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Long-term salinity changes in the wetlands and lakes of southwest Australia

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Ecosystem Science

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Acknowledgments

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Summary

Land use change and recent climate drying are significant stressors to the rich biodiversity of southwestern Australia. Land clearing has altered the hydrological balance leading to increased groundwater recharge and the remobilization of salts that had accumulated over millions of years in deep soils. Rising saline groundwater tables, because of the clearing, have led to the salinization of more than one million hectares in Western Australia. The salinization of freshwater ecosystems has in turn contributed to the loss of aquatic biodiversity and reductions in the range of numerous flora and fauna, endemic to Western Australia. Estimates suggest 850 Western Australian species are at risk of extinction due to salinization. Chronic drying since the 1970s, and a series of acute droughts, led to major reductions in streamflow and the drying of many lakes. While chronic drying may, in part, be a component of a much longer natural variability, only two other drought periods of similar duration and intensity have occurred over the last 2000-years. Climate projections for the region predict further rising temperatures, ongoing declines in winter rainfall and increasing frequency of droughts and their severity.

While many reports have described wetland salinization there has been no major update and analysis of the regional trends in southwestern Australian lakes and wetlands since Lane et al., (2004). The Office of the Auditor General (OAG) Western Australia noted that “Agencies do not have good information about the current extent, impact and cost of dryland salinity and are therefore not well positioned to manage the risks and provide direction and advice” (Office of the Auditor General, 2018). That report stressed the need to improve understanding since the last major evaluation conducted around the year 2000. Motivated to evaluate how wetland hydrology and salinity has been changing in southwest Australia, this report details an analysis of long-term records from 159 wetlands across the region. The salinity of a wetland can change due to both salinization and climate drying, and this study seeks to evaluate contributions from both effects. The data for this study stems from the South-West Wetland Monitoring Program (SWWMP) conducted by the Western Australian Department of Biodiversity Conservation and Attractions and its predecessors. SWWMP started in 1977 and concluded in 2019.

The water and salt balance of lakes and wetlands can be challenging to assess thoroughly, however this report simplifies the interpretation by focusing on how the relationships between salt concentration (salinity) and wetland water levels have been changing. Salinity decreases as wetlands fill with water during winter and then as the water evaporates, leaving the salt behind, the salinity increases again, following a seasonal cycle of freshening and evaporatively concentrating. For many wetlands, these seasonal and inter-annual fluctuations in water depth and salinity follow a consistent inverse relationship and changes to this pattern can give clues as to changing hydrology and salinization processes.

Here it is shown that for wetlands in southwest Australia there are strong relationships between wetland water level and its salinity. In the wetlands with sufficient data, 60% were found to have salinity – depth relationships which were

different post-2000 as compared to pre-2000. Approximately 40% of wetlands do not show any changes to this salinity – depth relationship, however, coupled with a regional drying trend, and lowering of wetland water levels the average salinities in many of these wetlands are increasing.

In 36% of wetlands the salinity – depth relationships are changing in ways indicative of ongoing salinization since 2000. Average salinities have increased more than expected from the drying effect alone. These wetlands occur across the entire southwest region. Altogether, 81% of the wetlands analysed have rising salinities due to the combined effects of climate drying and secondary salinization. In 11% of wetlands, freshening is occurring, and in many of these cases hydrological interventions by either pumping, streamflow diversion or installations of weirs are thought to be responsible.

As previous studies have demonstrated that species richness of waterbirds, invertebrates, riparian vegetation, and aquatic macrophytes are sensitive to changes in the salinity of western Australian wetlands and streams, increasing salinity is a threat to wetland biodiversity. With one third of freshwater aquatic invertebrate species are at risk of extinction due to salinization and with similar risks for halophilic species in saline playas, monitoring of wetland hydrology and water quality crucial to track the health and biodiversity of southwest Australia's wetlands.

The analysis of the SWWMP data conducted here illustrates the benefits of long-term monitoring of key wetlands to track wetland health and the ecosystem services they provide. SWWMP provided a globally unique, long-term view of the changing hydrology and water quality of wetlands in a region experiencing significant climate and land-use changes. The challenge of monitoring and assessing the health of thousands of wetlands across Western Australia cannot be underestimated and SWWMP was the result of a dedicated team of wetland scientists physically visiting sites at regular intervals. With modern technologies now available, that did not exist when SWWMP commenced, including satellite telemetered monitoring and remote sensing techniques, there are opportunities to improve the temporal and spatial resolutions of wetland monitoring to provide real-time data that can continue to guide wetland management and biodiversity conservation.

1 Introduction

Wetlands globally are facing numerous pressures, including dryland salinity, infilling, climate change, and eutrophication, to name a few (Asselen et al., 2013; Herbert et al., 2015; van Meter and Basu, 2015). The widespread degradation of freshwater systems has led some to suggest that current and historical approaches to governance are not adequately addressing these pressures to protect them and the ecosystem services they provide (Creed et al., 2017; Janse et al., 2019). The pressures on the wetlands of southwest Australia are particularly acute with combined impacts from chronic climate drying over the last 50 years and in some places, effects from severe dryland salinization resulting from widespread clearing of vegetation (Halse et al., 2003; Charles et al., 2010; Silberstein et al., 2012).

Salinization of the Wheatbelt region of southwest Australia has been documented for nearly 100 years and resulted from the clearing of native woodlands and their replacement with annual crops and pasture (Wood, 1924). This clearing increased groundwater recharge, leading to rising groundwater levels and mobilisation of salts stored in the regolith. Approximately 1,748,366 ha (7.3% of the 23,789,250 ha mapped) of the southwestern Australian agricultural region is classified as salt affected (Caccetta et al., 2022). This salinization has had dramatic effects on the regions wetlands.

The salinity of wetlands plays a fundamental role in regulating their biogeochemical cycling, carbon storage, productivity, ecology, and biodiversity (Halse et al., 2003; Muresan et al., 2020). The salinity of wetlands of semi-arid environments varies naturally due to the seasonal cycles in evaporation, rainfall, groundwater levels, and river inflows (Jolly et al., 2008). As wetlands dry their salinity increases and then when they fill, they tend to freshen, and this seasonal or interannual variation in water level and salt concentration strongly regulates the aquatic ecology (Márquez-García et al., 2009; Waterkeyn et al., 2010). Increasing salinity can tip this balance causing declines in species richness (Pinder et al., 2005; Beatty et al., 2011; Muresan et al., 2020). Across southwest Western Australia, both climate drying and salinization are contributing to increasing the concentration of salts in wetland waters however, the extent to which each contributes is not yet clear.

Changes in salinity are related to variations in both the mass of salt and the volume of water in a wetland. Natural fluctuations in both these factors can contribute to the changes in the concentration of salts observed in wetlands (Perri and Porporato, 2022). Water volume and salt mass do not vary independently of one another, both vary depending upon the magnitudes of flows entering and passing through a wetland and the salinities of each water source (Jolly et al., 2008). Water level fluctuations in lakes and wetlands are strongly controlled by the climate, particularly endorheic wetlands, i.e., those without permanent outlets, which tend to occur where annual evaporation exceeds annual precipitation (Langbein, 1961; Szesztay,1974; Mason et al., 1994). Water levels in closed wetlands tend to fluctuate more than open lakes of the humid zone because variations in inflow can be compensated for by changes in surface area only (Langbein, 1961). For humid lakes, where inflows often exceed evaporative losses, the outlet elevation regulates water level fluctuations. Many lakes and wetlands in semi-arid regions however are not perfectly closed, with seasonal or intermittent outflows commonplace, particularly where there is a strongly seasonal Mediterranean-like climate or where rare extreme rain events fill them, initiating episodes of downstream connectivity. Even in the absence of surface water outlets many wetlands exchange water and salts with intersecting aquifers (Figure 1). In response to these drivers, water levels in wetlands and lakes respond on a myriad of times scales, depending upon the climate, the wetland size, and the dominant hydrological processes (Mason et al., 1994).

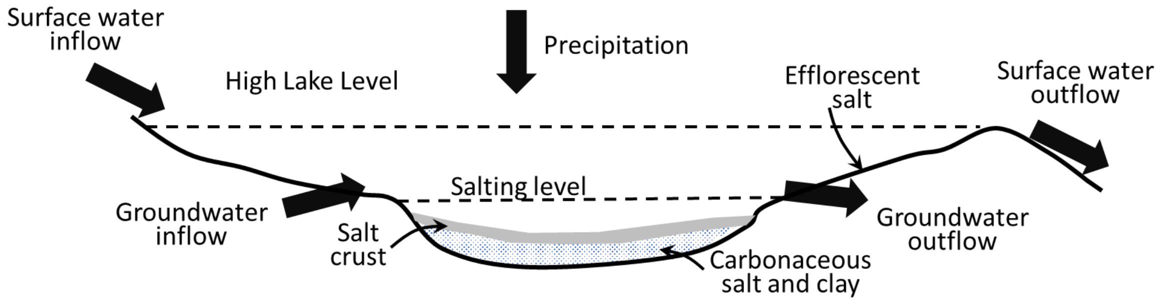


Figure 1: Conceptual hydrological wetland model with major fluxes of salt.Like water levels, the salinity of closed wetlands can also be highly variable and the two tend to strongly covary inversely. Indeed, the strong inverse relationship between water level and salinity in some lakes and its effect on lake ecology is used in paleo-limnological studies to reconstruct wetland hydrology, salinity and climate from sensitive diatom assemblages stored in wetland sediments (Fritz et al., 1991; Gasse et al., 1997; Taukulis and John, 2009). While the inverse relationship is well known, surprisingly few studies quantify the empirical relationships between salinity and wetland water depth.

Langbein, (1961) was one of the first to develop a model of the variation in salinity with lake water depth. With a focus on closed lakes, it was demonstrated that variation in salinity could be explained from a combination of lake morphology and climate. Furthermore, a power-law relationship between salinity and lake depth was proposed based on reasoning and empirical observations. A negative non-linear relationship between dissolved salt concentration and lake volume (or depth) is to be expected with the potential for salt saturation at low lake volumes (Figure 2). Interestingly, Langbein (1961) also reported apparent loss of salt after some lakes dried, though the exact mechanism was unclear and was speculated to be some combination of wind transport, or mineral entrapment, though possibly groundwater exchange and loss to saline/hypersaline groundwater could be another reasonable mechanism to explain such observations.

Trigg et al., (2014) also recognized the importance of wetland bathymetry on salinity variations and applied a numerical hydrological model to evaluate the effect of uncertainty in bathymetry on the salt balance. While these and other studies have progressed the physical explanations for a water depth salinity relationship there is a need to improve understanding of the relative roles of hydrology and bathymetry on wetland water depth – salinity relationships. There is also a need to better quantify empirical relationships between salinity and water depth and how changes in this relationship might inform of changes to wetland hydrology.

This report summarises an assessment of changes to the salinity and hydrology of wetlands monitored as part of the South-West Wetland Monitoring Program (SWWMP) conducted by the Western Australian Department of Biodiversity, Conservation and Attractions (DBCA) and its predecessors. The SWWMP measured water depth and water chemistry of a total of 159 wetlands over the course of 42 years. During that time wetlands were added to the program and others dropped as funding and priorities changed. The first wetland monitoring sites were established in 1977 and in 2019 the program ceased. Lane et al., (2004) reported on the trends in hydrology and salinity of wetlands in the SWWMP for the period prior to 2000. In that and subsequent reports the focus was primarily on the temporal trends and inter-annual variability. There was evidence of a general drying trend and a general increasing salinity trend across the population of wetlands, although there was a significant degree of variation between sites. Furthermore, it was not clear from the past analyses the extent of the relative influences of dryland salinization and climate drying across the population of wetlands in the study.

This study looked to evaluate how salinity – water depth relationships have changed in the SWWMP wetlands from pre-2000 to the post-2000 period. Changes to the salinity – depth relationship are expected to reflect changes to the dominant hydrological processes delivering water and salt to the wetlands. They may also provide evidence for the occurrence of salinization that is otherwise challenging to characterise from highly temporally variable data. The SWWMP data provides an opportunity to explore long-term changes to these processes and to identify local and regional effects contributing to changes.

The report is organised as follows. First the data and statistical methods used in the analyses are described. Next a mathematical framework for exploring salinity – water depth relationships is developed which provides a means to better interpret the empirical relationships from individual sites. The report ends with a reinterpretation of salinization effects on the wetlands, open questions, and opportunities for further study.

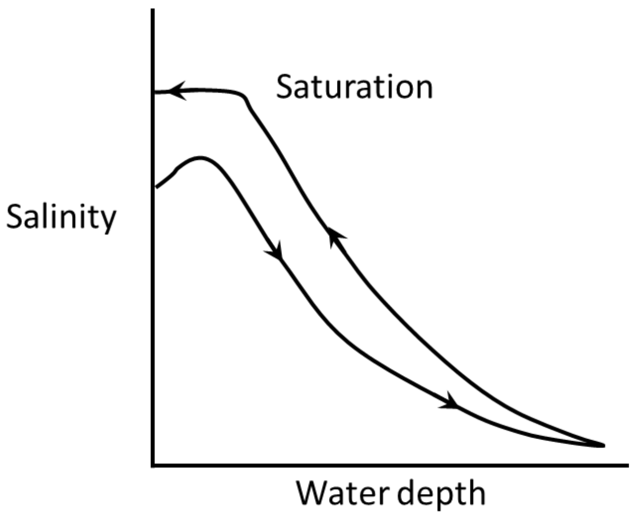


Figure 2: Conceptual salinity water depth relationship after Langbein (1961).

2 Methodology

Salinity is the quantity of salts dissolved in water, the units of which are often reported as grams per litre (g/L) or equivalently one part per thousand (ppt). There are several classification systems to describe salinity. The Department of Water and Environmental Regulation has used a simple salinity scale with fresh water at <0.5 ppt and brines >35 ppt primarily to inform drinking water and agricultural applications. A longer standing classification system is the Venice System (1958) which attempted to define thresholds that distinguished ecological communities, particularly those in Mediterranean-like climates. Both systems are compared in Table 1. This report will principally use the Venice System to refer to ecologically relevant salinities.

Table 1: Salinity classifications.

DWER		Venice	
Classification	Salinity	Salinity	Classification
Fresh	<0.5		
Marginal	1		
Brackish	2		
		<5	Oligohaline
Saline	10		
		18	Mesohaline
		30	Polyhaline
Highly Saline	35		
Brine	>35	40	Mixoeuhaline
		60	Metahaline
		>60	Hyperhaline

Salinity in parts per thousand.

Water levels and water quality were monitored in terrestrial wetlands and lakes throughout the southwest of Western Australia as part of SWWMP. A summary of the wetlands in the SWWMP is provided in Appendix 2. Water levels were determined by visual checking of depth gauges (0.01 m graduations) installed to indicate the level relative to the deepest point of each wetland (Lane et al., 2004). Gauges were surveyed to benchmarks established to Australian Height Datum. Most readings were conducted in September and November. Water salinities were determined from near surface (<20 cm depth) water samples. Samples were collected and then measured in the laboratory using a variety of bench-top salinity probes calibrated and standardised to 25°C. Salinities were also verified against independent laboratory measurements (Lane et al., 2017).

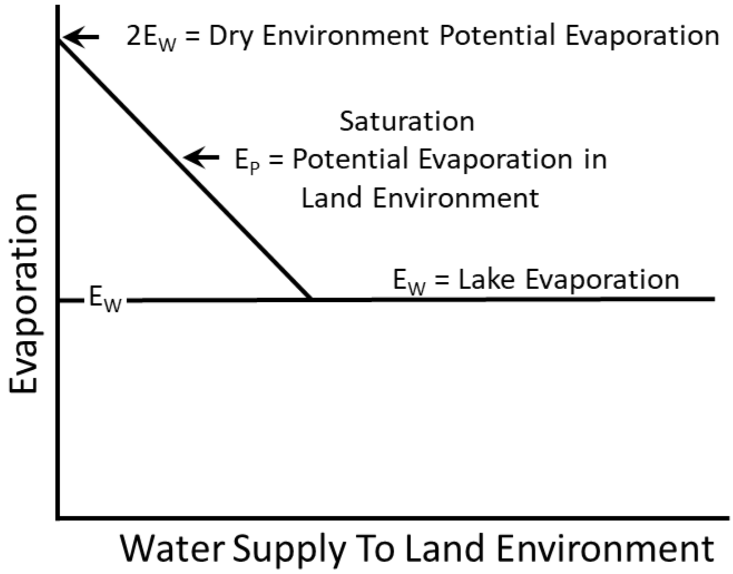


Figure 3: The concept of shallow lake evaporation after Morton (1983).

Ground-based and boat surveys were conducted on a small subset of wetlands to measure bathymetry by professional surveyors and hydrographers. Point data was interpolated and from these wetland volume – area and depth relationships were established. Key features including outflow and inflow elevations were also recorded where present.

Climate data was obtained from SILO, a database maintained by the Queensland Government (SILO, 2022). SILO is spatially interpolated from the Australian Bureau of Meteorology's network of monitoring stations (Jeffrey et al., 2001). Daily rainfall and shallow lake evaporation were extracted from this database for each wetland. Shallow lake evaporation, as described by Morton (1983; 1986), includes the concept of the complementary relationship between actual and potential evaporation (Bouchet, 1963; Nash, 1989). "The complementary relationship predicts that the potential evaporation in a completely dry land environment would be twice the lake evaporation and that it would decrease in response to increases in the water supply to the land surface until it reached a minimum equal to the lake evaporation" (Morton, 1983; see Figure 3).

2.1 Data Analysis

Salinity and water depth data were separated into two periods, pre-2000 (up to and including data collected in 2000) and post-2000. The reason for this choice stemmed from the Auditor General's recommendation to update knowledge since the last regional assessment. The summer of 2000-2001 was also marked by a significant drought and is recognized as a breakpoint in the levels of regional stream flows (Charles et al., 2010). Initial data analyses indicated both log-linear and log-log relationships between salinity and water depth described observations from various wetlands. Linear regressions for both relationships were both performed and based on the Akike Information Criterion (AIC) the best linear model was selected. Five observations in each epoch were specified as the minimum number of observations to perform these regressions. A post-hoc comparison between epochs was performed to evaluate the significance of differences in the slopes and the intercepts of the regressions via estimated marginal means (Russell, 2021).

Seasonal-Mann Kendal trend tests were applied to September and November data to evaluate long-term trends in water depth and salinity across the available data (Sen, 1968; Millard, 2013). Similarly, Mann Kendal trend tests were applied to annual and seasonal rainfall and shallow lake evaporation data. Additionally, time series of water depth and salinity were classified using a partitional clustering algorithm using a distance metric based upon dynamic time warping with a window of 3 years (Sarda-Espinosa, 2019). Time series clustering was based upon normalised (zero mean, unit standard deviation) September observations for the period 1984 to 1992 and 2001 to 2017 as there was a significant decline in the numbers of observations for wetlands with long term monitoring in the intervening years. Medians of observations for each time were computed to characterise each cluster. Statistical significance for regression slopes, intercepts, and trend tests, was selected at the 95% confidence interval (i.e., $p<0.05$). All statistical analyses were performed using the software R (R Core Team, 2020).

3 A model of salinity variation with water depth

To provide a basis with which to better interpret SWWMP data, this section explores the role that wetland morphology and then hydrology have on salinity – water depth relationships and dynamics.

3.1 Water depth – area - volume relationships

The bathymetry of wetlands plays a role in regulating water depth salinity relationships (Langbein, 1961). Hayashi and van der Kamp (2000) found a mean bottom elevation h at a distance x from the deepest point of wetlands often followed a power-law according to:

$$h = h_0 \, x^{\frac{2\,(1-\beta)}{\beta}} \tag{1}$$

Where h_0 and β are empirical coefficients. Assuming a circular shape, this leads to the wetted volume (V) and surface area (A) to be given by:

$$V = \pi(1-\beta)h_0^{\frac{-\beta}{(1-\beta)}}h^{\frac{1}{(1-\beta)}} \tag{2}$$

$$A = \pi\left(\frac{h}{h_0}\right)^{\frac{\beta}{(1-\beta)}} \tag{3}$$

and their inter-relationships as:

$$\frac{V}{V_m} = \left(\frac{A}{A_m}\right)^{\frac{1}{\beta}} = \left(\frac{h}{h_m}\right)^{\frac{1}{1-\beta}} \quad (4)$$

where V_m, and A_m, are scaling coefficients, which can be derived as wetland volume, and area, at an arbitrarily selected water depth, h_m. Without loss of generality, it can be assumed $h_m = 1$, then:

$$V_m = \pi(1-\beta)h_0^{\frac{-\beta}{(1-\beta)}};\ A_m = \pi h_0^{\frac{-\beta}{(1-\beta)}} \quad (5)$$

Brooks and Hayashi (2002) found β to range from 0.20 to 0.65. In a study of larger lakes Cael et al., (2017) instead found wetland volumes to scale with wetland areas as $V{\sim}A^{1.2}$ suggesting more commonly $\beta{\sim}0.83$ in their study. Across populations of wetlands probability distributions of maximum depth were shown to be related to wetland volume and were consistent with mathematical descriptions of topography as a fractal Brownian landscape (Cael and Seekel, 2022).

