the Town of Hempstead's 1968 water quality study.

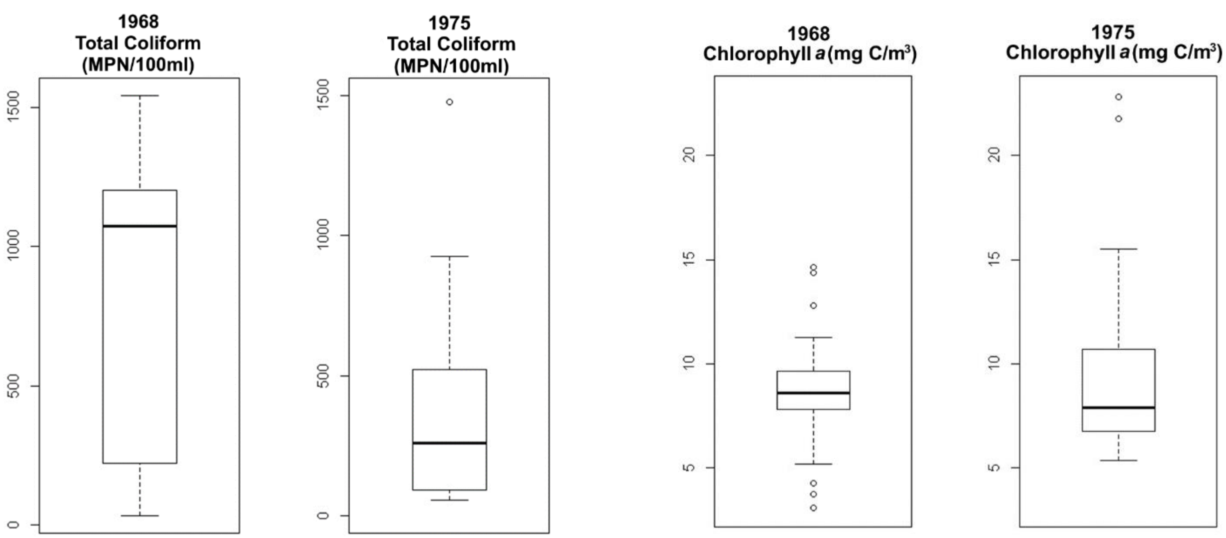

Figure 49. Median total coliform counts (left) and median chlorophyll a concentrations (right) at comparable sampling stations in 1968 and 1975.

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APPENDICES

A1. Two Year Moving Averages for Water Quality Data in Hempstead Bay

These two-year moving averages smooth high-frequency variability allowing us to better view long term differences among the three embayments (West, Middle, and East Bay) over time.

Table of Contents

Parameters of the analysis

Region: All three bays (East Bay; EB, Middle Bay; MB, and West Bay of Hempstead; WB), and all bays together as Hempstead Bay (HB).

Included stations are:

“WS_1” “WS_10” “WS_11” “WS_11A” “WS_12” “WS_13” “WS_13A”
“WS_14” “WS_146” “WS_147” “WS_15” “WS_15A” “WS_15B” “WS_16”
“WS_17” “WS_17.1” “WS_18” “WS_18A” “WS_18D” “WS_19” “WS_2”
“WS_20” “WS_21” “WS_22” “WS_23” “WS_24” “WS_25” “WS_26”
“WS_27” “WS_28” “WS_2A” “WS_3” “WS_30” “WS_31” “WS_32”
“WS_33” “WS_34” “WS_4” “WS_5” “WS_6” “WS_6A” “WS_7”
“WS_8” “WS_9”

Methodology:

Moving average

The data were averaged using a geometric mean (the product of their values on an annual basis), and then a backward moving average was applied with a window size of 25 months for k=3 iterations. The window size is always an odd number (not an even number), therefore it cannot be exactly 24 months.

NA values

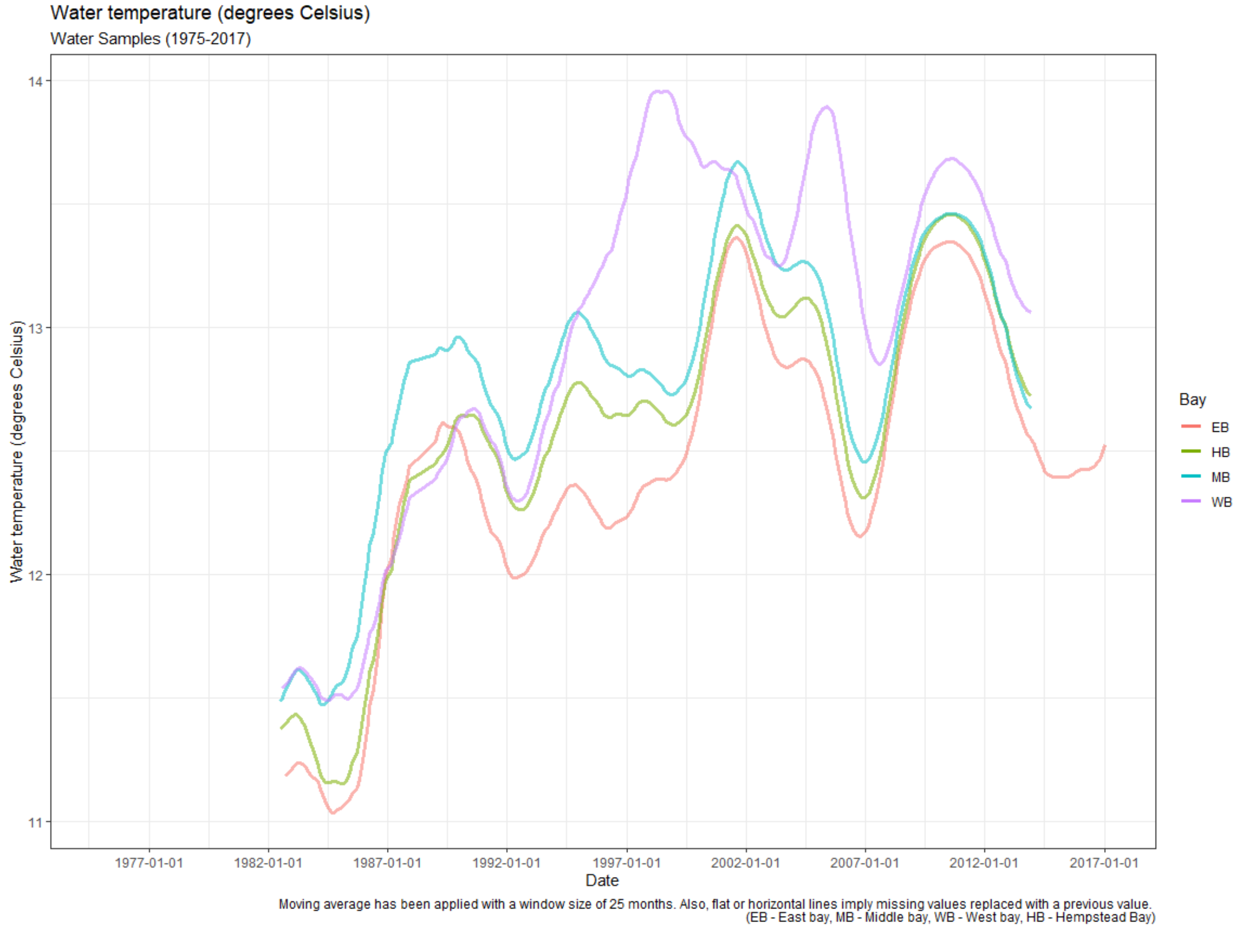
NA values were replaced in the raw data with a previous value or with a linear interpolation between the previous and next values. NA located at the beginning or the end of the dataset for each variable was not removed or replaced; these NA values are reported below each graph as missing. Also, there are 72 NA values at the beginning of each dataset. This is common due to the application of the backward moving average with a window size of 25 months with an iteration of k=3 (3x24).

Extreme high or low values

For some variables, a few extremely high or low values were replaced with “NA”.

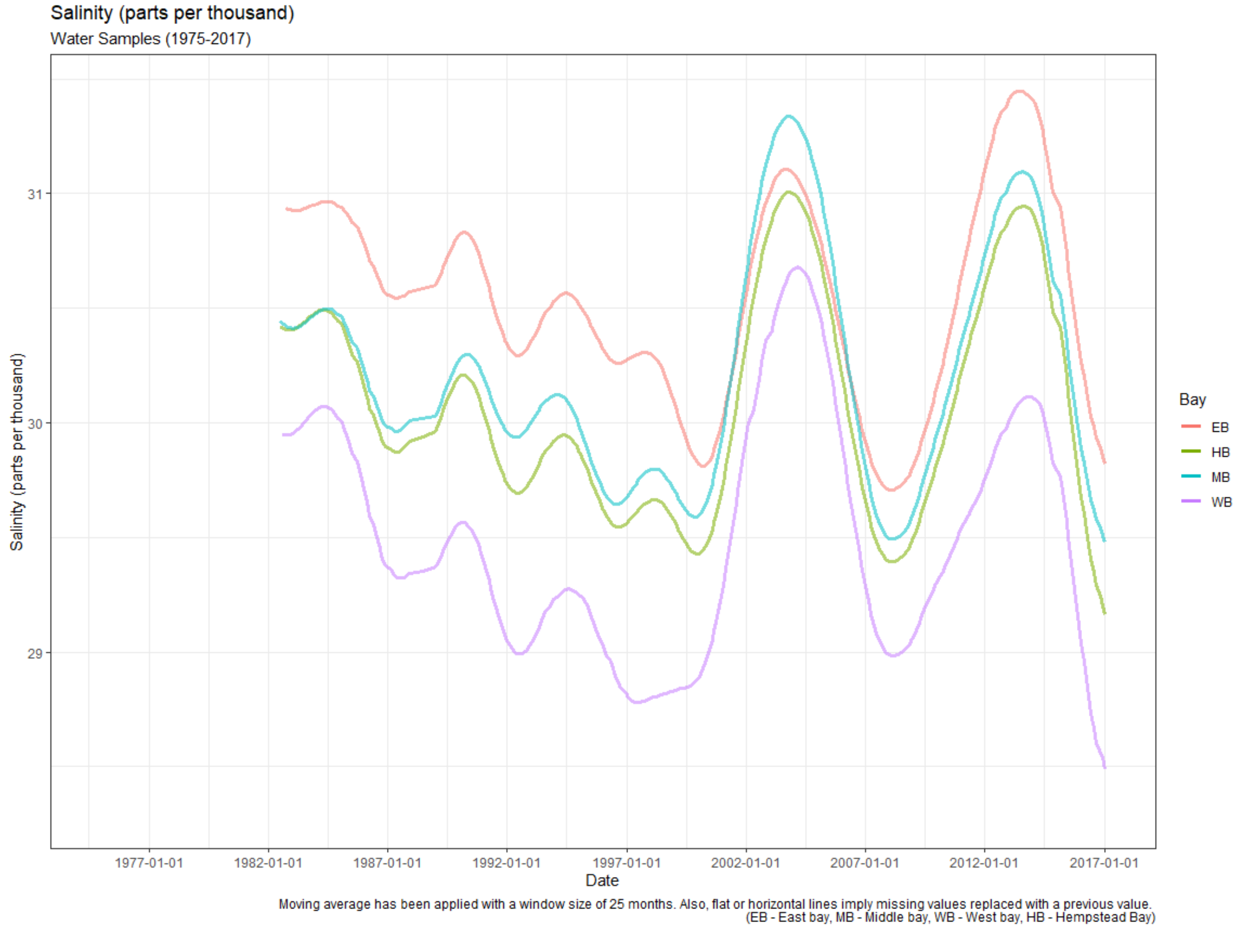
Water temperature (°C)

variable: Temp_C



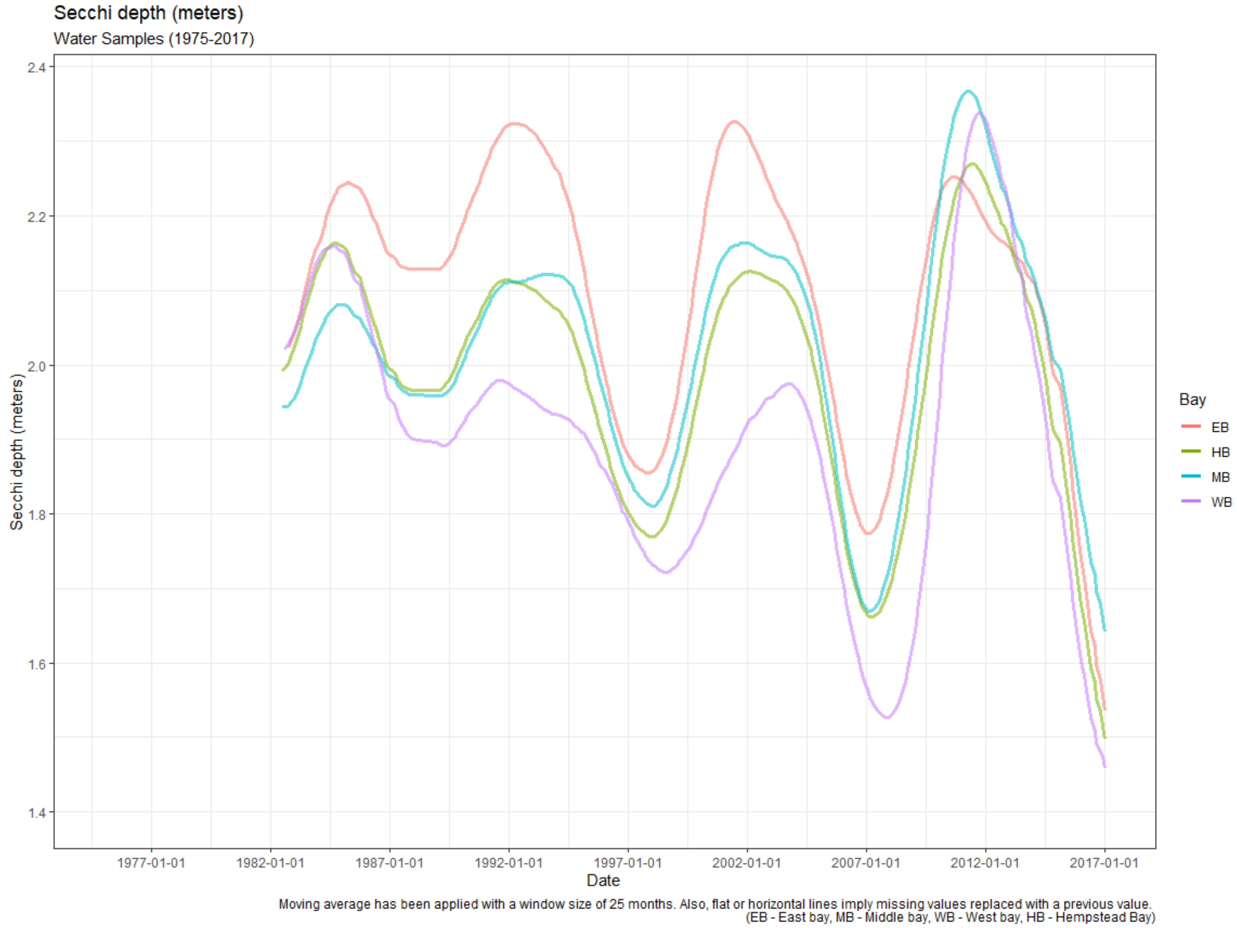
Salinity (parts per thousand)

variable: Salinity_PPT



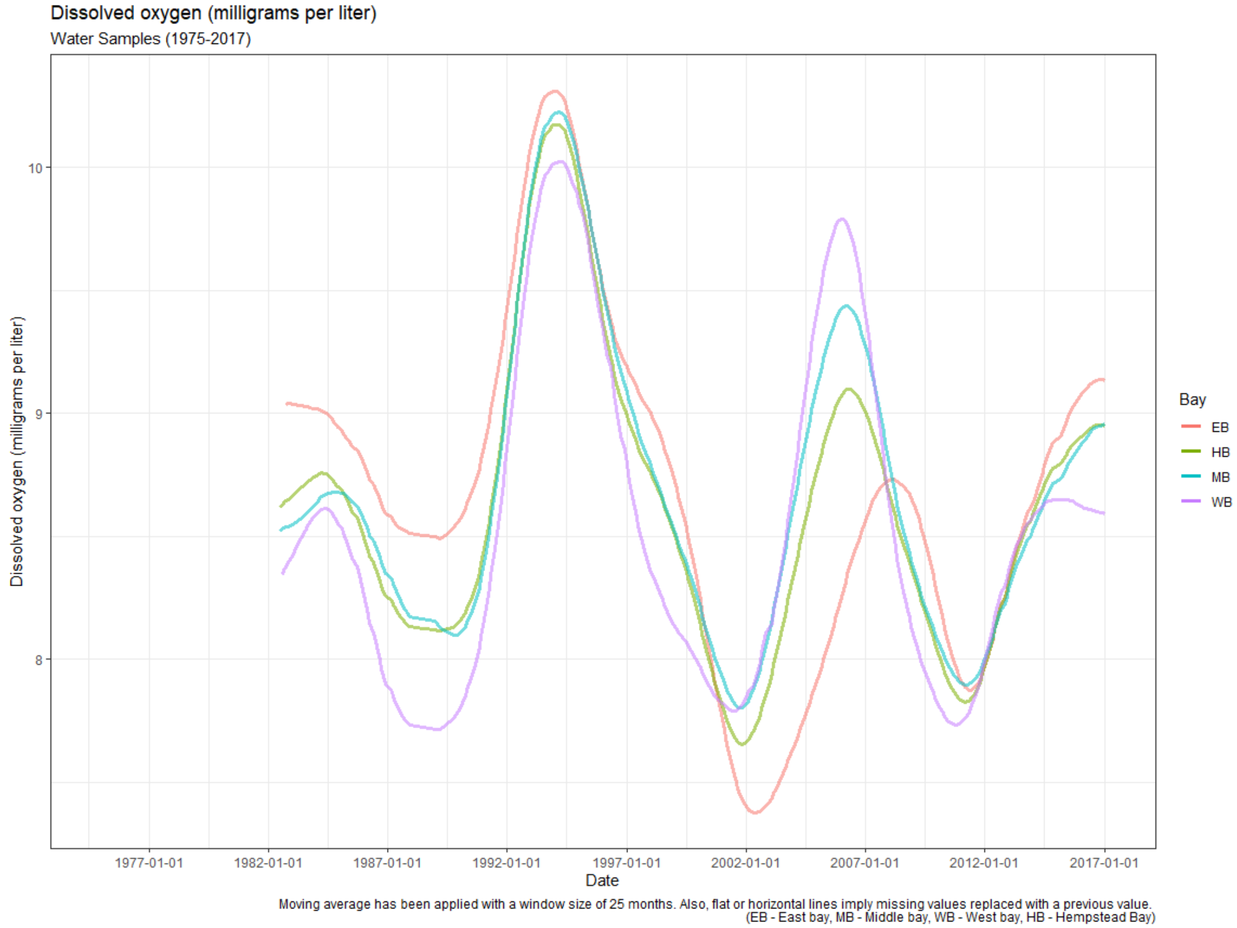
Secchi depth (meters)

variable: Secchi_M



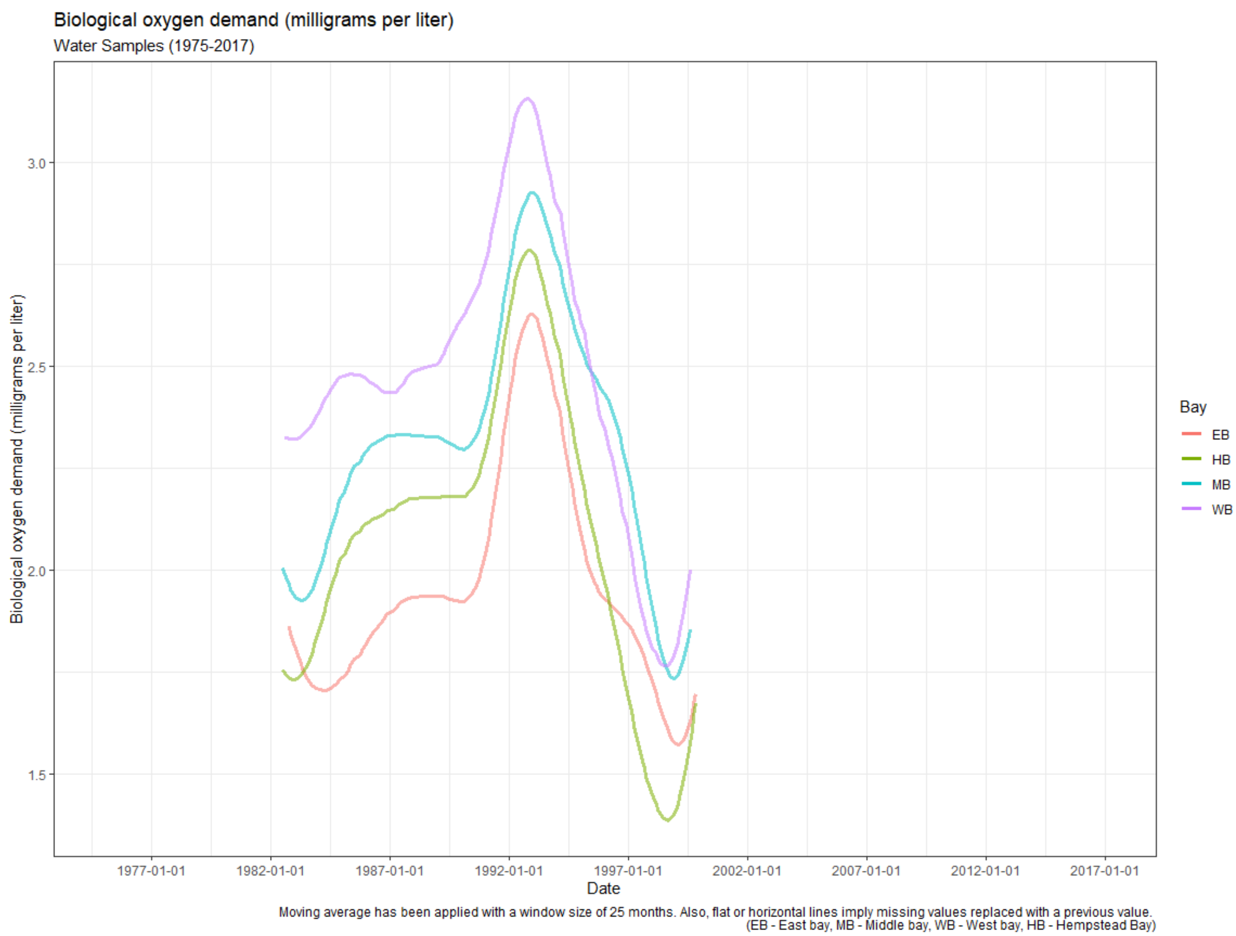
Dissolved oxygen (milligrams per liter)

variable: Disol_O2_mg_L



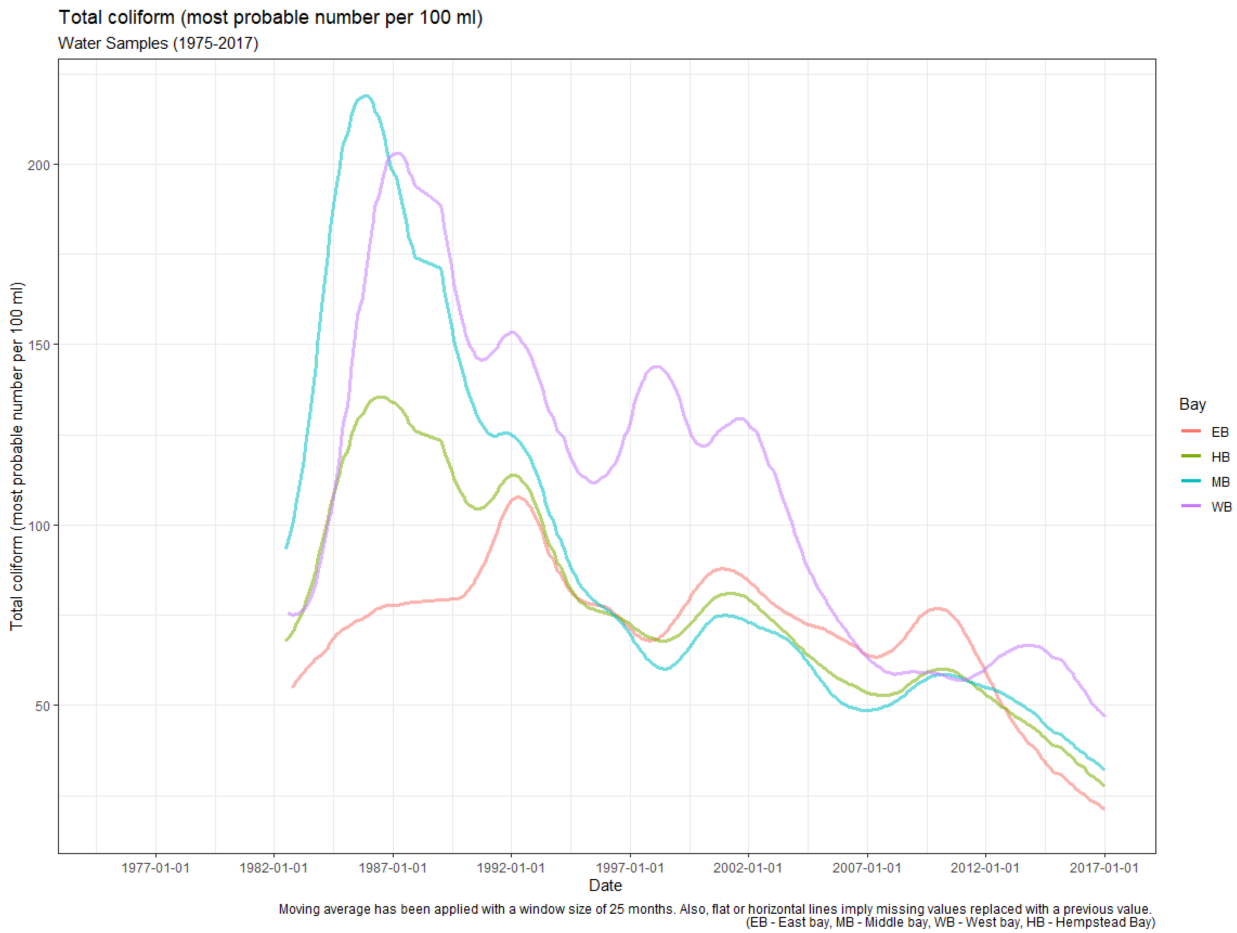
Biological oxygen demand (BOD) (milligrams per liter)

variable: BOD



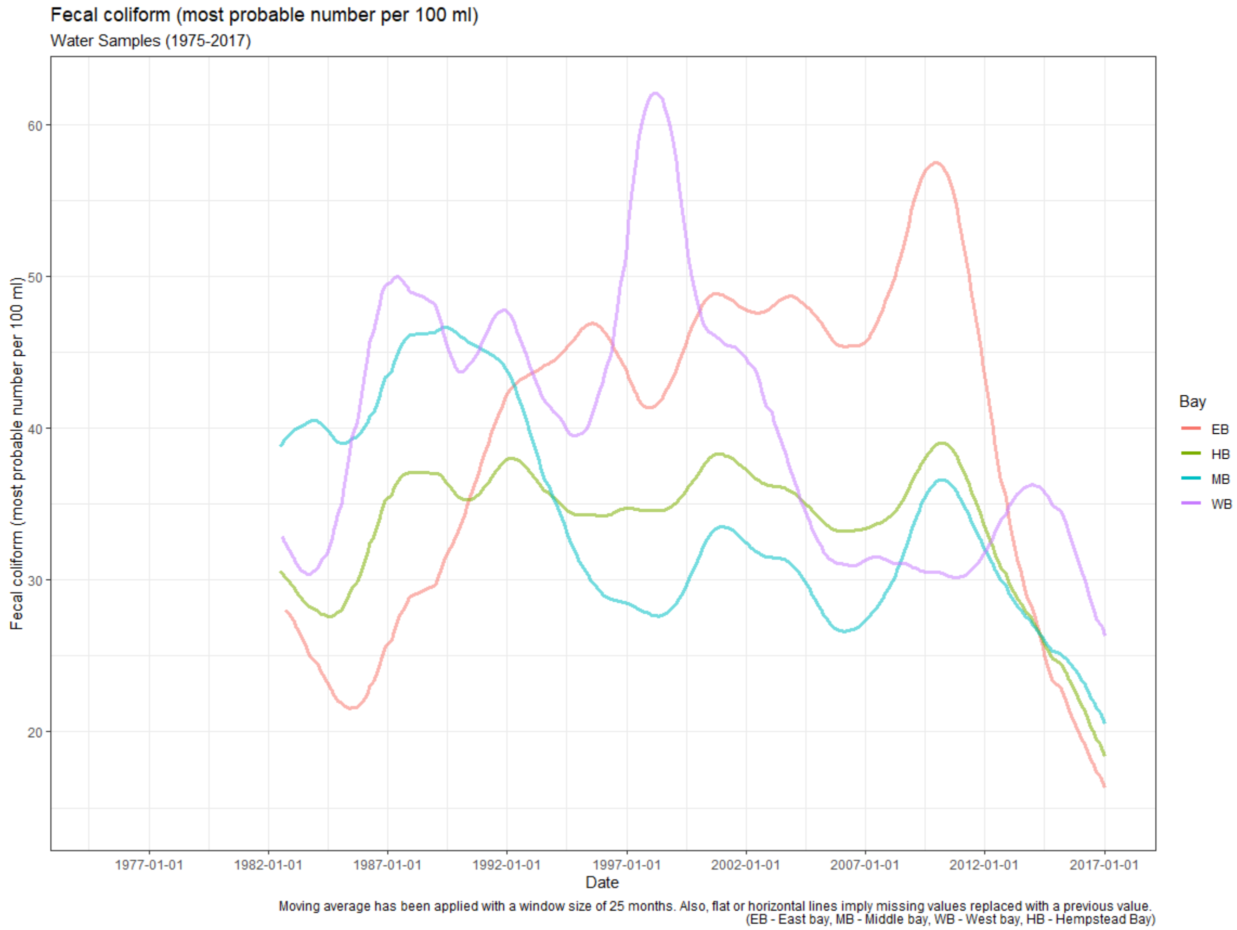
Total coliform (most probable number per 100 ml)

variable: MPN_colfm_100ml



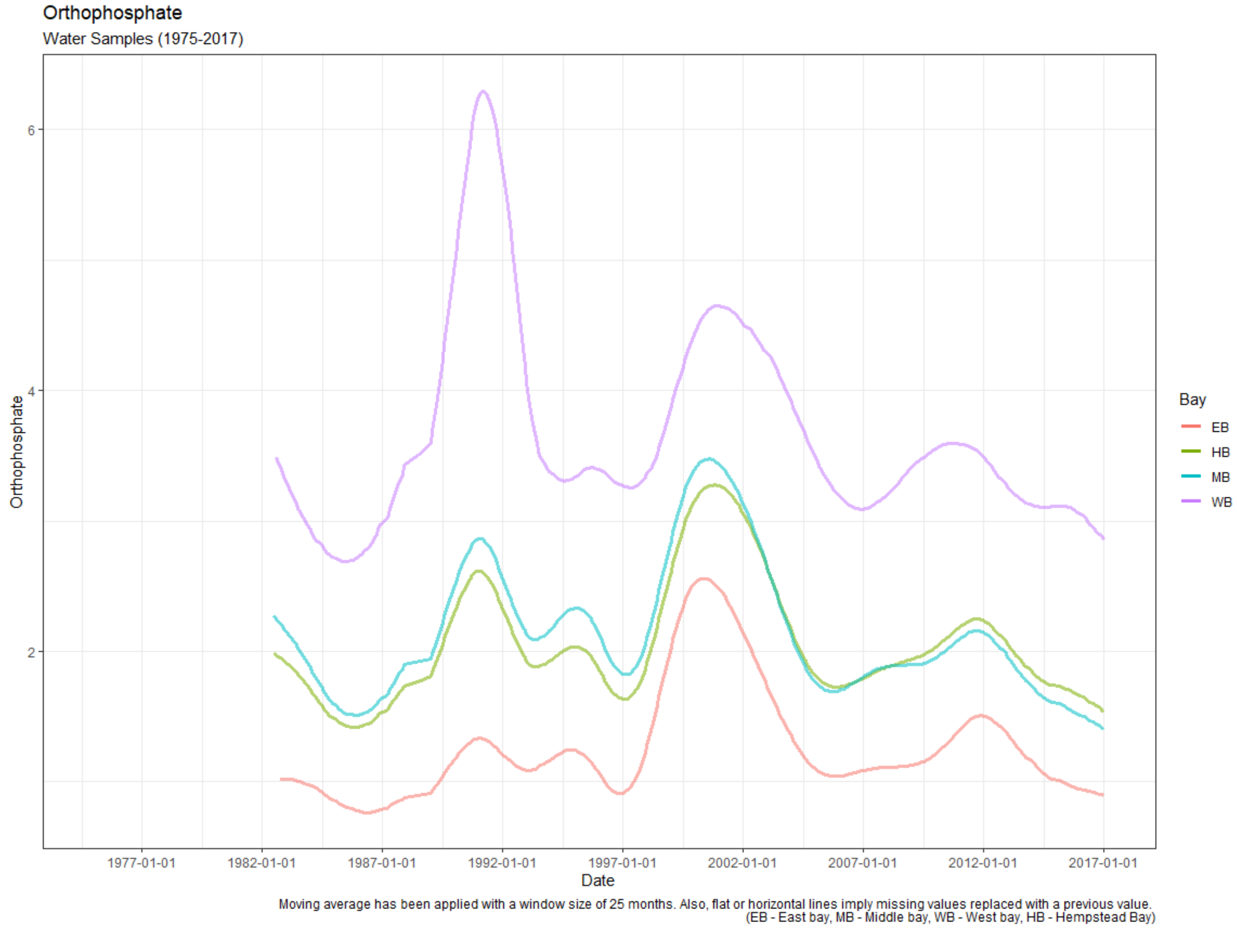
Fecal coliform (most probable number per 100 ml)