3.2 Bathymetric controls on salinity

Considering M as the mass of salt in a well-mixed wetland, whose volume of water is V, then the concentration of salt in solution is $C = M/V$. In the case where the mass of salts in solution is constant then the change in concentration varies only with the change in volume of water in the wetland. Using the above depth – volume relationship the following salinity water depth relationship results:

$$C = \frac{M}{V_m} h^{-\frac{1}{(1-\beta)}} \quad (6)$$

Taking logarithms of both sides gives a log-log linear relationship between salinity and water depth of the form:

$$\log C = a - b \log h \quad (7)$$

where $a = \log(M/V_m)$ and $b = 1/(1-\beta)$. This indicates a negative relationship between log-salinity and log-water depth. Furthermore, the slope of the log-log relationship is controlled solely by the bathymetry of the wetland, encapsulated in the parameter β, and the intercept, a, is determined by the total salt mass and wetland bathymetry. For the range of bathymetries evaluated by Brooks and Hayashi (2002) and Cael et al., (2017) b would be expected to vary from 1.25 to 6.0. For conical shaped wetlands it can similarly be shown the concentration would scale with depth according to $C{\sim}\ h^{-3}$, and for cylindrical wetlands as: $C{\sim}\ h^{-1}$.

Wetland bathymetry is more complex than that described above, nevertheless the above equations demonstrate a role for the wetland shape to influence the expected slope of salinity – depth relationships in wetlands with little inflow, other than direct precipitation. The extent to which this bathymetry effect will be expressed depends upon how stable the total salt mass is over time. This is likely to be influenced by the size of the wetland, the total amount of salt stored as well as the magnitudes of the dominant hydrological processes and their respective salt loads which contribute to delivering, diluting and exfiltrating salts. These processes can vary over time scales from a single rainfall-event, seasonally and at inter-annual times scales (Mason et al., 1994).

3.3 Hydrological regulation of salinity

In a drying climate with lower wetland water levels, average salinities would be expected to increase. In the absence of a change in the depth-salinity relationship though, this would suggest no evidence for salinization, just a drying effect. This is illustrated in Figure 4. On the other hand, a sudden increase in the salt mass but no change to the hydrology would cause a shift upwards in the log-log linear relationship and no change in the value of the exponent b, while gradual increases in salt mass and gradual drying may be expressed as an increased value of the exponent b. Therefore, there is information in changes in the water- depth salinity relationship that can potentially inform of salinization processes and changing hydrology.

Changes to the salinity – depth relationship may stem from a dynamic climate or from anthropogenic modification of the landscape. Seasonal streamflow and rainfall filling wetlands may also alter salt concentrations and thus the slope of salinity – depth relationships as well as the spread about a mean trend. Chronic drying may cause groundwater, stream flows, direct precipitation, and wetland overflow to reduce, altering the loads of salts these processes carry. Land clearing may cause long term rises in groundwater tables leading to greater inflows of saline groundwater, lesser variation in water levels and an overall greater stored salt mass (Clarke et al., 2002). Agricultural drainage which been extensively developed in the wheatbelt, discharging saline groundwater to ephemeral streams and ultimately wetlands may be contributing to shifts in salinity – depth relationships (McFarlane and Williams, 2002). Increased urban drainage is also a common pressure for wetlands adjacent cities and towns leading to freshening and deeper mean water levels. Stream diversions for irrigation or conservation are another cause of changes to surface water inflows affecting lakes in the wheatbelt and the southwest of Australia (Lane et al., 2004).

In the circumstances just described, it is unlikely that the depth – salinity relationship would remain stable over time as the overall salt balance and the temporal distributions of loads during a year and between years are expected to change. Wetlands with a large variation in the magnitude of dominant hydrological processes, relative to the size of the wetland, are expected to display a greater variance in the salinity - depth relationship and possible deviations from a log-log relationship.

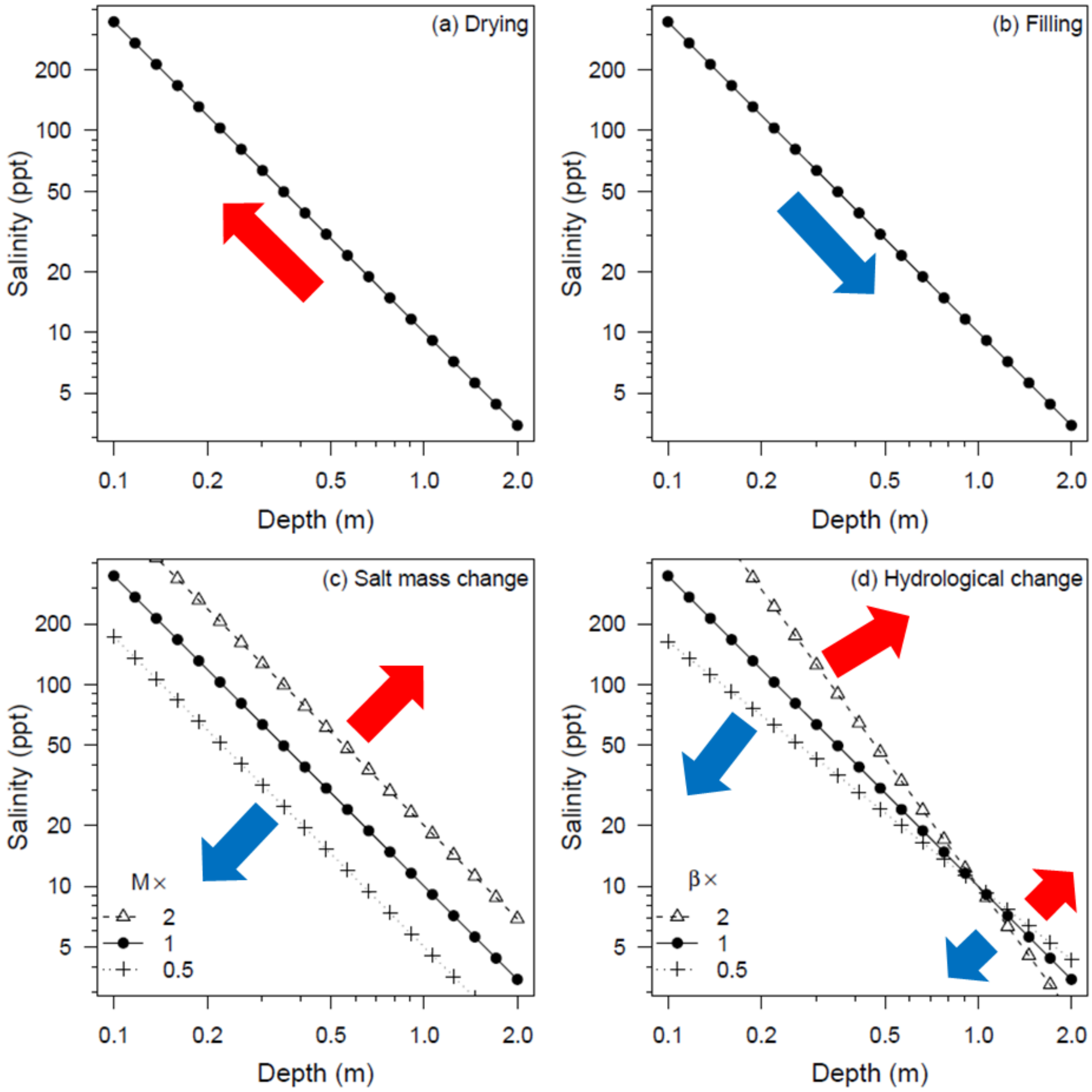


Figure 4: Conceptual shifts and changes of salinity – water depth relationships. (a) During drying mean water levels decline and salinities increase; (b) during filling mean water levels increase and salinities increase; (c) the addition of a mass of salt causes the salinity- depth relationship to shift upwards while the loss of salt causes it to shift downwards (shown as a doubling or halving of salt mass); and (d) changes to the wetland morphology or the wetland hydrology is expected to cause the salinity depth relationship to change slope which may lead to both increases and decreases in salinity for a given water level (show as doubling or halving in β). Red arrows showing increasing salinity while blue arrows suggest freshening.

A more realistic representation of wetland salinity would therefore consider the temporal fluctuations in various water sources and sinks and their respective salt concentrations. A water and salt mass balance of an ideal, well-mixed wetland can be described by the following two equations. The first describes the water balance:

$$\frac{dV}{dt} = P + S + G - O - E \tag{8}$$

where dV/dt is the rate of change in water volume in the wetland due to direct rainfall (P), surface water inflows (S), groundwater inflows (G), total outflows via groundwater and surface runoff (O) and evaporation (E). The second, the salt balance:

$$\frac{dM}{dt} = C_p P + C_s S + C_g G - MO/V \tag{9}$$

describes the rate of change in dissolved salt mass in the wetland (dM/dt), with C_p, C_s and C_g the salt concentrations in rainfall, streamflow, and groundwater respectively and M/V is the wetland's salinity assumed to be the salt concentration of outflowing water. For the sake of developing tractable analytical solutions, it is assumed here that direct rainfall to the wetland is given by:

$$P(h,t) = P_p(t)\, A(h,t) \tag{10}$$

where P_p describes a time variable rainfall rate and A the open surface water area. Similarly, a time varying shallow-lake evaporate rate, E_w, is considered, giving evaporative losses as:

$$E(h,t) = E_w(t)\, A(h,t) \tag{11}$$

Groundwater inflow is assumed to follow Darcy's Law and to depend upon a regional groundwater head, z, independent of the wetland water depth, i.e.

$$G(h,t) = K\, z(t)\, A(h,t) \tag{12}$$

where K [1/T] is the effective transfer rate. Lastly, outflow as streamflow and/or exfiltration to groundwater is assumed to occur as a power-law of wetland depth, i.e.

$$O(h,t) = Q_o\, h(t)^q \tag{13}$$

where Q_o and q are parameters which characterise the stage discharge relationship. Given these assumptions governing equations for water depth and salinity can be derived (see Appendix 1).

It can be informative to look at simplifications of these models to gain insights into wetland function. In the case when all water fluxes are constant and given sufficient time the wetlands reach an equilibrium water depth and salinity. Analytical expressions for the equilibrium water depth, h^*, and equilibrium salinity C^* can be found by setting the time derivatives in Eq. 8 and 9 to zero, changing variables and rearranging terms. Doing this gives an implicit solution for h^* as:

$$h^* = \left(\frac{\left(P_p + K\, z - E_w\right)}{Q_o} A_m h^{*\frac{\beta}{(1-\beta)}} + \frac{S}{Q_o} \right)^{1/q} \tag{14}$$

And in the case when surface water inflows are negligible ($S \sim 0$) the equilibrium water depth is given explicitly by:

$$h^* = \left(\frac{A_m}{Q_o} \left(P_p - E_w + K\, z\right) \right)^{\frac{(1-\beta)}{q\,(1-\beta)-\beta}} \tag{15}$$

The equilibrium salinity, C^*, is given by:

$$C^* = \frac{A_m}{V_m Q_0} h^{*^{-q+\frac{\beta}{(1-\beta)}}} \left(C_p P_p + C_g\, K\, z\right) + \frac{C_s S}{V_m Q_0} h^{*-q} \tag{16}$$

This shows that under steady conditions outflow from the wetland modifies the exponent of the scaling relationship between equilibrium salinity and equilibrium water depth. With weak outflow the salinity increases significantly, though in reality concentrations are limited by supersaturation and then precipitation of salts. When more significant outflow occurs there is the possibility of two scaling regimes, one with an exponent which is a mixture of bathymetry and the outflow hydrology (first term on the right of Eq. 16) and the other which is controlled solely by the inflow and outflow hydrology (second term on the right of Eq. 16). The breakpoint between regimes can be shown to occur at:

$$h^* = \left(\frac{C_s\, S}{A_m\left(C_p P_p + C_g K\, z\right)} \right)^{\frac{(1-\beta)}{\beta}} \tag{17}$$

Substituting Eq. 14 into 16 gives the equilibrium salinity in terms of water depth and all the climate/hydrological variables:

$$C^* = \frac{C_s S + \left(C_p P_p + C_g K\, z\right) A_m h^{*\frac{\beta}{(1-\beta)}}}{S + (P - E_w + K\, z\,) A_m h^{*\frac{\beta}{(1-\beta)}}} \tag{18}$$

and when surface water inflows are negligible ($S \sim 0$), a simpler expression for the equilibrium salinity results, which is the ratio of salt mass flux entering via rainfall and groundwater to the net inflow:

$$C^* = \frac{C_p P_p + C_g K\, z}{P_p - E_w + K\, z} \tag{19}$$

Langbein (1961) derived a similar expression for a much simpler geometry of wetland, which in effect, was the ratio of salt inputs to wetland volume. Similarly setting $S = 0$ in Eq. 16 gives:

$$C^* = \left(C_p P_p + C_g K\, z\right) \frac{A_m}{Q_o} h^{*\,-q+\frac{\beta}{(1-\beta)}} \tag{20}$$

which shows equilibrium salinity scales inversely with water depth when $q > \beta/(1-\beta)$. An analytical model for the seasonal variability is developed in Appendix 1.

3.4 A dynamic model

The dynamic model (Equations 8, and 9) was solved via numerical methods after specification of initial conditions (Soetaert et al., 2010). The set of parameters used for exploratory purposes are listed in Table 2. These values reflect Mediterranean-like seasonal rainfall (~550 mm/a), shallow lake evaporation, and significant surface water inflows. Concentrations of salt in precipitation and groundwater reflects local rainfall and groundwater conditions (Crosbie et al., 2012; Cale et al., 2004). Wetland bathymetric parameters were adopted from the fit to Lake Woody data.

An example simulation is shown in Figure 5. With the selected parameters and initial conditions, it takes approximately 2000 days for the system to reach a stable seasonal pattern. The seasonal pattern that results reflects what is typically observed, with a peak in salinity and lowest water levels in early autumn and peak in water levels and lowest salinity in early spring. The resulting salinity – water depth relationship shows a strong inverse relationship with an exponent of -1. In fact, using these base parameters and conducting an initial sensitivity analysis by gradually varying one parameter at a time an exponent close to -1 is a robust result of the model.

Table 2: Base parameters for the full seasonal model. Length scales in m, time scales in days, concentrations in g/L.

Parameter	Value	Parameter	Value	Parameter	Value
a_p	0.0015	a_s	0.1	a_e	0.0015
ω_p	$2\pi/365$	ω_s	$2\pi\ /365$	ω_e	$2\pi/365$
φ_p	$-\pi/2$	φ_s	$-3\pi/4$	φ_e	$-3\pi/2$
a_{p0}	0.0015	a_{s0}	0	a_{e0}	0.0015
a_c	0	a_z	0.5	β	0.0015
ω_c	0	ω_z	$2\pi/365$	h_0	2.5×10^{-10}
φ_c	0	φ_z	$-3\ \pi\ /4$	q	3
a_{c0}	0.1	a_{z0}	0.5	Q_0	1
C_p	0.01	C_g	20	K	1×10^{-6}

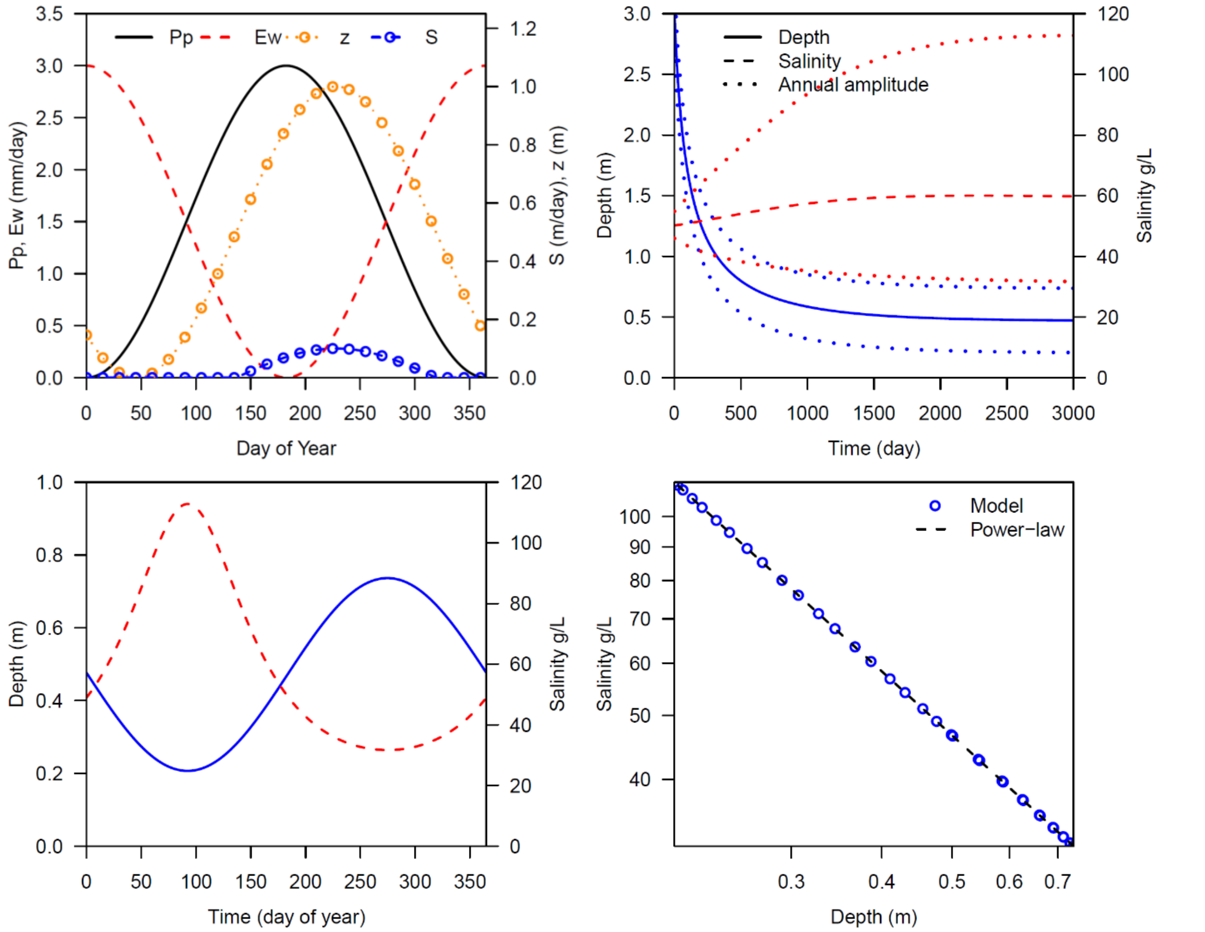


Figure 5: Seasonal model results. Climate and catchment forcing (top left), modelled transient behavior of the annual mean water depths and salinities and their amplitudes (top right), the long-term seasonal variation (bottom left) and the salinity – depth relationship that turns out to be a power law with an exponent b~ -1 (bottom right).

3.5 The influence of extreme events

The rate at which the wetland approaches steady state conditions is controlled primarily by the rate of outflow (parameters Q_0 and q). Depending upon the rate of outflow, extreme events like flooding from tropical cyclones, or droughts, can have long lasting impacts that influence apparent trends. For example, the above seasonal model was first run for a simulation time of 2000 days and then the effects of a tropical cyclone, causing fresh floodwaters to fill a wetland were simulated by modifying the rainfall and surface water inflow rates and concentration as follows: $a_{p0} = 0.2$, $a_{s0} = 10$, and $a_{c0} = 100$, for five days then returning to previously set values gives the results as shown in Figure 6. Following the extreme event, water depths rapidly increase, salinities decrease and thereafter, for a prolonged period the wetland has trends of declining water levels and rising salinity, which is just the gradual return to pre-event conditions. The timescales may be exaggerated in this example; however the results suggest care should be employed when attributing causes to observed trends in wetland state over short (sub-decadal) time periods.

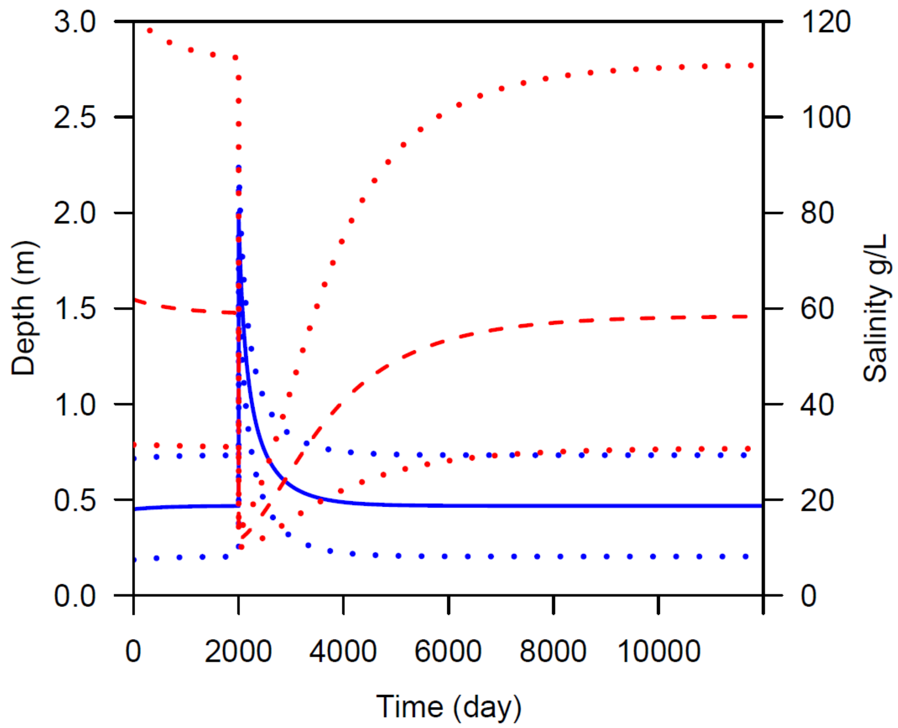


Figure 6: Modelled response to an extreme event.See Figure 5 for the legend.