variable: MPN_Fecal_100ml



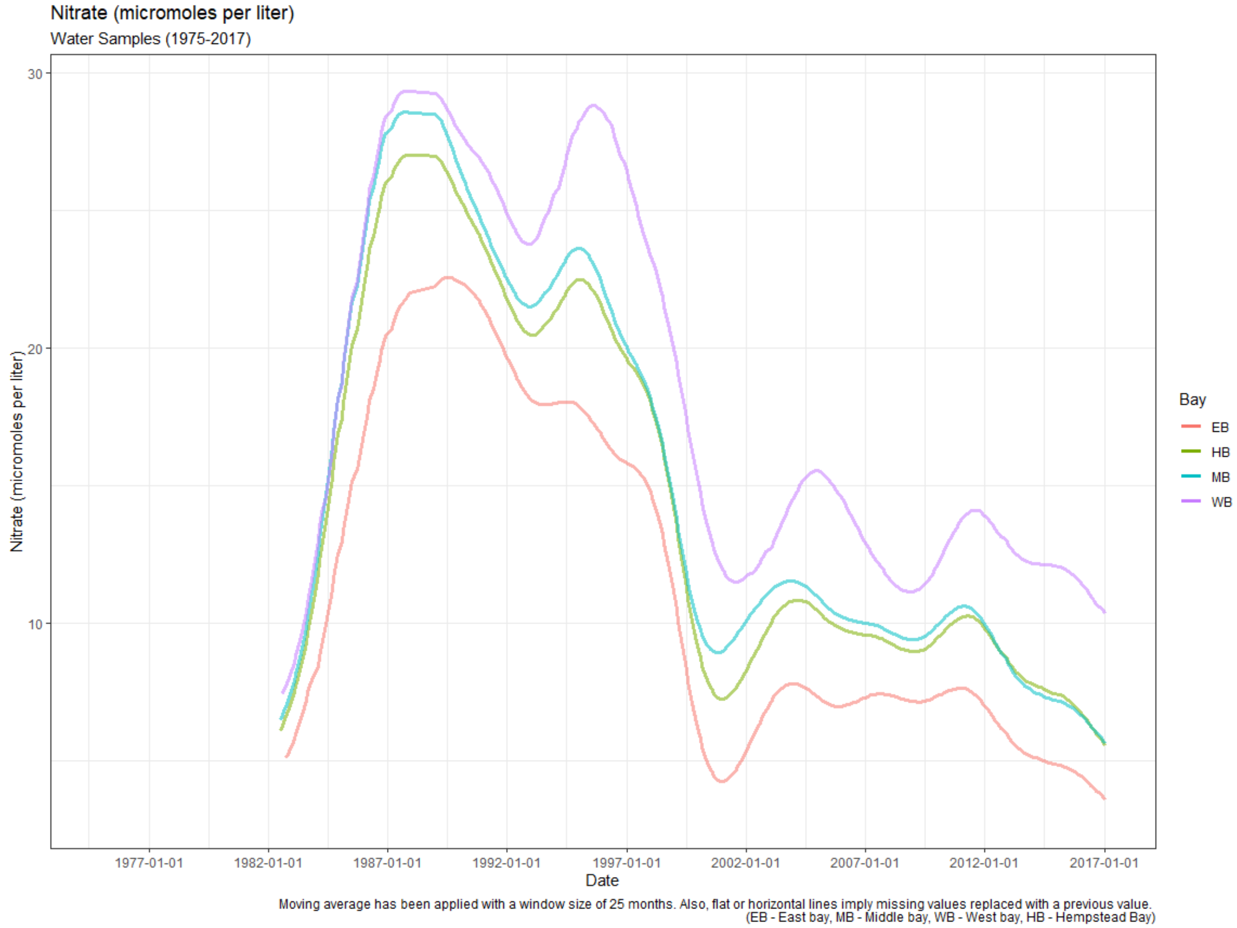
Orthophosphate (micromoles per liter)

variable: OrthoPhos_umol_L



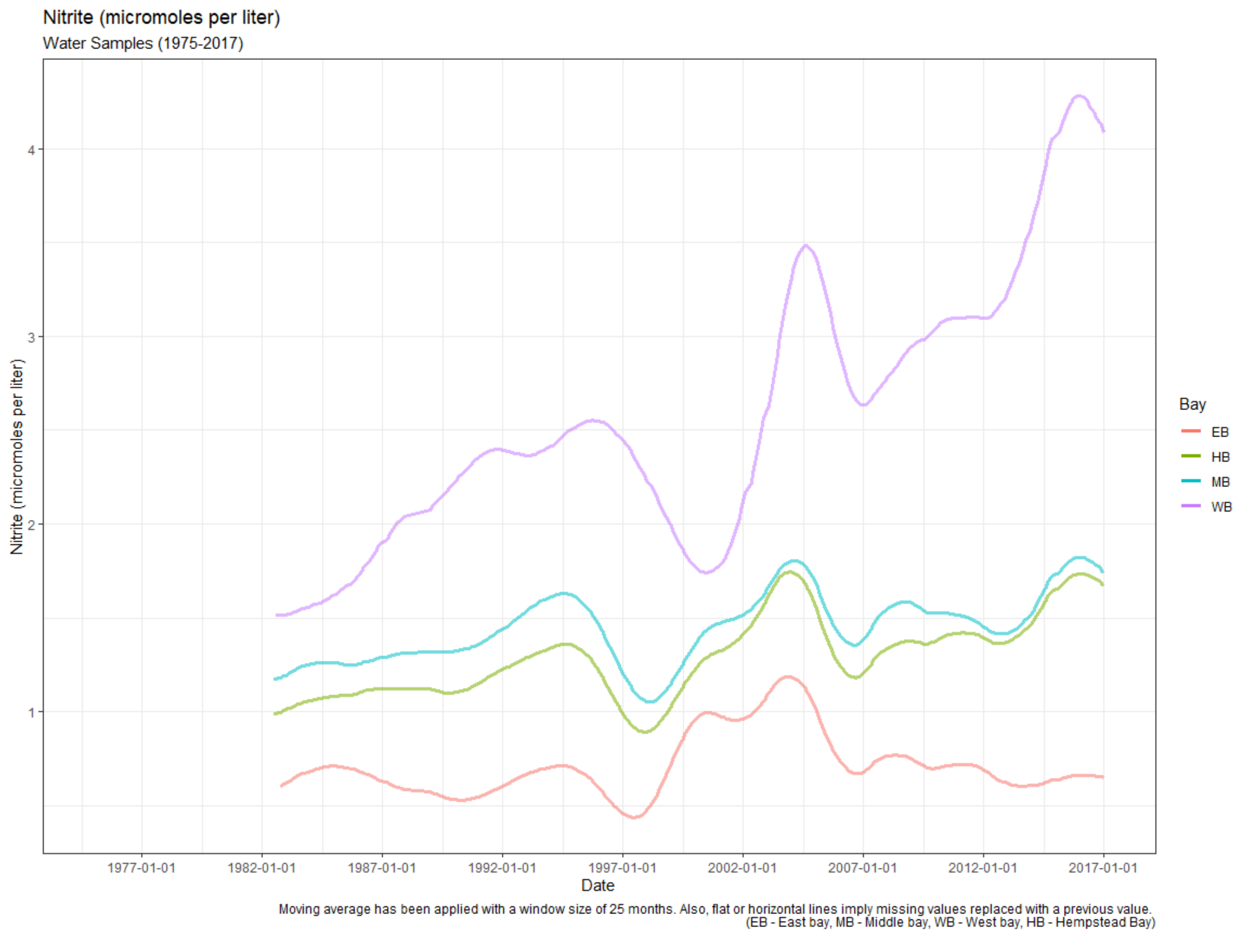
Nitrate (micromoles per liter)

variable: ReacNate_umol_L



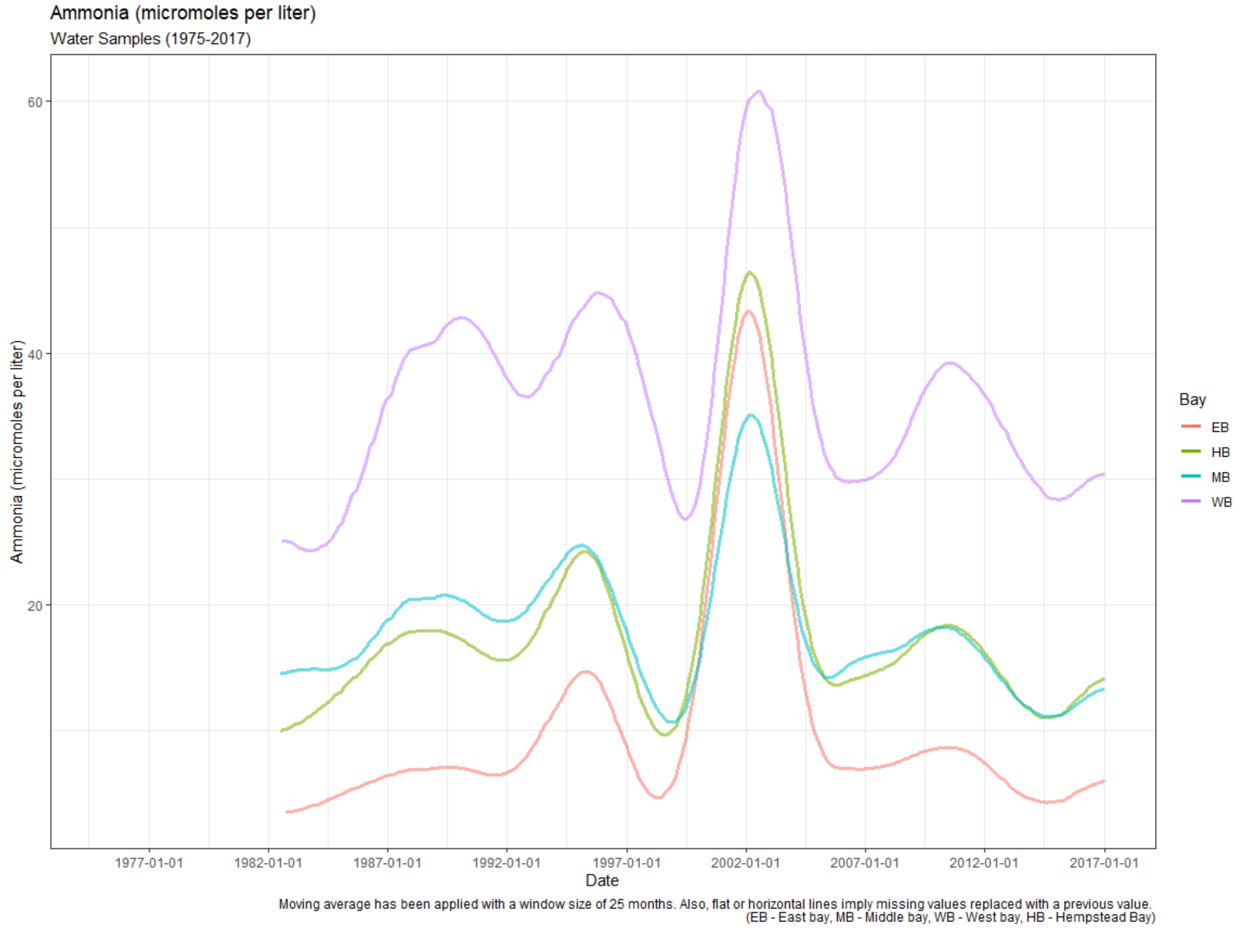
Nitrite (micromoles per liter)

variable: ReacNite_umol_L



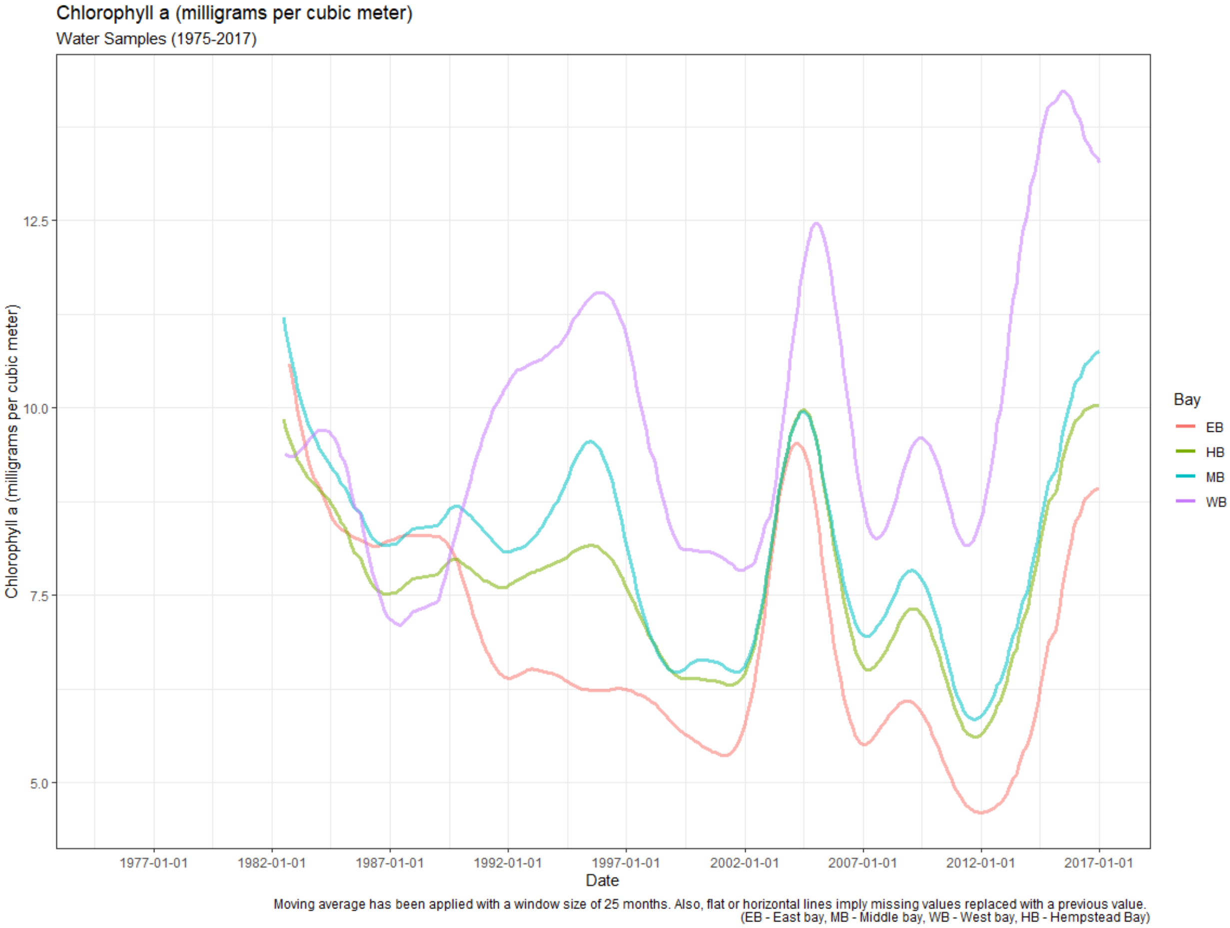
Ammonia (micromoles per liter)

variable: Ammonia_umol_L



Chlorophyll a (milligrams per cubic meter)

variable: Chloro_a_mg_m3

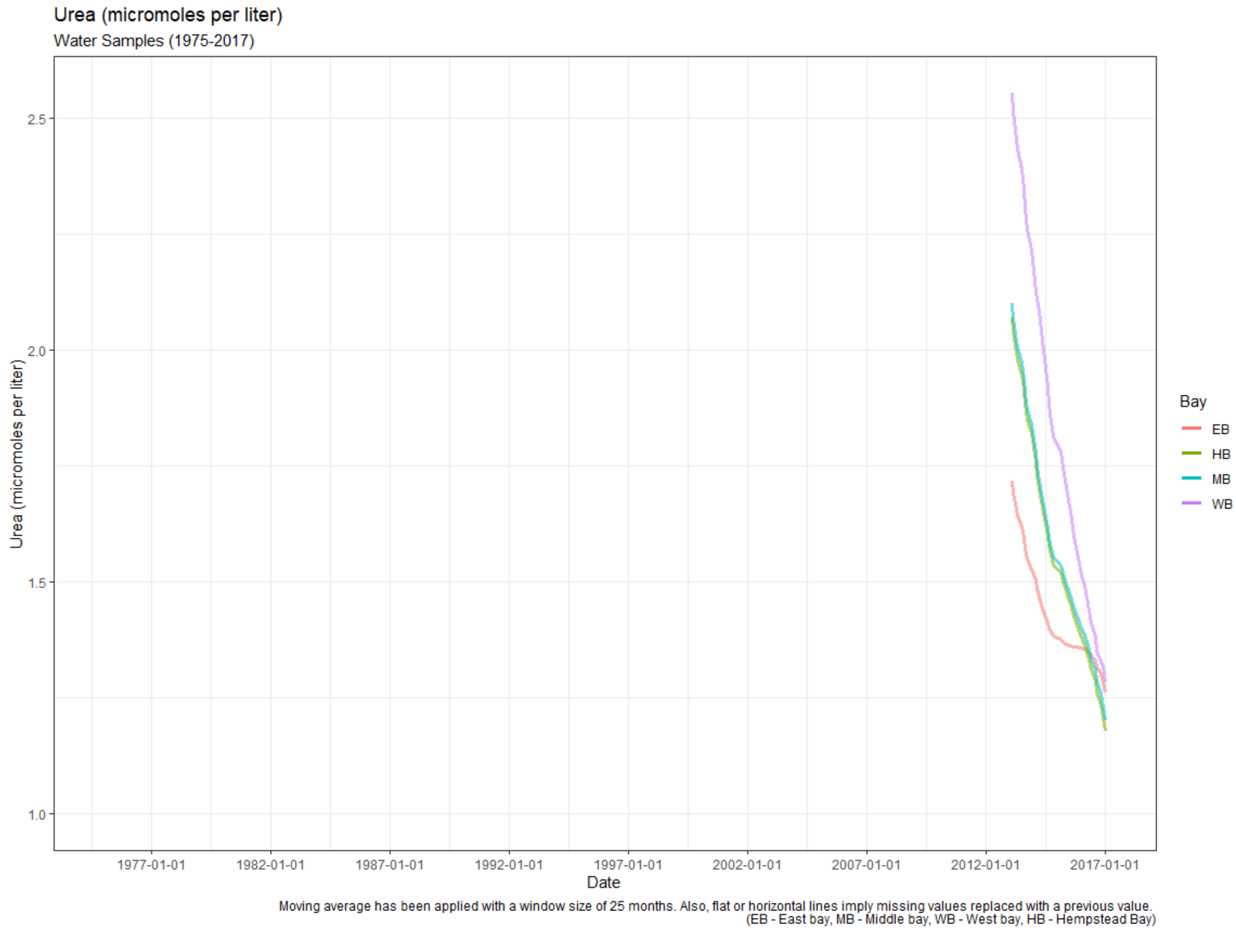


Particulate organic matter (milligrams per cubic meter)

variable: Partic_Organ_mgC_m3

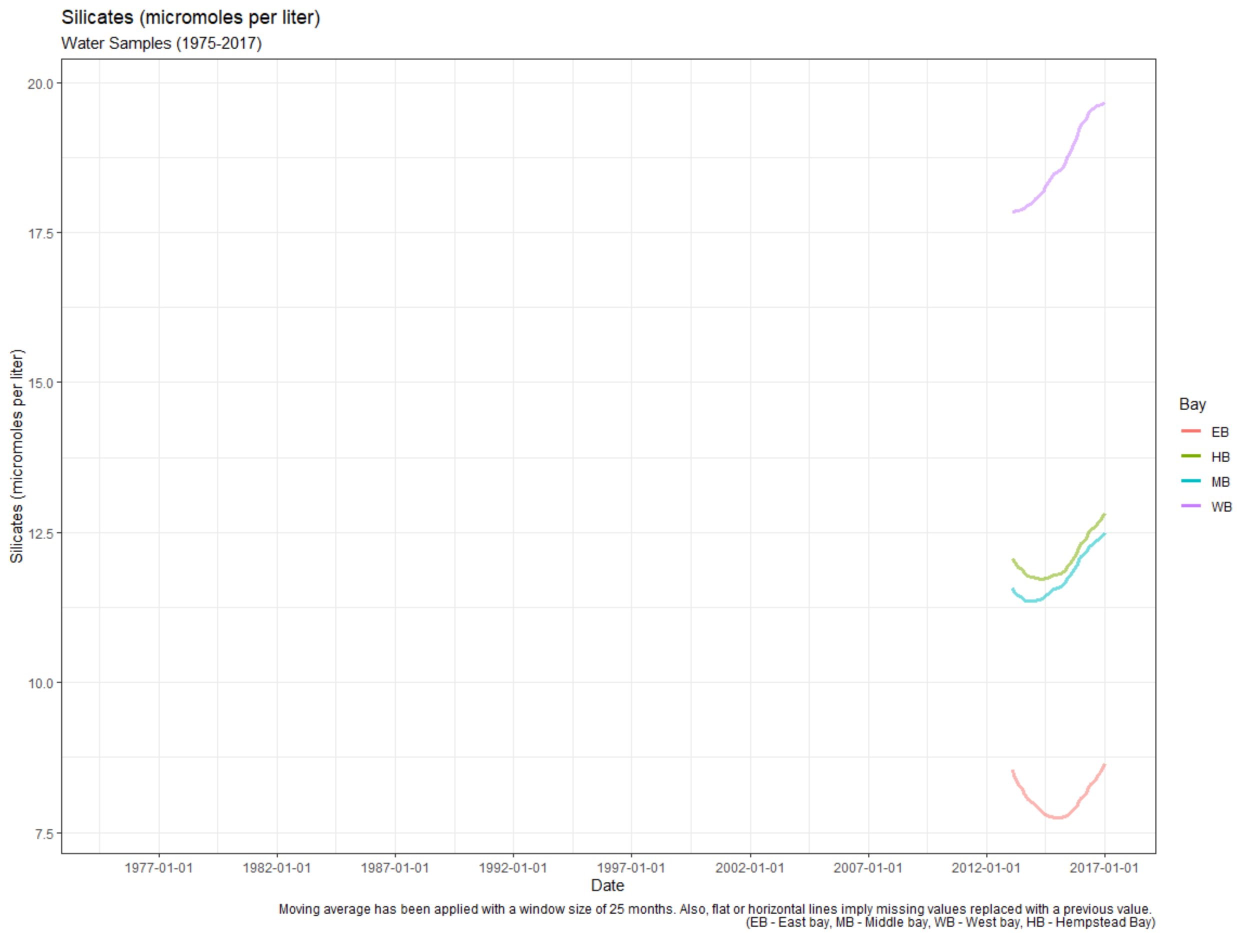
Urea (micromoles per liter)

variable: Urea



Silicates (micromoles per liter)

variable: Silicates



A2. Detailed Annual Data for Water Quality Variables in Hempstead Bay

Table of Contents

Parameters of the analysis

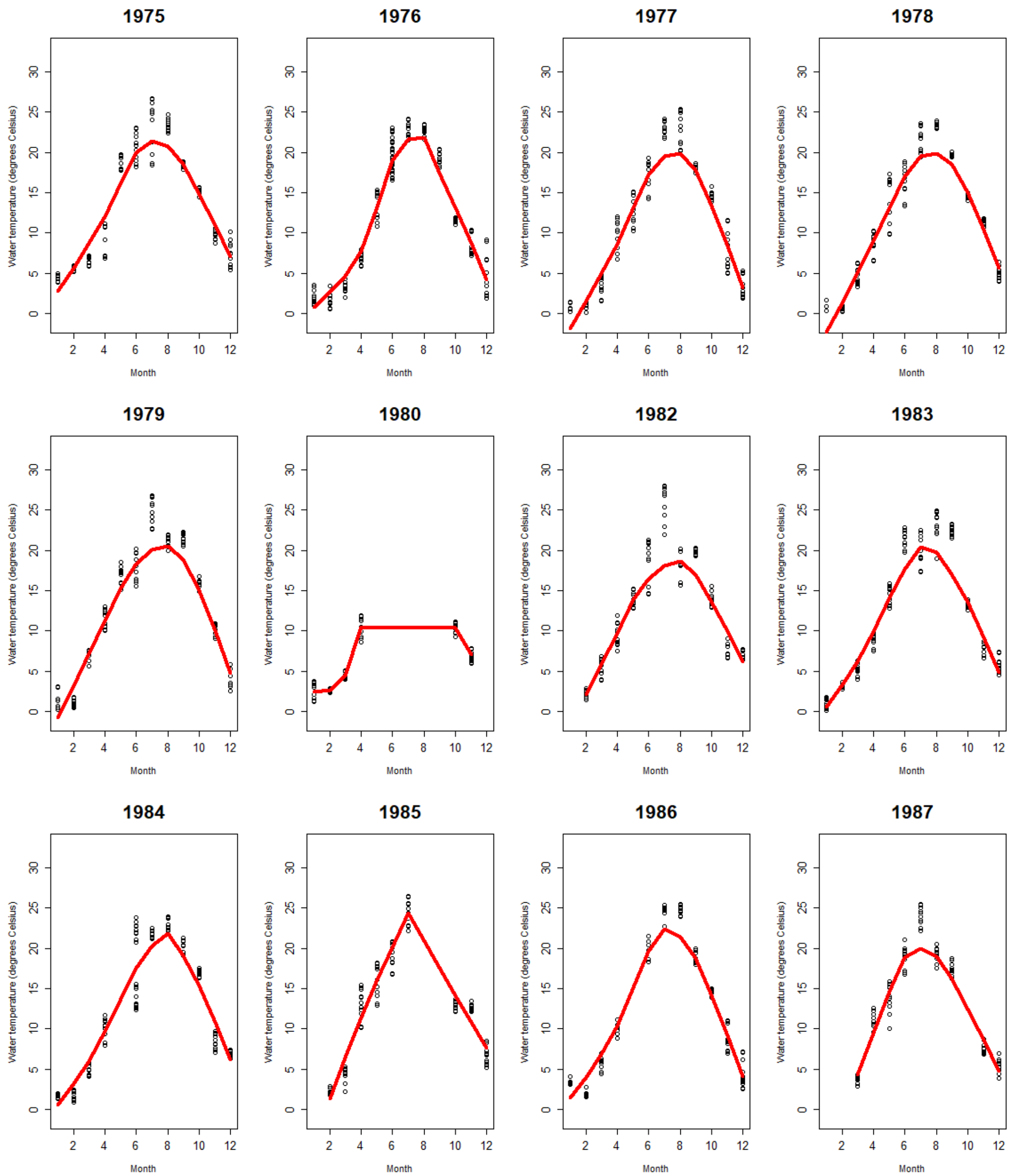
Region: All stations together as Hempstead Bay (HB).