4 Results

4.1 Climate trends and extreme events

Rainfall across the region has experienced a gradual decline albeit with inter-decadal variability evident and punctuated by severe drought years (1972, 1994, 2001, 2006, 2011, 2015, 2019) and wet years (1974, 1992, 2011, 2021). Mean annual rainfall (1980- 2020) across the region varies from 200 – 1200 mm, with highest rainfalls along the coastal southwest corner (Figure 7). Potential shallow lake evaporation on the other hand tends to increase from south to north.

Statistically significant linear trends in annual rainfall ranged from -6 to -1 mm/a, and these were concentrated in the western coastal areas from Kalbarri to Augusta and smaller areas along the south-coast. Trends in shallow lake evaporation tended to show an increase of the order of 2 – 4 mm/a around Perth, the Capes, Albany, and Esperance, though few areas were statistically significant. On the other hand, declining shallow lake evaporation occurred inland in the eastern Wheatbelt of the order of 5 – 6 mm/a though there were few areas, coinciding with wetlands, that were found to have statistically significant trends. Looking seasonally, mean summer rainfall has increased about 20 mm over much of the southwest in the post-2000 period, except in the Northern Jarrah Forest to the east of Mandurah. For the remaining seasons, rainfall has declined, with autumn rainfall decreasing most strongly in the north and east (20 – 40 mm), winter rainfall decreasing most strongly from Perth to the Capes (50 – 150 mm) and spring rainfalls have declined primarily in western areas (10 – 30 mm).

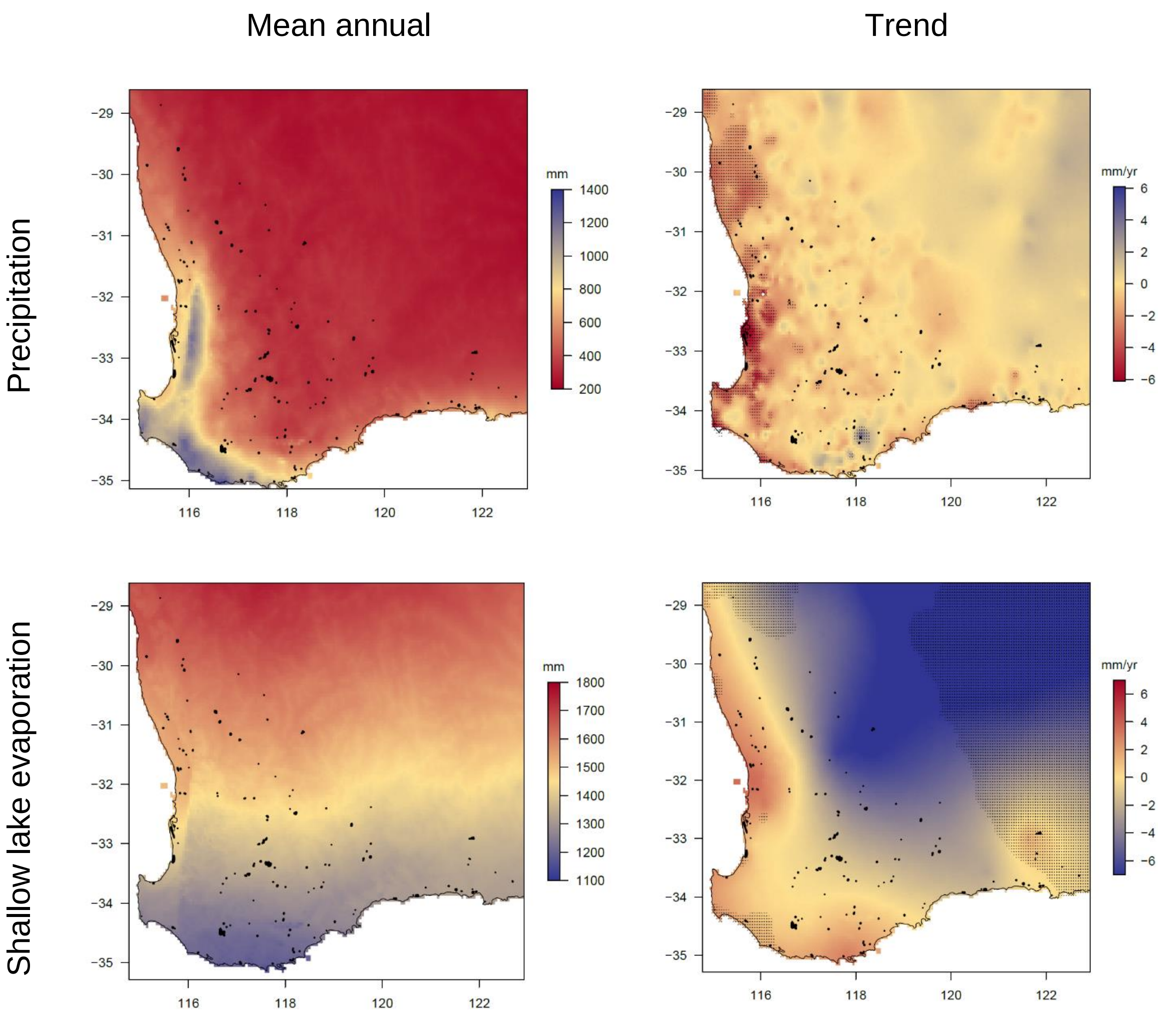


Figure 7: Regional mean annual precipitation and shallow lake evaporation and their respective trends. Stippling denotes significant (p<0.05) linear trends. Black marks are the SWWMP wetlands and lakes. Trends for the period 1961 – 2021.

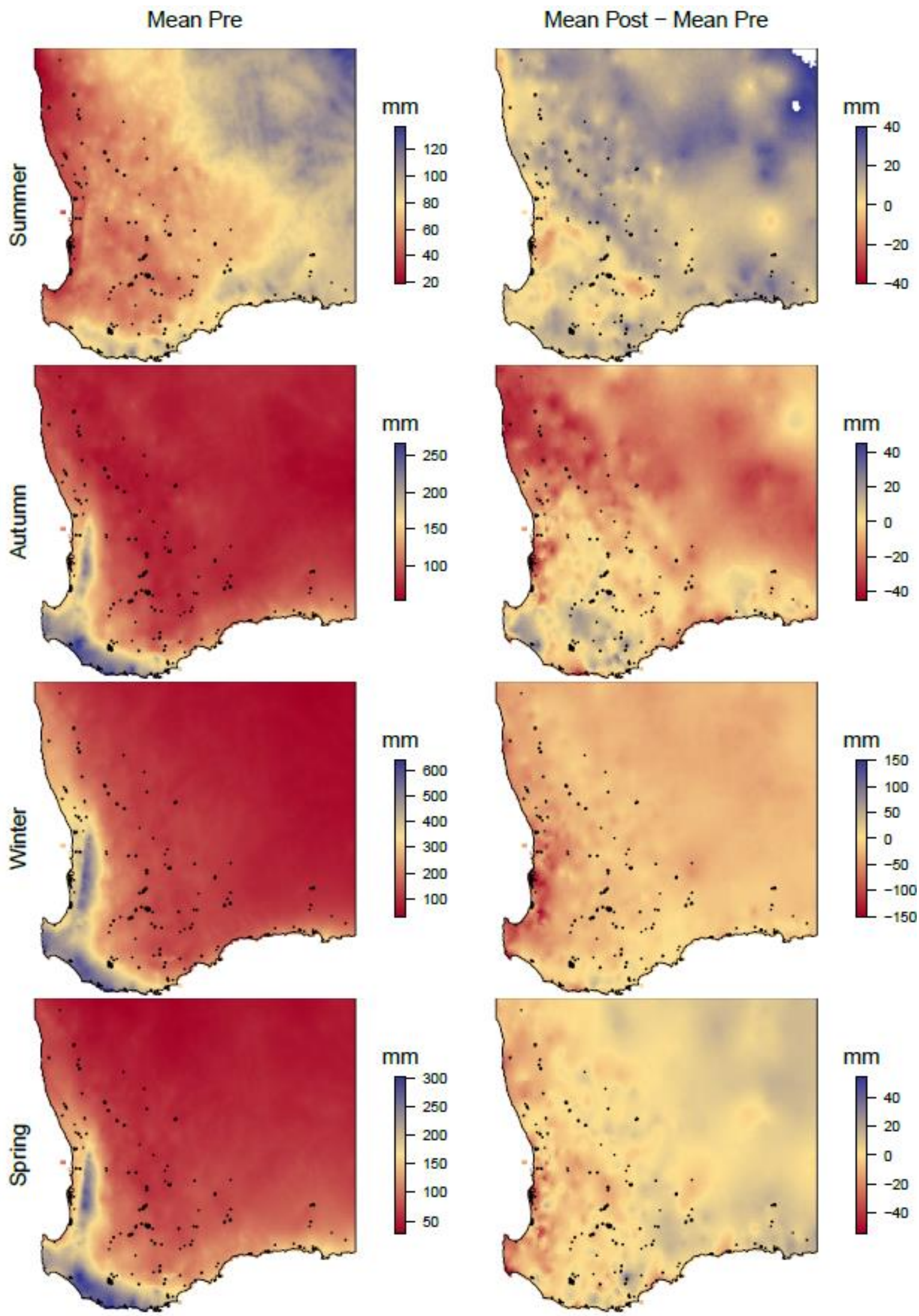


Figure 8: Mean seasonal rainfall for the pre-2000 period and the difference between the mean of post 2000 rainfall. Pre-2000 includes 1980 – 2000, post-2000 includes 2001 – 2019.

4.2 Salinity and depth data

The suite of wetlands in the SWWMP encompass a wide range of salinities and water depths, from <0.05 ppt to >400 ppt and <0.1m to >10 m depth (Figure 9). Within each wetland salinities typically vary by one to two orders of magnitude while depths usually vary by 1 to 2 m. Over the course of the SWWMP the annual number of measurements peaked in the mid 1980's and then stabilised to ~200 measurements per year by 2000. There was a lower frequency of measurement during the mid-1990's.

There is a slight increase in the proportion of samples in the polyhaline to hyperhaline range and a decrease in the relative frequency of fresher samples in the post-2000 period (Figure 10). This may not necessarily reflect an effect from salinization but could also be influenced by sampling bias as monitoring priorities changed over time and shifted to include the effects of salinity (Lane et al., 2017).

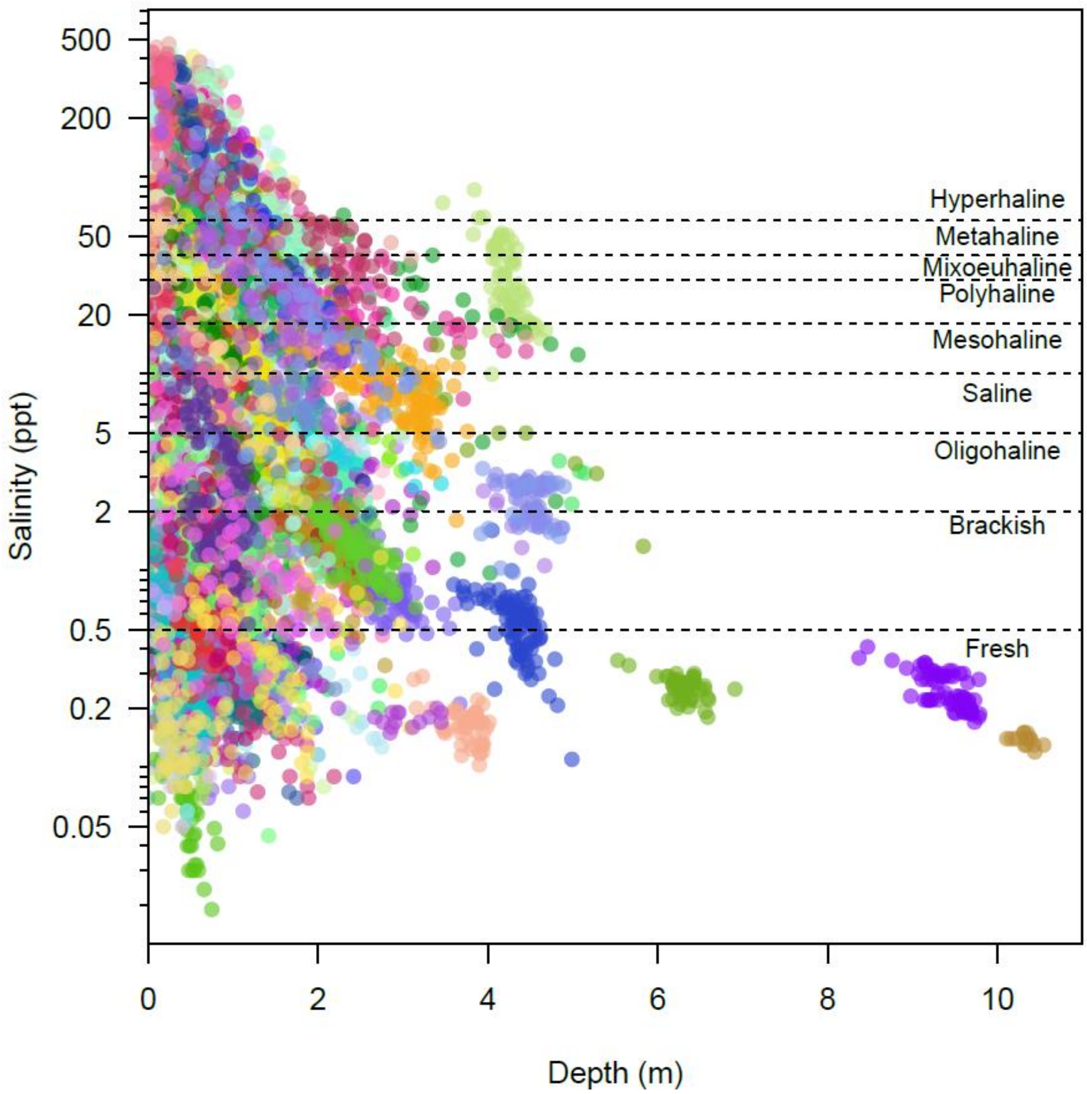


Figure 9: Salinities and water depths in the SWWMP database. Colours denote different sites.

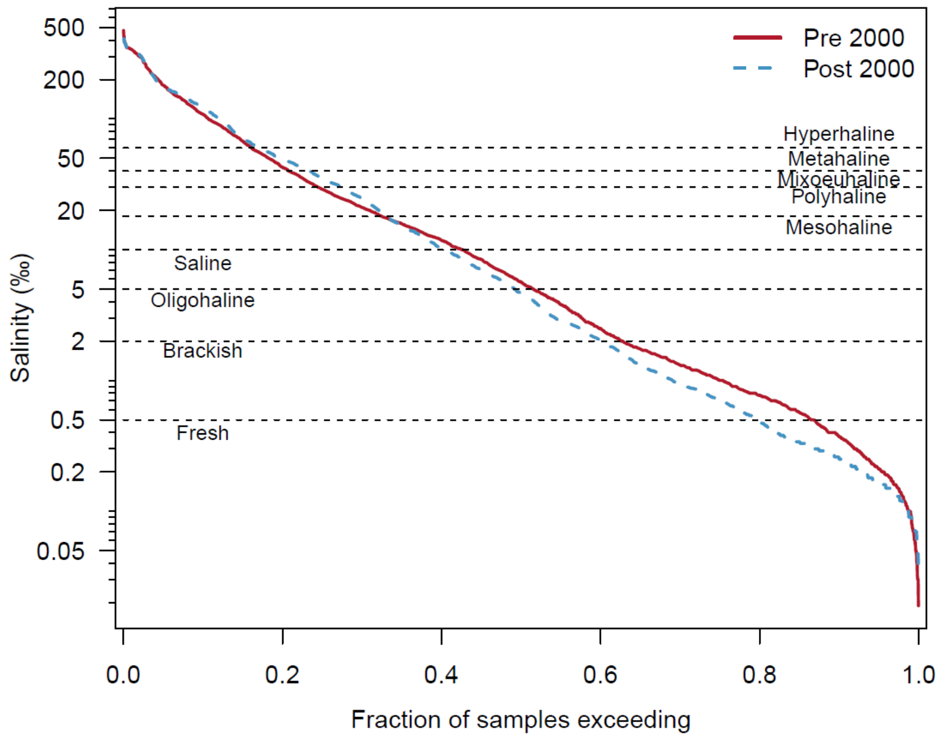


Figure 10: Fraction of samples exceeding salinity concentrations.

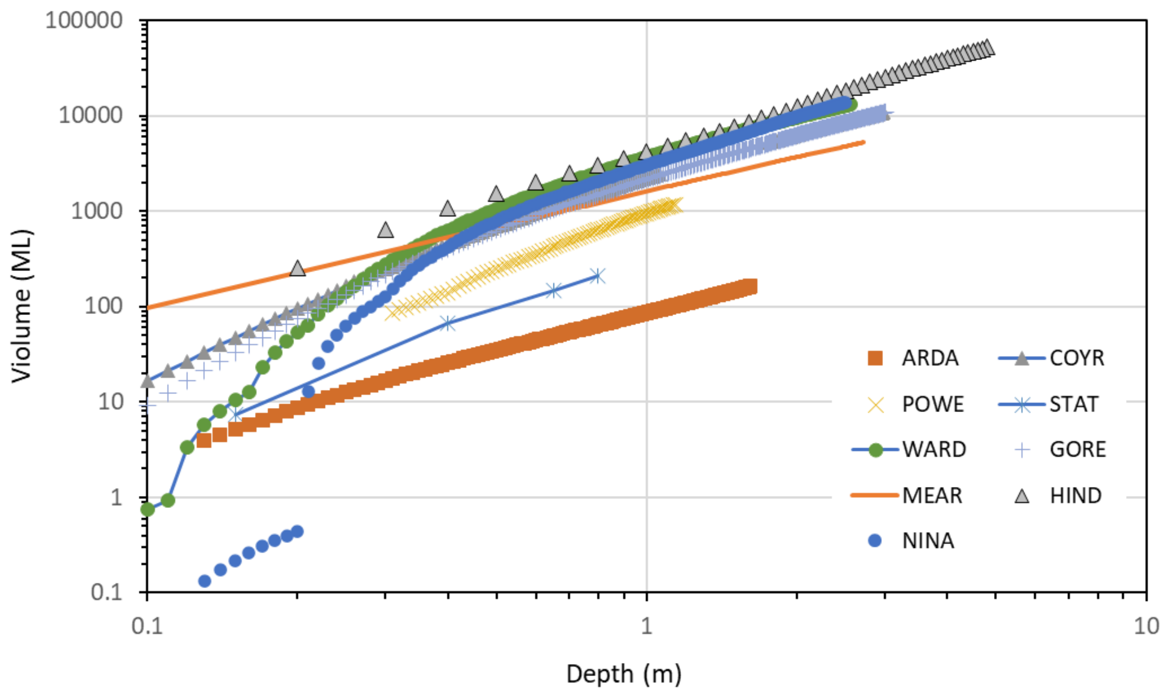


Figure 11: Surveyed wetland volume – depth relationships.

Table 3: Fitted power-law relationships of wetland volume (m^3) vs depth (m).

Wetland	V_m ML	A_m ha	β	b	R^2
ARDA	86	11.6	0.26	1.35	0.99
COYR	2111	325	0.35	1.54	0.99
GORE	2101	323	0.35	1.54	0.99
HIND	4201	678	0.38	1.61	0.99
MEAR	1627	187	0.13	1.15	0.99
NINA	2691	464	0.42	1.72	0.99
POWE	923	178	0.48	1.94	0.99
STAT	358	72	0.50	2.02	0.99
WARD	3473	518	0.33	1.49	0.99

The SWWMP had previously surveyed the bathymetry of several wetlands from which volume – depth relationships were established (Figure 11). Power-law relationships were fit to volumes and depths greater than 0.4 m as below this depth wetlands volumes tended to deviate from the log-log linear form. The estimated parameters for the wetlands with available data are listed in Table 3. The exponent *b* ranged from 1.15 to 2.02 with corresponding values of β ranging between 0.13 and 0.5, within the range of values reported for other lakes (Brooks and Hayashi, 2002).