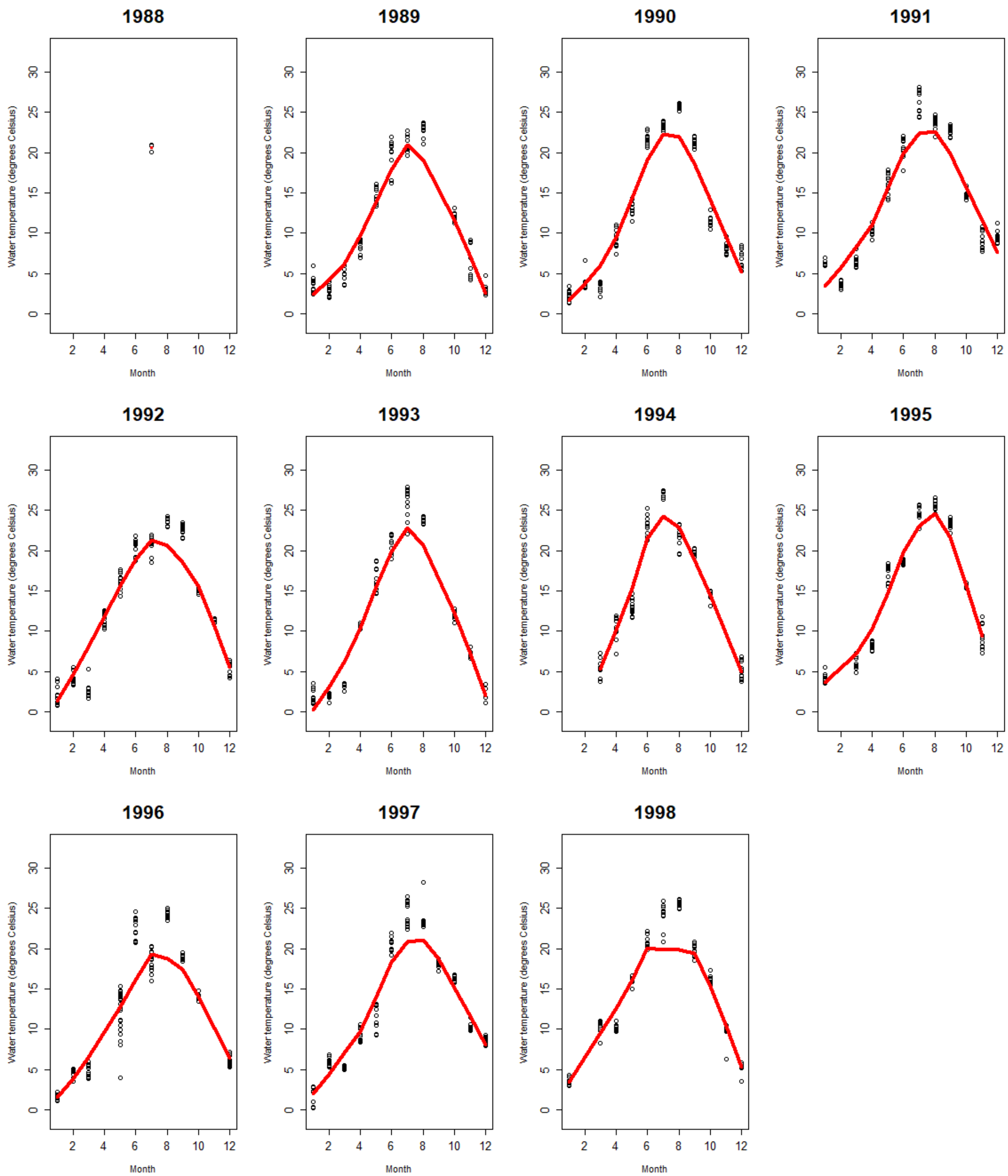
Included stations are:

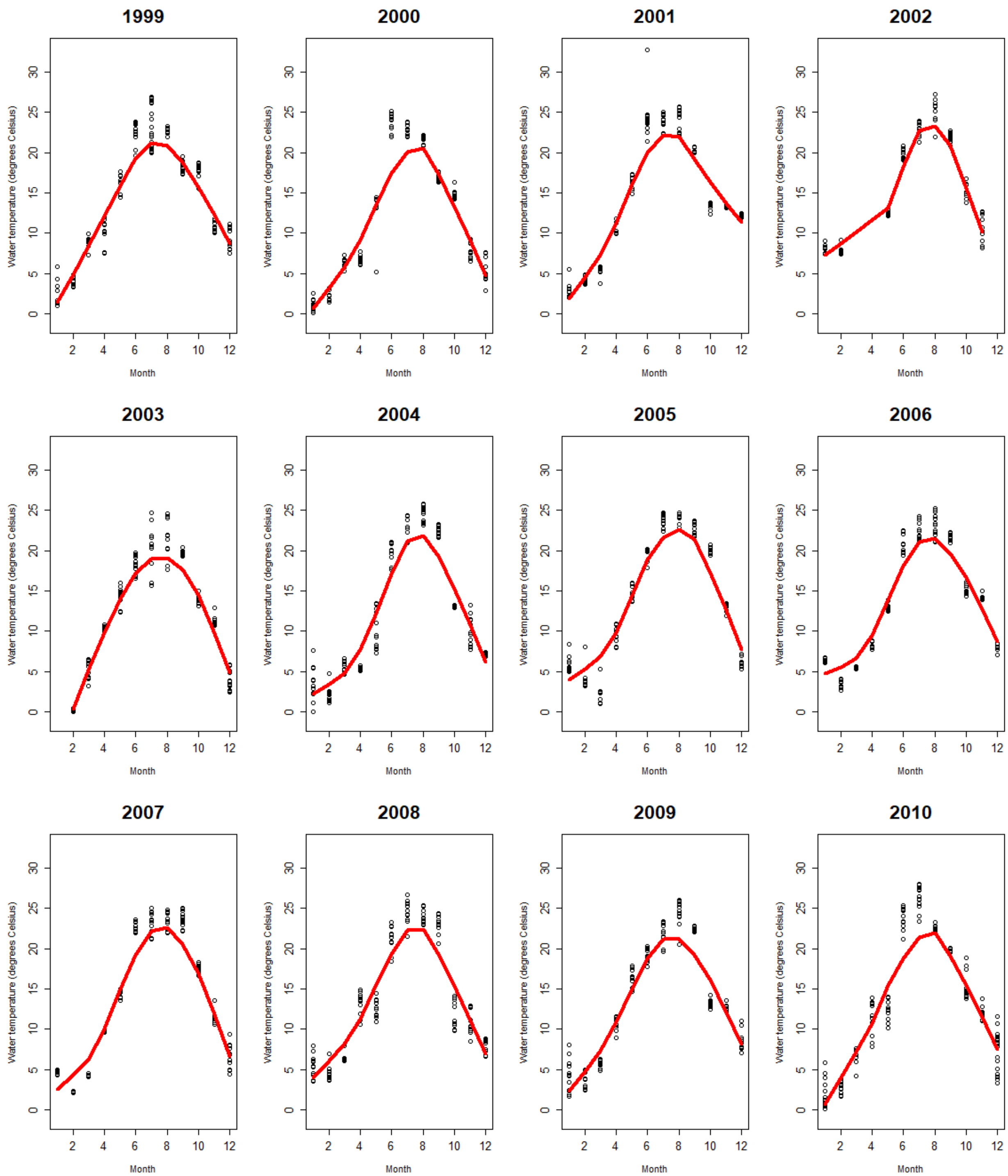
“WS_1” “WS_10” “WS_11” “WS_11A” “WS_12” “WS_13” “WS_13A”
“WS_14” “WS_146” “WS_147” “WS_15” “WS_15A” “WS_15B” “WS_16”
“WS_17” “WS_17.1” “WS_18” “WS_18A” “WS_18D” “WS_19” “WS_2”
“WS_20” “WS_21” “WS_22” “WS_23” “WS_24” “WS_25” “WS_26”
“WS_27” “WS_28” “WS_2A” “WS_3” “WS_30” “WS_31” “WS_32”
“WS_33” “WS_34” “WS_4” “WS_5” “WS_6” “WS_6A” “WS_7”
“WS_8” “WS_9”

Water temperature (^oC)

variable: Temp_C




1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
Water temperature (degrees Celsius)
Month
0 5 10 15 20 25 30
2 4 6 8 10 12


1999
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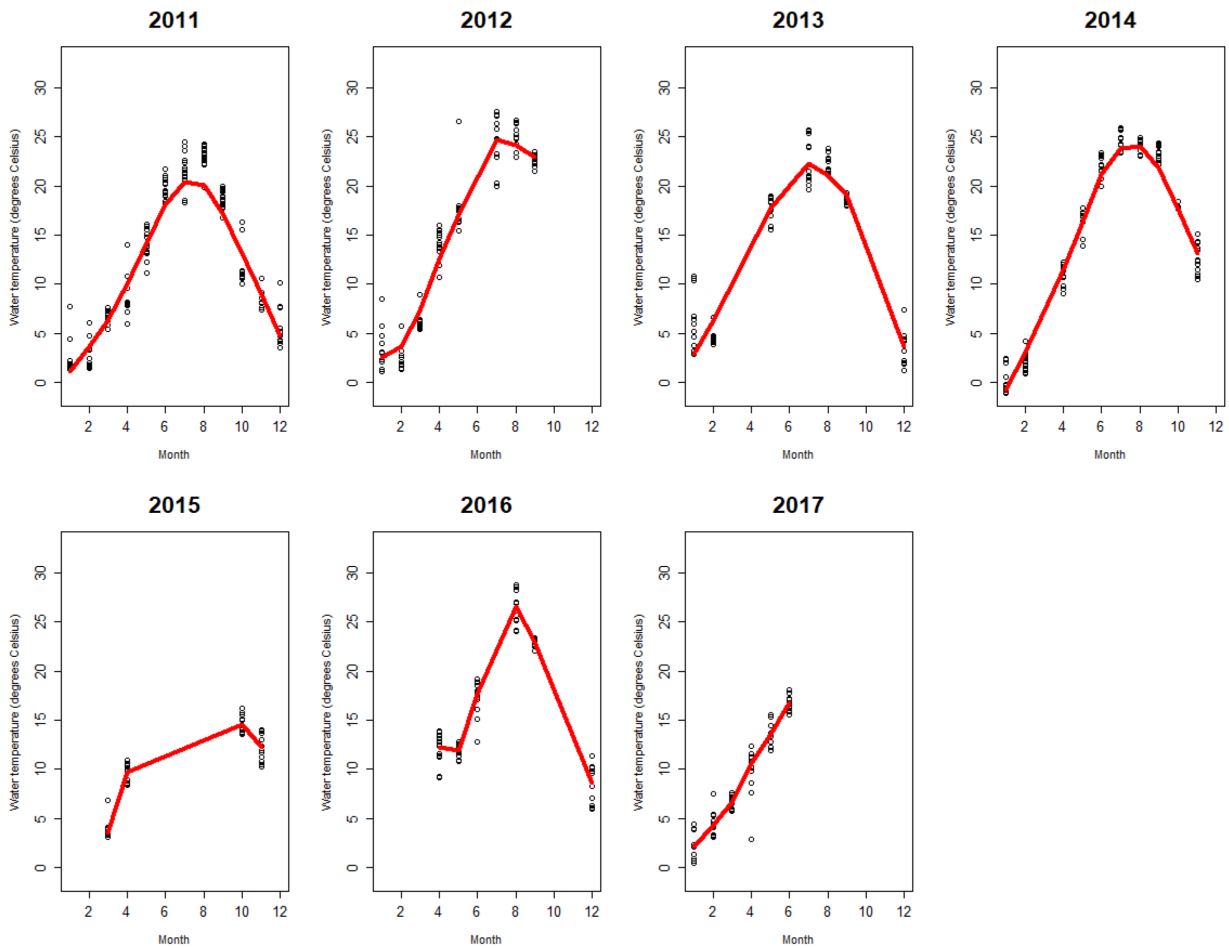
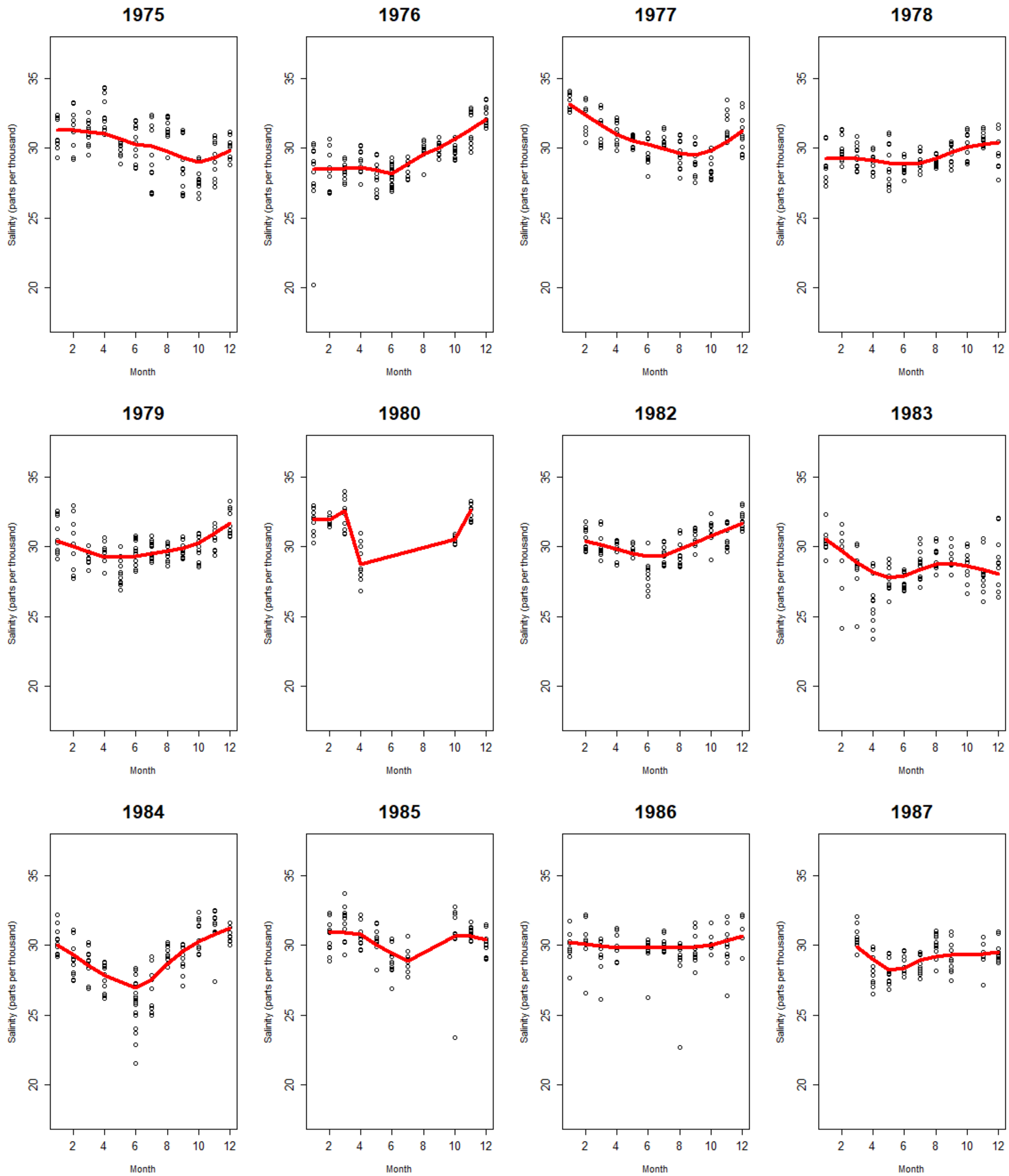
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
Water temperature (degrees Celsius)
0
5
10
15
20
25
30
Month
2
4
6
8
10
12

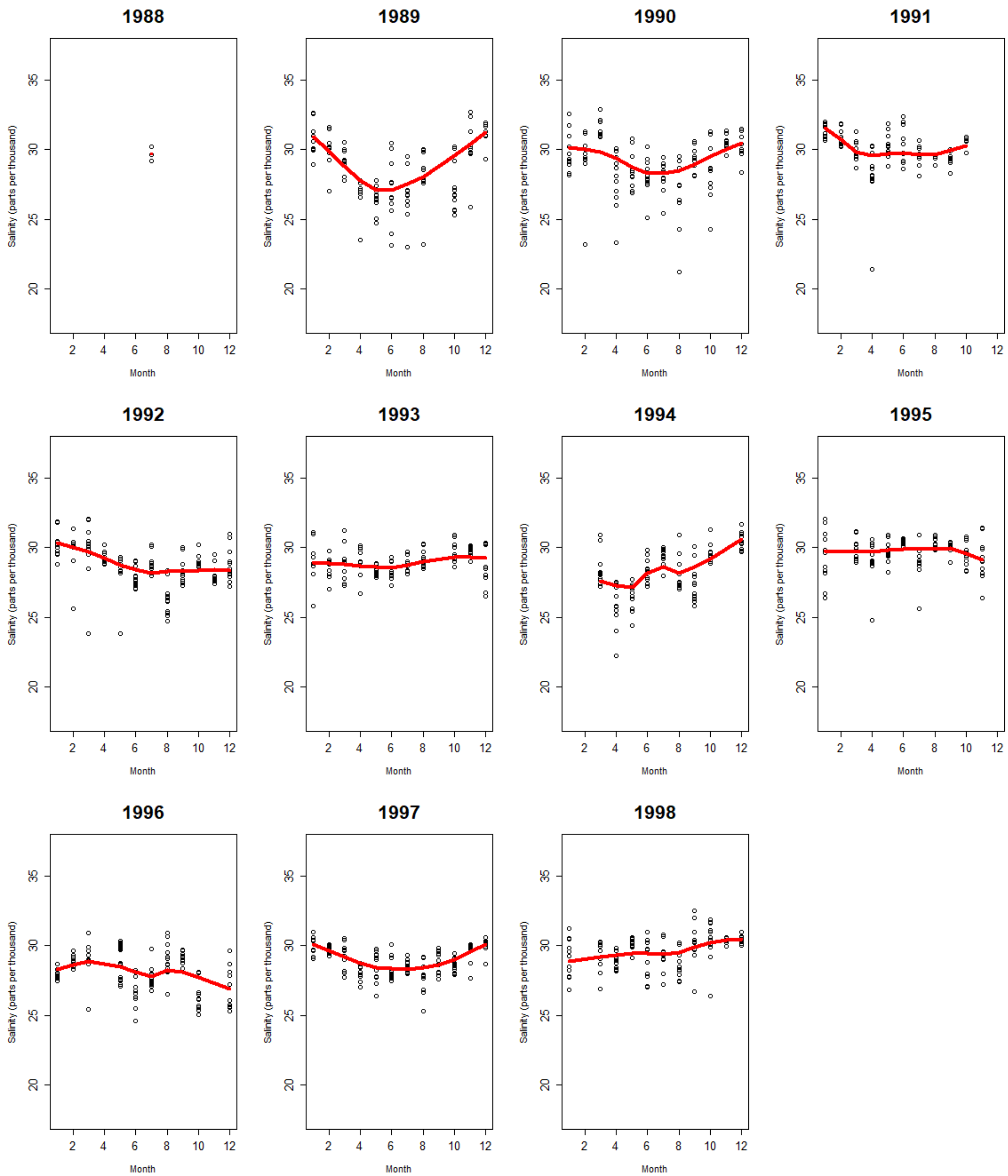

2011
2012
2013
2014
2015
2016
2017
Water temperature (degrees Celsius)
Month

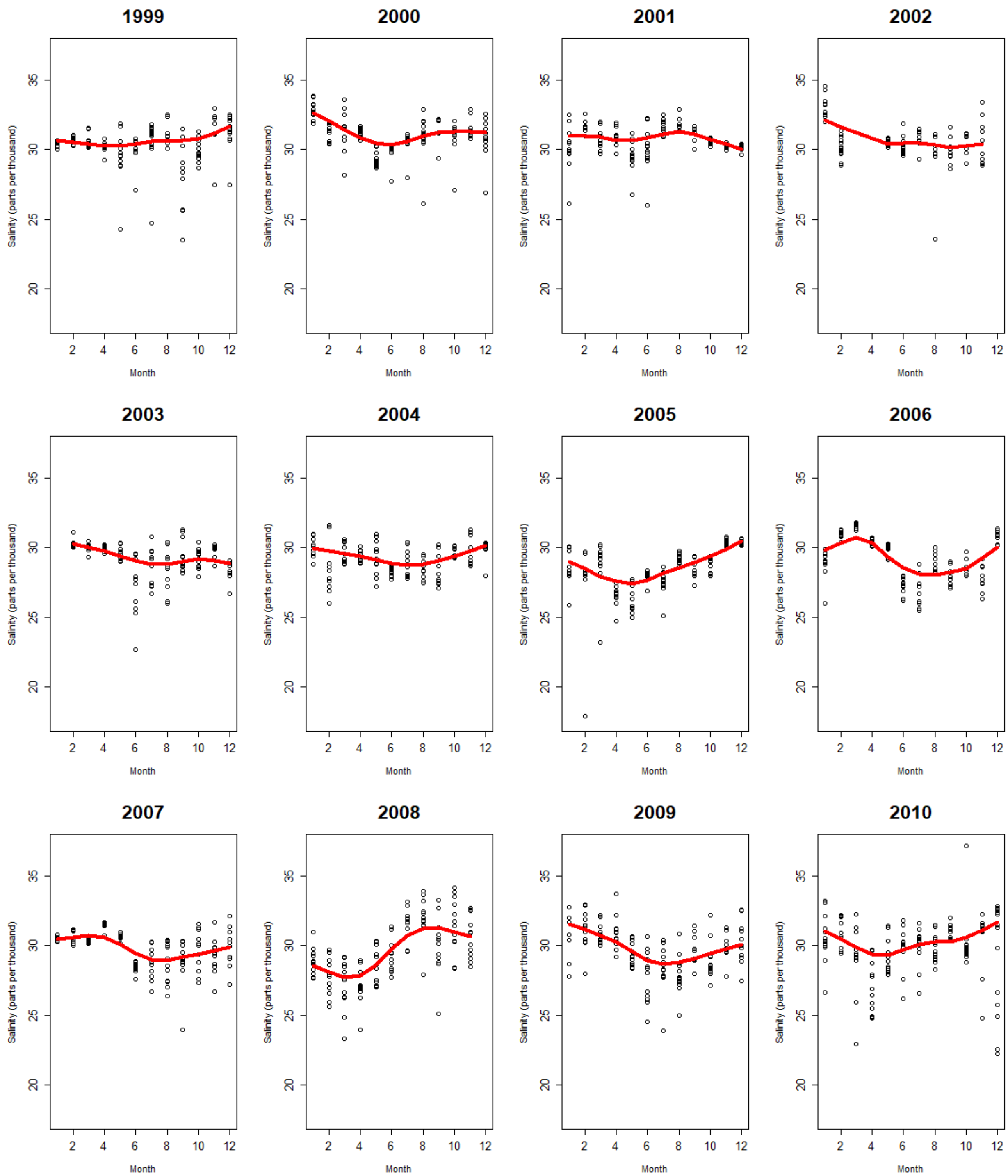
***

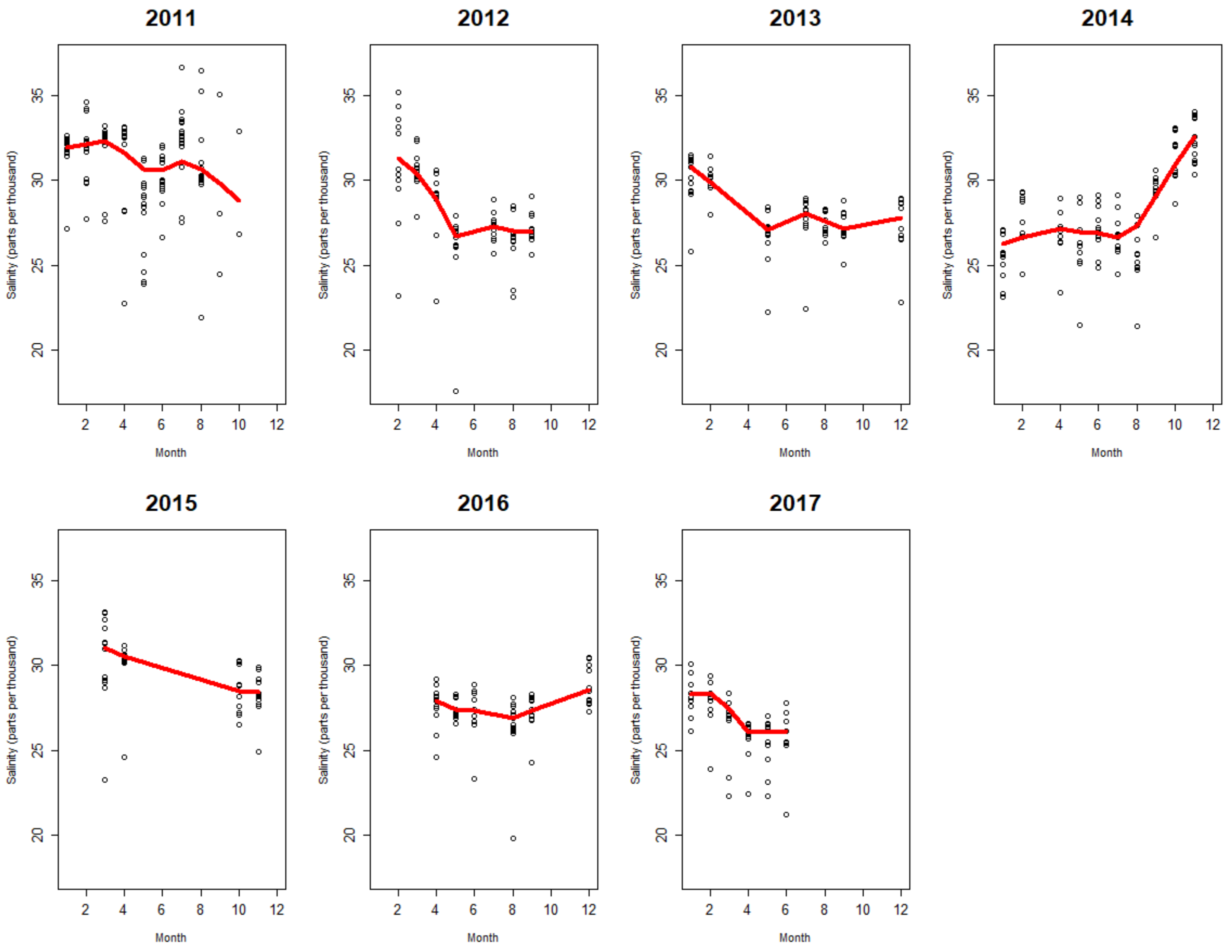
Salinity (parts per thousand)

variable: Salinity_PPT



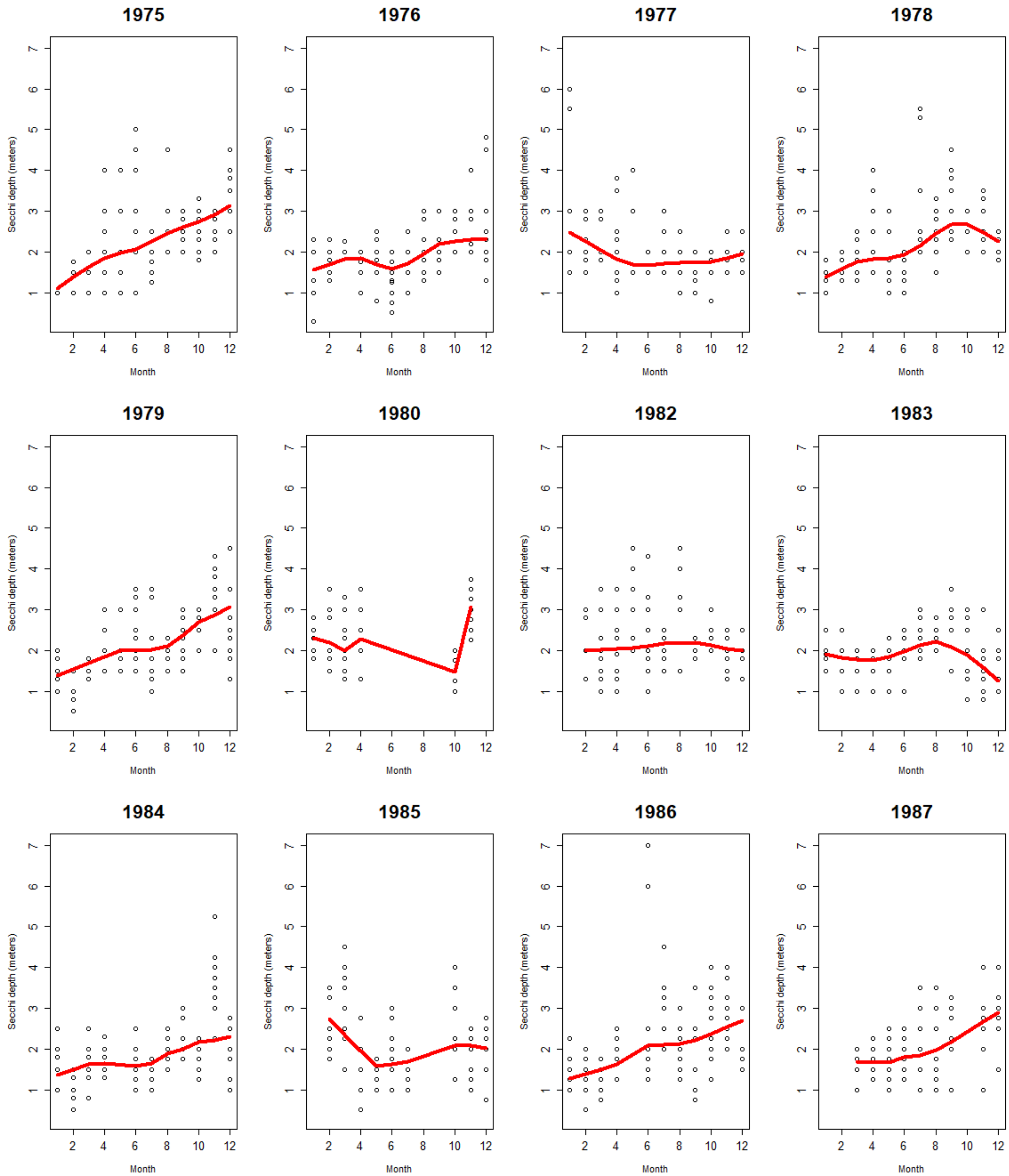

1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
Salinity (parts per thousand)
Month
20
25
30
35
2
4
6
8
10
12

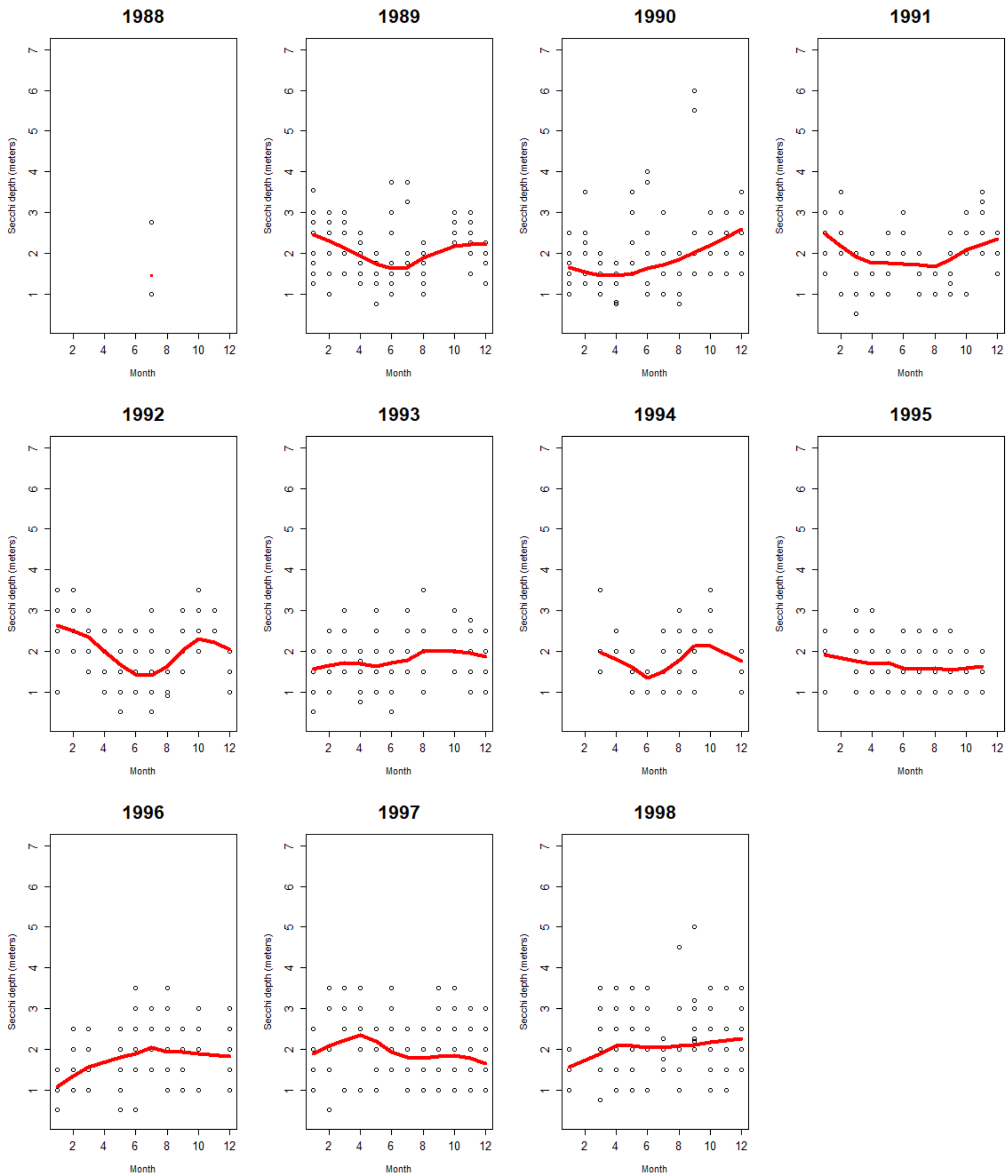

1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
Salinity (parts per thousand)
Month