4.3 Temporal Trends

Time series clustering of normalized (zero mean, unit standard deviation) September water levels for a selection of wetlands with available data only delineated two main clusters of temporal dynamics (Figure 12). The first cluster shows a trend of falling water levels, albeit with a high degree of inter-annual variability. Cluster 2 on the other hand, with just six members, shows stable levels for the entire period 1984 – 2017, albeit with a slight increase in the 1980’s and a slight decrease since 2005. The corresponding normalized salinities show an upward trend for cluster 1 wetlands and for cluster 2 an inverse relationship to the water levels.

Mann-Kendal trend tests identified statistically significant declining water level trends in 32 wetlands (24%), increasing trends in 5 wetlands (4%) and significant positive trends in an additional 2 wetlands whose magnitude was less than the accuracy of measurement (Table 10). Wetlands with falling water levels had an average trend of -29 mm/a while wetlands with a rising trend had an average increase of 24 mm/a (after excluding one anomalous wetland with few data). The wetlands contributing to time series cluster 1 and the declining Mann-Kendal trends were consistent. Similarly, after log-transformation, positive trends in salinity were found in 34 wetlands (26%) and declining trends in just two wetlands (1.5%). The spatial distributions of water level and salinity trends are shown in Figure 13. Declining water level trends and rising salinity trends are widespread across the region.

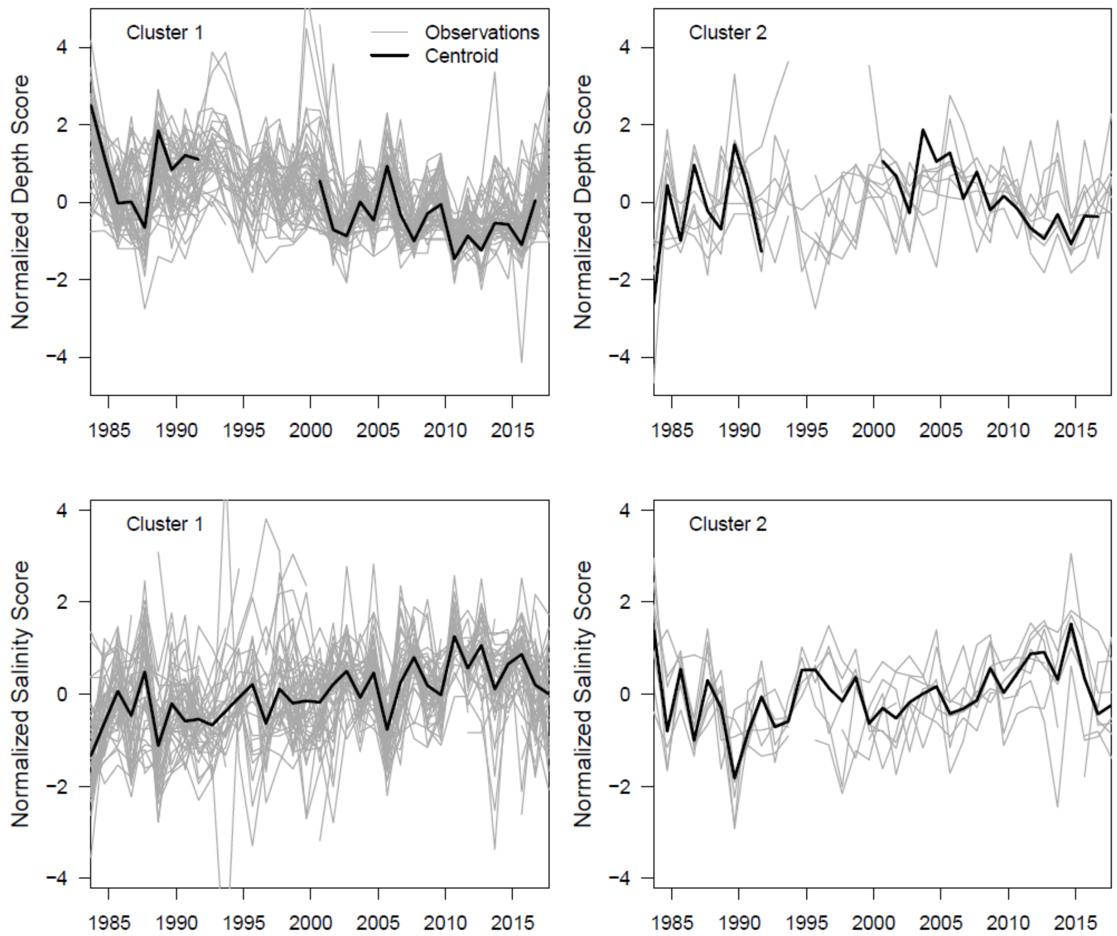


Figure 12: Time series clusters of September water depths and corresponding normalized salinity. Time series are normalized to have zero mean and unit standard deviation. Gray lines are observed data and the black lines are the cluster centroids (top) and median (bottom) values.

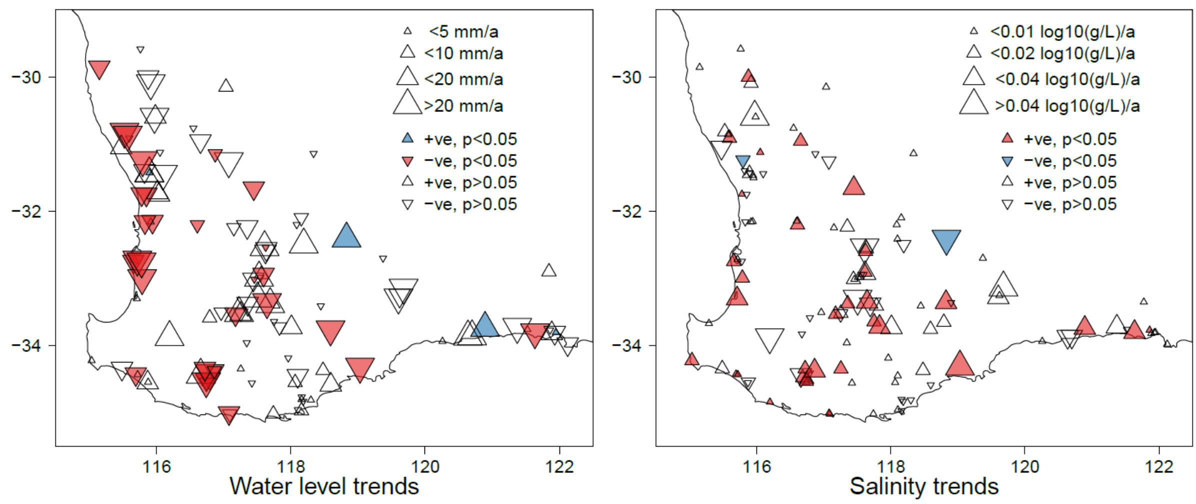


Figure 13: Spatial distribution of September water levels and salinities. Coloured symbols are statistically significant trends (p<0.05). Two sample t-tests identified 17 sites with significantly lower mean September and/or November water levels post-2000 as compared pre-2000 (Table 11). Three sites had statistically significant

deeper mean water levels in September and/or November post-2000. There were 24 sites with significantly larger mean salinities post-2000 and just one site with lower mean salinities.

4.4 SWWMP Salinity – depth relationships

A total of 81 sites had sufficient data to determine salinity depth relationships for both pre- and post-2000 periods. Most of the salinity – depth relationships were well described by either a power-law (41%) or an exponential (52%) relationship with the remainder (7%) not having slopes statistically different from zero (Table 9). For the power-law models the exponents ranged from 0.3 to -4.0 with a median of -0.9 and for the exponential model the exponents ranged -0.2 to -8.0 with a median of -1.4. Seven sites showed a statistically significant difference in the slopes pre- and post-2000 but no change in the intercepts, 18 sites had significantly different slopes and intercepts and 13 sites had statistically significant different intercepts.

General additive models were fitted to the exponents of the depth – salinity relationships as they varied with a smooth spine basis of mean wetland water depth (Figure 15). The smooth term for the power-law exponents explained 40% of the deviance (R-sq.adj = 0.4; p<0.01) and for the exponential exponents 39% (R-sq.adj = 0.4; p<0.01). Power-law exponents tended to decline slightly from values near -0.5 to -1 as mean water depths increased from 0.1 m to 1 m and then to decrease more rapidly as water depths increased beyond 1 m. The exponents of the exponential relationships showed the opposite pattern with exponent values increasing rapidly up to mean water depths of 1 m then stabilising to values near -1. Applying Equation 6, which predicts the scaling exponent of a non-interacting wetlands using the measured wetland bathymetries (Table 3), this would predict exponents in the range of -1.1 to -2, the upper end of which is similar to the mean exponent observed empirically. The mean value of -0.9 is also close to -1, the value identified in the sensitivity analysis of seasonal model (Section 4.5).

In the case when outflow occurs then it was shown above that equilibrium salinity scales with equilibrium water depth and that two scaling regimes occur, similarly to Figure 15. Assuming wetlands are close to equilibrium then, the wetland outflow exponent required to satisfy these observations should follow $q\sim 1.26 + 0.17\log\langle h\rangle$ for $\langle h\rangle < 1$ m and $q\sim 1.26 + 1.4\log\langle h\rangle$ for $\langle h\rangle > 1$. To satisfy $q - 1/(1-\beta) = 1$ requires $1.9 < \langle h\rangle < 3.5$ m. Therefore, a proportion of the wetlands in this study may satisfy this simplifying assumption.

Nine basic archetypes of changes in the salinity – depth relationships were found across the population of wetlands (Figure 14). These archetypes were classified based on the statistical significance of differences in slope and the change in salinity at corresponding water levels. A two letter code was used to describe these archetypes with the first letter indicating whether the slope of the relationship had either: no change (N); steepened (S); or flattened (F); while the second letter referred to the overall change in salinity by water level with: no change (N); salinization (S) whereby salinities tended to be greater at comparable water levels; freshening (F), whereby salinities tended to be smaller at comparable water levels;

or an ambiguous (A) change, with both greater and smaller salinities at comparable water levels . Archetype NN reflects a wetting and drying effect (Figure 4a,b). Archetypes NS and NF resemble changes in salt mass (Figure 4c), while SA and FA resemble hydrological changes (Figure 4d). The remaining types (FS, SF, FF, and SS) resemble combinations of salt mass and hydrological changes.

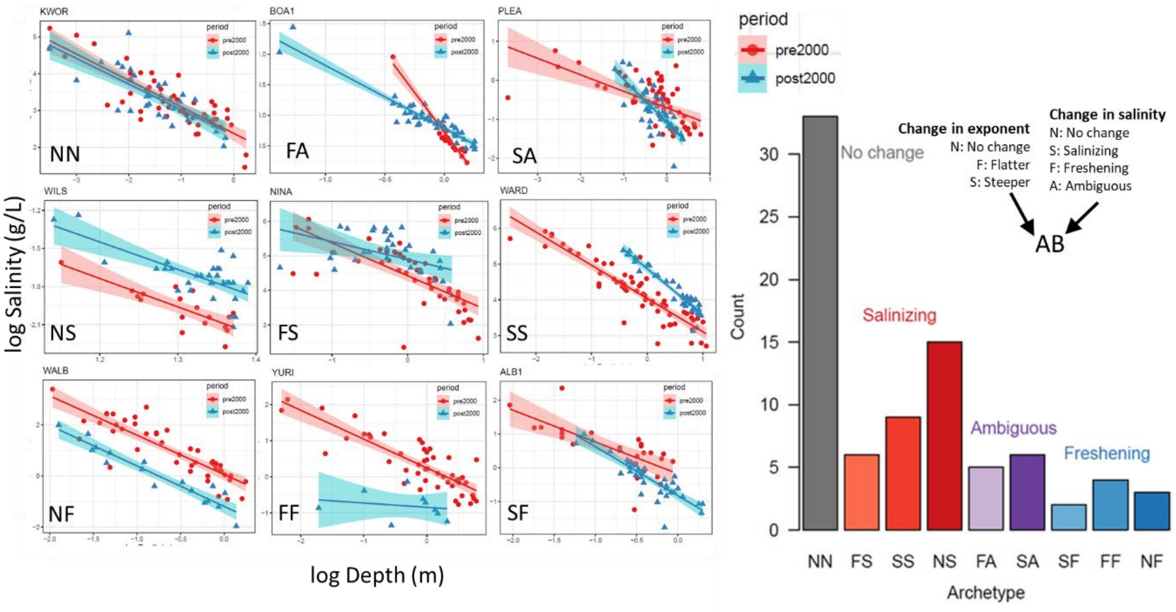


Figure 14: Examples of salinity – water depth archetypes and their frequencies. See Table 2 for archetype descriptions. The four-letter code refers to the site name (see Table 7). The straight lines are the linear regressions and the shaded regions their 95% confidence bands.

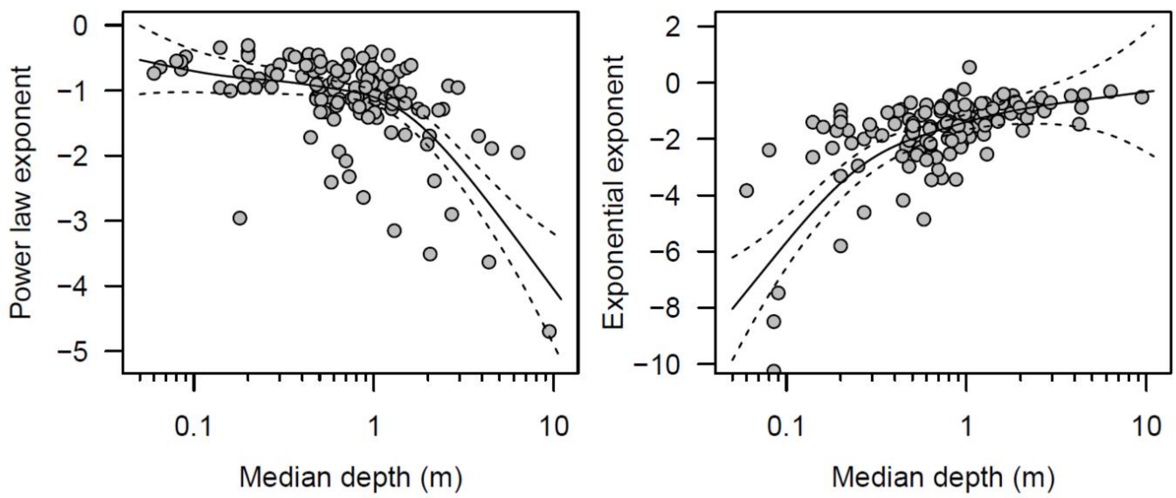


Figure 15: Exponent values for statistically significant power-law and exponential regressions in relation to median wetland depth. The no change archetype (NN) comprised 40% of the wetlands. Of the 13 wetlands of this type with significant trends in either salinity or water levels, 12 look to be salinizing due to drying.

Salinizing archetypes (NS, FS, SS) accounted for 36% of the sites, with upward shifts in salt mass but no significant changes to the hydrological loads of salt (NS) the most frequent, occurring in 18% of wetlands. Freshening types (NF, FF, SF) made up 11% of sites, with shifts downward leading to freshening (NF) occurring in 4% of lakes. Of the 11 lakes classified as ambiguous (FA, SA), six had significant trends in water levels suggesting salinization.

Extrapolating from above, approximately 81% of the region's lakes appear to be salinizing through one or more mechanisms. Analysis of salinity depth relationships, together with trends in salinity and water levels provides a means to evaluate the regional extent of salinization and moreover, to interpret mechanisms contributing to salinization within individual lakes.

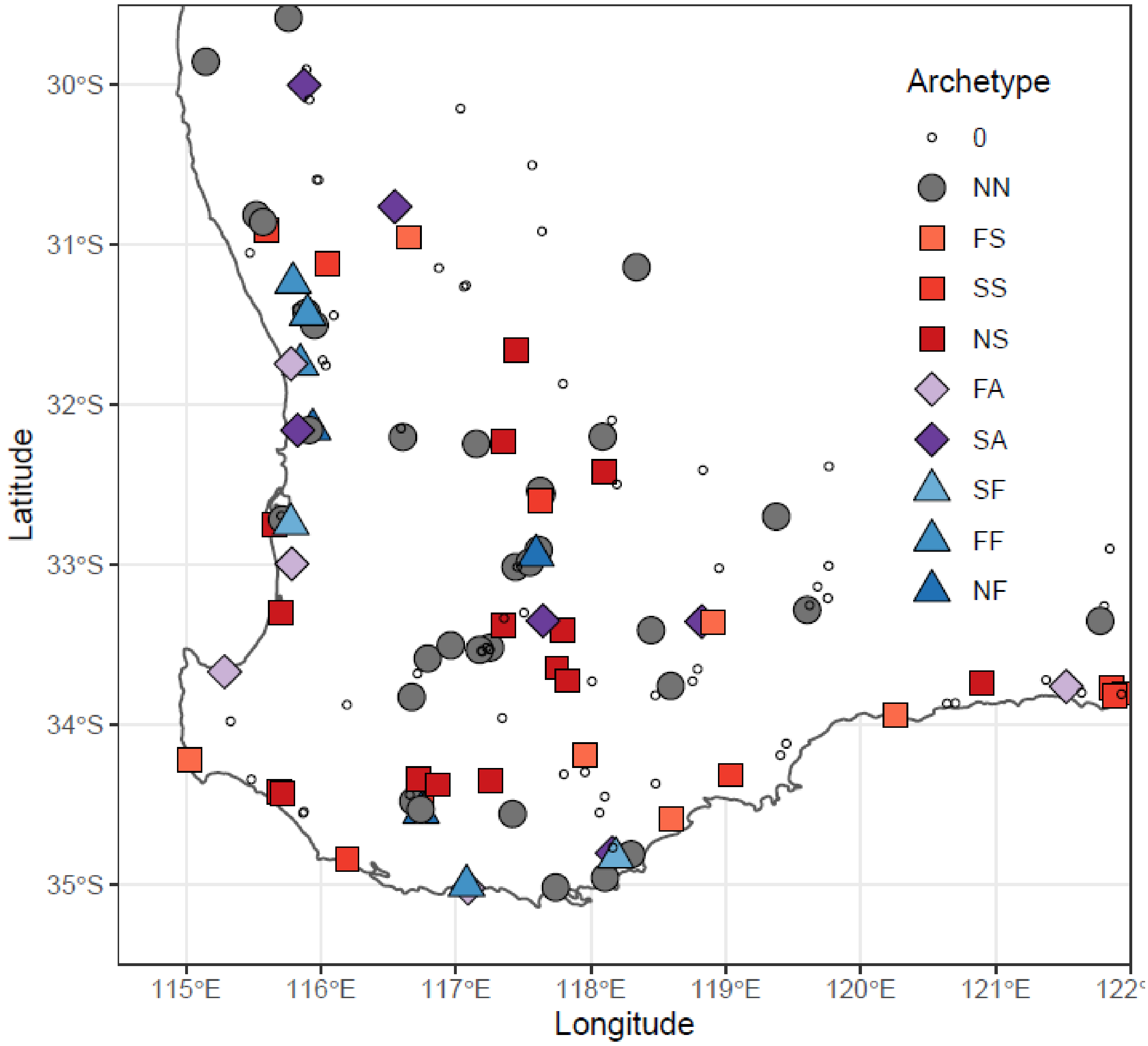


Figure 16: Spatial distribution of archetypes. Type 0 are sites with insufficient data.

The spatial distribution of archetypes shows salinizing types scattered throughout the region (Figure 16). Freshening types mostly occur around coastal areas near major population centers, Perth, Mandurah, and Albany. Similarly, the ambiguous type, FA, occurs mostly near coastal sites while SA are distributed throughout the region.

Based upon the above indicators for the changing status of salinity and hydrology of wetlands a Wetland Score Card is developed. A key to the Score Card is summarized in *Table 4* which describes increasing, decreasing, or stable measure of salinity and hydrology. The Score Card for available wetlands is presented in Table 5

*Table 4: The Key to the Wetland Score Card (*Table 5*).*

Variable	Description	Symbol
Archetype	Changes in the salinity vs water depth relationships.	
	No change	
	Generally fresher	
	Generally more saline	
	More saline at low water levels, fresher at high water levels	
	Fresher at low water levels, more saline at high water levels	
$\Delta h/\Delta t$	September water level trends.	
	Increasing water depth trend	
	Decreasing water depth trend	
	No statistically significant trend	
$\Delta C/\Delta t$	September salinity trends.	
	Increasing salinity trend	
	Decreasing salinity trend	
	No statistically significant trend	
$\Delta\langle h\rangle$	Change in mean September and/or November water levels.	
	Increasing mean depth	
	Decreasing mean depth	
	No statistically significant change in mean depth	
$\Delta\langle C\rangle$	Change in mean September and/or November salinities	
	Increasing mean salinity	
	Decreasing mean salinity	
	No statistically significant change in mean salinity	

Table 5: Wetland Score Card. A summary of changes in wetland condition from pre- to post-2000. See Table 4 for details. Blank values had insufficient data.

Wetland	Archetype	Water level trend $\Delta h/\Delta t$	Salinity trend $\Delta C/\Delta t$	Change in mean water level $\Delta\langle h\rangle$	Change in mean salinity $\Delta\langle C\rangle$
ALB1	⤡	⇔	⇔	⇔	⇔
ALB2	⇔	⇔	⇔		
ALTH	⇔	⇔	⇔	⇔	⇔
ANDE	↑	⇔	⇔	⇔	⇔
ARDA		⇔	⇔		
ATKI		⇔	⇔		
BAMB	⇔	↑	⇔	↑	⇔
BENN	⇔	⇔	⇔	⇔	⇔
BEVE	⇔	⇔	⇔	⇔	⇔
BIGB		⇔	⇔		
BLUE		⇔	⇔		
BOA1	⤡	⇔	↑	⇔	↑
BOKA		⇔			
BOYU	⇔	⇔	⇔	⇔	⇔
BROA	⤡	⇔	⇔	⇔	⇔
BROW	⇔	⇔	⇔	⇔	⇔
BRYD	⤡	⇔	↑	⇔	⇔
BYEN	↑	↓	↑	↓	↑
CAMP	⇔	⇔	⇔	⇔	⇔
CASU	↑	⇔	↑	⇔	↑
CHAN	⇔	⇔	⇔	⇔	⇔
CHIT		⇔	⇔		
CLIF	↑	↓	↑	↓	↑
CMBG		⇔	⇔		
COOM	↑	⇔	⇔	⇔	↑
CORR	↑	⇔	⇔	⇔	⇔
COYR	↑	⇔	↑	⇔	↑
CRAC	↑	⇔	↑	⇔	↑

Wetland	Archetype	Water level trend $\Delta h/\Delta t$	Salinity trend $\Delta C/\Delta t$	Change in mean water level $\Delta\langle h\rangle$	Change in mean salinity $\Delta\langle C\rangle$
DAVI	⬆	⬌	⬆	⬌	⬆
DOBA	⬌	⬇	⬆	⬆	⬌
DULB	⬌	⬌	⬆	⬌	⬌
DUMB	⬉⬊	⬇	⬆	⬌	⬌
EGAN	⬉⬊	⬌	⬆	⬌	⬌
EGRE	⬆	⬌	⬆	⬌	⬆
ENEM	⬌	⬇	⬌	⬌	⬌
ESP1	⬆	⬆	⬆	⬌	⬆
ESP3	⬌	⬌	⬌	⬌	⬌
FLAG	⬌	⬌	⬌	⬌	⬌
FORR	⬇	⬇	⬌	⬇	⬌
FRAS		⬌	⬌		
GARD		⬌	⬌		
GIBB	⬌	⬌	⬌	⬌	⬌
GINL		⬌	⬌		
GING		⬌	⬌		
GNO1		⬌	⬌		
GIUN		⬌	⬇		
GOUN		⬆			
GOON		⬌	⬌		
GOOR		⬌	⬌		
GORE	⬆	⬌	⬌	⬌	⬌
GUND		⬌	⬌		
GURA	⬌	⬇	⬌	⬌	⬌
HARV	⬉⬊	⬇	⬆	⬇	⬆
HIND	⬉⬊	⬌	⬌	⬌	⬌
JAND	⬇	⬇	⬌	⬇	⬌

Wetland	Archetype	Water level trend $\Delta h/\Delta t$	Salinity trend $\Delta C/\Delta t$	Change in mean water level $\Delta\langle h\rangle$	Change in mean salinity $\Delta\langle C\rangle$
JASP	↑	↓	↑	↓	↑
JERD	↑	↔	↔	↔	↔
JOON	↖↘	↓	↑	↓	↔
KARA		↔	↔		
KENT	↑	↔	↔		
KOND		↔	↔		
KWOB		↔	↔		
KWOR	↔	↔	↔	↔	↔
LITT	↔	↔	↔	↔	↔
LOGU	↔	↓	↔	↔	↔
MARI	↑	↔	↑		
MART	↔	↓	↑	↓	↑
MCLA	↔	↓	↔		
MEAR	↑	↔	↔	↔	↔
METT	↑	↔	↔	↔	↔
MLGR		↔	↔		
MOAT	↔	↔	↔	↔	↔
MORT		↓	↑		
MTMA		↔	↔		
MUIR	↔	↓	↑	↓	↔
MUNG		↔	↔		
NAMB		↔	↔		
NGOP		↔	↔		
NINA	↑	↔	↑	↔	↔
NINE	↓	↓	↔	↓	↔
NONA		↔	↔		
NOOB		↓	↔		
NOON	↑	↓	↑	↓	↑
NPAR		↔	↔		

Wetland	Archetype	Water level trend $\Delta h/\Delta t$	Salinity trend $\Delta C/\Delta t$	Change in mean water level $\Delta\langle h\rangle$	Change in mean salinity $\Delta\langle C\rangle$
OWIN	↓	↓	↑	↓	↔
PABE		↔			
PARK	↑	↔	↑	↔	↑
PILL		↔	↔		
PINJ		↔	↔		
PLAN		↔	↔		
PLEA	↓	↔	↔	↔	↔
POOR	↓	↓	↔	↓	↔
POWE	↔	↔	↔	↔	↑
QUEE		↑	↔		
RANG		↔	↔		
REDB	↔	↔	↔		
REDM		↔	↔		
RONN		↔	↔		
SHAR	↑	↔	↑	↔	↔
SHAS		↔	↔		
STAT	↑	↑	↔	↔	↔
STRE		↔	↔		
TAAN		↔	↔		
TAAR	↔	↔	↔	↔	↔
THOM	↖↘	↓	↔	↓	↔
TOOL		↔	↔	↔	↔
TORD	↔	↓	↑	↓	↑
TOWE	↔	↔	↔	↔	↔
UNIC	↑	↓	↑	↔	↑
VARL	↔	↔	↔	↔	↔
WALB	↓	↓	↔	↔	↔
WALY	↓	↓	↔	↔	↔
WANN	↑	↔	↑	↔	↑

Wetland	Archetype	Water level trend $\Delta h/\Delta t$	Salinity trend $\Delta C/\Delta t$	Change in mean water level $\Delta\langle h\rangle$	Change in mean salinity $\Delta\langle C\rangle$
WARD	↑	↔	↔	↔	↔
WARG		↔	↔		
WARR	↑	↔	↑	↔	↑
WEST	↔	↔	↔	↔	↔
WHEA		↔	↔		
WHIN		↓	↔	↔	↔
WHIW	↔	↓	↔	↔	↔
WILS	↑	↔	↑	↑	↑
YAAL	↔	↓	↔	↔	↔
YARN	↑	↓	↑	↓	↑
YARR	↔	↔	↔	↔	↔
YEAG		↔	↔		
YEAS		↔	↔		
YEAL	↑	↔	↑	↔	↑
YELL	↑	↓	↑	↓	↑
YURI	↓	↓	↓	↔	↓

5 Discussion

5.1 Comparison with previous wetland assessments

Several wetland reports were conducted by DBCA’s predecessors during the 2000’s to assess their hydrology, biodiversity, and effects from salinity. Qualitative descriptions of the wetland hydrology and salinization from these reports are compared to the results of this study.

Coyrecup Lake (COYR)

The effects of salinisation have been evident at Coyrecup Lake, near Katanning, with the vegetation exhibiting stress in the form of mortality of the fringing paperbark (Melaleuca cuticularis) although it was thought that salinity was not increasing (Nowicki et al., 2009a). Intensive rainfall events were also thought to be contributing to the problem. The results of the present study suggest it has a salinity – water depth relationship showing signs salinization consistent with a sudden input of salt (archetype NS) with little change to the hydrology. This is also consistent with the absence of significant trends or differences in mean water levels. The archetype is therefore consistent with ecological indicators of salinization and contradicts the suggestion that salinities are stable.

Lake Gore (GORE)

Lake Gore is a large open, near-permanent saline lake, approximately 30 km west of Esperance, one of a series of inter-connected lakes and swamps of various sizes which are intermittently inundated. Lake Gore has a moderate threat of waterlogging and salinisation which was indicated by the deaths of fringing vegetation (Jaensch, 1992; Nowicki et al., 2009b). There was insufficient data to evaluate changes in salinity – depth relationships however trend tests suggest levels and salinities are stable.

Lake Guraga (GURA)

Lake Guraga lies west of the Brand Highway, approximately 14 km south of Cataby in the Shire of Dandaragan. Water is supplied to Lake Guraga primarily from direct precipitation and secondarily from the intermittent Caren Brook, which enters the lake via Namming Lake (Jaensch 1992; Nowicki et al., 2009c). It has previously been described as hyposaline and poikilohaline with low salinity in spring (5 ppt), moderate salinity in autumn (14 ppt) and sometimes high salinity when water levels are low in summer (Jaensch 1992). Large variations in water levels have also been reported. Surface water inflows to Lake Guraga have decreased significantly due to flood control works on Caren Caren Brook and the diversion of water for irrigation. While altered hydrology and salinisation of surface and groundwater has been identified as a threat affecting Lake Guraga the data available in the SWWMP database shows the salinity depth relationship is stable (archetype NN). The trend of declining water levels therefore suggests increasing salinity is occurring because of lake drying however the Mann-Kendal trend test for temporal changes in salinity were not statistically significant.

Lake Logue (LOGU)

Lake Logue lies approximately 13 km west-southwest of Eneabba. Lake Logue receives surface water via several creeks and overflow from Weelawadgi Lake and is thought to perched above the regional groundwater table (Rutherford et al., 2005; Nowicki et al., 2009d). Lake Logue is naturally a seasonal – intermittent wetland, though it began to hold water permanently from the 1960s, after extensive clearing in the catchment. It began a return towards its pre-clearing hydrology in the early 1980's. Like Lake Guraga the salinity – depth relationship has not changed and there are no significant differences in water levels or salinity.

Lake Eganu (EGAN)

Lake Eganu is in the Pinjarrega Nature Reserve, 220 km north of Perth which had undergone secondary salinization (Cale et al., 2010). The bulk (70%) of surface water inflow to Lake Eganu comes from the Marchagee Tributary which drains a

430,000 ha catchment to the east and southeast and enters the Coonderoo River immediately north of Lake Eganu. Rare episodes of overflow also occur from Lake Yarra.

Previously Lane et al., (2004) reported a significant trend of increasing depth, but no significant trend of increasing salinity. This study, which brings the data up to date, found a salinity – water depth archetype SA, indicating a change since 2000 to a freshening at deep water levels but more saline when water levels are shallow. No significant trends in water depth were found however the salinity trend was significant and increasing.

Jandabup Lake (JAND)

Lake Jandabup, located on the Swan Coastal Plain, is a flow-through groundwater lake which has experienced significant clearing for agriculture and then urbanization. In response to declining groundwater levels, lake levels were observed to be declining since at least the mid-1970's (Natural Systems Research Pty Ltd, 1984; Cake, 1998; Turner and Townley, 2006). After water levels fell during a series of droughts between 1997 to 1999 the pH dropped from near neutral to as low as 4. Water supplementation by groundwater pumping has since raised water levels and returned pH to near neutral conditions again {Sommer and Horwitz, 2009).

The analysis of the SWWMP data suggests the water supplementation at Jandabup Lake is showing signs that it is decreasing the salinity despite long term water level declines.

Crackers Swamp (CRAC)

Crackers Swamp is one of six freshwater wetlands located within Namming Nature Reserve, 13 km northwest of Regans Ford. The wetlands flow north from the southernmost wetland to Crackers Swamp, which is the northernmost wetland within the reserve (Lane, 2004a). These wetlands then eventually discharge to Lake Namming and then to the terminal Lake Guraga (see above) however, interventions and diversions appear to have significantly changed the surface water hydrology. It is believed that a levee was constructed at the outlet of Crackers Swamp in the 1930s to prevent overflow to Lake Namming. Also Caren Brook, which may have occasionally delivered more saline water due to land clearing, was diverted to Lake Guraga since the 1970's, with occasional breaches during flood events. At Crackers Swamp there is only sufficient data available for the present study to suggest salinity is rising despite stable water levels.

Lake Towerinning (TOWE)

Lake Towerrinning is in the West Arthur Shire, 1 km north of the Moodiarrup townsite and 1 km west of the Arthur River. Clearing within the catchment of Lake Towerrinning began around 1910 and increased rapidly around the 1950s (Froend and McComb, 1991). Lake Towerrinning was still considered to be fresh in 1966, however, estimates suggest that salinity began increasing in the early 1960s and an obvious decline in the water quality was observed since 1973 (Lane, 2004b). The lake completely dried during the summer of 1981, then refilled and overflowed the following summer (1982) because of rain generated by cyclones Errol and Bruno

(George and Bennett, 1994). Surface water has been diverted into Lake Towerinning since 1993 and outflows are now managed such that prior to 1994, outflow events occurred when the lake reached 3.46 m, and post-1994, following the lowering of the lake spillway, outflows occurred when the lake reached a depth of 3.0 m (or 2.83 m depending upon the survey).

The analysis of the SWWMP database in the present study suggest all indicators are stable.

Thomsons Lake (THOM)

Thomsons Lake is in the southern suburbs of the city of Perth. Most of the clearing of privately owned land around the reserve occurred during the 1960s and then in 1992 the surrounding land became urban. Urbanization had earlier begun to cause raised water levels in several wetlands upstream of Thomsons Lake by the 1980s (Lane, 2004c). A hydrogeological investigation suggested that of an average annual water inflow of 6,000 m^3, 51% was from groundwater inflow, 37% from precipitation, and 12% from surface runoff (Kazemi and Rathur, 1995). They further suggest that evapotranspiration represents 63% and groundwater outflow 37% of water losses. Since at least 2004, surface water has been diverted into Thomsons Lake to reverse the effects of long-term drying.

The salinity depth relationship suggests more saline conditions when the lake levels are shallower and a trend of declining water levels however salinity trends were not significant.

5.2 Comparison with Lane et al., (2004).

For the period prior to 2001, Lane et al., (2004) assessed linear trends in water depth and salinities of 41 wetlands with at least 20 years of data collection (c.f. Table 1 in Lane et al., 2004 and simplified here Table 6). Here, these same wetlands are reassessed with the longer data record and in the context of water depth salinity relationships as opposed to temporal trends as conducted by Lane et al., (2004).

Previously they found salinity to be increasing in six wetlands with water levels increasing in three of those and stable in the other three. They found salinity to be decreasing in six wetlands, with water levels rising in one wetland and stable in five. Salinity was stable in 29 wetlands with water levels rising in nine, stable in 18 and falling in two wetlands.

Now nine wetlands have salinity depth relationships suggesting greater salinity post-2000 than pre-2000 with five of these showing falling water levels and four had stable water levels. Only one wetland had rising water levels, and this site had stable salinity-depth relationships. Four wetlands had a stable depth-salinity relationship and lower water levels indicating the average salinity has risen. Eight wetlands had stable relationships and stable water levels, suggesting little change. Five wetlands had lower salinities, despite falling water levels and one had lower salinity despite stable water levels. Overall, there has been a decline in the number of wetlands with rising or stable water levels to falling levels and stable or falling salinity to rising salinity.

Table 6: Reappraisal of depth and salinity trends from long term sites reported in Lane et al., (2004).

Lane et al., (2004)		Water Level Changes		
		↓	↔	↑
Salinity Changes	↑		LOGU, THOM, TOOL	BRYD, CRAC, YARN
	↔	FORR, NINE	BOYU, BYEN, CASU, COYR, DUMB, GORE, HARV, JAND JERD, JOON, KWOR MOAT, PLEA, POWE, SHAR, TAAR TORD, WALB	DULB, EGAN, MUIR, STAT, UNIC, WANN, WARD, WARR, YAEL
	↓		BAMB, BEVE, CHAN, DOBA, POOR	TOWE
This study		↓	↔	↑
Salinity Changes	↑	BYEN, DUMB, HARV JERD, THOM	CASU, COYR, GORE, SHAR	
	↔	LOGU, JOON, KWOR, TORD	TOOL, BOYU, MOAT, POWE, TAAR, BEVE, CHAN, DOBA	BAMB
	↓	FORR, NINE, JAND, WALB, POOR	PLEA	

5.3 Long-term trends, sudden shifts, and response times

Many of the salinity – depth relationships show distinct differences from pre- to post-2000 with little indication of a gradual transition between states. Partly this may stem from gaps in sampling which occurred for many sites during the 1990's. However, very sudden shifts can also be seen for wetlands with near continuous records (e.g. BROA, BYEN, CASU, COYR, NOON, WALB) and others show a transition over a span of five to ten years (e.g. BRYD, EGAN, MARI, METT, NINE, OWIN, PARK, SHAR). For some the switch looks to be the result of long-term trends (e.g. CLIF, DAVI) but for the others, trends are less clear.

Major changes to regional surface water hydrology have been noted previously to have occurred at around 1975, 2001 and then again after 2010, associated with drought events (McFarlane et al., 2020). Each time, regional surface water runoff appears to have shifted downwards to a new lower mean. The data in this study therefore coincides with two of these shifts. Changes to surface water inflows to wetlands due to this drying may be contributing to the various archetypes. Lower outflow and weaker flushing of salts may in some instances be contributing to archetypes FS, SS and NS. In some places this drying has resulted in streamflow freshening, due to the disconnection of groundwater from stream sections (Kinal and

Stoneman, 2012). In other places the drying climate has been attributed to the stabilization or the decline in groundwater levels that had been previously rising from the effects of historical land clearing (McFarlane et al., 2020). Apart from the wetlands where there has been some obvious hydrological intervention, declines in groundwater contributions and freshening of streamflow may be contributing to the archetypes describing freshening i.e. types SF, FF, and NF.

There has also been a reduction in rainfall from ex-tropical cyclones which passed through the region. Between 1977 – 1999, there were 18 tropical cyclones or their rain bearing depressions which passed within 500 km of 118°E, 30°S, whereas since 2000 there has been just 6 events (BOM, 2022). Groundwater storage can have a long memory of these extreme events (McGrath et al., 2012). The modelling also showed timescales of water level and salt readjustment after extreme events can be quite long, resembling drying trends seen in some wetlands (c.f. Figure 6). There is a need therefore to better untangle the contributions from different climate drivers on wetland response. Wetland sediments may hold a key to better characterising long-term water depth and salinity variations and thus the significance of extreme events (Fritz et al., 1991; Mason et al., 1994; Gasse et al., 1997; Jolly et al., 2008).

The mathematical model of water depth salinity relationships highlighted the importance of wetland bathymetry in controlling salinity depth relationships. However, too few wetlands had bathymetry and long-term monitoring to fully appraise this effect. With future drying projected, then we could expect that as wetland water levels decline, they would tend to increase in salinity along their salinity – depth relationship. Therefore, data on wetland bathymetry can assist with improved prediction of climate change impacts to wetland salinity. The development of models to reproduce water levels and wetland salinity, particularly in wetlands with long records can help elucidate the past changes to the hydrology and better constrain conceptual models of local hydrological processes to better inform their management. This may also require more sophisticated representation of water and sediment chemistry to better capture mineral interactions, solute precipitation, and dissolution (Langbein, 1961). This would allow modelling of wetlands that completely dry and rewet, for example.

6 Conclusions

There is a regional trend of declining wetland water levels, that in and of itself would be expected to lead to increasing average salinities. Salinity – water level relationships were strongly correlated and showed characteristic changes from pre- to post-2000. Of the wetlands evaluated this way, 40% exhibited no change in the salinity – depth relationship from the pre-2000 to post-2000 period which suggests rising average salinities in these wetlands is a result of the regional drying. In the remaining wetlands, 36% of sites exhibited changes indicative of ongoing salinization since 2000. Freshening occurred in 11% of the wetlands while the remaining 13% had ambiguous changes with the potential for both freshening and salinization depending upon the water levels. Of these 11 lakes, six had significant trends in water levels suggesting salinization. The net effect of these changes suggest that

81% of the region's wetlands have rising salinities due to various combinations of climate drying, hydrological changes and salinization.

There also appears to have been rapid changes to the hydrology and salt budgets of many wetlands at around the turn of the last century. This is evidenced by sudden changes in the slope and/or the intercepts of salinity – depth relationships in the SWWMP database with few data mixing between the empirical relationships. The transition therefore coincides with the severe drought of 2001 and possibly the wet summer prior.

The long-term drying of the climate may have contributed to the freshening of some wetlands due to weakened groundwater interaction freshening surface water inflows in some places though this requires further evaluation. Additionally, the drying climate may have stemmed the legacy effects of rising saline groundwater from land clearing and secondary salinization at a few locations. Several instances of freshening however look to be primarily the result of catchment or wetland intervention measures.

The SWWMP database provided a unique insight into regional long-term wetland dynamics that is rare globally, for both the number of sites and the duration or records. As hydrology and salinity plays a fundamental role in regulating both the biodiversity and abundance of aquatic flora and fauna, the SWWMP data illustrate the benefits of long-term monitoring of key wetlands to track wetland health and the ecosystem services they provide (Pinder et al., 2005; Lyons et al., 2007; Cale et al., 2010).