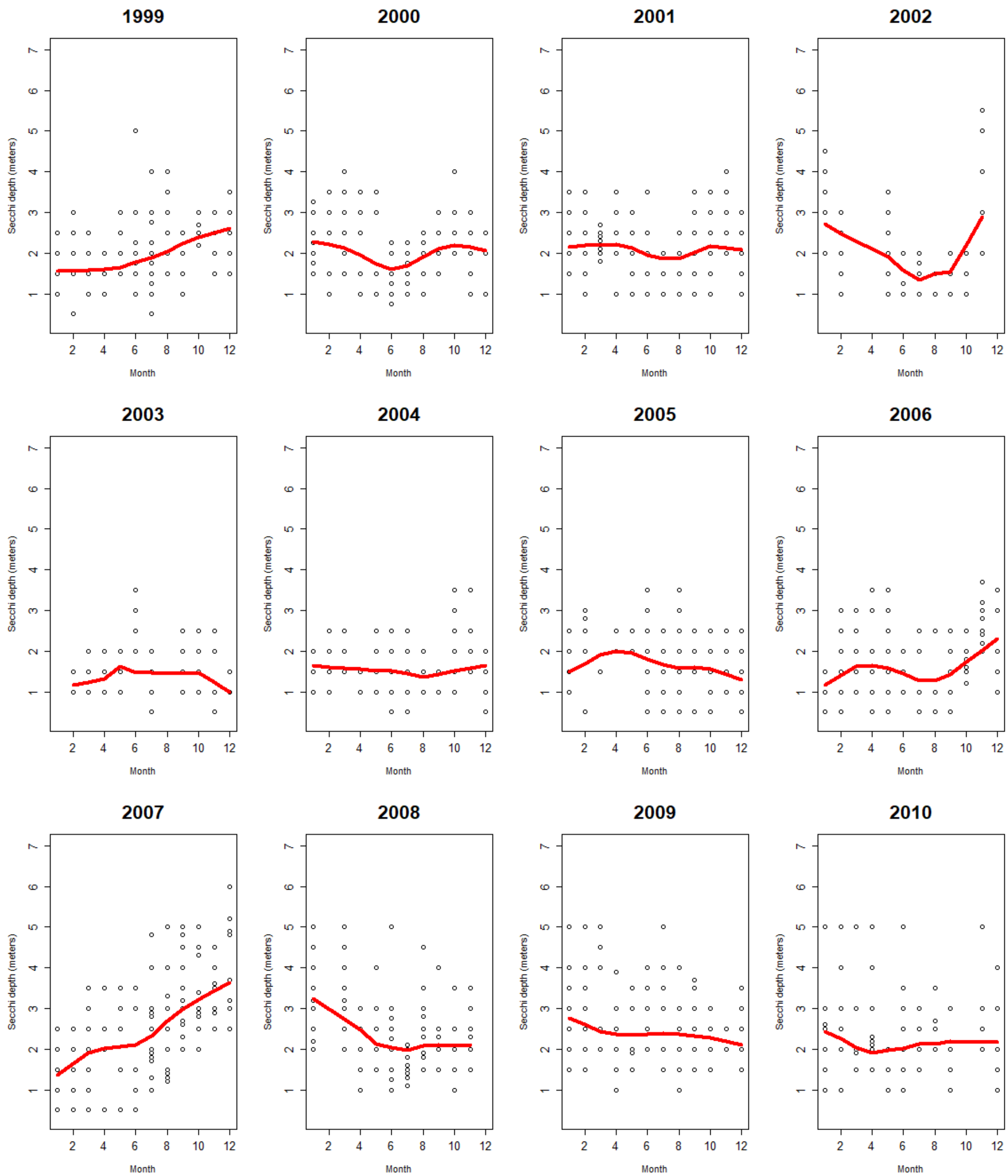

2011
2012
2013
2014
2015
2016
2017
Salinity (parts per thousand)
Month

Secchi depth (meters)

variable: Secchi_M




1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
Secchi depth (meters)
Month
1 2 3 4 5 6 7
2 4 6 8 10 12


1999
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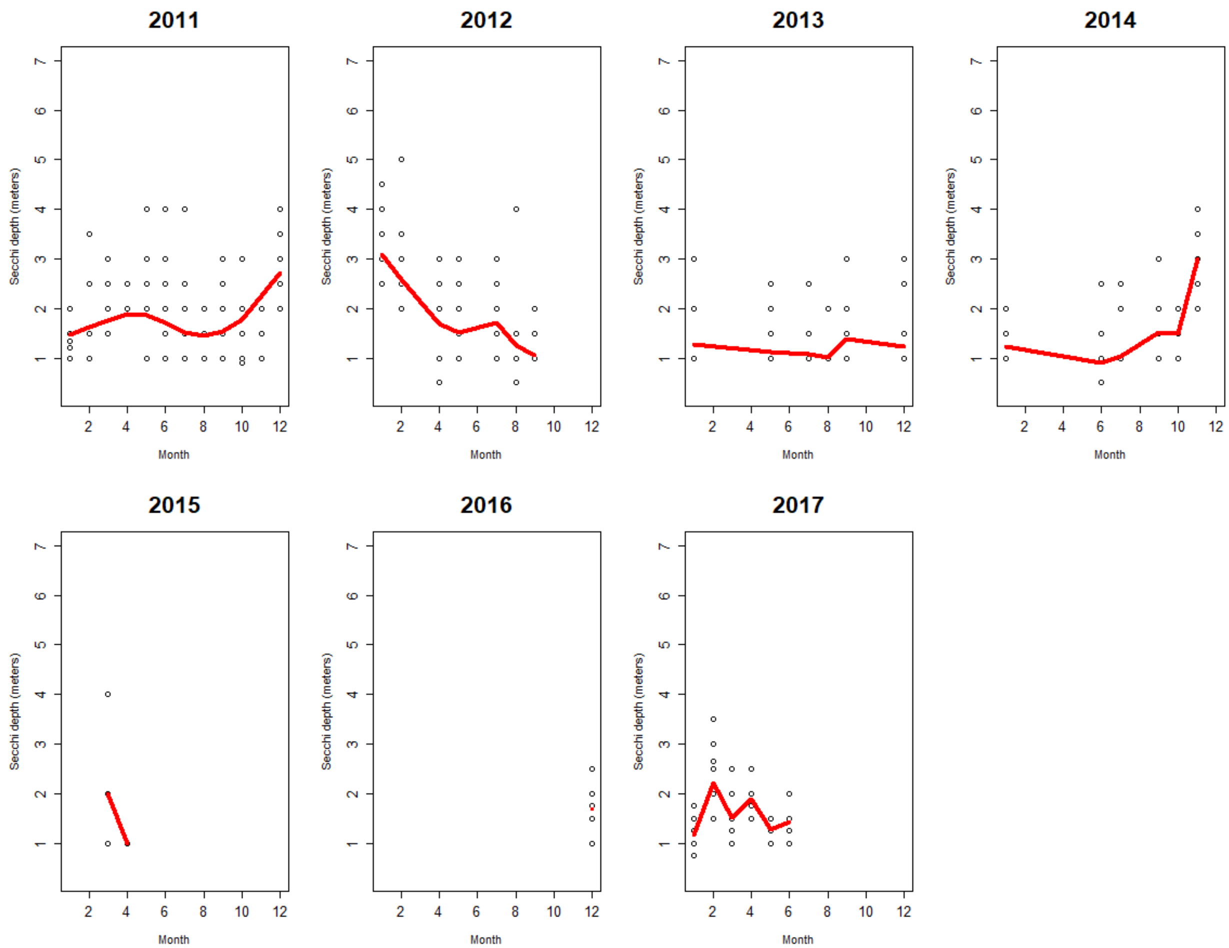
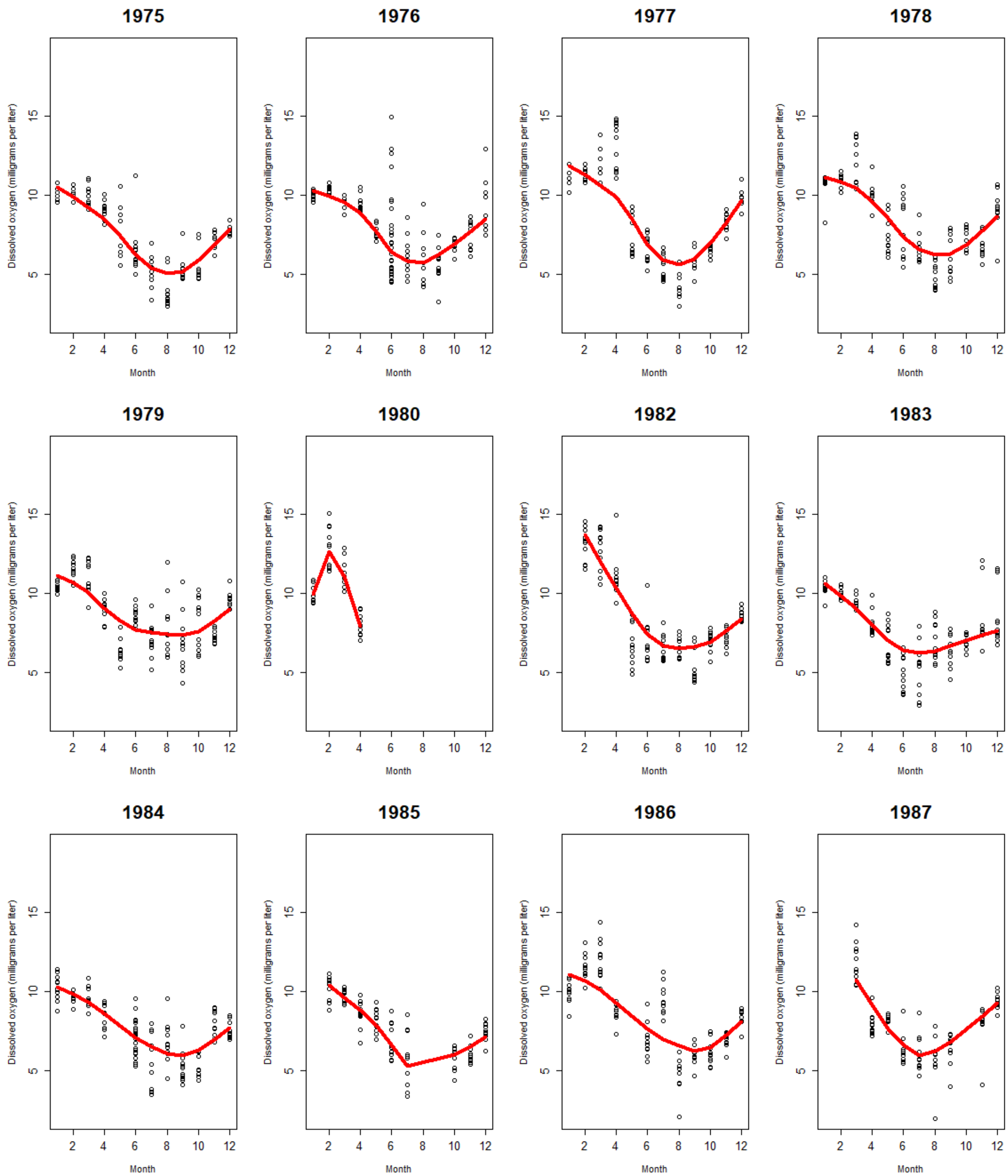
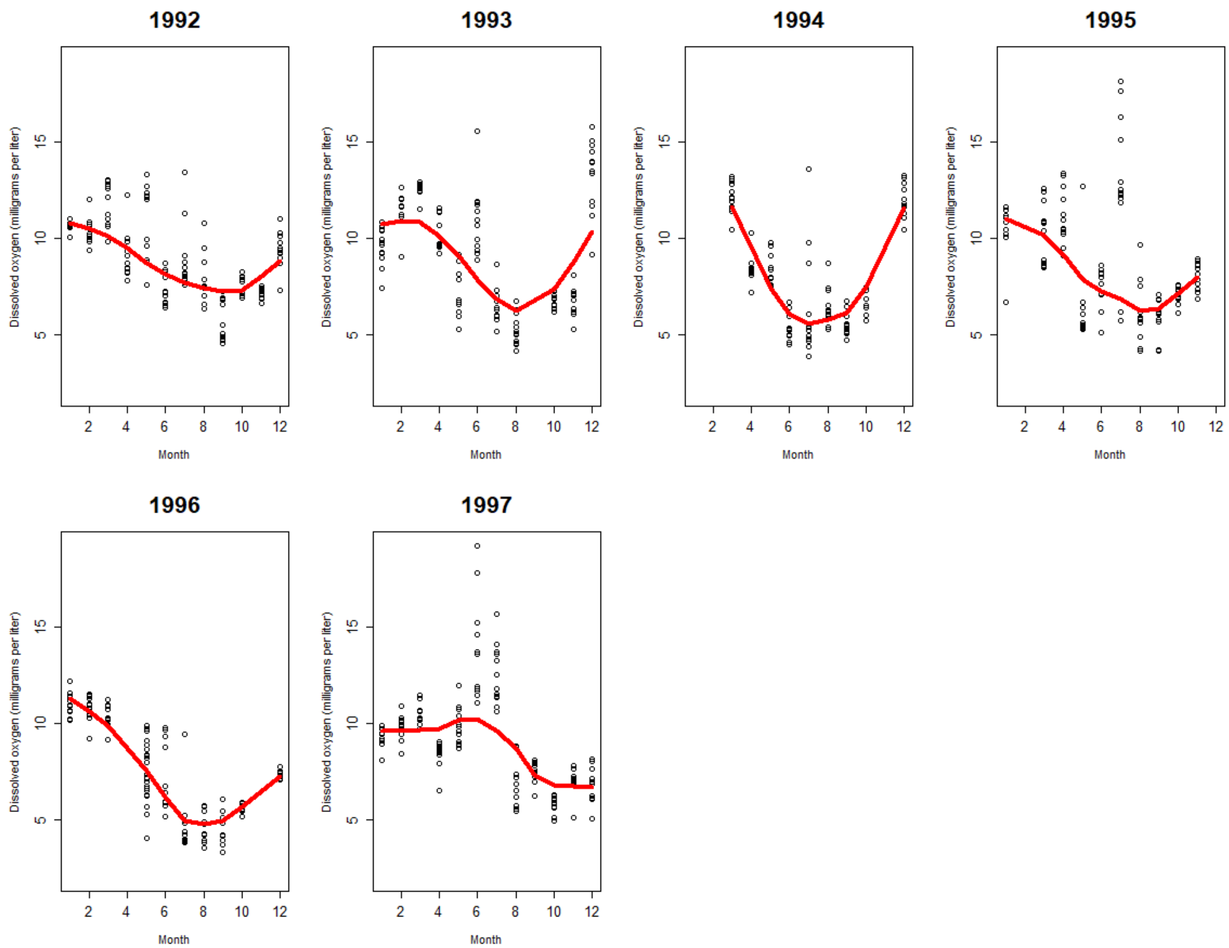
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
Secchi depth (meters)
Month

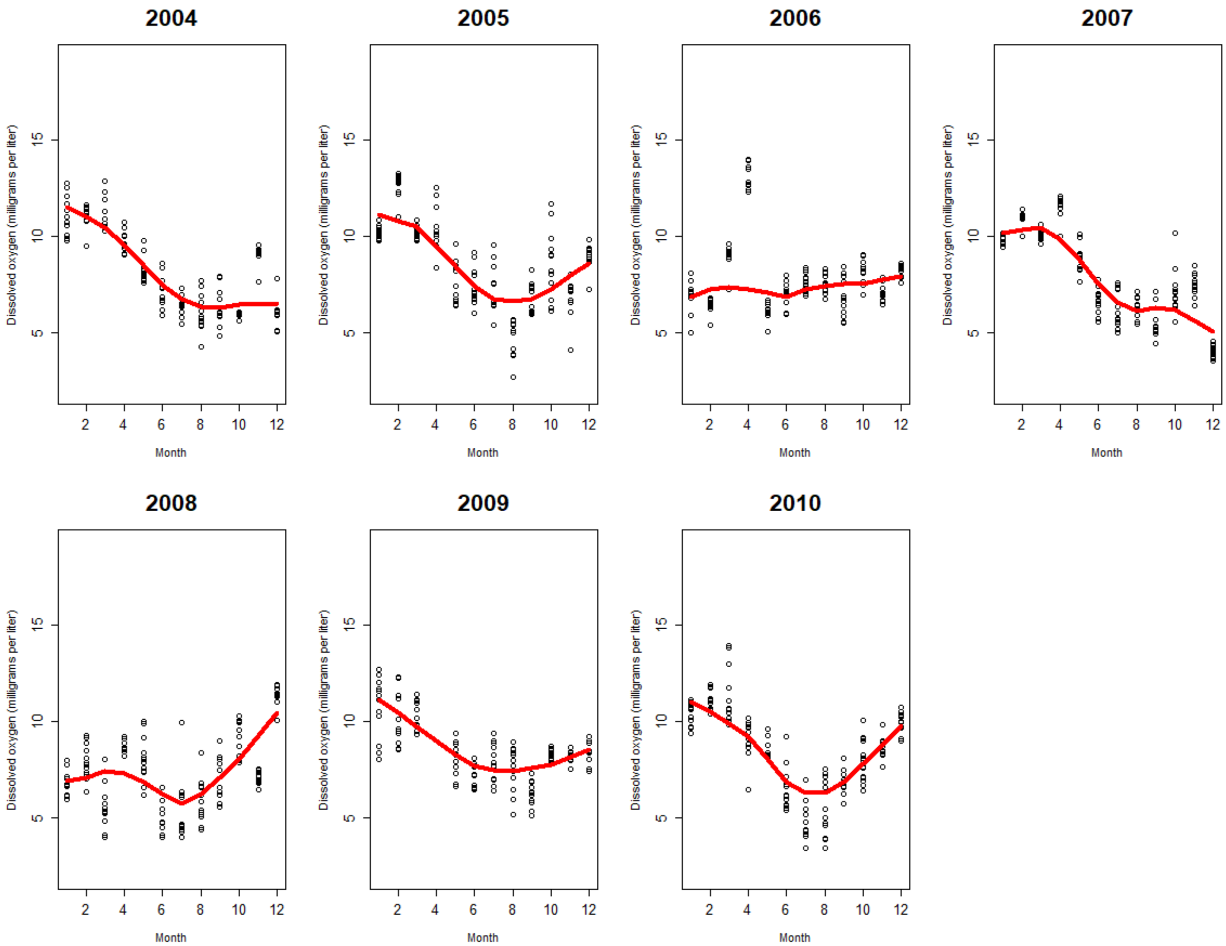

2011
2012
2013
2014
2015
2016
2017
Secchi depth (meters)
Month

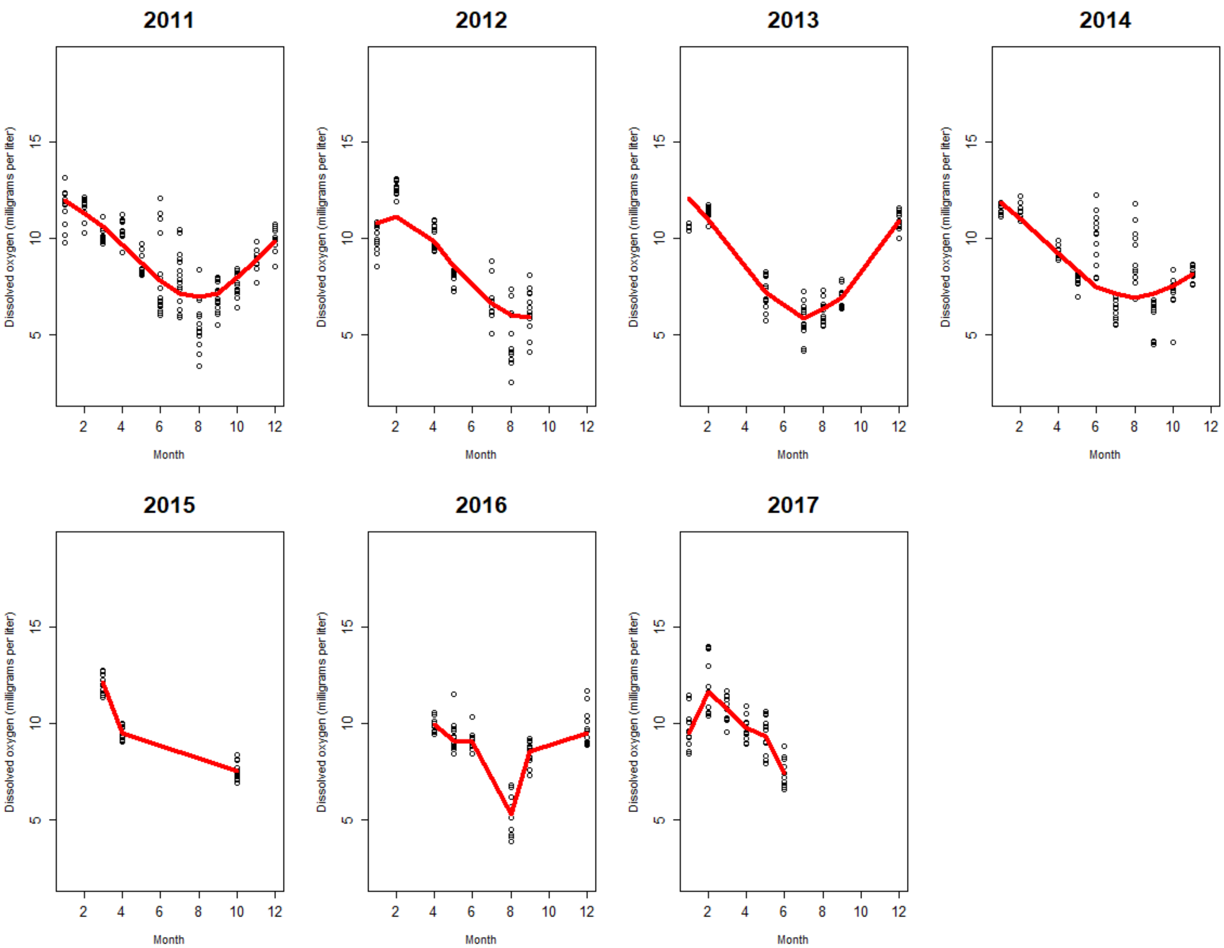
Dissolved oxygen (milligrams per liter)

variable: Disol_O2_mg_L



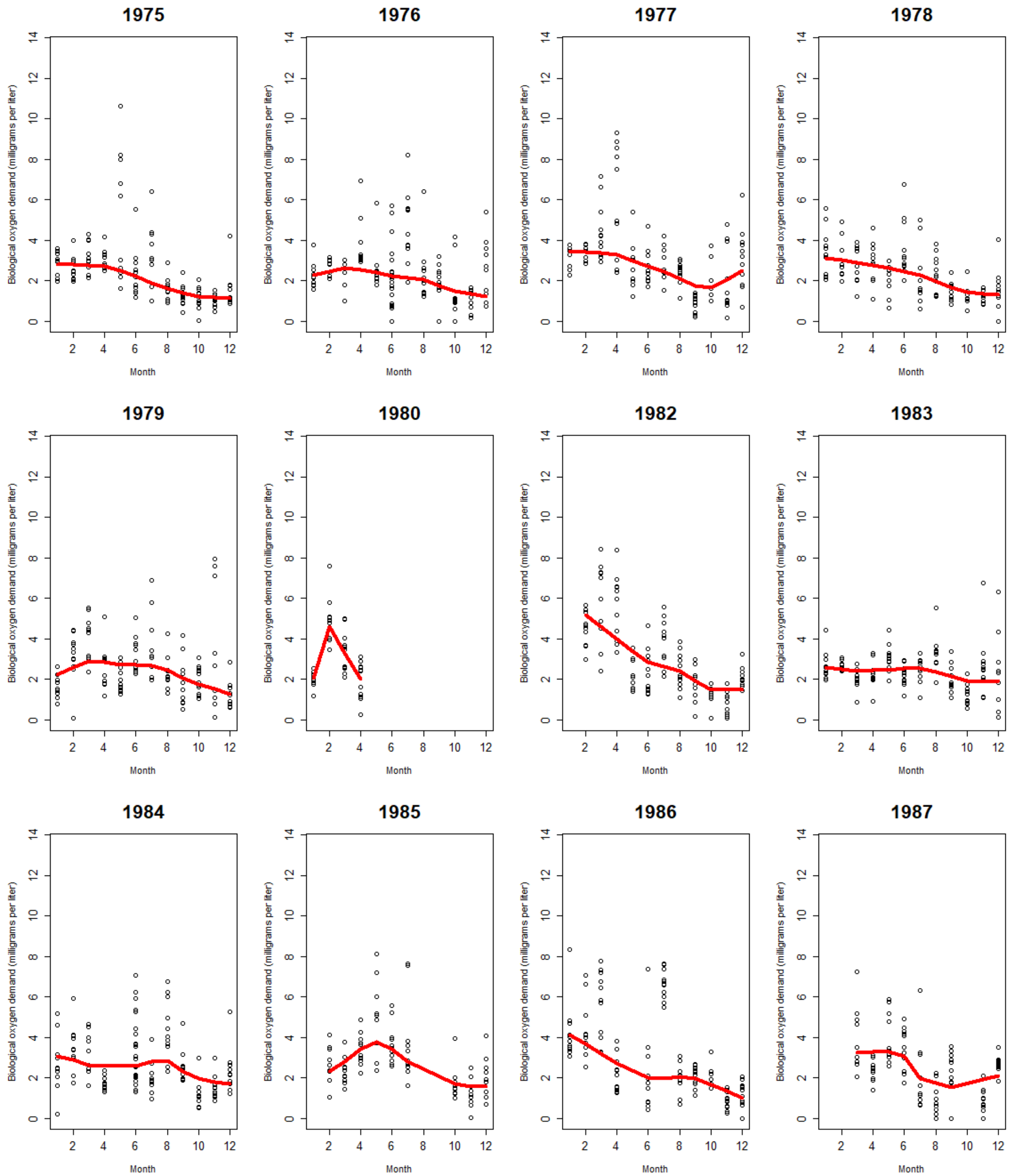

1992
1993
1994
1995
1996
1997
Dissolved oxygen (milligrams per liter)
5
10
15
Month
2
4
6
8
10
12

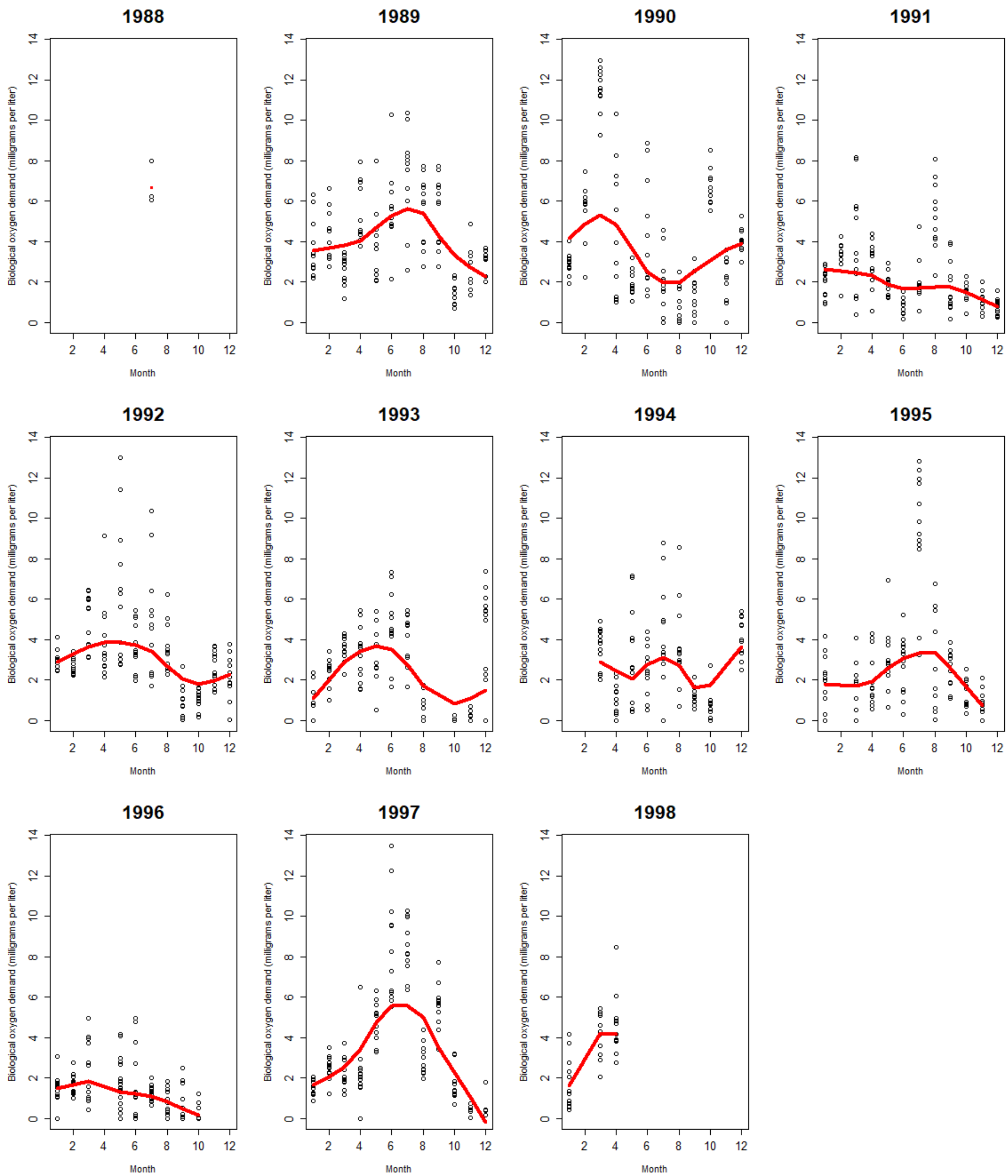

2004
2005
2006
2007
2008
2009
2010
Dissolved oxygen (milligrams per liter)
Month

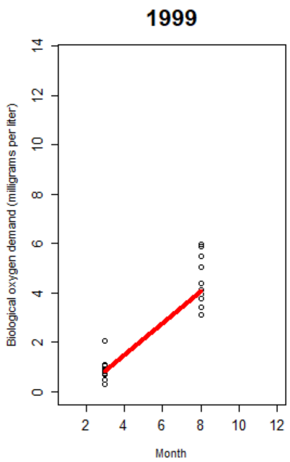

2011
2012
2013
2014
2015
2016
2017
Dissolved oxygen (milligrams per liter)
Month
5
10
15
2
4
6
8
10
12