Appendices

Appendix 1 Derivation of Salinity – Depth Relationships

The steady-state solutions developed in Section 2 do not describe seasonal or interannual variation in the relationship between salinity and water depth. A model which parameterizes dynamic inputs and outputs is required for that. To begin to do so it is assumed seasonal variations in climate dominates the dynamics such that the rainfall rate, surface water inflow, potential evaporation rate, stream salinity and groundwater head, follow sinusoidal patterns i.e.

$$P_p(t) = a_p \sin(\omega_p t + \varphi_p) + a_{p0} \tag{21}$$

$$S(t) = a_S \sin(\omega_S\, t + \varphi_s) + a_{S0}$$

$$E_p(t) = a_e \sin(\omega_e t + \varphi_e) + a_{e0}$$

$$C_s(t) = a_c \sin(\omega_c t + \varphi_c) + a_{c0}$$

$$z(t) = a_z \sin(\omega_z t + \varphi_z) + a_{z0}$$

where a_i are the corresponding amplitudes, a_{i0} their annual means, ω_i their frequencies and φ_i phase shifts.

An analytical solution to Equation 8, assuming the seasonal variability as described above, is possible when $S = 0$, and $q - \frac{1}{(1-\beta)} = 1$. The solution is given by (see derivation below):

$$\begin{aligned} h(t) = {} & \frac{a_p\left(Q_o^* \sin(\omega_p t + \varphi_p) - \omega_p \cos(\omega_p t + \varphi_p)\right)}{{Q_o^*}^2 + \omega_p^2} + \frac{a_{p0}}{Q_o^*} \\ & - \frac{a_e\,(Q_o^* \sin(\omega_e t + \varphi_e) - \omega_e \cos(\omega_e t + \varphi_e))}{{Q_o^*}^2 + \omega_e^2} - \frac{a_{e0}}{Q_o^*} + \frac{K\, a_{z0}}{Q_o^*} \\ & + \frac{K\, a_z\,(Q_o^* \sin(\omega_z t + \varphi_z) - \omega_z \cos(\omega_z t + \varphi_z))}{{Q_o^*}^2 + \omega_z^2} \end{aligned} \tag{22}$$

after specifying the initial condition to remove transient effects:

$$\begin{aligned} h(0) = {} & \frac{a_p\left(Q_o^* \sin(\varphi_p) - \omega_p \cos(\varphi_p)\right)}{{Q_o^*}^2 + \omega_p^2} + \frac{a_{p0}}{Q_o^*} - \frac{a_e\,(Q_o^* \sin(\varphi_e) - \omega_e \cos(\varphi_e))}{{Q_o^*}^2 + \omega_e^2} \\ & - \frac{a_{e0}}{Q_o^*} + \frac{K\, a_{z0}}{Q_o^*} + \frac{K\, a_z\,(Q_o^* \sin(\varphi_z) - \omega_z \cos(\varphi_z))}{{Q_o^*}^2 + \omega_z^2} \end{aligned} \tag{23}$$

In the case of salinity, an analytical expression that results from the above assumptions is given by (see below):

$$C(t) = c\exp\left(-\int^{t} g(x)\,dx\right) + \exp\left(-\int^{t} g(x)\,dx\right)\int^{t}\exp\left(\int^{z} g(x)\,dx\right)f(z)dz \tag{24}$$

where x and z are variables of integration, c is a constant, dependent upon the initial condition $C(0)$, and $f(t)$ and $g(t)$ are given by:

$$f(t) = \frac{A_m}{V_m h(t)}\left(C_p P_p(t) + C_g K\ z(t)\right) \tag{25}$$

$$g(t) = \left(\frac{Q_o}{V_m}\ h(t) + \frac{1}{h(t)}\frac{dh}{dt}\right) \tag{26}$$

Complete analytical solutions for the second term on the right of Equation 25 do not appear possible, however straight forward numerical methods can be applied to enable a rapid assessment of water depth vs salinity relationships that result.

Water Balance

For power-law shaped wetlands, a change in volume is related to a change in water depth via:

$$\frac{dV}{dt} = \frac{dV}{dh}\frac{dh}{dt} = V_m h^{\frac{\beta}{(1-\beta)}}\frac{dh}{dt} \tag{27}$$

Substituting into Eq. 8, and rearranging gives:

$$V_m h^{\frac{\beta}{(1-\beta)}}\frac{dh}{dt} = P_p A_m h^{\frac{\beta}{(1-\beta)}} + S + K\ z\ A_m h^{\frac{\beta}{(1-\beta)}} - Q_o\ h^q - E_w A_m h^{\frac{\beta}{(1-\beta)}} \tag{28}$$

Rearranging equation 28 gives:

$$\frac{dh}{dt} = \frac{A_m}{V_m}\left(P_p(t) + K\ z(t) - E_w(t)\right) + \frac{S}{V_m}h^{\frac{-\beta}{(1-\beta)}} - \frac{Q_o}{V_m}h^{q-\frac{\beta}{(1-\beta)}} \tag{29}$$

In general, this equation has no analytical solution, however if $S = 0$ and $q - \frac{\beta}{(1-\beta)} = 1$, it becomes a first order linear differential equation:

$$\frac{dh}{dt} = \frac{A_m}{V_m}\left(P_p(t) + K\ z(t) - E_p(t)\right) - \frac{Q_o}{V_m}h \tag{30}$$

This has a form:

$$\frac{dh}{dt} = f(t) - \ g(t)h \tag{31}$$

which can be solved using an integrating factor $v(t)$, assuming $v(t)$ satisfies:

$$v(t)\, g(t) = v'(t) \tag{32}$$

Multiplying Eq 33 by $v(t)$:

$$v(t)\, h' - v(t)\, g(t)\, h = v(t) f(t) \tag{33}$$

Substituting $v'(t)$:

$$v(t)\, h' + v'(t)\ \ h = v(t)\, f(t) \tag{34}$$

The left-hand side of which is the product rule, i.e.

$$\big(v(t)\, h(t)\big)' = v(t)\, f(t) \tag{35}$$

Integrating both sides:

$$\int \big(v(t)\, h(t)\big)' dt = v(t)\, h(t) + c = \int v(t) f(t) dt \tag{36}$$

Solving for $u(t)$ gives:

$$u(t) = \frac{\int v(t)\, f(t) dt + c}{v(t)} \tag{37}$$

where c is a constant of integration. Solving the integrating factor via a separation of variables gives:

$$v(t) = k \exp\left(\int g(t)\, dt\right) \tag{38}$$

Substituting into the above and merging the constants:

$$h(t) = \exp\left(-\frac{Q_o}{V_m}\ t\right) \int \exp\left(\frac{Q_o}{V_m}\ \ t\right)\ f(t) dt + c\ \ \exp\left(-\frac{Q_o}{V_m}\ \ t\right) \tag{39}$$

The analytical solution that results after substituting the sinusoidal terms (Equation 21) is the following, where an initial condition is assumed, such that $c = 0$.

$$\begin{aligned} h(t) = {} & a_p^* \left(Q_o^* \sin\left(\omega_p t + \varphi_p\right) - \omega_p \cos\left(\omega_p t + \varphi_p\right)\right) + \frac{a_{p0}}{Q_o^*} \\ & - a_e^* \left(Q_o^* \sin(\omega_e t + \varphi_e) - \omega_e \cos(\omega_e t + \varphi_e)\right) - \frac{a_{e0}}{Q_o^*} + \frac{K\ a_{z0}}{Q_o^*} \\ & + \ K\ a_z^* \left(Q_o^* \sin(\omega_z t + \varphi_z) - \omega_z \cos(\omega_z t + \varphi_z)\right) \end{aligned} \tag{40}$$

with

$$Q_o^* = \frac{Q_o}{V_m}\ ;\ a_p^* = \frac{a_p}{{Q_o^*}^2 + \omega_p^2};\ \ a_e^* = \frac{a_e}{{Q_o^*}^2 + \omega_e^2};\ a_z^* = \frac{a_z}{{Q_o^*}^2 + \omega_z^2} \tag{41}$$

It can be shown that the initial condition to ensure the initial transient is zero (i.e., $c = 0$) must be:

$$h(0) = \frac{a_p\left(Q_o^* \sin(\varphi_p) - \omega_p \cos(\varphi_p)\right)}{{Q_o^*}^2 + \omega_p^2} + \frac{a_{p0}}{Q_o^*} - \frac{a_e\,(Q_o^* \sin(\varphi_e) - \omega_e \cos(\varphi_e))}{{Q_o^*}^2 + \omega_e^2} - \frac{a_{e0}}{Q_o^*} + \frac{K\,a_{z0}}{Q_o^*} + \frac{K\,a_z\,(Q_o^* \sin(\varphi_z) - \omega_z \cos(\varphi_z))}{{Q_o^*}^2 + \omega_z^2} \quad (42)$$

Salt Balance

In relation to salinity, $C = M/V$ the mass balance is given by:

$$\frac{dM}{dt} = C\frac{dV}{dt} + V\frac{dC}{dt} = C_p P + C_s S + C_g G - MO/V \quad (43)$$

Substituting terms into Eq 9. gives

$$CV_m h^{\frac{\beta}{(1-\beta)}}\frac{dh}{dt} + V_m h^{\frac{1}{(1-\beta)}}\frac{dC}{dt} = C_p P_p A_m h^{\frac{\beta}{(1-\beta)}} + C_s S + C_g G\,A_m h^{\frac{\beta}{(1-\beta)}} - C\,Q_o\,h^q \quad (44)$$

and then rearranging gives

$$\frac{dC}{dt} = \frac{A_m}{V_m}\frac{1}{h(t)}\left(C_p P_p(t) + C_g\,K\,z(t)\right) + \frac{C_s S}{V_m}h^{\frac{-1}{(1-\beta)}} - \left(Q_o^*\,h(t)^{q-\frac{1}{(1-\beta)}} + \frac{1}{h(t)}\frac{dh}{dt}\right)C \quad (45)$$

For the case when $S = 0$ and $q - \frac{1}{(1-\beta)} = 1$ this equation is a linear first order differential equation, whose general solution is given by:

$$C(t) = c\exp\left(-\int^t g(x)\,dx\right) + \exp\left(-\int^t g(x)\,dx\right)\int^t \exp\left(\int^z g(x)\,dx\right)f(z)dz \quad (46)$$

Where x and z are variables of integration and $f(t)$ and $g(t)$ are:

$$f(t) = \frac{A_m}{V_m h(t)}\left(C_p P_p(t) + C_g K\;\; z(t)\right) \quad (47)$$

$$g(t) = \left(\frac{Q_o}{V_m}h(t) + \frac{1}{h(t)}\frac{dh}{dt}\right) \quad (48)$$

The integral of $g(t)$ evaluates to:

$$\int^{t} g(x)\,dx \;=\; Q_o^* \int^{t} h(x)\,dx + \log h(t) \tag{49}$$

Which, after substituting Equation 30, gives:

$$\begin{aligned}\int^{t} g(x)\,dx \;=\; Q_o^* \Bigg(& \frac{a_p^*}{\omega_p}\left(-Q_o^* \cos(\omega_p t + \varphi_p) - \omega_p \sin(\omega_p t + \varphi_p)\right) + \frac{a_{p0}}{Q_o^*} t \\ & - \frac{a_e^*}{\omega_e}\left(-Q_o^* \cos(\omega_e t + \varphi_e) - \omega_e \sin(\omega_e t + \varphi_e)\right) - \frac{a_{e0}}{Q_o^*} t \\ & + \frac{K\,a_{z0}}{Q_o^*} t + K\,\frac{a_z^*}{\omega_z}\left(-Q_o^* \cos(\omega_z t + \varphi_z) - \omega_z \sin(\omega_z t + \varphi_z)\right)\Bigg) \\ & + \log\Bigg(a_p^*\left(Q_o^* \sin(\omega_p t + \varphi_p) - \omega_p \cos(\omega_p t + \varphi_p)\right) + \frac{a_{p0}}{Q_o^*} \\ & - a_e^*\left(Q_o^* \sin(\omega_e t + \varphi_e) - \omega_e \cos(\omega_e t + \varphi_e)\right) - \frac{a_{e0}}{Q_o^*} + \frac{K\,a_{z0}}{Q_o^*} \\ & + K\,a_z^*\left(Q_o^* \sin(\omega_z t + \varphi_z) - \omega_z \cos(\omega_z t + \varphi_z)\right)\Bigg)\end{aligned} \tag{50}$$

The second part of Equation 49 evaluates to:

$$\begin{aligned}&\int^{t} \exp\left(\int^{z} g(x)\,dx\right) f(z)dz \\ &\qquad = \frac{A_m}{V_m}\int^{t} \exp\left(Q_o^* \int^{z} h(x)\,dx\right)\left(C_p P_p(t) + C_g K\;\; z(t)\right)dz\end{aligned} \tag{51}$$

A complete analytical solution is not immediately apparent for sinusoidally varying forcing, nevertheless numerical methods can be applied to the solution of Eq. 46. and the estimation of the constant.

Appendix 2 Wetland Details

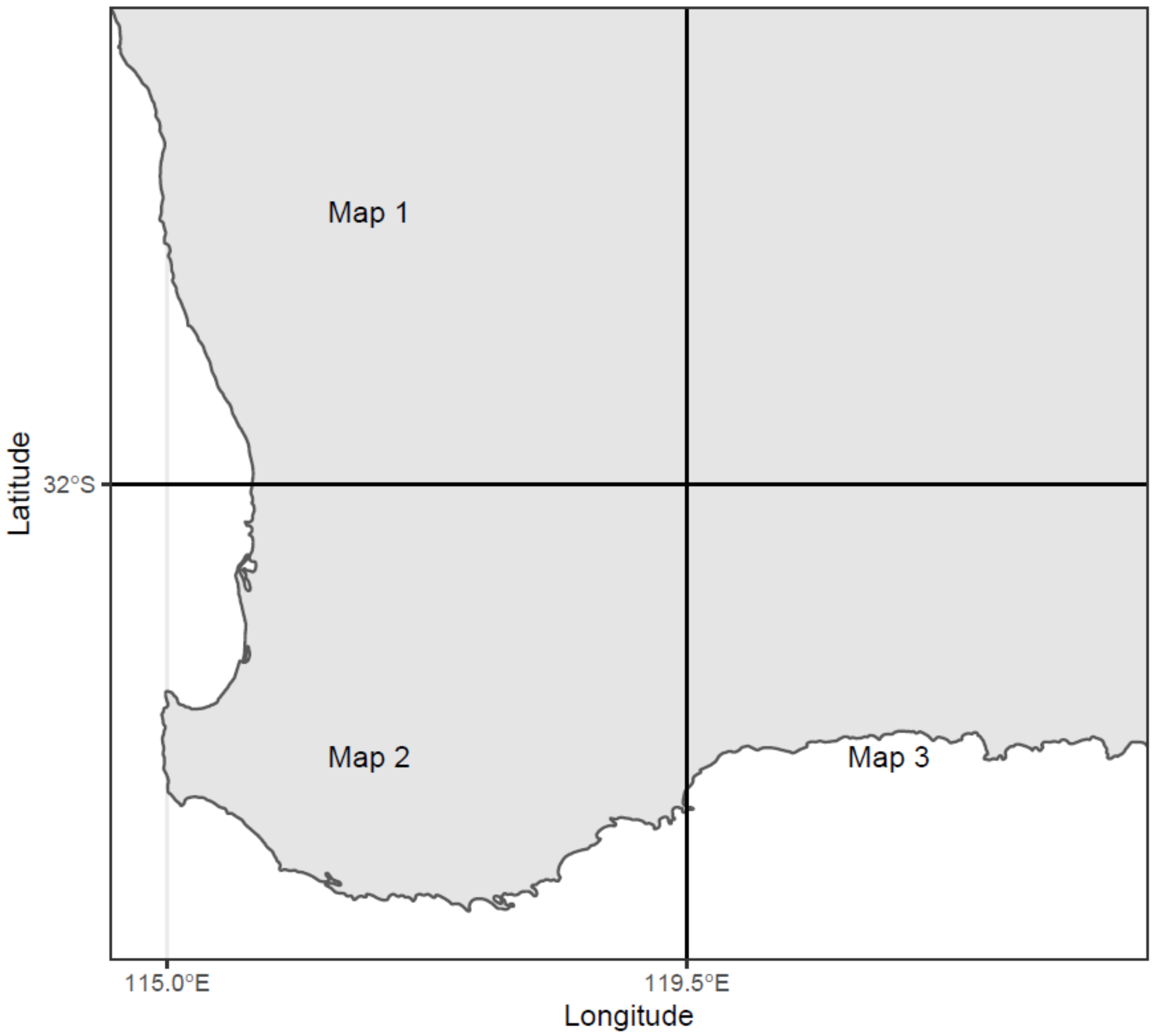


Figure 17: Key to the wetland location maps.

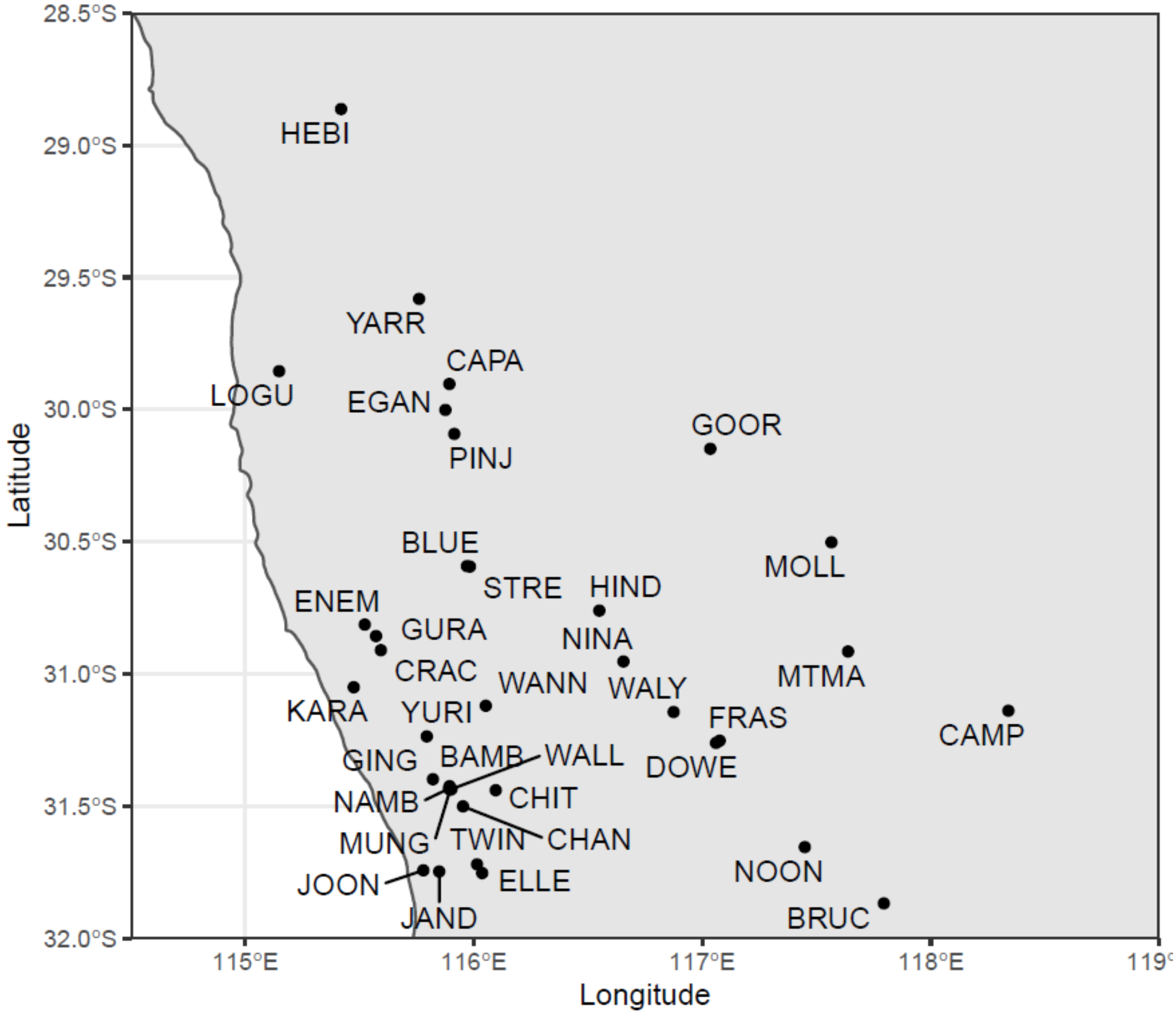


Figure 18: Wetland locations in the northern region (Map 1).

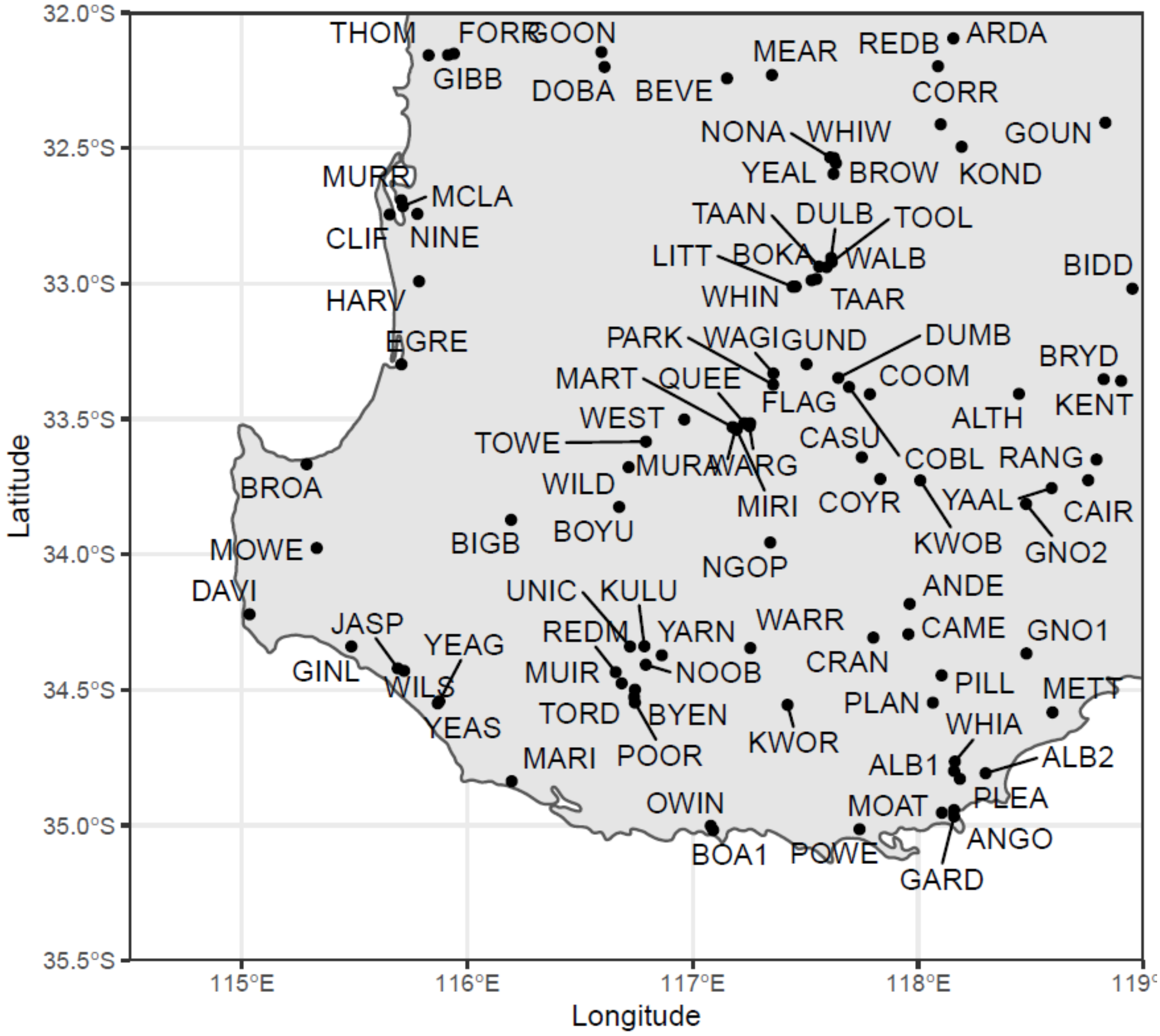


Figure 19: Wetland locations in the southern region (Map 2).

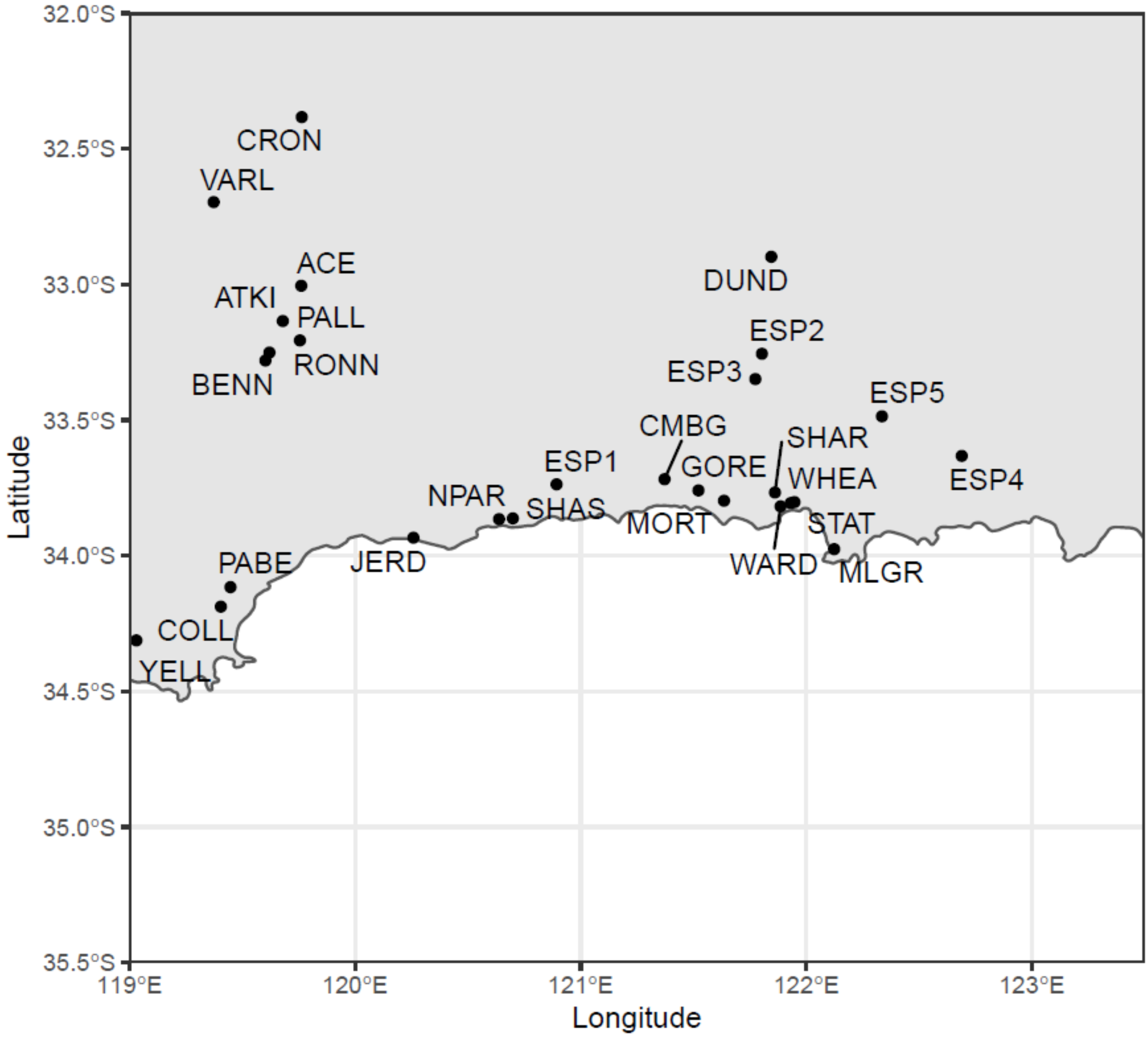


Figure 20: Wetland locations in the southeastern region (Map 3).

Table 7: Wetland details

Code	Name	Easting	Northing	Zone	LGA	Reserve No.	Reserve Name
ACE	Ace	758029	6344741	50	Lake Grace	A 34522	Lake Ace NR
ALB1	Albany 1	606041	6148594	50	Albany	26385	
ALB2	Albany 2	618826	6147490	50	Albany	27157	Cheyne Road NR
ALTH	Altham	634562	6302593	50	Kent	A 28395	Chinocup NR
ANDE	Anderson	588666	6217158	50	Tambellup	A 25914	Anderson Lake NR
ANGO	Angove	605850	6132590	50	Albany	A 27956	Two Peoples Bay NR
ARDA	Ardath	609068	6448377	50	Bruce Rock	A 25062	Seagroatt NR
ATKI	Atkins Yate	750023	6330530	50	Lake Grace		
BAMB	Bambun	394880	6522829	50	Gingin	A 26756	Bambanup NR
BENN	Bennetts	742440	6314572	50	Lake Grace	36445	Dunn Rock NR
BEVE	Beverley	514297	6432612	50	Beverley / Brookton / Quairading	31837	Yenyenning Lakes NR
BIDD	Biddy	682152	6344888	50	Lake Grace	17617	Lake Biddy NR
BIGB	Big Boom	425452	6251675	51	Esperance		
BLUE	Blue Gum	401231	6615183	50	Moora		
BOA1	Boat Harbour 1	508245	6124962	50	Denmark	A 41010	Owingup NR
BOKA	Bokan	549253	6349883	50	Narrogin	9628	Bokan NR
BOYU	Boyup Brook 1	469777	6257199	50	Boyup Brook	18239	Kulicup NR
BROA	Broadwater	341176	6273426	50	Busselton	27080	
BROW	Brown	559606	6397735	50	Corrigin	A 24428	Nonalling NR
BRUC	Bruce Rock 1	575133	6473941	50	Bruce Rock	A 30969	Kwolyin NR
BRYD	Bryde	669625	6308051	50	Kent	48436	
BYEN	Byenup	476449	6182437	50	Manjimup	A 31880	Lake Muir NR
CAIR	Cairlocup	662520	6266817	50	Kent	28324	Cairlocup NR
CAME	Camel	588033	6204762	50	Cranbrook	A 26161	Camel Lake NR

Code	Name	Easting	Northing	Zone	LGA	Reserve No.	Reserve Name
CAMP	Campion	627676	6554227	50	Nungarin / Merredin	24789	Lake Campion NR
CAPA	Capamaura	393132	6691441	50	Carnamah	A 24618	Capamauro NR
CASU	Casuarina	569525	6277315	50	Katanning	A 25136	Coblinine NR
CHAN	Chandala	400545	6514425	50	Chittering	A 37060	Chandala NR
CHIT	Chittering	414089	6521328	50	Chittering	A 29538	Chittering Lakes NR
CLIF	Clifton	374037	6376139	50	Mandurah / Waroona		Yalgorup NP
CMBG	Coomalbidgup	349163	6267892	51	Esperance	24633	
COBL	Coblinine	564476	6306117	50	Dumbleyung	A 25133	Coblinine NR
COLL	Collets Road	721700	6214473	50	Jerramungup		Fitzgerald River NP
COOM	Coomelberrup	573060	6303130	50	Dumbleyung	A 10472	Coomelberrup NR
CORR	Corrigin 1	603415	6413294	50	Corrigin	12900	Paperbark NR
COYR	Coyrecup	577072	6268374	50	Katanning	A 28552	Coyrecup NR
CRAC	Crackers	365586	6579519	50	Dandaragan	28558	Namming NR
CRAN	Cranbrook 1	573707	6203482	50	Cranbrook	A 25812	
CRON	Cronin	760036	6413700	50	Kondinin	A 36526	Lake Cronin NR
DAVI	Davies	318852	6211560	50	Augusta-Margaret Riv.	30826	Leeuwin-Naturaliste NP
DOBA	Dobaderry	463077	6437224	50	Beverley	A 43281	Wandoo Cons. Park
DOWE	Dowerin	505689	6541494	50	Dowerin	4244	
DULB	Dulbinning	557418	6359015	50	Wickepin	A 9617	
DUMB	Dumbleyung	560071	6309876	50	Dumbleyung / Wagin	26664	Dumbleyung Lake NR
DUND	Dundas 1	391998	6359382	51	Dundas	A 33113	
EGAN	Eganu	391567	6680556	50	Coorow	A 25210	Pimjarrega NR
EGRE	Egret	379666	6314855	50	Harvey	38393	Morangel NR
ELLE	Ellen Brook	408758	6486521	50	Swan	A 27620	Ellen Brook NR
ENEM	Eneminga	358697	6590178	50	Dandaragan	A 27394	Eneminga NR
ESP1	Esperance 1	304849	6265010	51	Esperance	26410	

Code	Name	Easting	Northing	Zone	LGA	Reserve No.	Reserve Name
ESP2	Esperance 2	388786	6319769	51	Esperance	27768	
ESP3	Esperance 3	385963	6309342	51	Esperance	27985	
ESP4	Esperance 4	471180	6278570	51	Esperance	A 32128	
ESP5	Esperance 5	438274	6294596	51	Esperance	A 32776	
FLAG	Flagstaff	523642	6291467	50	Woodanilling	A 27609	Flagstaff Lake NR
FORR	Forrestdale	400062	6442240	50	Armadale	A 24781	Forrestdale Lake NR
FRAS	Frasers	507236	6542443	50	Dowerin		
GARD	Gardner	605828	6129943	50	Albany	A 27956	Two Peoples Bay NR
GIBB	Gibbs	397627	6441667	50	Armadale	48797	
GING	Gingin 1	387922	6525676	50	Gingin	31241	
GINL	Gingilup	361431	6200023	50	Nannup	30626	Gingilup Swamps NR
GNO1	Gnowangerup 1	636100	6196278	50	Gnowangerup	26264	Mailalup NR
GNO2	Gnowangerup 2	636830	6257497	50	Gnowangerup	A 26569	
GOON	Goonaping	461797	6443309	50	Beverley	A 43281	Wandoo Cons. Park
GOOR	Goorly	503350	6664801	50	Dalwallinu		
GORE	Gore	363166	6263536	51	Esperance	A 32419	Lake Gore NR
GOUN	Gounter	672878	6413022	50	Kondinin	A 21253	Lake Gounter NR
GUND	Gundaring	546974	6315587	50	Wagin	A 24373	Gundaring Lake NR
GURA	Guraga	363476	6585412	50	Dandaragan	31223	
HARV	Harvey 1	386550	6348919	50	Harvey	12632	Riverdale NR
HEBI	Hebitons	345831	6806160	50	Mullewa		
HIND	Hinds	456859	6596884	50	Wongan-Ballidu	A 16305	Lake Hinds NR
JAND	Jandabup	390937	6486982	50	Wanneroo	7349	Jandabup NR
JASP	Jasper	379737	6190394	50	Nannup	36996	D'Entrecasteaux NP
JERD	Jerdacuttup	246655	6241791	51	Ravensthorpe	A 40156	Jerdacuttup Lakes NR
JOON	Joondalup	384352	6487435	50	Joondalup	A 31048	Lake Joondalup NR

Code	Name	Easting	Northing	Zone	LGA	Reserve No.	Reserve Name
KARA	Karakin	354428	6563848	50	Gingin	7504	
KENT	Kent 29020	676818	6307259	50	Kent	A 29020	Lake Bryde NR
KOND	Kondinin	612045	6404006	50	Kondinin	A 22519	Kondinin Lake NR
KULU	Kulunilup	480427	6200001		Cranbrook	A 26677	Kulunilup NR
KWOB	Kwobrup	593500	6267648	50	Kent		
KWOR	Kwornicup	538575	6176168	50	Plantagenet	32284	Kwornicup NR
LITT	Little White	541357	6347281	50	Narrogin	A 26786	Carmody NR
LOGU	Logue	321114	6695888	50	Carnamah	29073	Lake Logue NR
MARI	Maringup	426553	6144690	50	Manjimup	36996	D'Entrecasteaux NP
MART	Martinup	516363	6289934	50	Woodanilling	A 17055	Martinup NR
MCLA	McLarty	379489	6379596	50	Murray	A 39404	Lake McLarty NR
MEAR	Mears	533098	6433941	50	Brookton	A 12398	Lake Mears NR
METT	Mettler	646369	6172015	50	Albany	26894	Mettler Lake NR
MIRI	Miripin	518066	6288832	50	Woodanilling	A 24912	Miripin NR
MLGR	Mount Le Grand	419066	6240163	51	Esperance	A 22795	Cape Le Grand NP
MOAT	Moates	600908	6131536	50	Albany	A 27956	Two Peoples Bay NR
MOLL	Mollerin	554214	6625482	50	Koorda	A 14429	Mollerin NR
MORT	Mortijinup	373710	6259469	51	Esperance	A 35557	Lake Mortijinup NR
MOWE	Mowen	345889	6239182	50	Augusta-Margaret Riv.		SF 'F32' (proposed NR)
MTMA	Mount Marshall	560937	6579648	50	Mt Marshall	A 26687	North Wallambin NR
MUIR	Muir	471032	6185028	50	Manjimup	A 31880	Lake Muir NR
MUNG	Mungala	395151	6521364	50	Gingin	A 26756	Bambanup NR
MURA	Murapin	517681	6289397	50	Woodanilling	A 17257	Murapin NR
MURR	Murray 1	378784	6382052	50	Murray	A 24739	
NAMB	Nambung	394607	6521821	50	Gingin	A 26756	Bambanup NR
NGOP	Ngopitchup	531747	6242644	50	Broomehill	2184	

Code	Name	Easting	Northing	Zone	LGA	Reserve No.	Reserve Name
NINA	Ninan	467029	6575597	50	Wongan-Ballidu	A 27026	Lake Ninan NR
NINE	Nine Mile	385536	6376505	50	Murray	A 16907	Nine Mile Lake NR
NONA	Nonalling	557243	6400132	50	Corrigin	A 24428	Nonalling NR
NOOB	Noobijup	480867	6192653	50	Cranbrook	A 26680	Noobijup NR
NOON	Noonying	542507	6497744	50	Tammin	A 10313	Noonying NR
NPAR	North Parriup	281562	6250268	51	Ravensthorpe	A 32339	Lake Shaster NR
OWIN	Owingup	507258	6126756	50	Denmark	A 41010	Owingup NR
PABE	Pabelup South	725800	6222286	50	Jerramungup		Fitzgerald River NP
PALL	Pallarup	756890	6322416	50	Lake Grace	A 29860	Pallarup NR
PARK	Parkeyerring	533156	6307263	50	Wagin	A 10733	Parkeyerring NR
PILL	Pillenorup	601412	6187773	50	Plantagenet		Stirling Range NP
PINJ	Pinjarrega	395416	6670552	50	Coorow	A 25210	Pimjarrega NR
PLAN	Plantagenet 2	597710	6176617	50	Plantagenet	A 25386	Chillinup NR
PLEA	Pleasant View	608357	6145314	50	Albany	A 15107	Lake Pleasant View NR
POOR	Poorginup	476447	6177128	50	Manjimup	A 31880	Lake Muir NR
POWE	Powell	567497	6125091	50	Albany	A 25809	Lake Powell NR
QUEE	Queerearrup	521251	6291518	50	Woodanilling	17255	
RANG	Range Road Yate	666083	6275186	50	Kent	29124	
REDB	Red (Bruce Rock)	602548	6437065	50	Bruce Rock	A 16493	Red Lake NR
REDM	Red (Manjimup)	468592	6189580	50	Manjimup		
RONN	Ronnerup	744169	6317786	50	Lake Grace	A 39422	Lake King NR
SHAR	Shark	394568	6263073	51	Esperance	A 31197	Shark Lake NR
SHAS	Shaster	287219	6250710	51	Ravensthorpe	A 32339	Lake Shaster NR
STAT	Station	402615	6259237	51	Esperance	A 23825	Mullet Lake NR
STRE	Streets	402493	6614985	50	Moora		
TAAN	Taarblin North	552241	6355660	50	Narrogin	A 9550	Taarblin Lake NR

Code	Name	Easting	Northing	Zone	LGA	Reserve No.	Reserve Name
TAAR	Taarblin South	551258	6350395	50	Narrogin	A 9550	Taarblin Lake NR
THOM	Thomsons	389516	6441482	50	Cockburn	A 15556	Thomsons Lake NR
TOOL	Toolibin	557650	6357248	50	Wickepin	A 24556	Toolibin NR
TORD	Tordit-Gurrup	476135	6179406	50	Manjimup	A 31880	Lake Muir NR
TOWE	Towerrinning	480708	6283950	50	West Arthur	A 24917	Towerrinning NR
TWIN	Twin Swamps N-W	406579	6490175	50	Swan	A 27621	Twin Swamps NR
UNIC	Unicup	474399	6200082	50	Cranbrook	A 25798	Unicup NR
VARL	Varley	722520	6379843	50	Kulin	A 27928	Lake Varley NR
WAGI	Wagin 1	533281	6311808	50	Wagin	A 2088	Casuarina NR
WALB	Walbyring	555534	6355214	50	Wickepin	A 14398	Walbyring NR
WALL	Wallering	395706	6521624	50	Gingin	A 26756	Bambanup NR
WALY	Walyormouring	488021	6554454	50	Goomalling	A 17186	Walyormouring NR
WANN	Wannamal	409642	6556691	50	Gingin	A 9838	Lake Wannamal NR
WARD	Warden	396947	6257428	51	Esperance	A 32257	Lake Warden NR
WARG	Wardering	523381	6290253	50	Woodanilling	A 17258	Wardering Lake NR
WARR	Warrinup	523495	6199485	50	Cranbrook	A 1931	Warrenup NR
WEST	West Arthur 1	496510	6293047	50	West Arthur	A 5456	Dead Man's Swamp NR
WHEA	Wheatfield	401069	6258818	51	Esperance	A 15231	Woody Lake NR
WHIA	White (Albany)	606407	6152434	50	Albany	A 36550	North Sister NR
WHIN	White (Narrogin)	542630	6347335	50	Narrogin	A 21284	Quongunnerunding NR
WHIW	White Water	558770	6399914	50	Corrigin	A 24428	Nonalling NR
WILD	Wild Horse	473637	6273462	50	West Arthur	A 1740	Wild Horse Swamp NR
WILS	Wilson	382325	6189429	50	Manjimup	A 36996	D’Entrecasteaux NP
YAAL	Yaalup	647443	6263830	50	Kent	A 36967	
YARN	Yarnup	487368	6196543	50	Cranbrook	29601	Yarnup NR
YARR	Yarra	379957	6726980	50	Carnamah	A 26442	Yarra Lakes NR

Code	Name	Easting	Northing	Zone	LGA	Reserve No.	Reserve Name
YEAG	Yeagarup	396813	6177185	50	Manjimup	A 47878	Greater Hawke NP
YEAL	Yealering	558587	6393389	50	Wickepin	9610	
YEAS	Yeagarup South	396321	6176122	50	Manjimup	A 36996	D'Entrecasteaux NP
YELL	Yellilup	686899	6201353	50	Jerramungup		
YURI	Yurine	385171	6543598	50	Gingin	A 9676	Yurine Swamp NR

LGA is local government authority.