Biological oxygen demand (BOD) (milligrams per liter)

variable: BOD

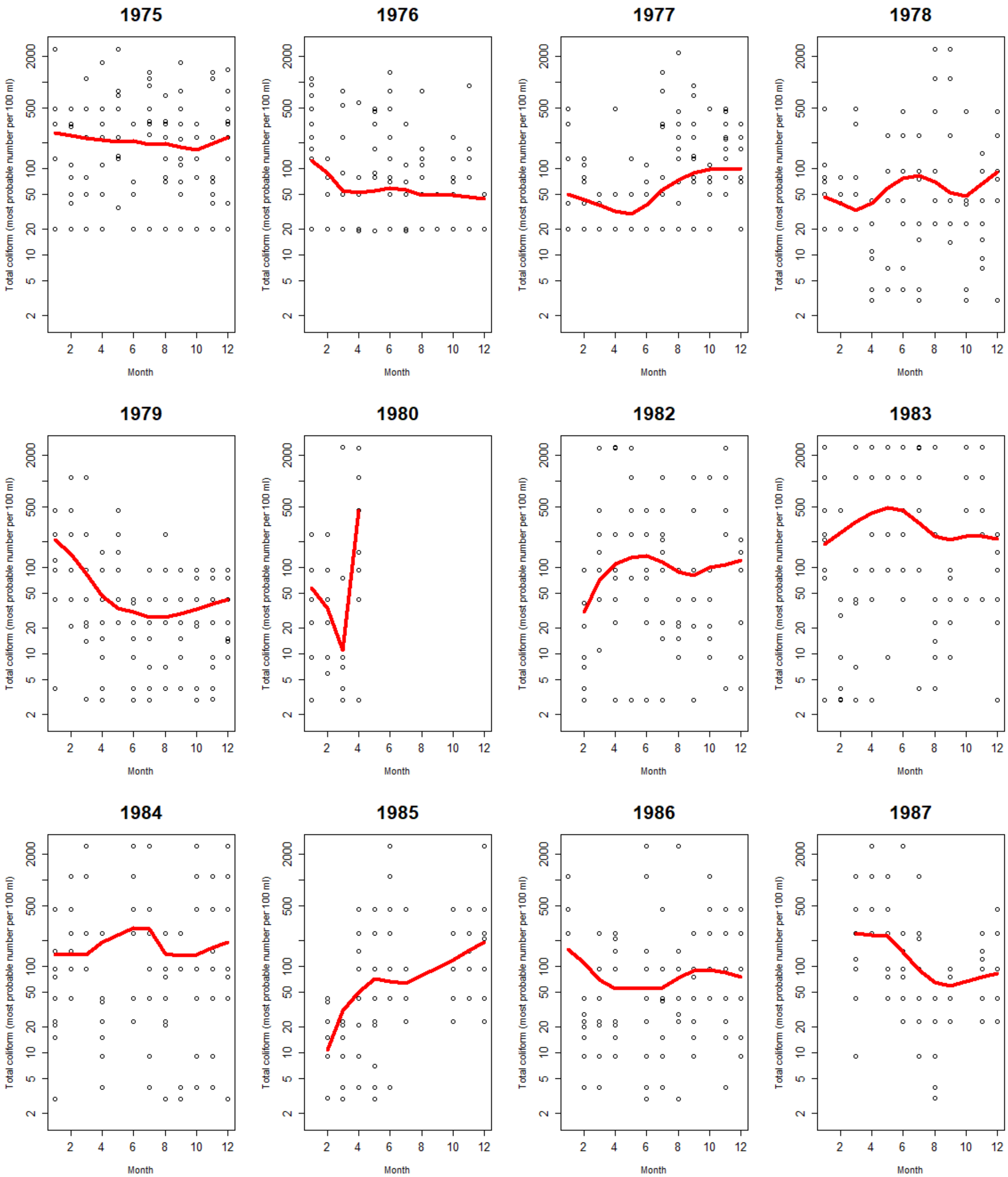


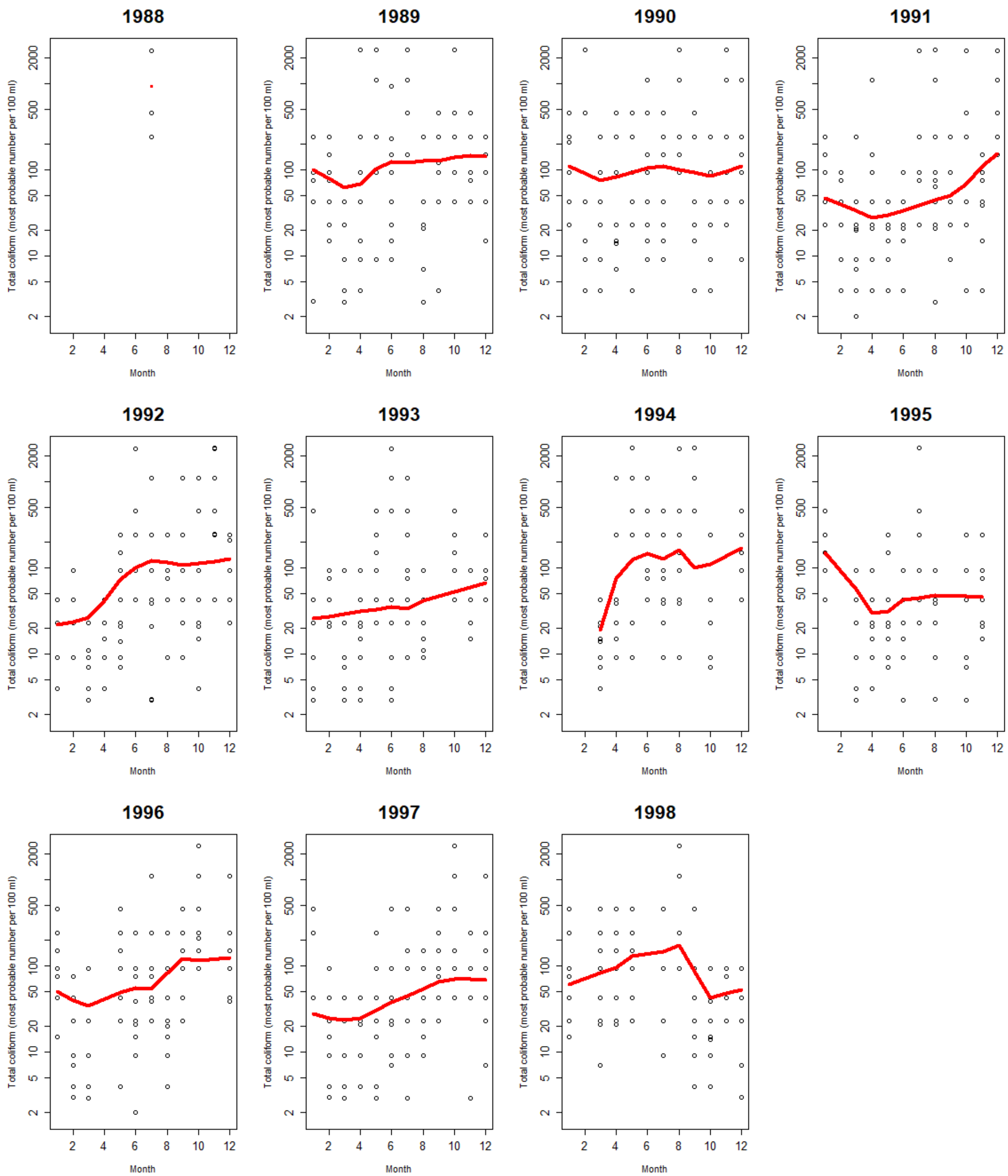

1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
Biological oxygen demand (milligrams per liter)
Month

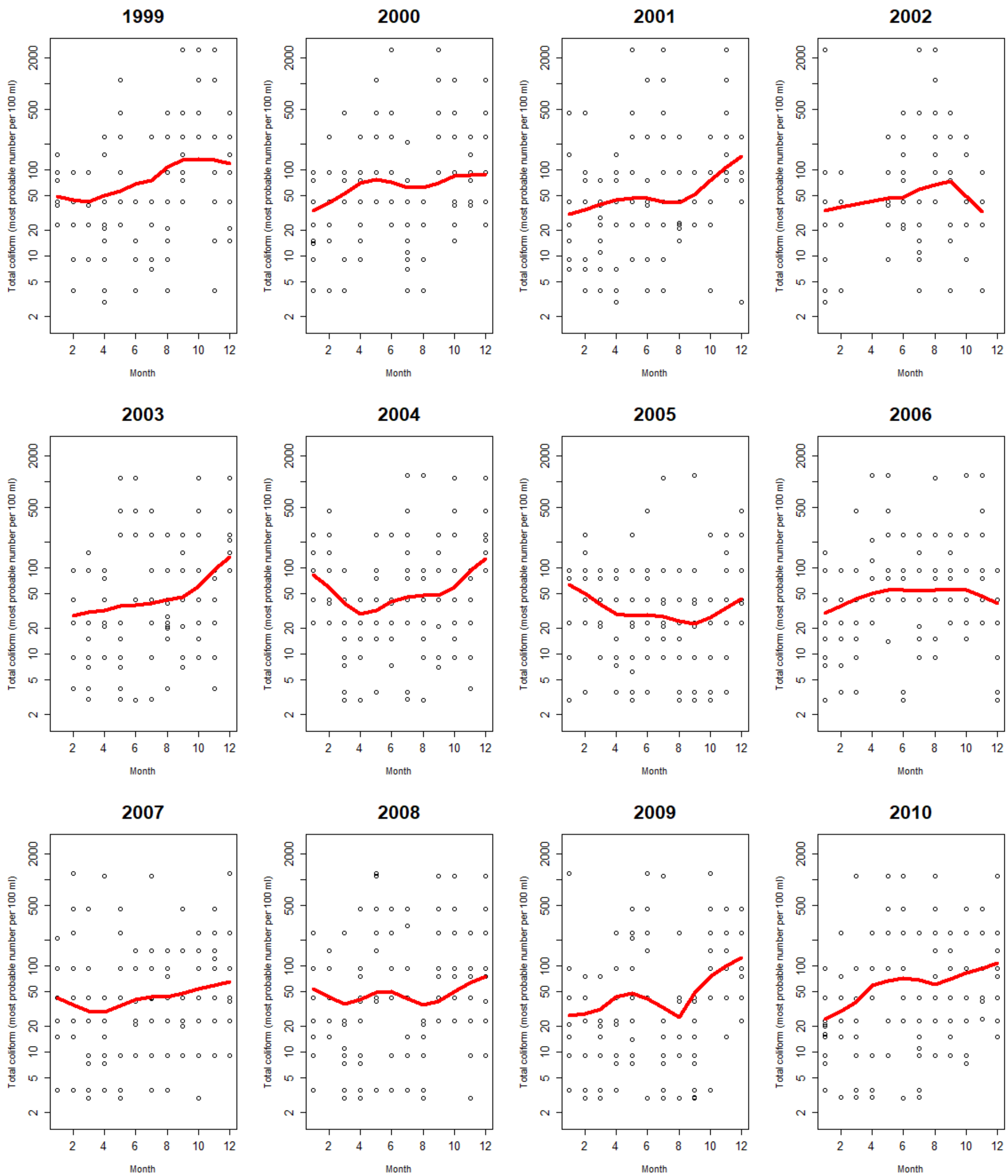

1999
Biological oxygen demand (milligrams per liter)
0
2
4
6
8
10
12
14
2
4
6
8
10
12
Month

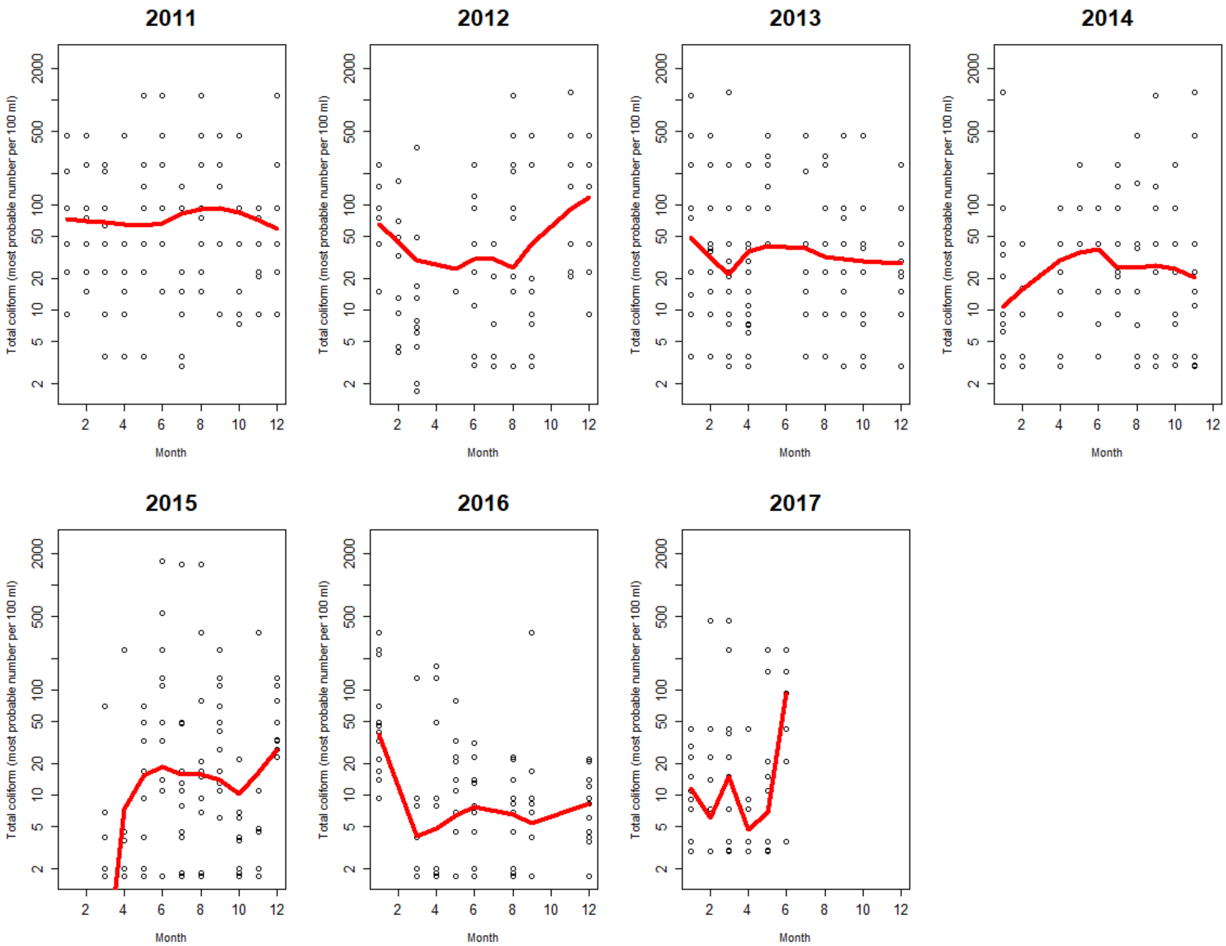
Total coliform (most probable number per 100 ml)

variable: MPN_colfm_100ml



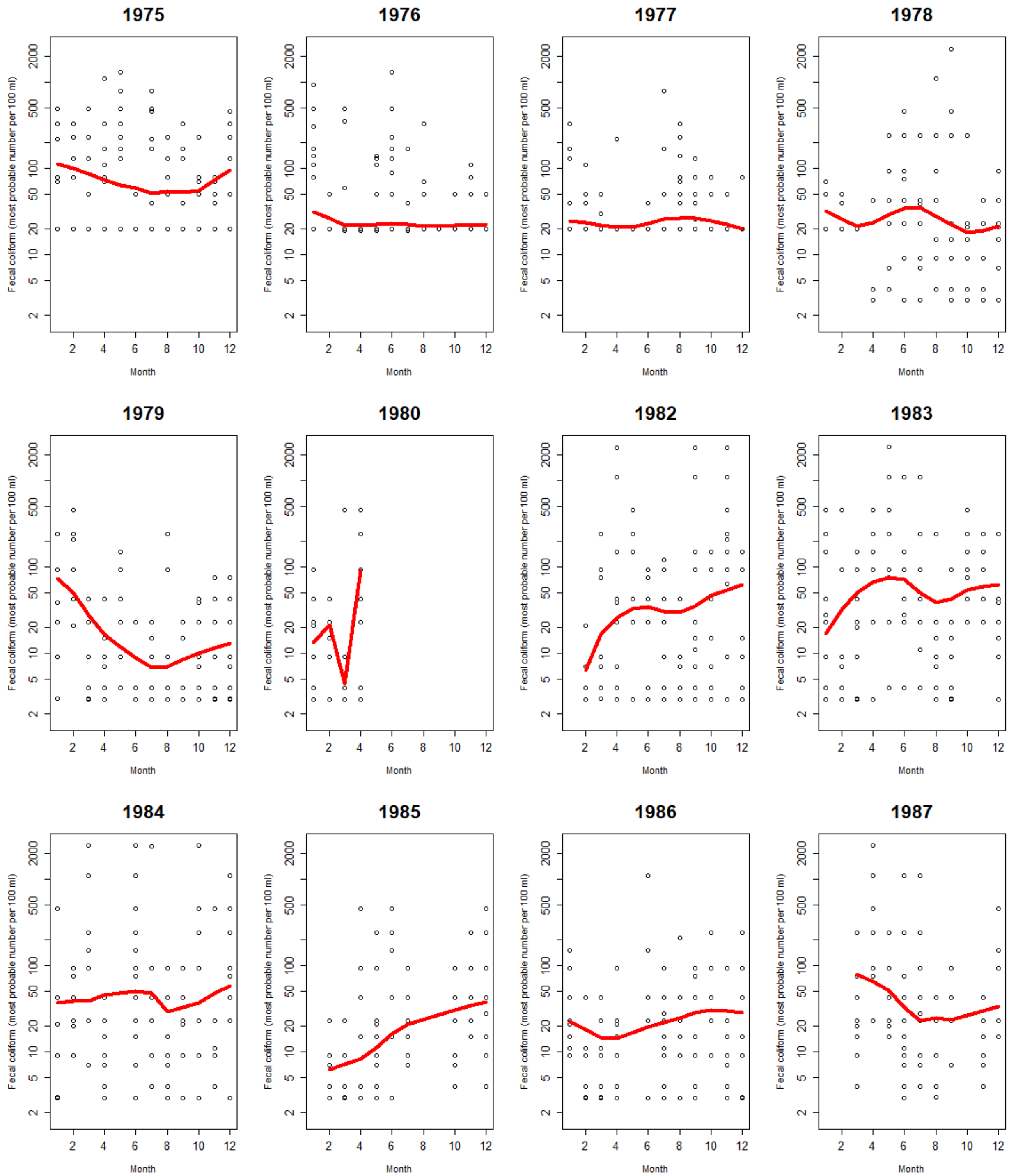

1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
Total coliform (most probable number per 100 ml)
2 5 10 20 50 100 500 2000
Month
2 4 6 8 10 12

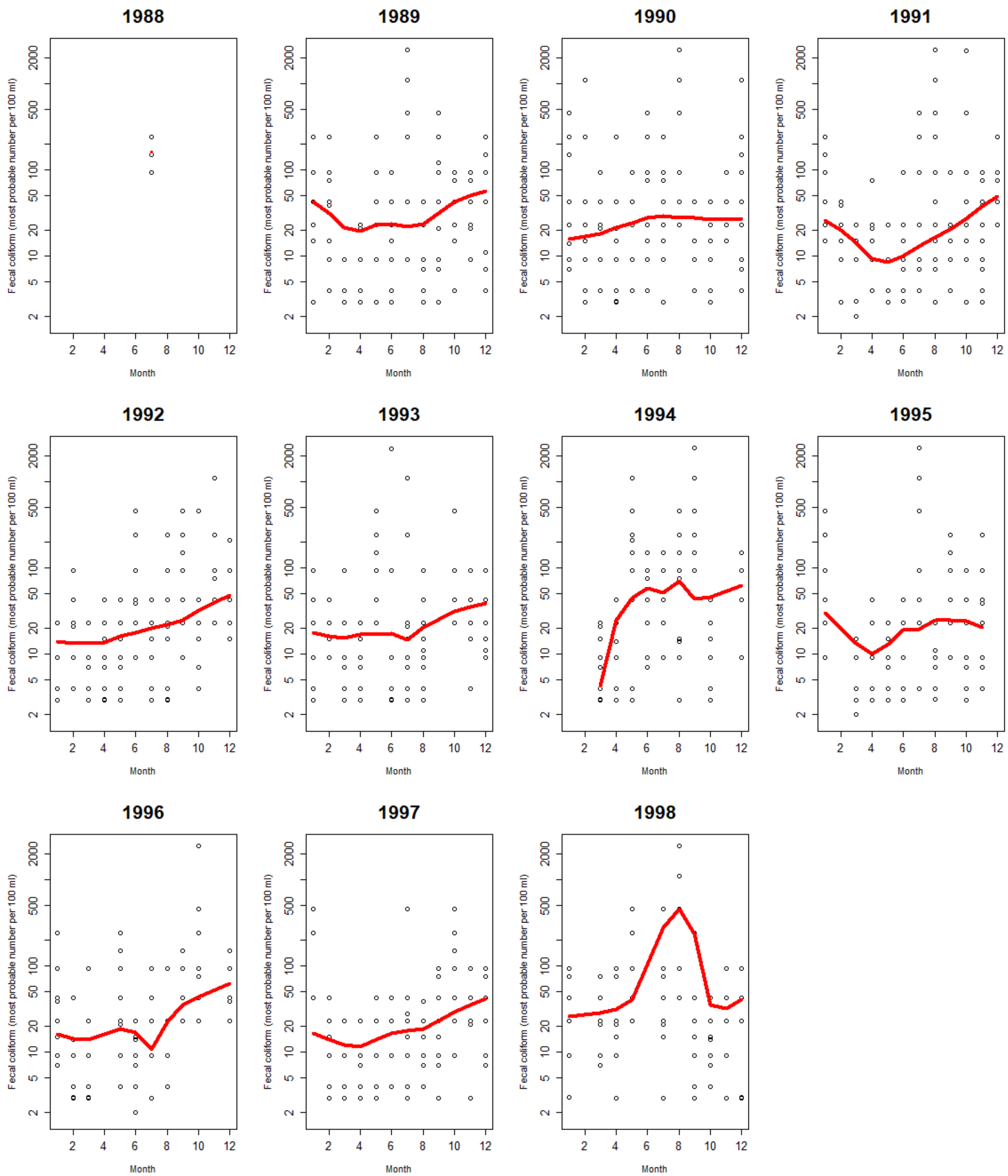

1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
Total coliform (most probable number per 100 ml)
Month

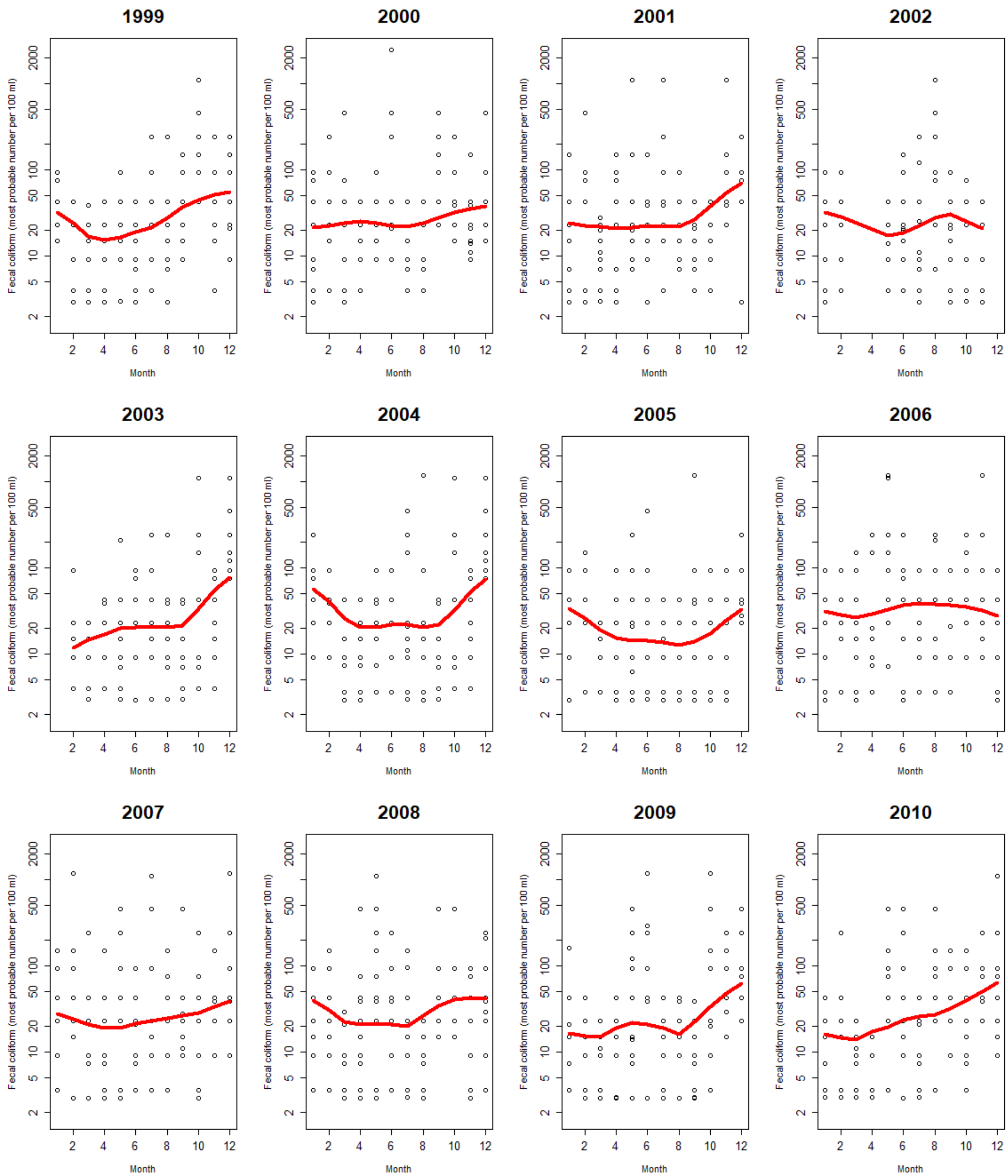

2011
2012
2013
2014
2015
2016
2017
Total coliform (most probable number per 100 ml)
Month
2
5
10
20
50
100
500
2000
2
4
6
8
10
12

Fecal coliform (most probable number per 100 ml)

variable: MPN_Fecal_100ml




1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
Fecal coliform (most probable number per 100 ml)
2 5 10 20 50 100 500 2000
Month
2 4 6 8 10 12


1999
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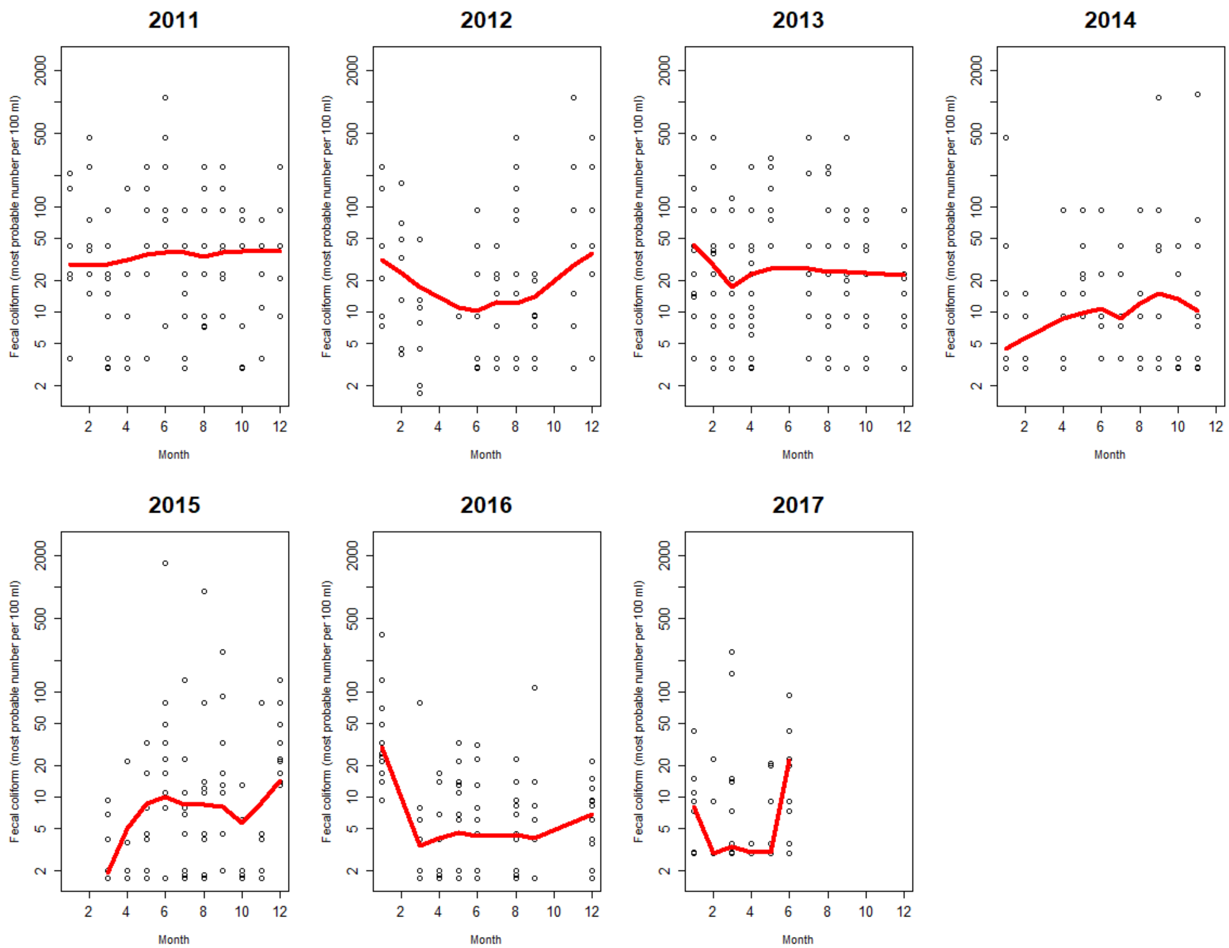
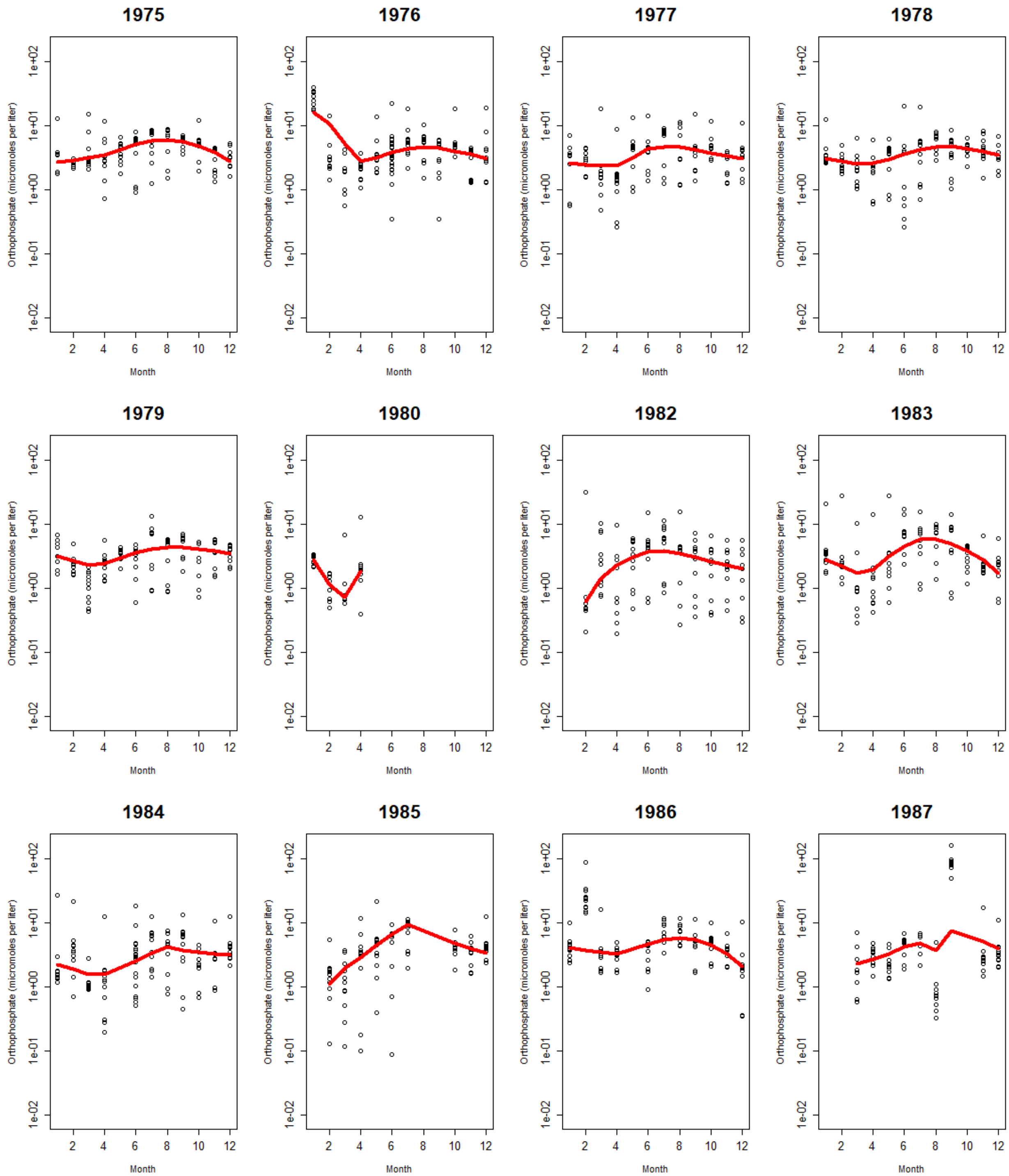
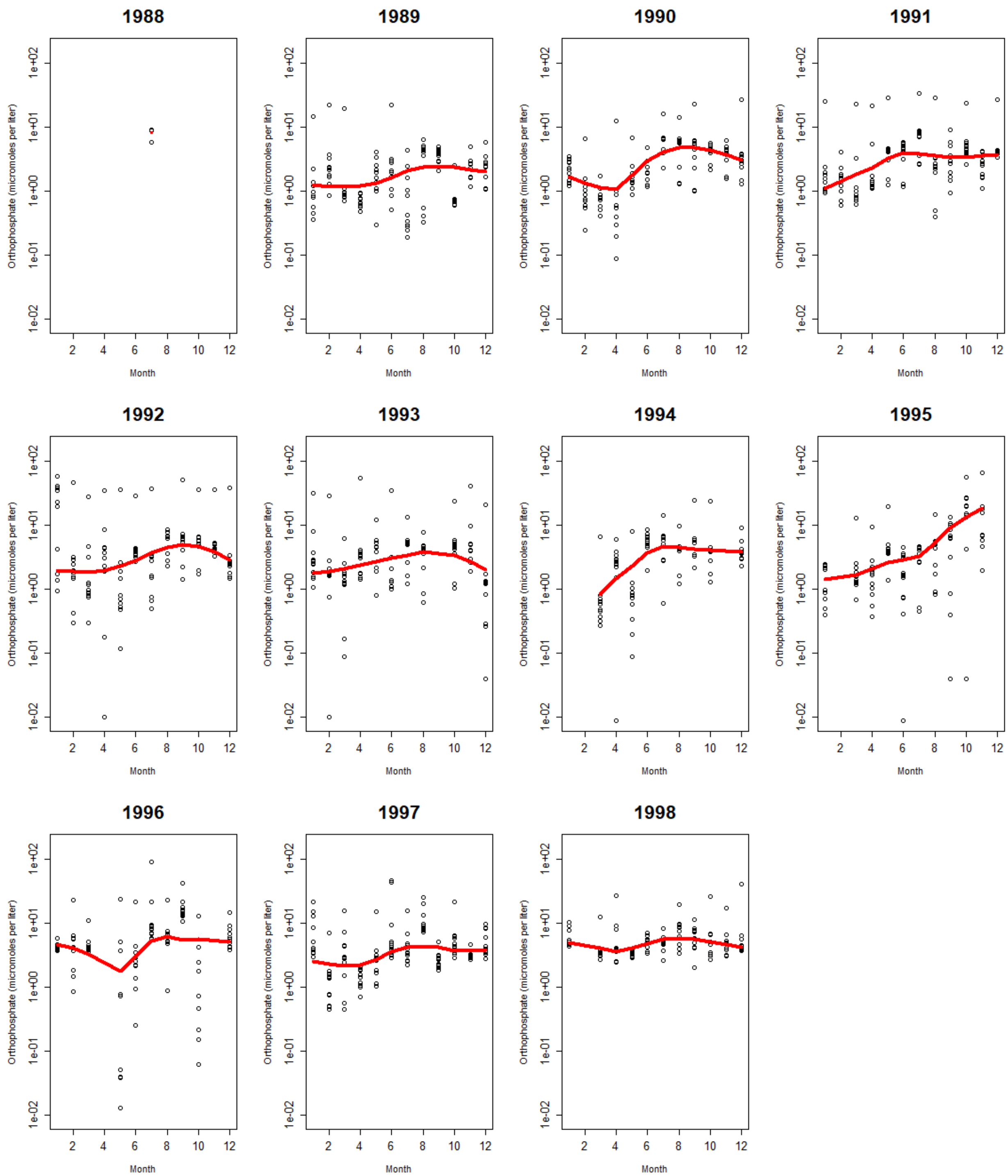
2006
2007
2008
2009
2010
Fecal coliform (most probable number per 100 ml)
Month

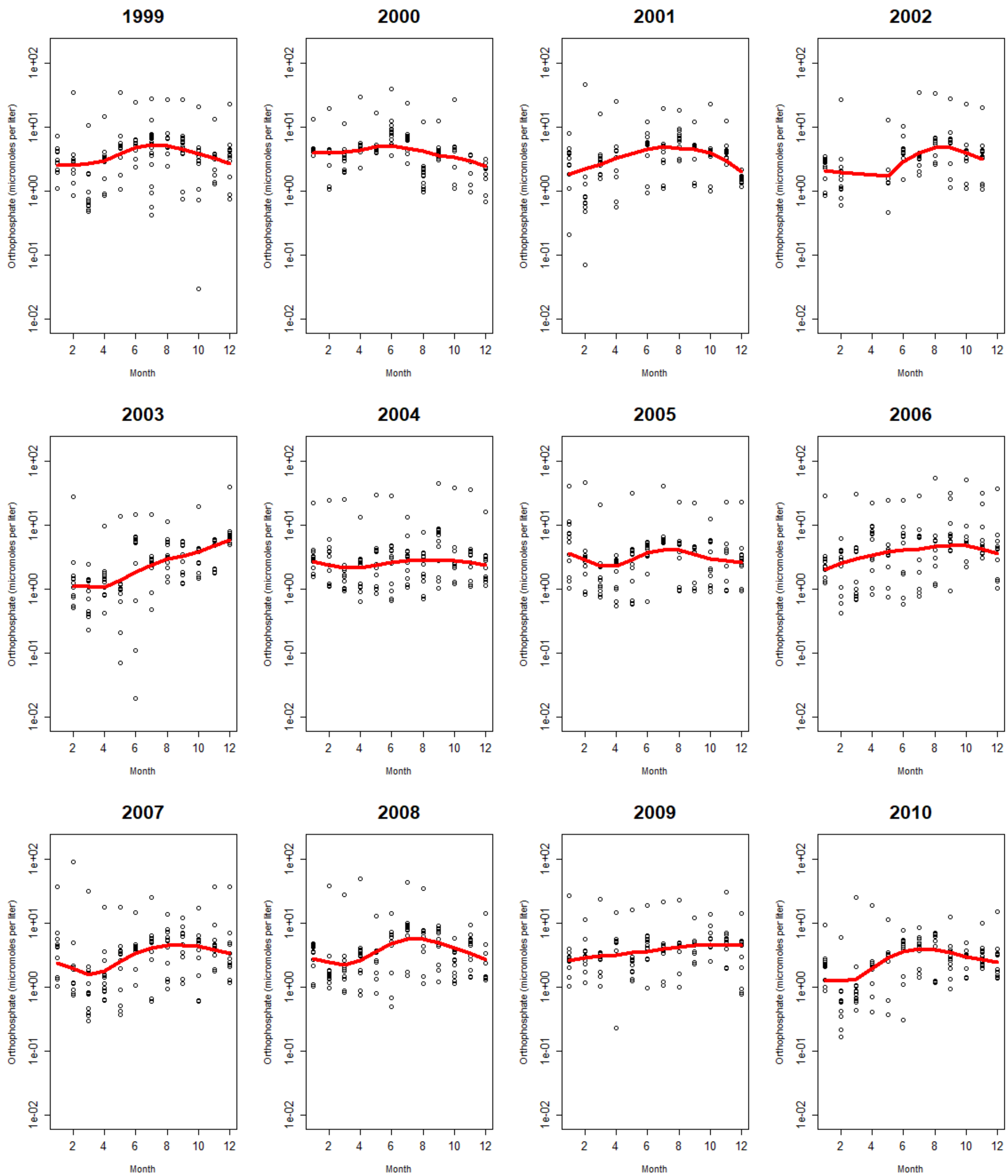

2011
2012
2013
2014
2015
2016
2017
Fecal coliform (most probable number per 100 ml)
2
5
10
20
50
100
500
2000
Month
2
4
6
8
10
12

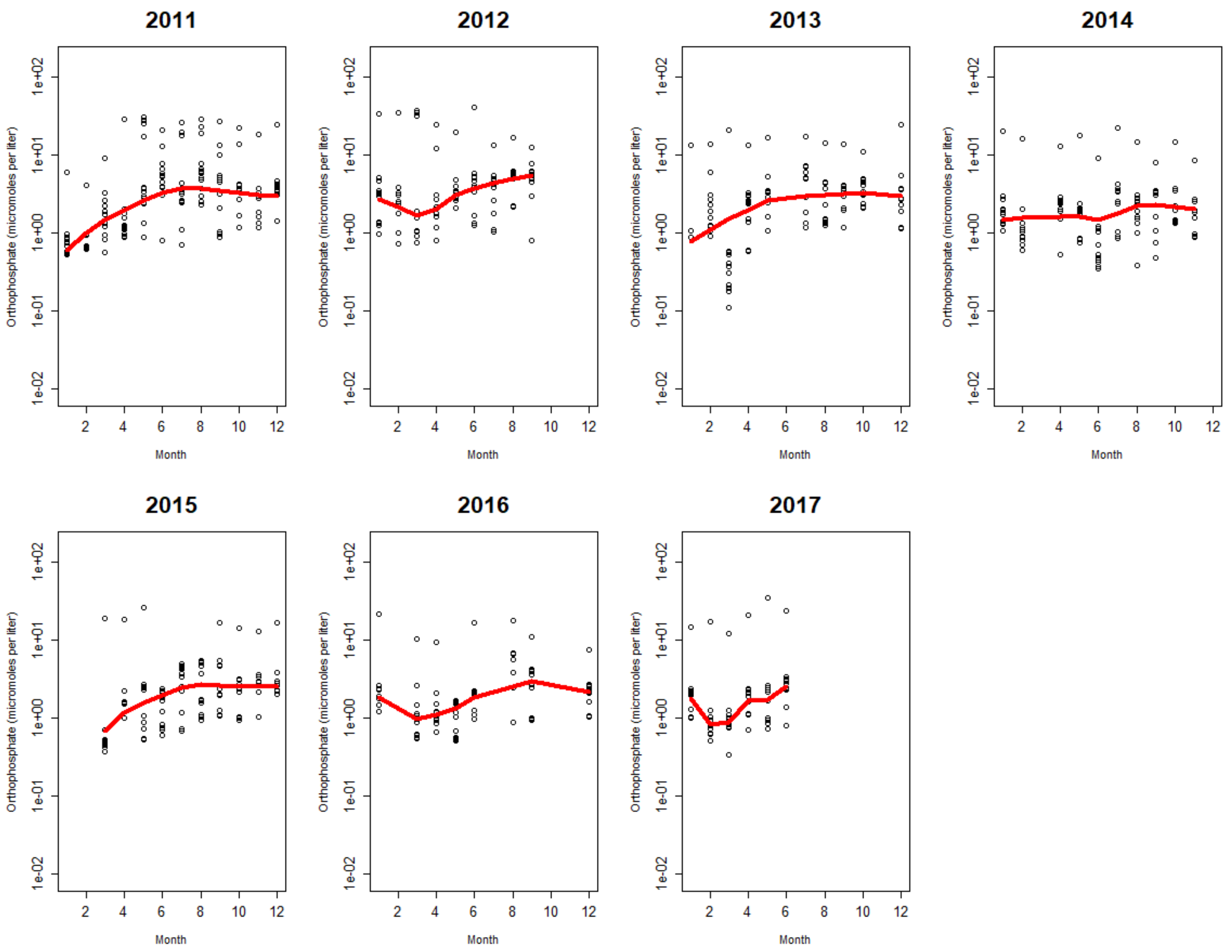
Orthophosphate (micromoles per liter)

variable: OrthoPhos_umol_L



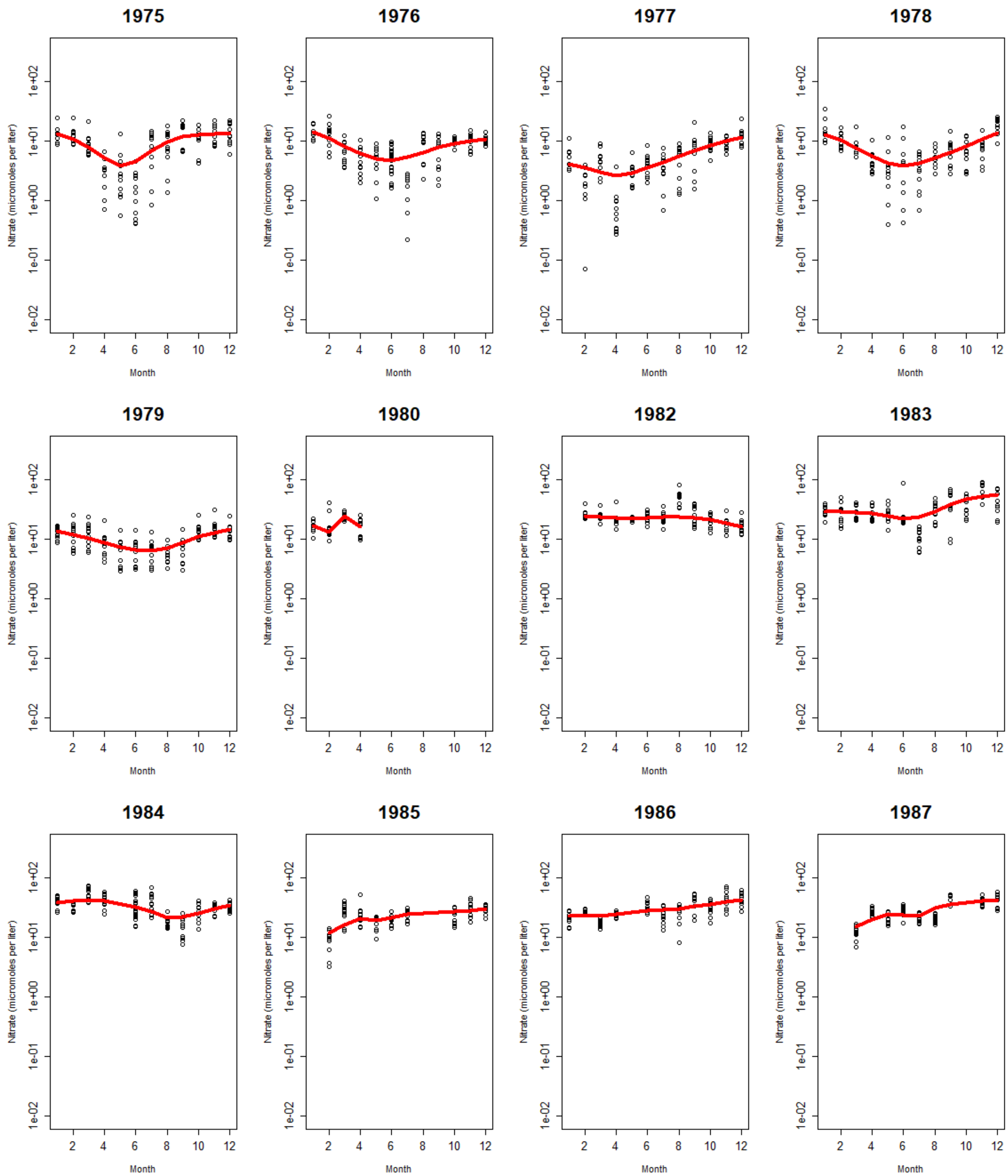

1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
Orthophosphate (micromoles per liter)
1e-02
1e-01
1e+00
1e+01
1e+02
Month
2
4
6
8
10
12

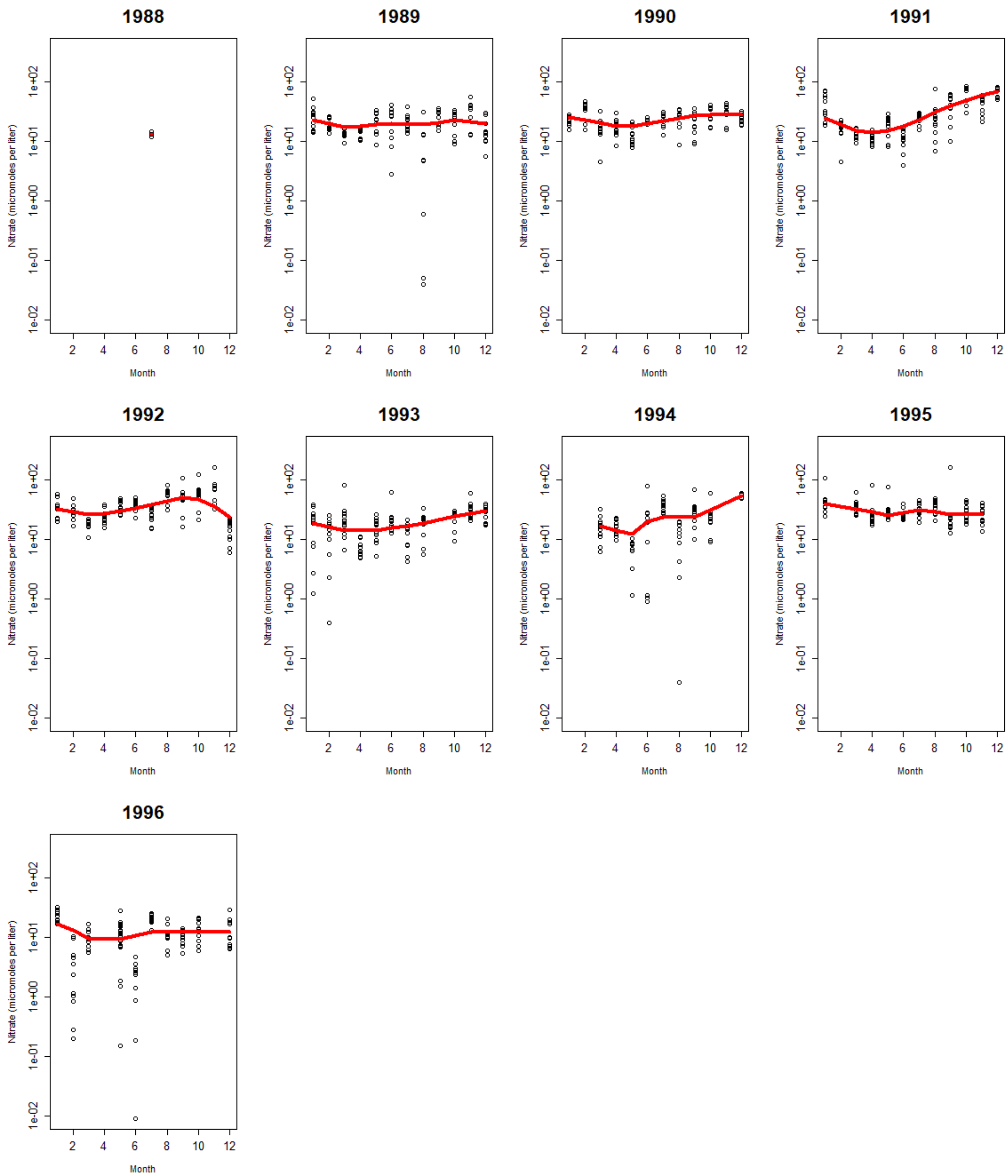

1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
Orthophosphate (micromoles per liter)
1e-02
1e-01
1e+00
1e+01
1e+02
Month
2
4
6
8
10
12

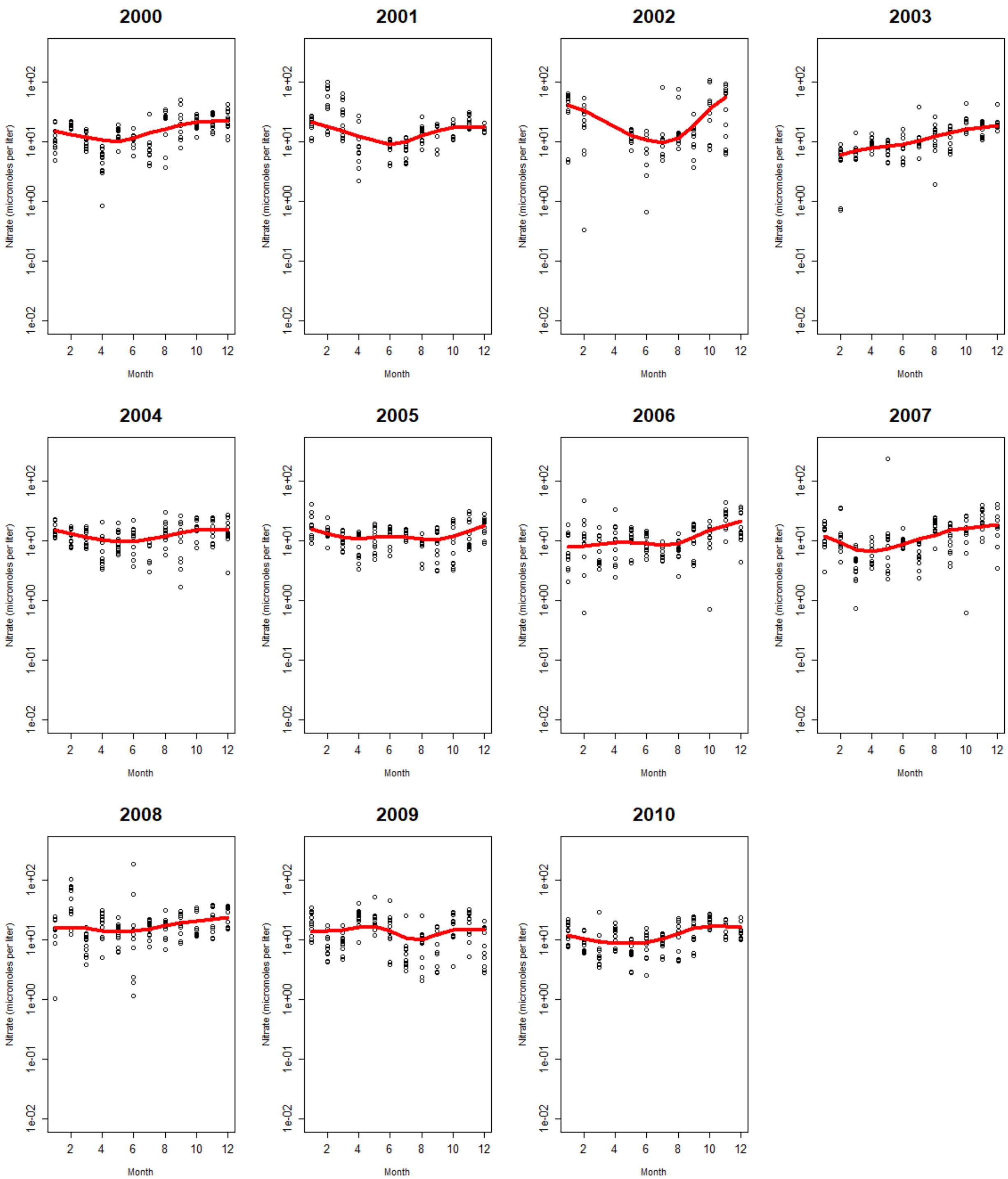

2011
2012
2013
2014
2015
2016
2017
Orthophosphate (micromoles per liter)
Month
1e+02
1e+01
1e+00
1e-01
1e-02
2
4
6
8
10
12

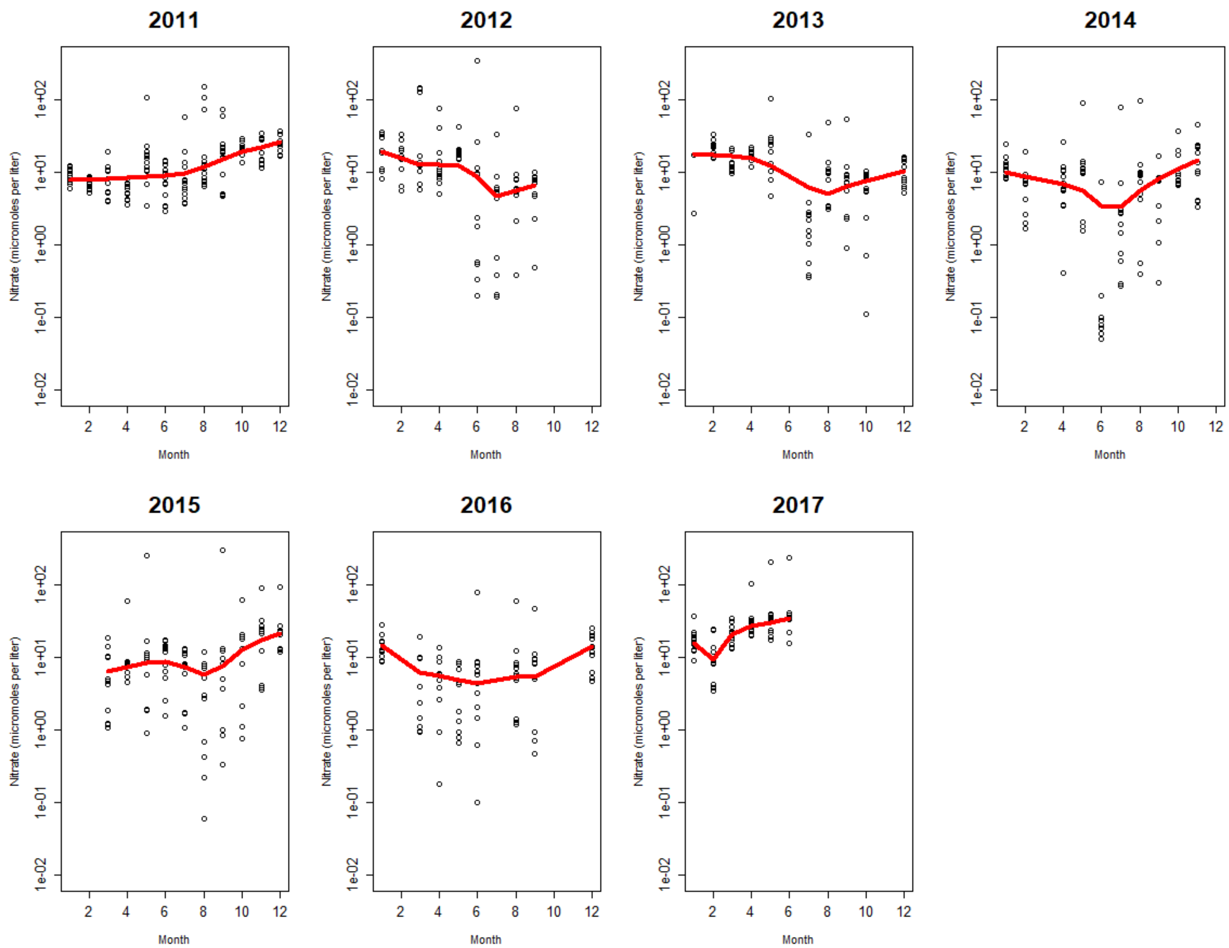
Nitrate (micromoles per liter)

variable: ReacNate_umol_L



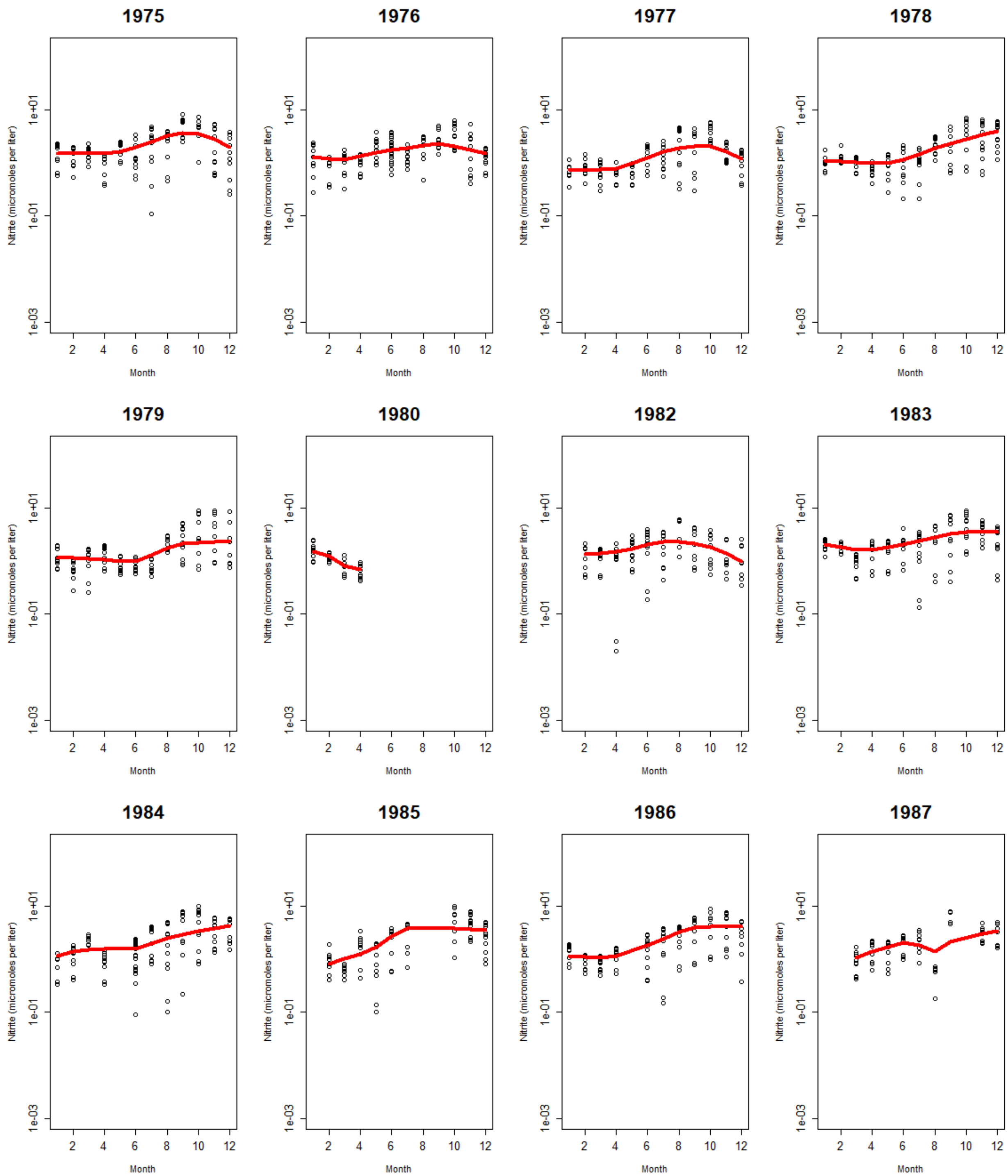

1988
1989
1990
1991
1992
1993
1994
1995
1996
Nitrate (micromoles per liter)
1e-02
1e-01
1e+00
1e+01
1e+02
Month
2
4
6
8
10
12

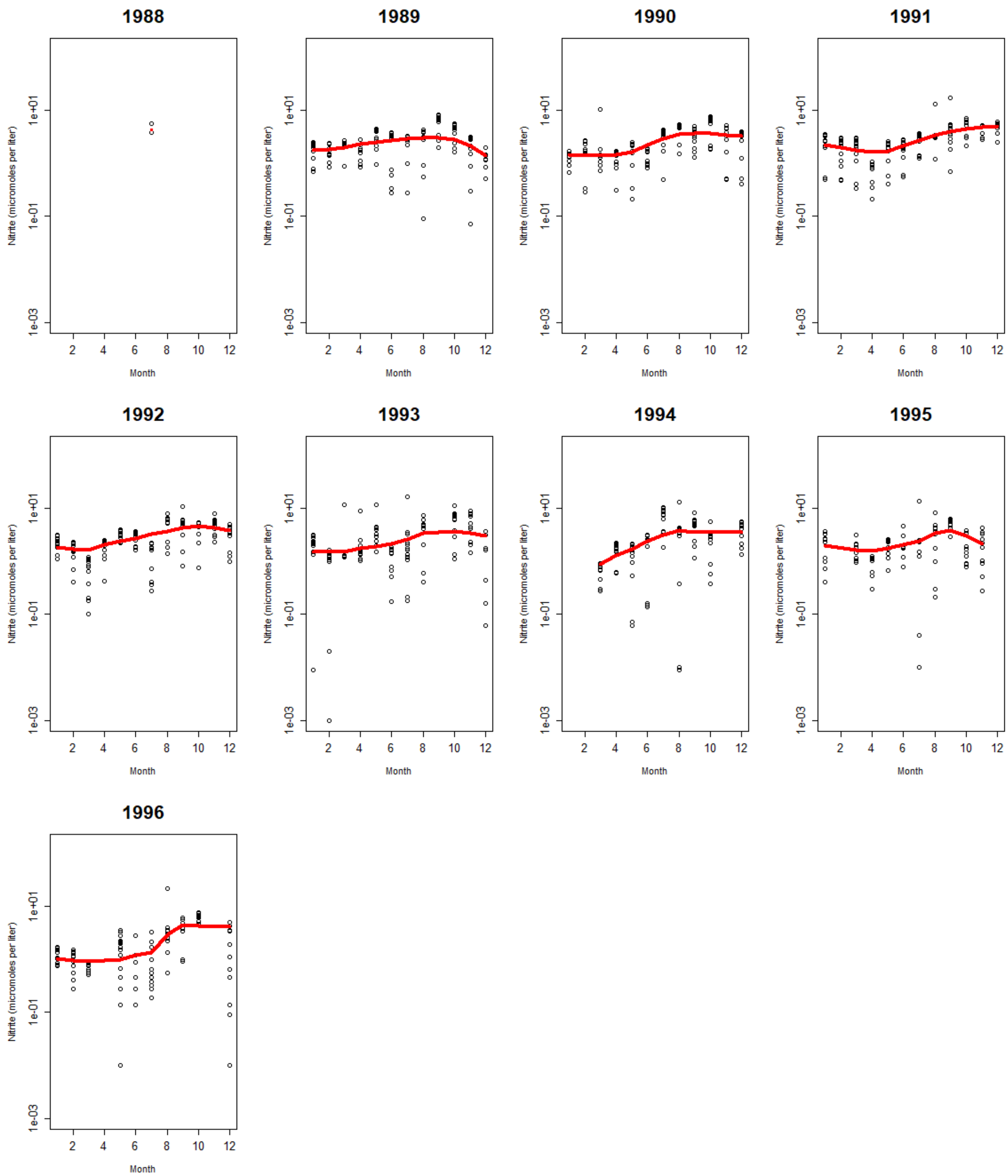

2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
Nitrate (micromoles per liter)
Month
1e+02
1e+01
1e+00
1e-01
1e-02
2 4 6 8 10 12

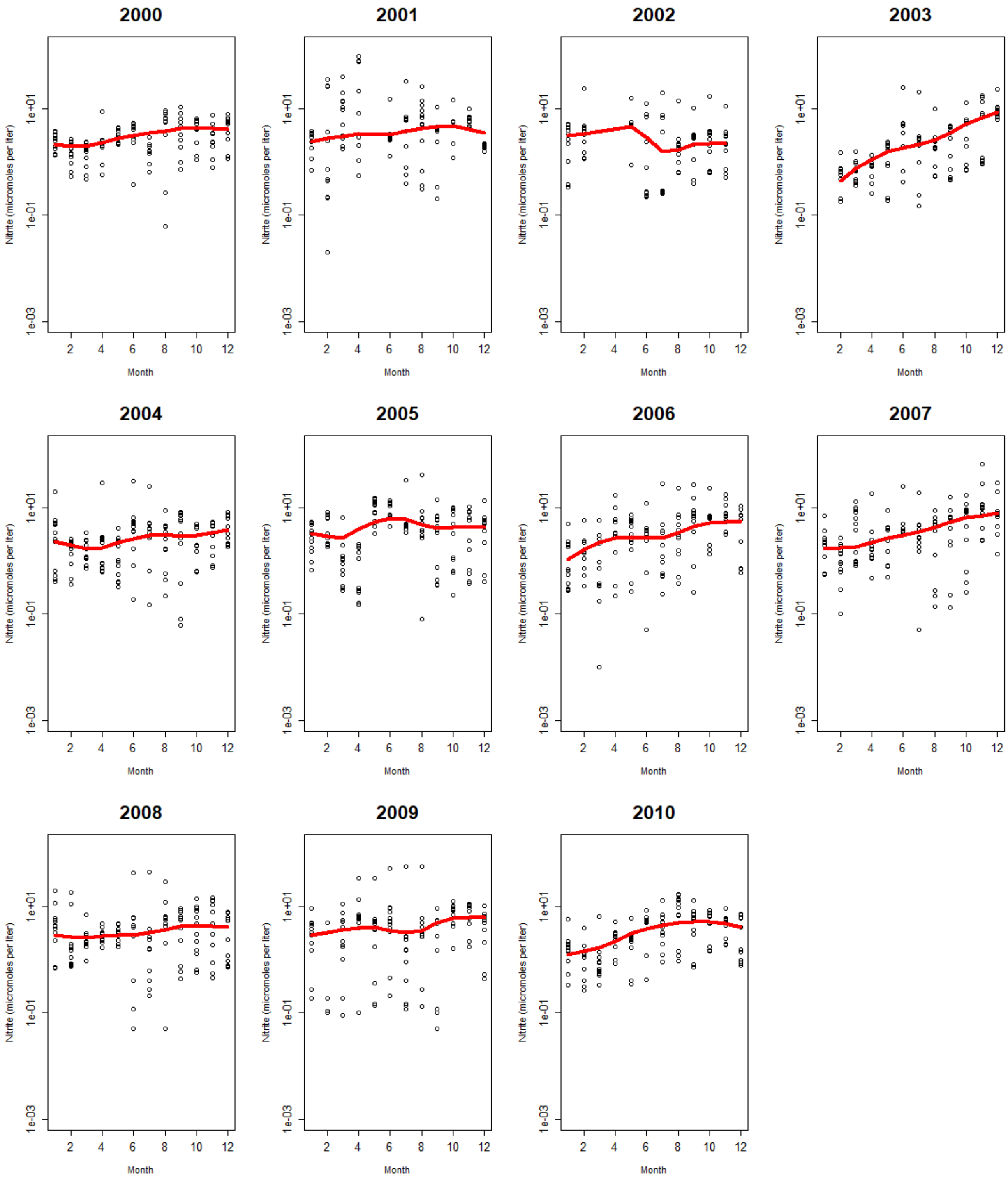

2011
2012
2013
2014
2015
2016
2017
Nitrate (micromoles per liter)
1e+02
1e+01
1e+00
1e-01
1e-02
2 4 6 8 10 12
Month

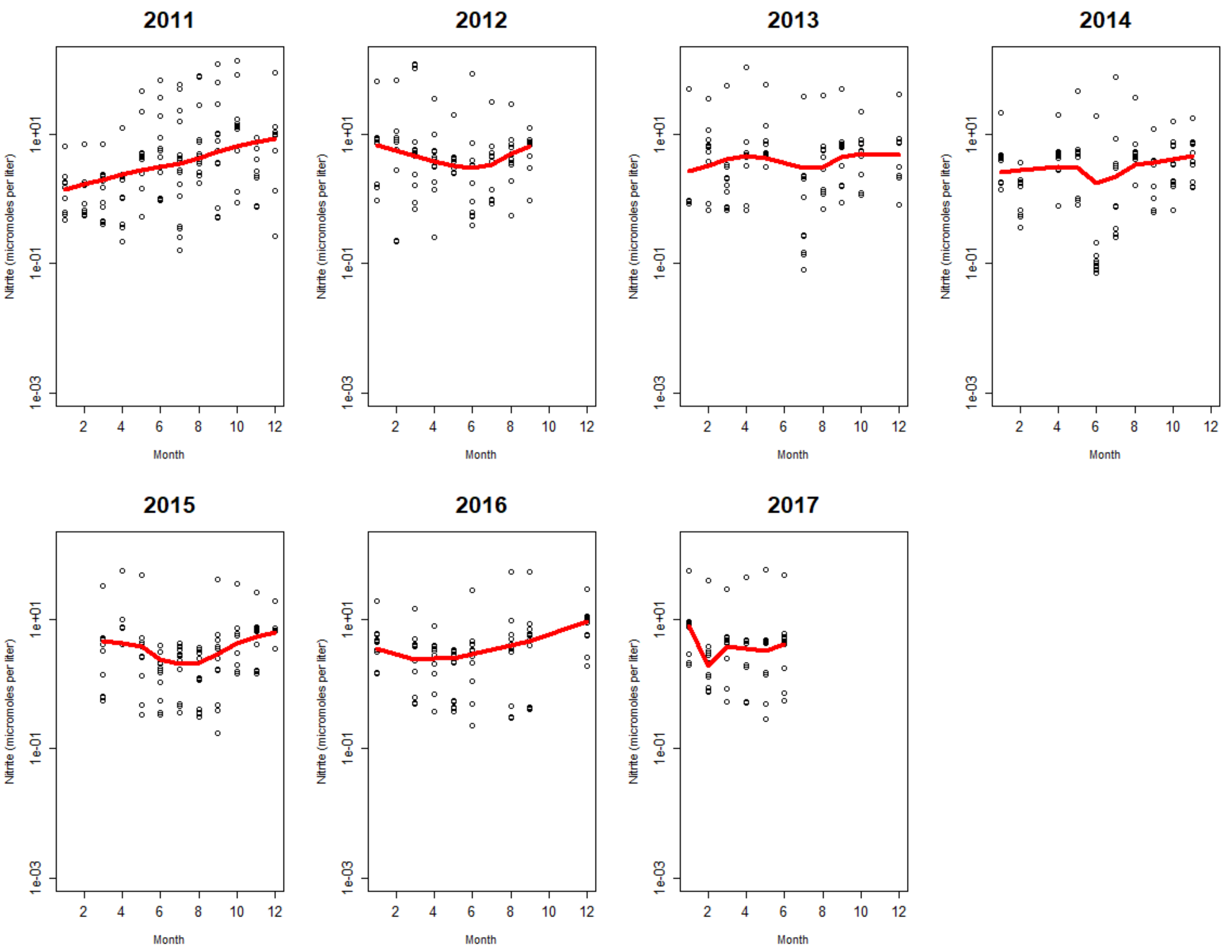
Nitrite (micromoles per liter)

variable: ReacNite_umol_L



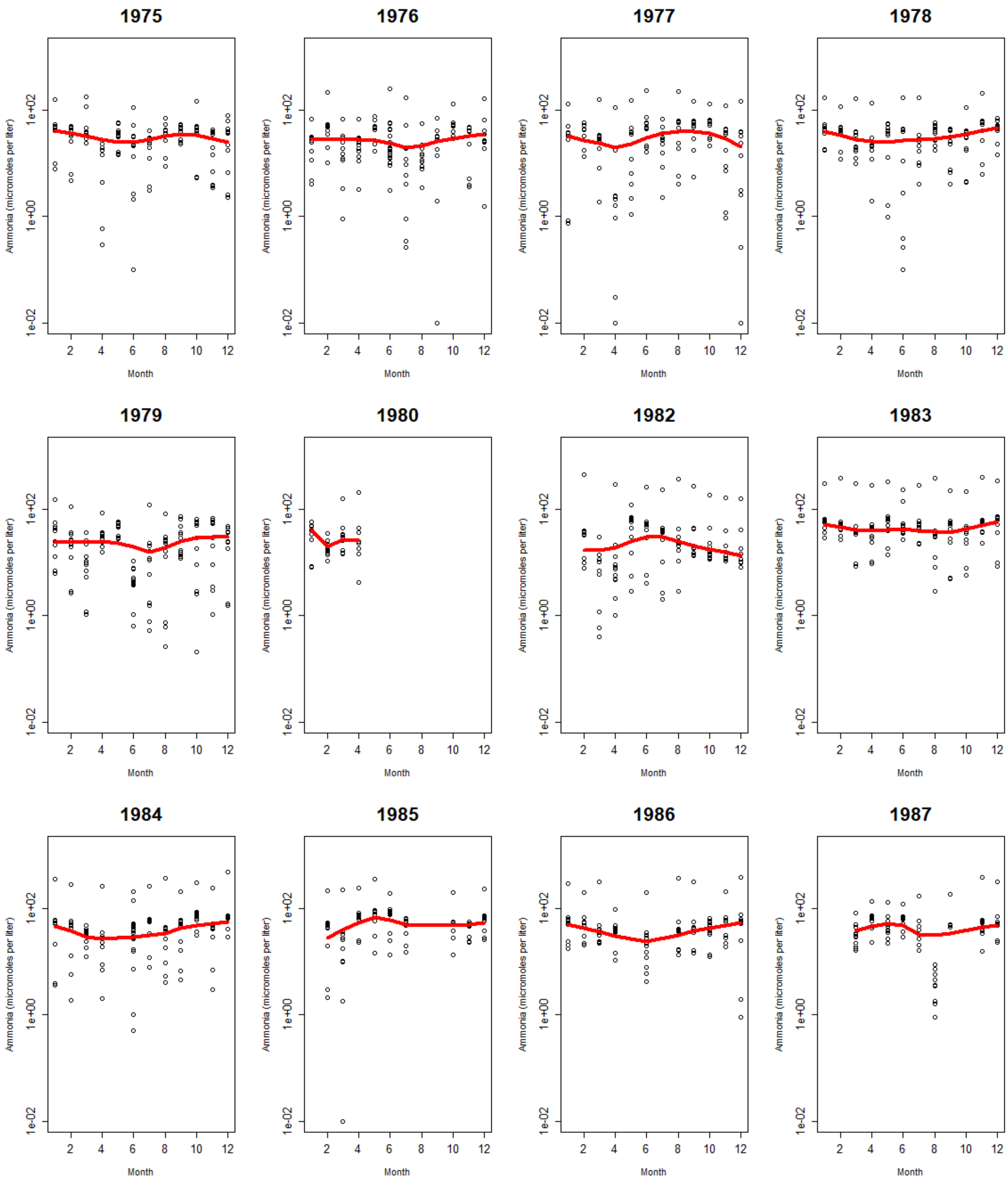

1988
1989
1990
1991
1992
1993
1994
1995
1996
Nitrite (micromoles per liter)
1e+01
1e-01
1e-03
Month
2
4
6
8
10
12

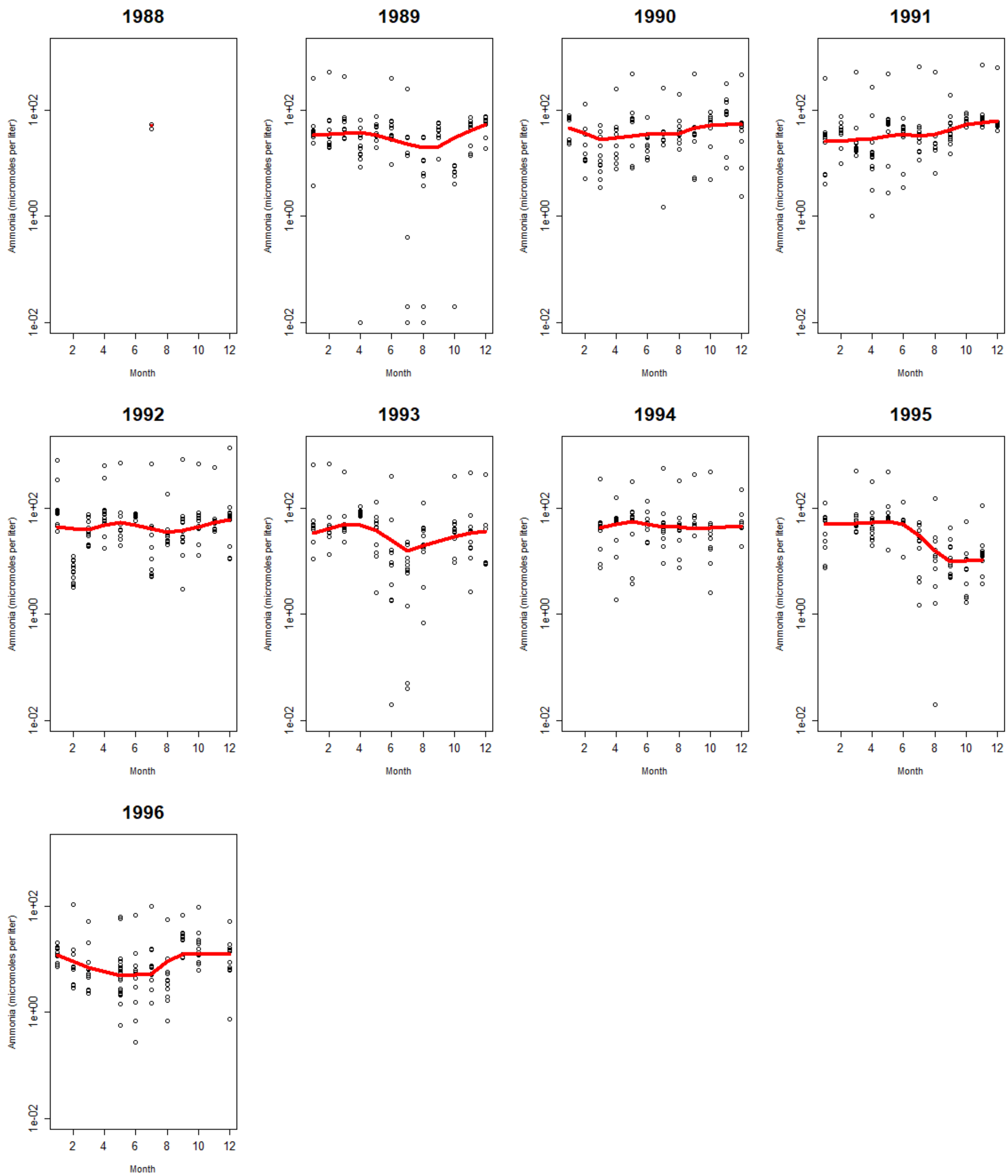

2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
Nitrite (micromoles per liter)
1e+01
1e-01
1e-03
2
4
6
8
10
12
Month

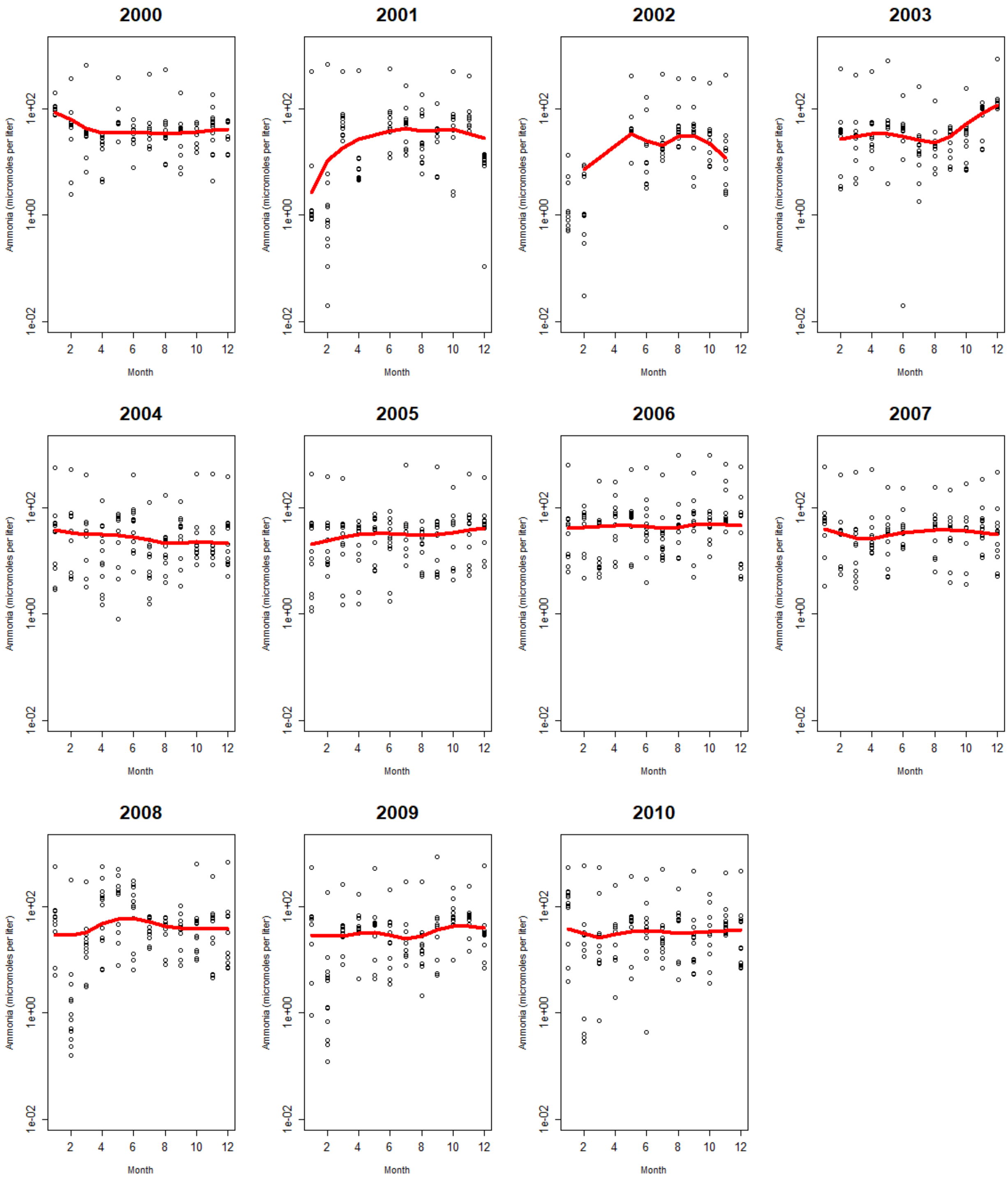

2011
2012
2013
2014
2015
2016
2017
Nitrite (micromoles per liter)
1e+01
1e-01
1e-03
2
4
6
8
10
12
Month

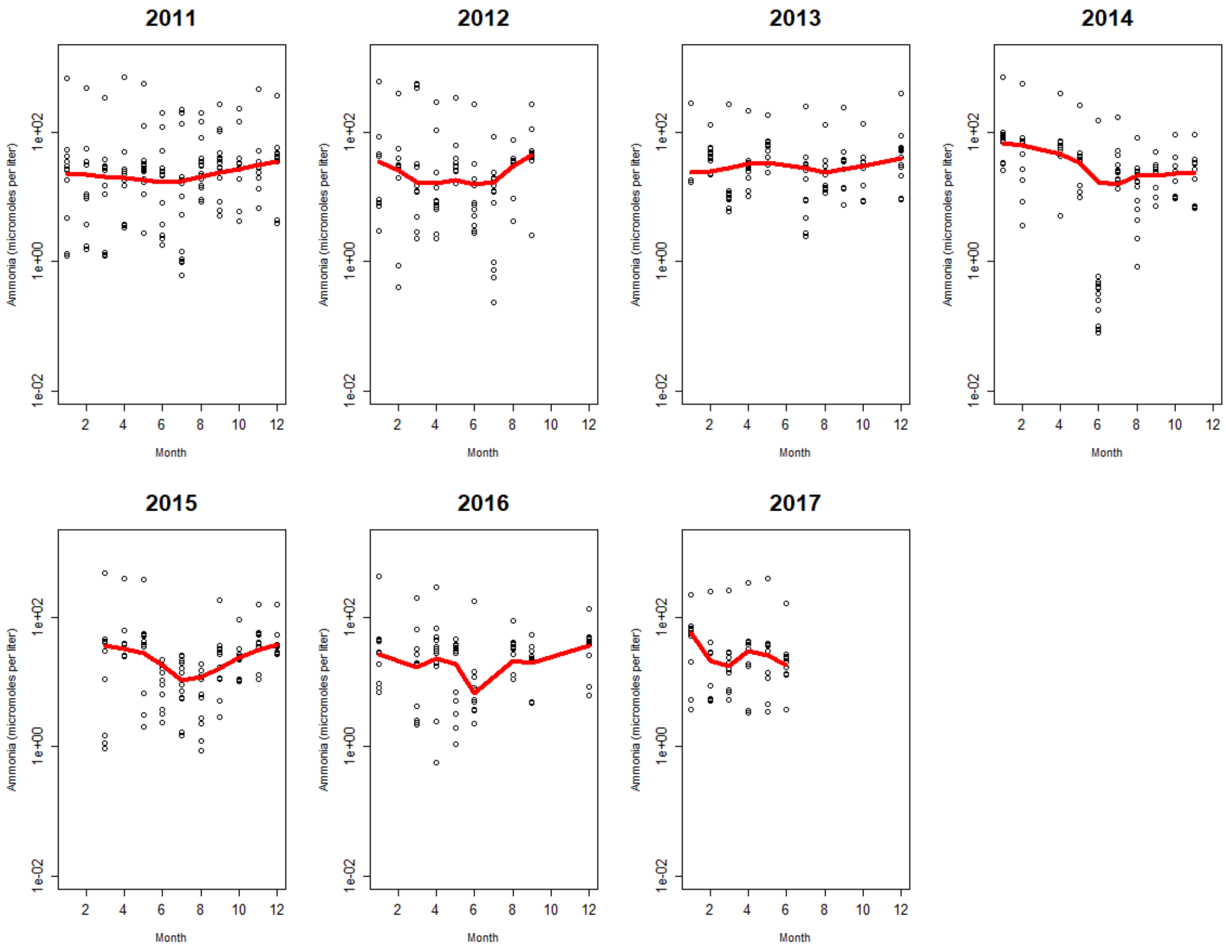
Ammonia (micromoles per liter)

variable: Ammonia_umol_L



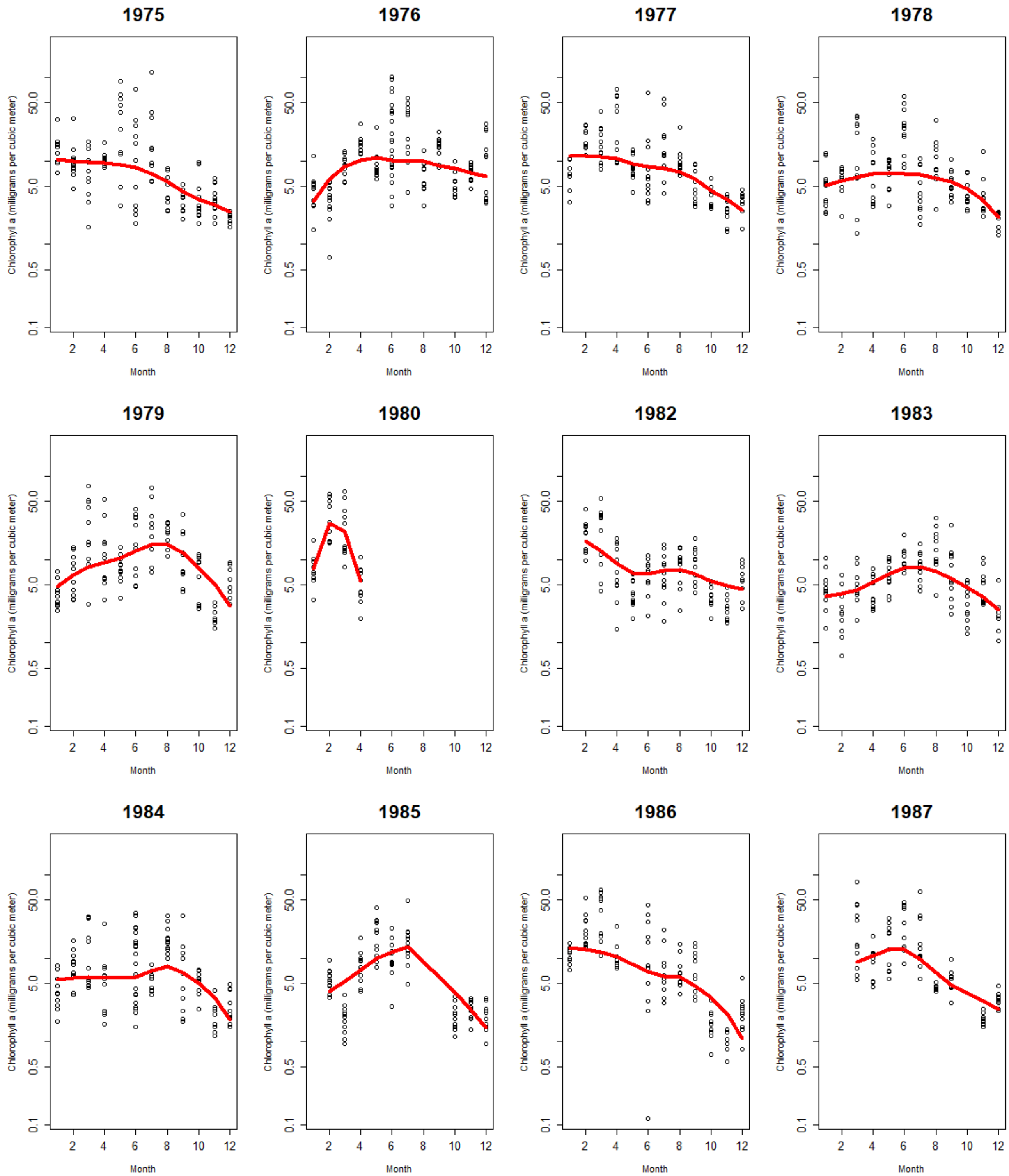

1988
1989
1990
1991
1992
1993
1994
1995
1996
Ammonia (micromoles per liter)
1e-02
1e+00
1e+02
Month
2
4
6
8
10
12

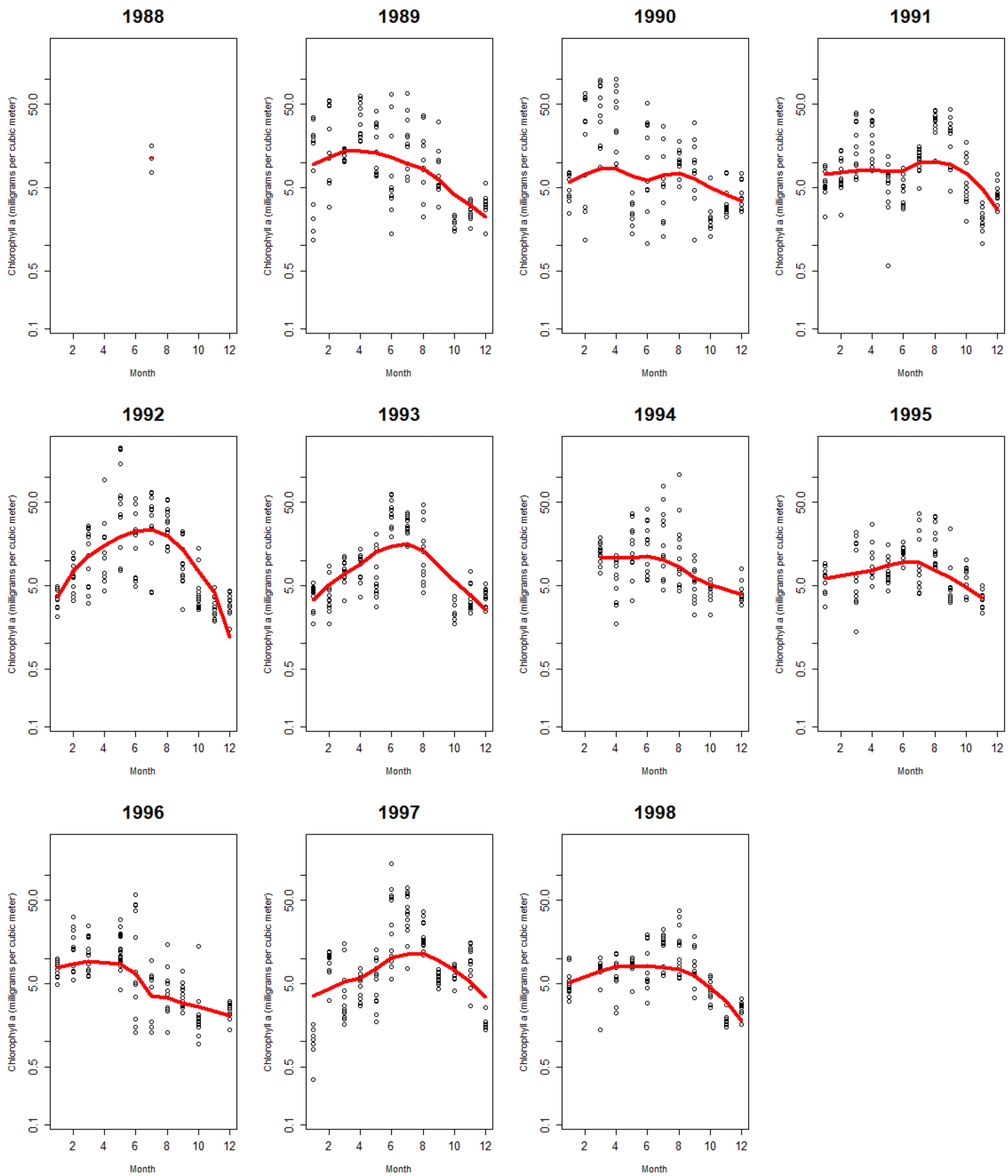

2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
Ammonia (micromoles per liter)
Month
1e-02
1e+00
1e+02
2
4
6
8
10
12

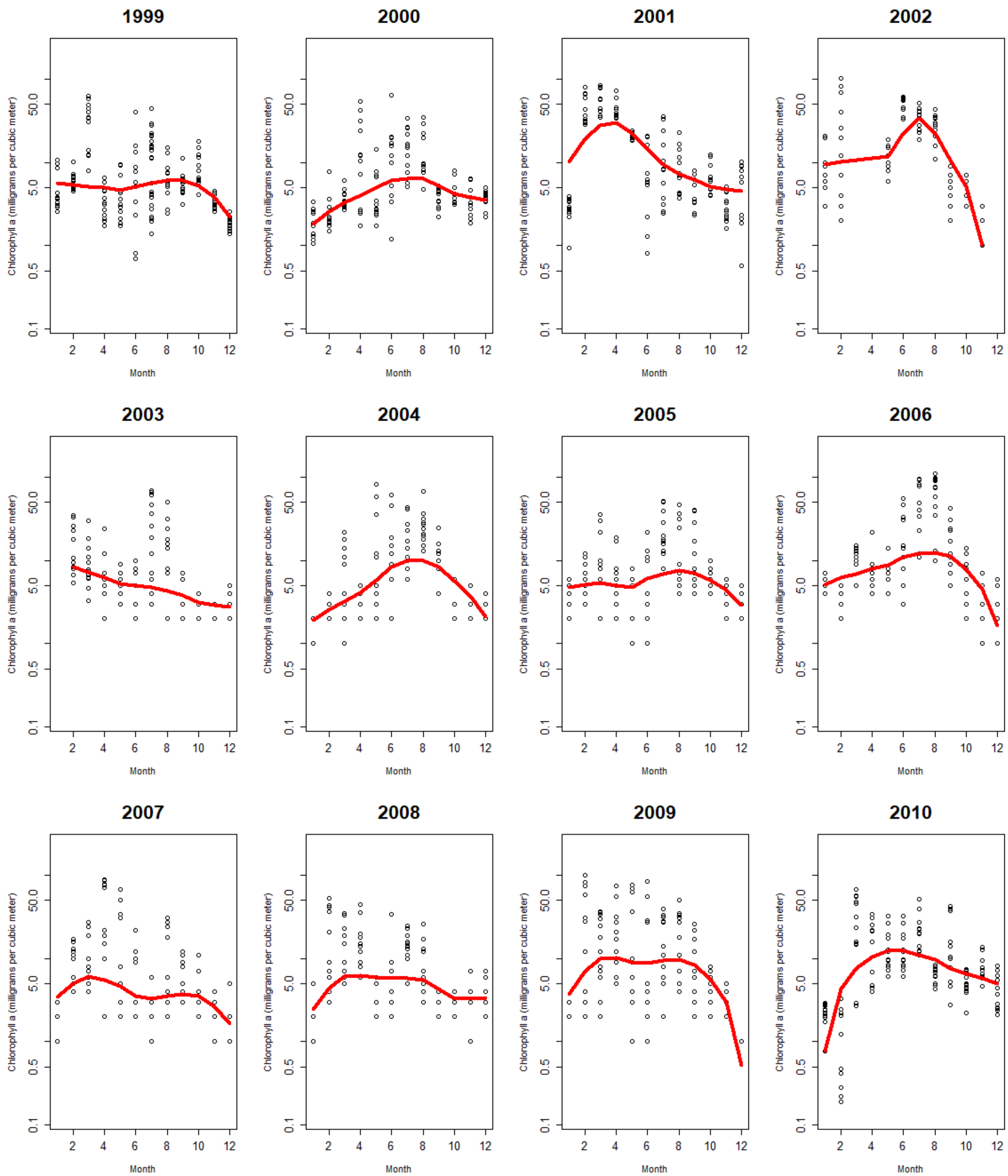

2011
2012
2013
2014
2015
2016
2017
Ammonia (micromoles per liter)
1e-02
1e+00
1e+02
Month
2
4
6
8
10
12

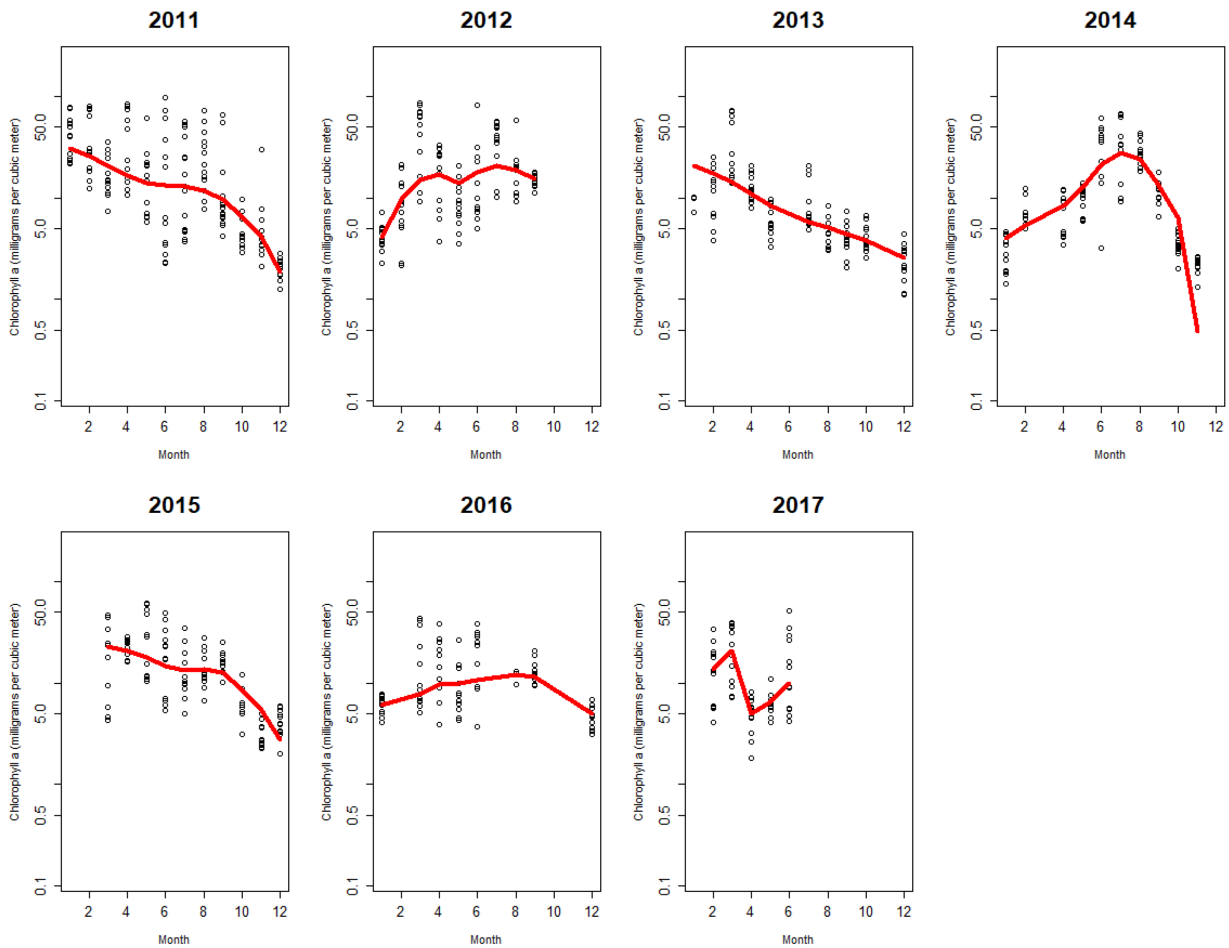
Chlorophyll a (milligrams per cubic meter)

variable: Chloro_a_mg_m3



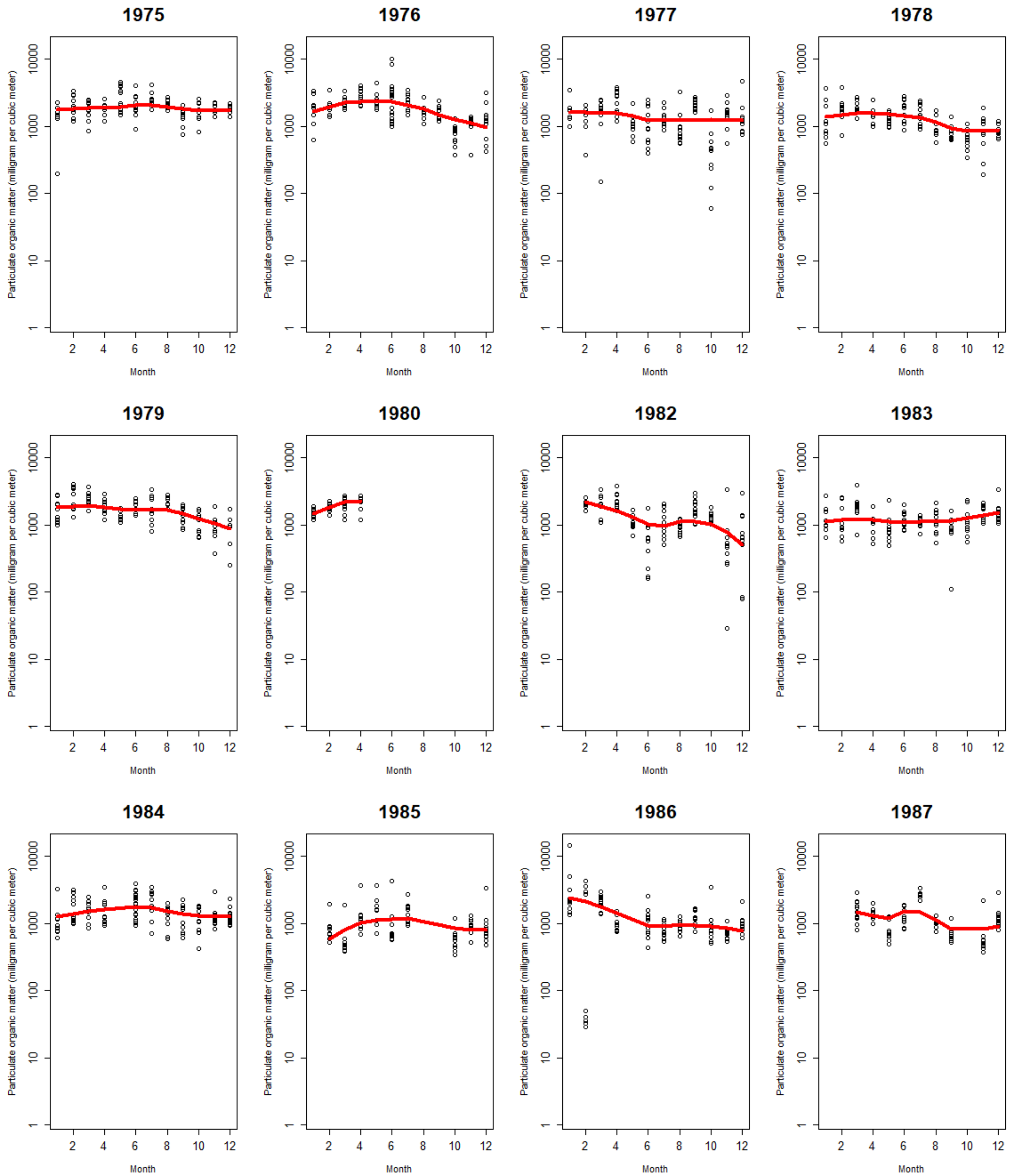

1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
Chlorophyll a (milligrams per cubic meter)
0.1
0.5
5.0
50.0
Month
2
4
6
8
10
12

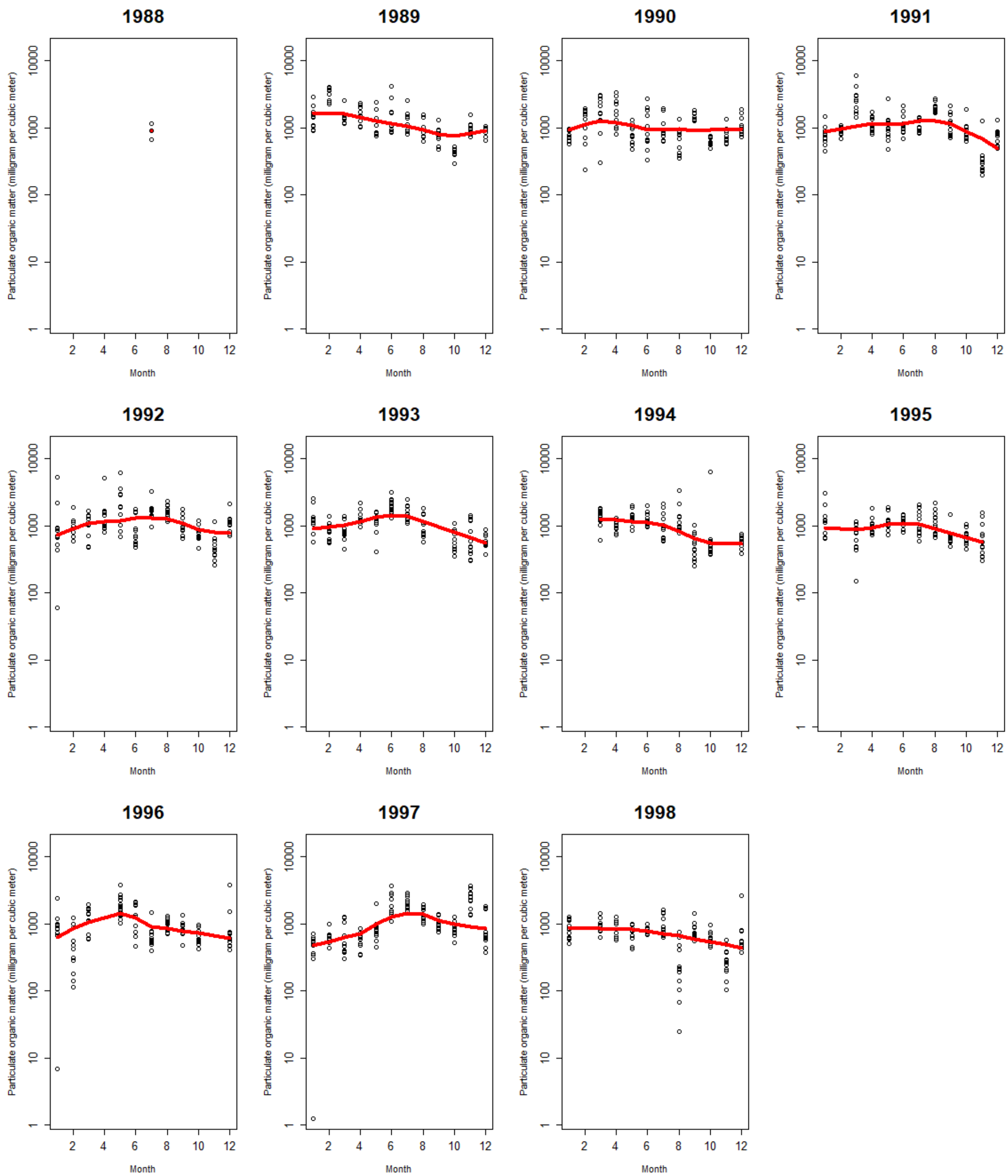

1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
Chlorophyll a (milligrams per cubic meter)
0.1
0.5
5.0
50.0
Month
2
4
6
8
10
12

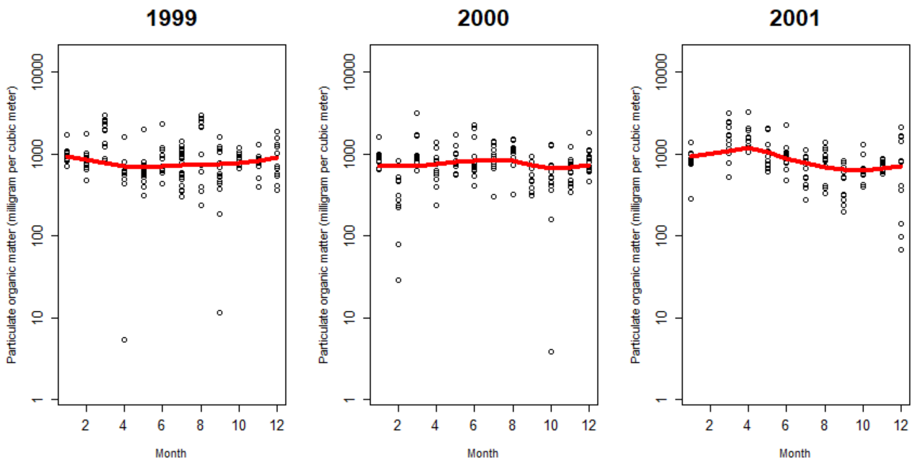

2011
2012
2013
2014
2015
2016
2017
Chlorophyll a (milligrams per cubic meter)
0.1
0.5
5.0
50.0
2
4
6
8
10
12
Month

Particulate organic matter (milligrams per cubic meter)

variable: Partic_Organ_mgC_m3

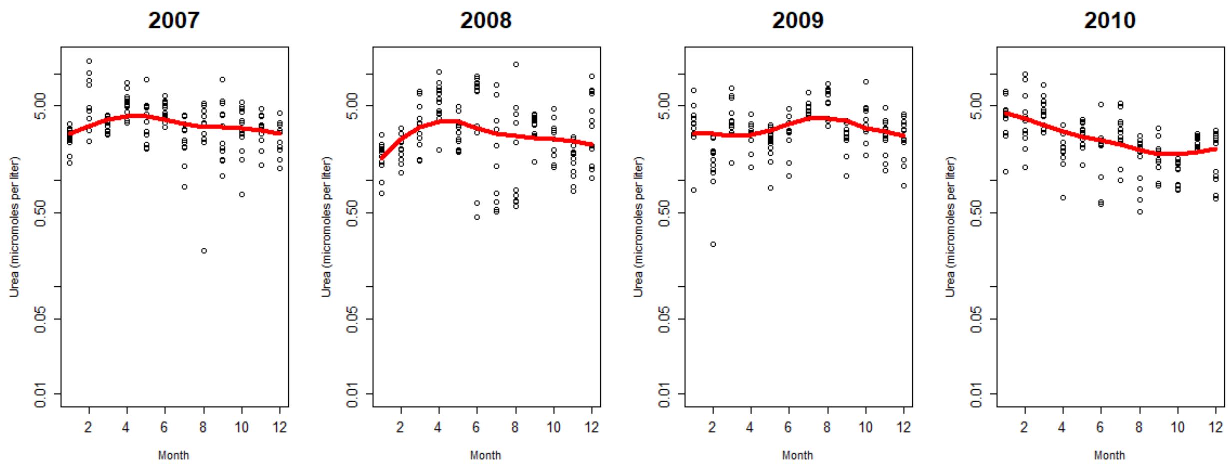


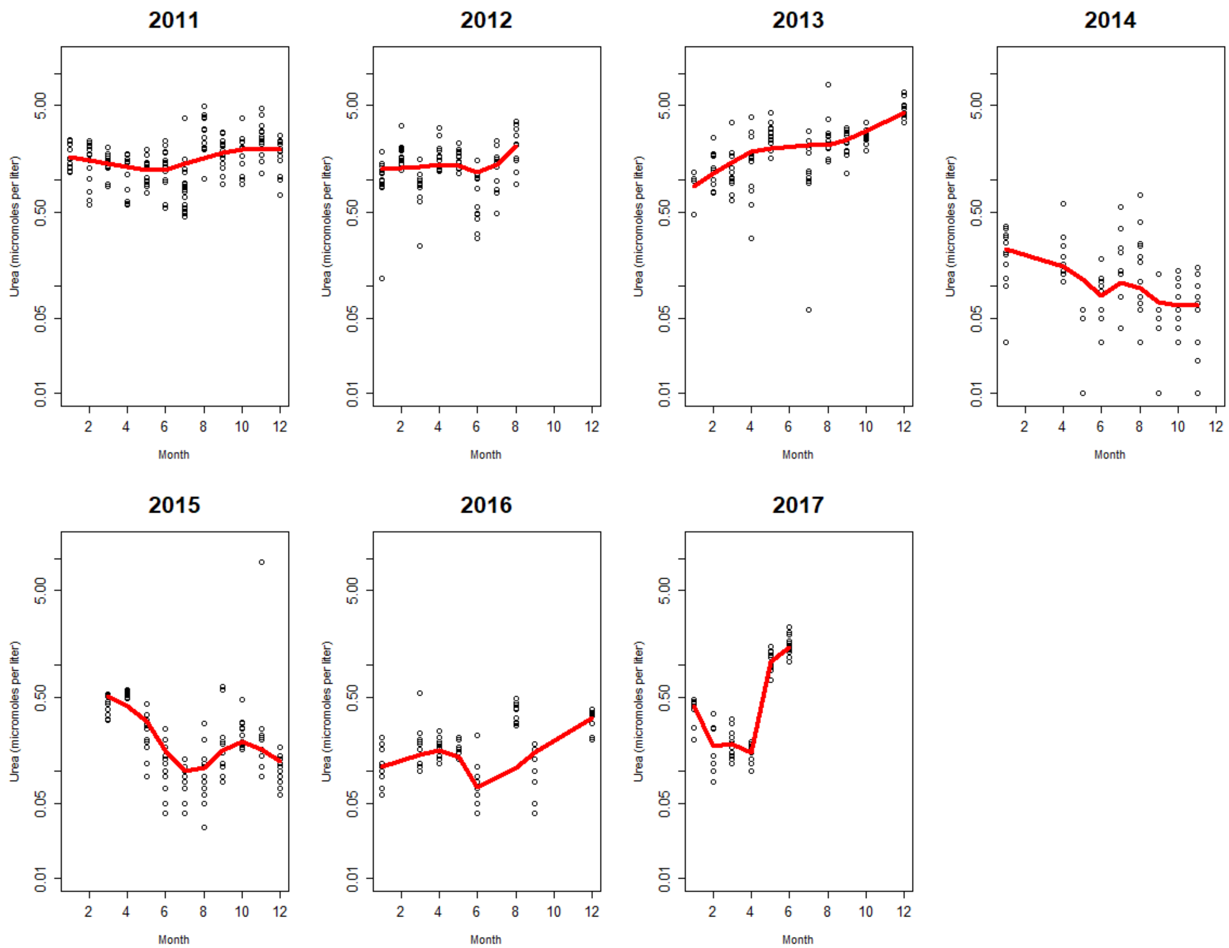

1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
Particulate organic matter (milligram per cubic meter)
1
10
100
1000
10000
Month
2
4
6
8
10
12


1999
2000
2001
Particulate organic matter (milligram per cubic meter)
1
10
100
1000
10000
2
4
6
8
10
12
Month

Urea (micromoles per liter)

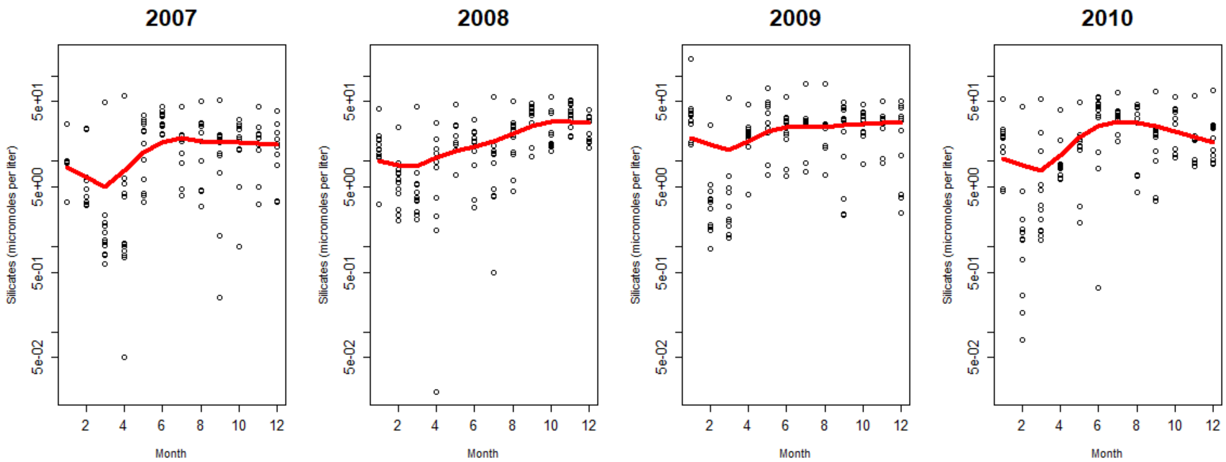
variable: Urea

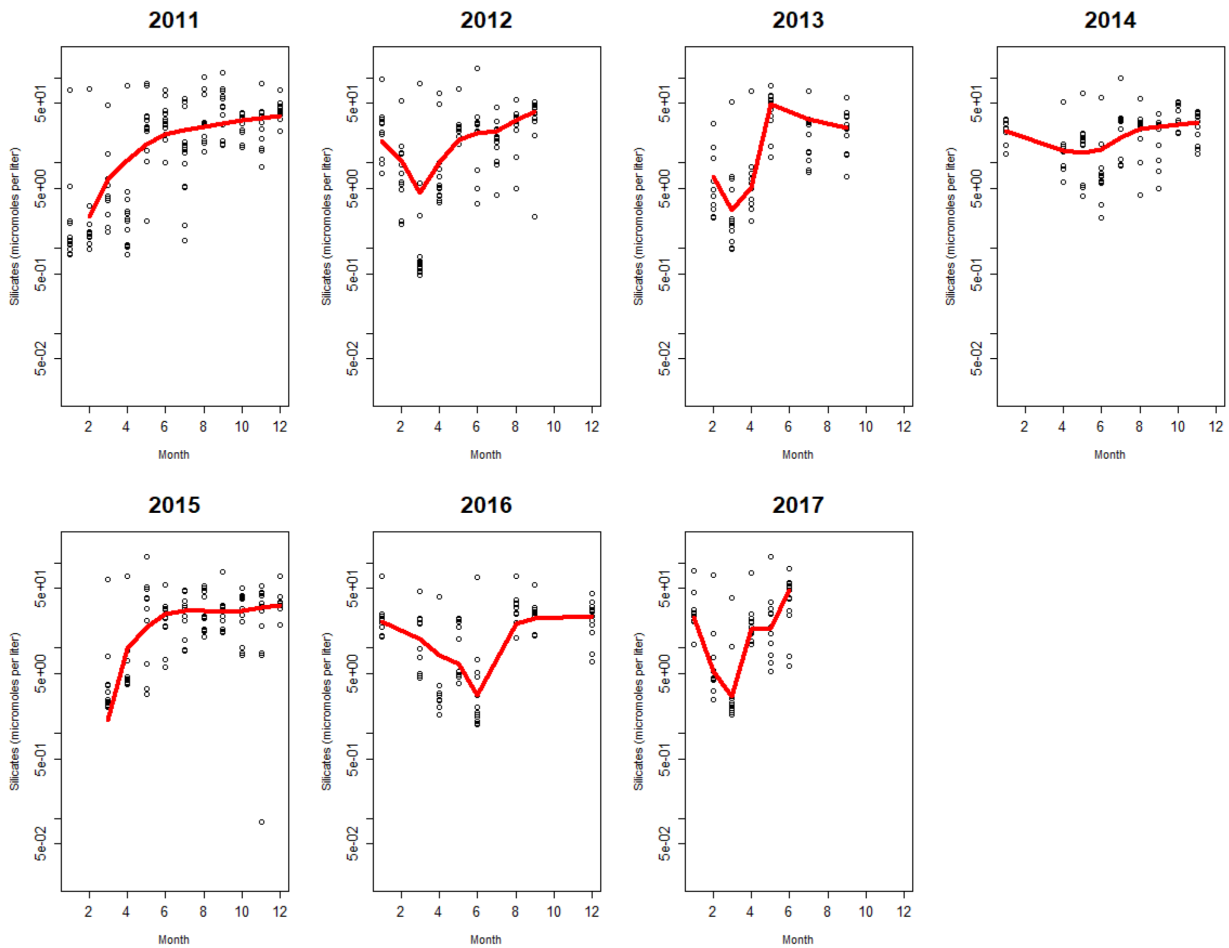



2011
2012
2013
2014
2015
2016
2017
Urea (micromoles per liter)
Month

Silicates (micromoles per liter)

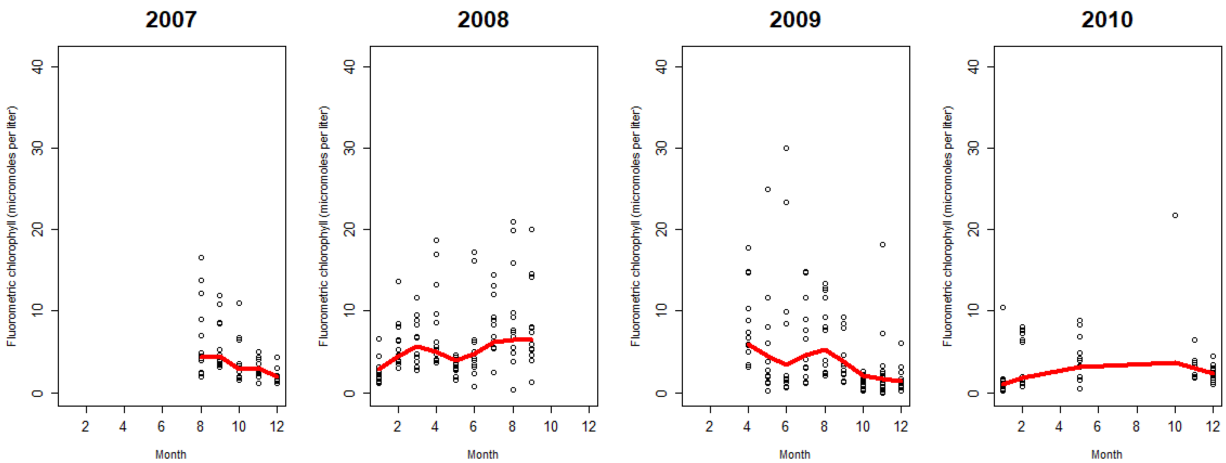
variable: Silicates

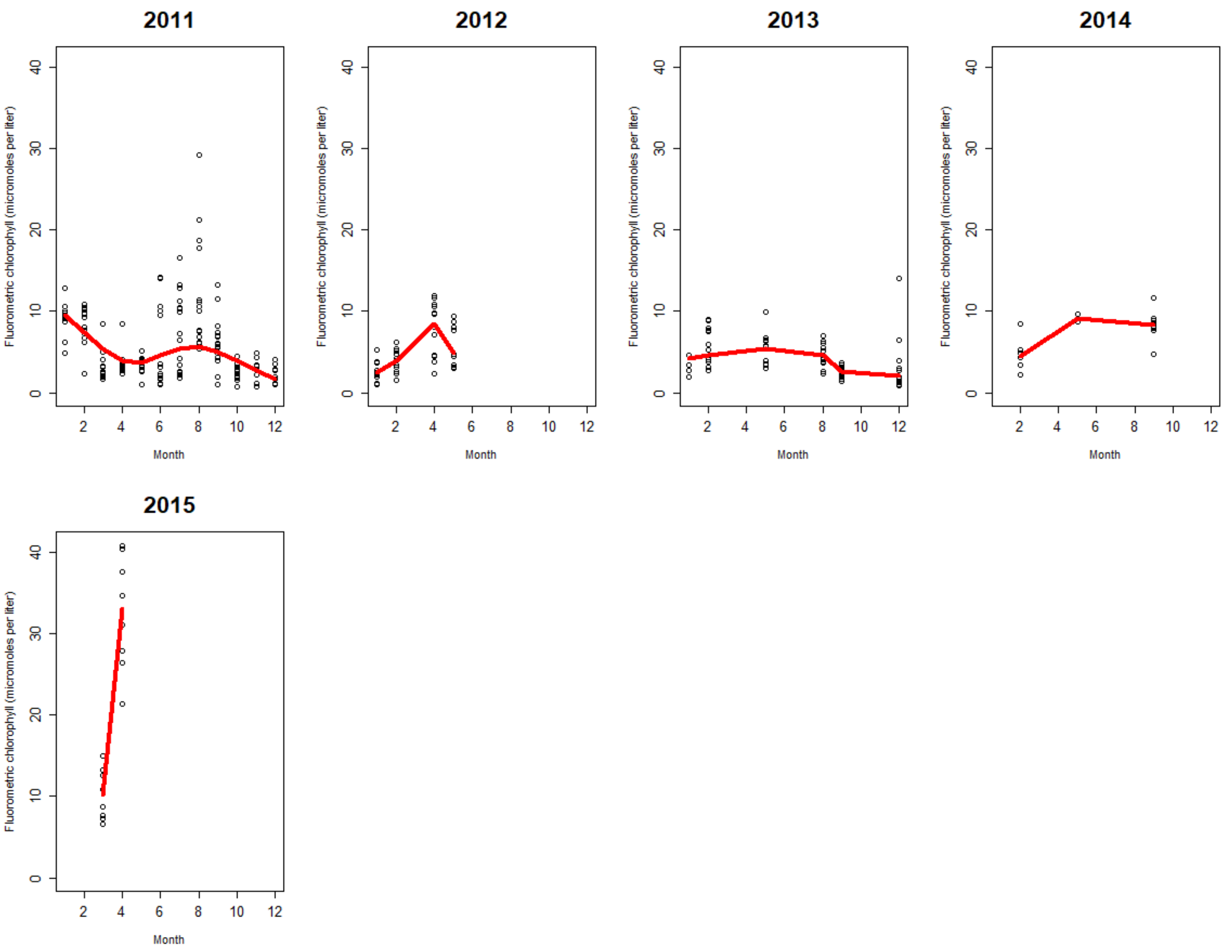



2011
2012
2013
2014
2015
2016
2017
Silicates (micromoles per liter)
5e+01
5e+00
5e-01
5e-02
2 4 6 8 10 12
Month

Fluorometric Chlorophyll (micromoles per liter)

variable: Chloro_Total




2011
2012
2013
2014
2015
Fluorometric chlorophyll (micromoles per liter)
Month
0
10
20
30
40
2
4
6
8
10
12