Appendix 3 Data and Regressions

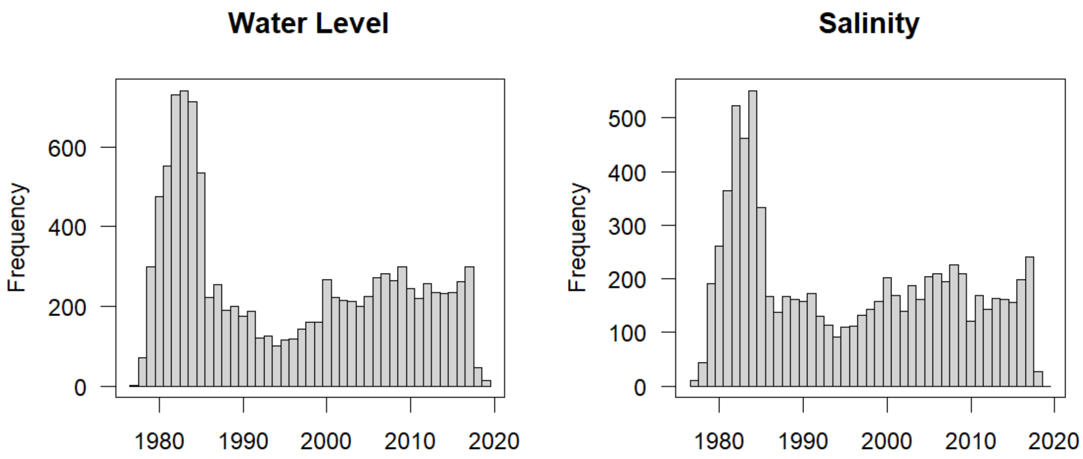


Figure 21: Numbers of measurements contributing to the database.

Table 8: Number of water level – salinity observation pairs in each wetland by decade.

Wetland Code	1970's	1980's	1990's	2000's	2010's
ACE	1	9	0	0	0
ALB1	0	21	5	22	17
ALB2	5	23	0	7	18
ALTH	1	21	3	12	12
ANDE	0	37	4	21	15
ANGO	2	26	0	0	0
ARDA	0	0	4	17	13
ATKI	0	0	2	15	10
BAMB	10	37	17	23	14
BENN	0	0	9	15	13
BEVE	11	39	20	21	15
BIDD	0	11	0	1	0
BIGB	0	0	0	0	14
BLUE	0	0	3	15	0
BOA1	0	0	18	26	16
BOKA	4	18	0	1	0
BOYU	1	15	16	13	12
BROA	0	11	20	22	14
BROW	5	29	10	15	9
BRUC	0	19	0	0	0
BRYD	3	24	15	12	4

Wetland Code	1970's	1980’s	1990’s	2000’s	2010’s
BYEN	18	58	19	23	15
CAIR	1	9	0	0	0
CAME	3	15	0	0	0
CAMP	3	22	5	13	10
CAPA	1	14	0	0	0
CASU	4	34	20	20	15
CHAN	9	38	20	24	14
CHIT	14	38	0	0	0
CLIF	0	12	20	23	14
CMBG	0	0	3	19	16
COBL	10	39	2	0	0
COLL	0	0	0	9	0
COOM	7	21	8	23	15
CORR	0	19	16	9	6
COYR	7	34	21	21	15
CRAC	1	27	20	20	14
CRAN	2	14	0	1	0
CRON	0	7	1	1	0
DAVI	0	0	18	27	15
DOBA	0	21	17	13	7
DOWE	5	0	0	0	0
DULB	0	19	18	14	9
DUMB	6	38	20	23	15
DUND	2	5	0	0	0
EGAN	8	40	19	17	10
EGRE	0	10	12	10	12
ELLE	1	2	0	0	0
ENEM	1	35	2	1	8
ESP1	0	12	15	23	15
ESP2	0	6	0	0	0
ESP3	0	16	2	16	0
ESP4	0	3	0	0	0
ESP5	0	8	0	0	0
FLAG	6	35	10	21	14
FORR	8	31	19	19	14
FRAS	0	0	2	13	0
GARD	0	27	0	1	0
GIBB	0	0	18	17	13
GING	10	25	0	1	0
GINL	0	0	0	0	13
GNO1	2	21	2	1	0

Wetland Code	1970's	1980's	1990's	2000's	2010's
GNO2	0	3	0	0	0
GOON	0	0	0	18	13
GOOR	0	0	1	9	0
GORE	7	36	20	21	16
GOUN	2	21	2	1	0
GUND	10	38	2	0	0
GURA	0	29	20	17	7
HARV	2	38	19	21	13
HEBI	0	0	0	3	0
HIND	3	31	9	15	7
JAND	14	36	20	21	14
JASP	0	12	20	21	16
JERD	7	34	19	21	15
JOON	13	38	20	21	14
KARA	6	14	0	0	0
KENT	0	6	2	10	2
KOND	5	28	2	0	0
KULU	0	0	0	0	9
KWOB	4	22	2	0	0
KWOR	4	26	19	20	15
LITT	5	32	9	15	13
LOGU	3	26	16	8	5
MARI	0	0	15	19	12
MART	6	36	10	19	13
MCLA	0	0	13	22	14
MEAR	10	34	10	18	11
METT	0	21	18	26	14
MIRI	0	22	0	1	0
MLGR	0	0	2	19	15
MOAT	7	38	19	22	15
MOLL	0	7	0	0	0
MORT	0	0	2	21	16
MOWE	0	0	0	0	6
MTMA	0	10	0	0	0
MUIR	4	26	21	21	14
MUNG	6	13	0	0	0
MURA	0	23	0	0	0
MURR	2	13	0	1	0
NAMB	5	14	0	0	0
NGOP	0	0	2	19	12
NINA	6	34	10	20	11

Wetland Code	1970's	1980's	1990's	2000's	2010's
NINE	0	37	20	24	13
NONA	7	16	0	0	0
NOOB	0	0	4	22	14
NOON	6	31	7	7	9
NPAR	0	0	2	21	15
OWIN	0	0	18	23	16
PABE	0	0	0	1	0
PALL	1	1	0	0	0
PARK	8	36	10	21	14
PILL	0	0	2	15	2
PINJ	5	30	2	0	0
PLAN	4	20	6	1	0
PLEA	7	33	22	25	18
POOR	12	39	19	20	14
POWE	0	36	23	22	14
QUEE	6	25	0	1	0
RANG	0	0	2	11	8
REDB	0	9	1	6	6
REDM	0	23	2	1	1
RONN	0	0	2	16	12
SHAR	7	38	20	23	15
SHAS	5	27	1	0	0
STAT	4	29	20	21	16
STRE	4	25	2	1	0
TAAN	0	0	0	13	11
TAAR	0	22	16	8	5
THOM	8	32	20	19	12
TOOL	0	24	13	2	3
TORD	17	59	19	21	14
TOWE	14	53	19	21	15
TWIN	1	2	0	0	0
UNIC	1	33	21	22	13
VARL	0	15	4	9	6
WAGI	0	12	0	0	0
WALB	0	27	19	14	3
WALL	0	15	0	0	0
WALY	4	26	9	14	8
WANN	14	42	20	20	14
WARD	7	33	20	21	16
WARG	9	35	2	0	0
WARR	3	16	20	14	11

Wetland Code	1970's	1980's	1990's	2000's	2010's
WEST	2	30	8	15	10
WHEA	0	0	2	22	17
WHIA	0	8	1	0	0
WHIN	0	16	5	8	5
WHIW	0	21	9	11	6
WILD	0	22	0	1	0
WILS	0	0	18	22	15
YAAL	0	26	18	16	9
YARN	2	39	21	26	15
YARR	0	12	6	12	4
YEAG	0	0	0	0	15
YEAL	13	35	19	19	14
YEAS	0	0	0	0	15
YELL	0	11	20	25	16
YURI	8	38	2	2	7

Table 9: Summary of salinity vs depth regressions. Wetland is the wetland code (c.f. Table 7); a *is the intercept,* b *is the slope; ARsq is the adjusted r -squared; Model is the statistical model chosen by AIC i.e.,* E *is an exponential relationship between depth and salinity i.e., log(salinity) ~ a* + b *depth, while* P *denotes a power law relationship i.e., log(salinity) ~* a + b *log(depth). Bold for b pre-2000 slope, denotes it is significantly different from zero. Bold for b post-2000 indicates the slope is significantly different from pre-2000 value. Lastly Archetype is the associated type of change in salinity vs depth cf. figures 10 - 12.*

	Pre-2000		Post-2000				
Wetland	a	b	a	b	ARsq	Model	Archetype
ALB1	-0.2	**-0.97**	**-0.83**	**-1.45**	0.77	P	SA
ALB2	-1.26	**-1.08**	-1.61	-1.78	0.32	P	NN
ALTH	5.41	**-2.76**	5.17	-2.68	0.89	E	NN
ANDE	6.38	**-1.65**	6.03	**-1.08**	0.85	E	FS
BAMB	1.8	**-0.74**	1.1	-0.46	0.61	E	NN
BENN	4.3	**-1.01**	4.71	-1.19	0.84	E	NN
BEVE	5.83	**-1.46**	5.65	-1.45	0.70	E	NN
BOA1	-0.28	**-2.6**	-0.22	**-1.03**	0.91	P	FA
BOYU	-1.65	**-0.41**	-2.00	-0.42	0.26	P	NN
BROA	3.5	**-3.52**	**1.81**	**-1.16**	0.64	E	FA
BROW	4.52	**-1.59**	**4.97**	-1.76	0.83	E	NN
BRYD	0.55	**-0.72**	**2.47**	**-2.06**	0.53	E	SA
BYEN	2.52	**-1.57**	**3.38**	**-2.29**	0.78	P	SS
CAMP	4.26	**-0.88**	**5.08**	-0.39	0.55	P	NN

	Pre-2000		Post-2000				
Wetland	a	b	a	b	ARsq	Model	Archetype
CASU	4.9	**-2.16**	**5.54**	-2.17	0.81	E	NS
CHAN	0.43	**-0.63**	-0.1	0.05	0.09	E	NN
CLIF	7.81	**-3.25**	8.18	-3.18	0.60	P	NS
COOM	4.7	**-1.9**	**5.61**	-1.83	0.74	E	NS
CORR	0.07	**-1.29**	**1.09**	-1.85	0.61	E	NS
COYR	4.46	**-1.49**	**4.97**	-1.31	0.84	E	NS
CRAC	-0.13	**0.32**	**0.48**	**-1.41**	0.38	P	SS
DAVI	3.51	**-1.93**	1.95	-0.67	0.68	P	FS
DOBA	-1.54	**-2.4**	-1.68	-2.16	0.24	E	NN
DULB	4.32	**-3.58**	3.86	-2.96	0.60	E	NN
DUMB	5.44	**-0.8**	**5.77**	**-0.96**	0.87	E	SA
EGAN	5.06	**-0.92**	**6.2**	**-1.44**	0.70	E	SA
EGRE	-0.06	0.23	0.54	-0.17	0.55	P	NS
ENEM	0.86	**-1.01**	0.51	-0.88	0.76	E	NN
ESP1	0.06	**-0.67**	**1.72**	-0.48	0.66	P	NS
ESP3	2.98	**-0.69**	4.33	-0.21	0.22	P	NN
FLAG	5.2	**-1.64**	5.42	-1.68	0.83	E	NN
FORR	0.33	**-0.64**	0.04	-0.52	0.46	P	NF
GIBB	-2.38	**-1.00**	**-1.66**	**0.27**	0.26	P	NN
GORE	4.34	**-1.83**	4.06	**-0.85**	0.72	P	FA
GURA	2.41	**-0.94**	2.46	-0.59	0.53	P	NN
HARV	0.73	**-1.23**	**0.35**	**-0.8**	0.74	E	FA
HIND	5.62	**-0.71**	**6.38**	**-1.49**	0.69	E	SA
JAND	-0.92	**-1.50**	**-1.37**	**-0.52**	0.70	P	FF
JASP	3.59	**-2.29**	4.46	-2.56	0.73	P	NS
JERD	5.25	**-1.00**	5.17	**-0.82**	0.90	E	FS
JOON	3.37	**-3.37**	**1.44**	**-1.69**	0.67	P	FA
KENT	-0.12	-1.76	0.25	-1.12	0.70	E	FS
KWOR	2.38	**-0.72**	2.32	-0.70	0.66	P	NN
LITT	2.58	**-1.07**	2.64	-1.11	0.82	P	NN
LOGU	0.81	-0.16	1.01	-0.29	-0.01	E	NN
MARI	-0.17	-0.72	2.03	-1.82	0.54	P	SS
MART	4.09	**-1.35**	4.31	-1.77	0.71	E	NN
MCLA	0.52	**-1.32**	0.32	-1.21	0.70	P	NN
MEAR	4.66	**-1.43**	4.91	-1.28	0.74	E	NS
METT	-0.46	**-1.54**	-0.45	-1.03	0.53	E	FS
MOAT	2.96	**-0.84**	4.36	-1.13	0.35	E	NN
MUIR	4.23	**-2.72**	4.90	-3.65	0.34	E	NN
NINA	5.7	**-1.07**	5.82	-0.88	0.62	E	FS
NINE	-0.26	**-0.49**	-0.58	**-1.18**	0.27	E	SF
NOON	4.6	**-2.33**	5.03	-2.25	0.81	E	NS

Wetland	Pre-2000 a	Pre-2000 b	Post-2000 a	Post-2000 b	ARsq	Model	Archetype
OWIN	0.7	**-3.96**	0.13	-3.13	0.64	P	FF
PARK	4.93	**-1.50**	**5.36**	-1.47	0.84	E	NS
PLEA	0.17	**-0.80**	0.34	**-1.38**	0.50	E	SF
POOR	0.29	**-2.99**	**-0.18**	-2.44	0.60	E	NF
POWE	-0.17	0.19	0.20	0.42	0.02	P	NN
REDB	4.78	**-8.02**	5.32	-14.36	0.38	E	NN
SHAR	2.91	**-1.22**	**4.01**	**-1.63**	0.71	E	SS
STAT	2.34	**-0.74**	2.2	**-1.49**	0.67	P	SS
TAAR	3.45	**-1.67**	2.97	-1.00	0.64	E	NN
THOM	0.28	**-0.58**	**-0.21**	**-0.95**	0.57	P	SA
TORD	2.24	**-0.82**	2.52	-0.92	0.88	E	NN
TOWE	3.06	**-0.96**	3.04	-0.91	0.79	P	NN
UNIC	1.46	**-0.60**	**1.88**	-0.65	0.58	P	NS
VARL	3.02	**-0.65**	3.76	-0.37	0.57	P	NN
WALB	0.06	**-1.54**	**-1.19**	-1.58	0.81	P	NF
WALY	2.44	**-0.59**	2.13	-0.42	0.48	P	FF
WANN	2.32	**-1.13**	**2.71**	**-1.62**	0.76	P	SS
WARD	4.04	**-0.93**	**4.87**	**-1.29**	0.83	P	SS
WARR	-2.15	-0.18	-1.6	-0.18	0.17	P	NS
WEST	3.92	**-2.42**	3.57	-1.86	0.81	E	NN
WHIW	4.03	**-1.65**	3.96	-1.61	0.82	E	NN
WILS	0.94	**-2.23**	1.14	-2.16	0.67	P	NS
YAAL	-0.34	**-1.00**	-0.66	-1.18	0.55	P	NN
YARN	0.35	**-0.54**	**1.33**	-0.85	0.80	P	NS
YARR	5.68	**-1.60**	**4.71**	**4.12**	0.34	E	NN
YEAL	4.94	**-1.3**	**5.69**	-1.46	0.74	E	SS
YELL	2.47	**-0.35**	**5.08**	**-1.02**	0.83	E	SS
YURI	0.24	**-0.8**	**-0.85**	**-0.12**	0.75	P	FF

Table 10: Summary of Mann-Kendal trend tests for September wetland water levels. η is the rate of change in water levels, τ is the Mann-Kendall tau test statistic, p is the significance level (bold values are significant at p<0.1 with red indicating negative trends, blue positive trends and orange were significant but less than the accuracy of depth measurement) and n is the number of observations.

Site	η m/a	τ	p	n	Site	η m/a	τ	p	n
ALB1	0.004	0.153	0.293	25	**ENEM**	**-0.044**	**-0.412**	**0.019**	**18**
ALB2	0.004	0.192	0.320	16	**ESP1**	**0.038**	**0.350**	**0.003**	**35**
ALTH	-0.002	-0.163	0.211	30	ESP3	0.000	-0.052	0.754	22
ANDE	-0.001	-0.017	0.910	29	FLAG	-0.007	-0.119	0.328	34

Site	η m/a	τ	p	n
ARDA	-0.010	-0.234	0.172	19
ATKI	**-0.160**	**-0.333**	**0.057**	**18**
BAMB	**0.002**	**0.332**	**0.004**	**37**
BENN	-0.027	-0.205	0.203	21
BEVE	-0.009	-0.105	0.352	39
BIGB	0.027	0.200	0.707	6
BLUE	-0.050	-0.218	0.387	11
BOA1	-0.005	-0.126	0.377	26
BOKA	0.146	0.733	0.060	6
BOYU	0.000	-0.021	0.864	37
BROA	0.000	-0.011	0.946	31
BROW	-0.011	-0.162	0.182	34
BRYD	0.000	-0.178	0.097	39
BYEN	**-0.011**	**-0.282**	**0.012**	**39**
CAMP	-0.001	-0.040	0.758	32
CASU	-0.005	-0.077	0.498	39
CHAN	0.000	-0.014	0.910	38
CHIT	-0.056	-0.250	0.402	9
CLIF	**-0.013**	**-0.478**	**0.000**	**32**
CMBG	-0.071	-0.235	0.202	17
COBL	0.157	0.231	0.300	13
COLL	0.000	0.055	0.855	11
COOM	0.005	0.080	0.573	27
CORR	0.000	-0.143	0.211	36
COYR	-0.006	-0.045	0.699	39
CRAC	-0.001	-0.077	0.512	37
DAVI	0.001	0.057	0.708	25
DOBA	**-0.008**	**-0.384**	**0.001**	**38**
DULB	0.000	0.012	0.921	39
DUMB	**-0.036**	**-0.269**	**0.017**	**39**
DUND	0.005	0.200	0.430	11
EGAN	-0.015	-0.174	0.121	39
EGRE	0.004	0.087	0.485	33
ELLE	0.018	0.733	0.051	6
MLGR	-0.014	-0.213	0.248	17
MTMA	0.000	0.018	1.000	11
MUIR	**-0.005**	**-0.233**	**0.040**	**38**
MUNG	0.070	0.333	0.452	6
NAMB	0.112	0.600	0.133	6
NGOP	-0.002	-0.085	0.648	18
NINA	-0.013	-0.172	0.163	33
NINE	**-0.046**	**-0.782**	**0.000**	**37**
NONA	0.160	0.733	0.060	6
NOOB	**-0.041**	**-0.561**	**0.001**	**19**

Site	η m/a	τ	p	n
FORR	**-0.015**	**-0.474**	**0.000**	**39**
FRAS	-0.040	-0.345	0.159	11
GARD	0.007	0.286	0.433	7
GIBB	0.002	0.022	0.895	26
GINL	-0.013	-0.048	1.000	7
GING	-0.016	-0.048	1.000	7
GNO1	0.005	0.192	0.390	13
GOON	0.000	-0.081	0.675	17
GOOR	0.006	0.244	0.362	10
GORE	0.004	0.080	0.489	38
GOUN	**0.057**	**0.606**	**0.007**	**12**
GUND	0.089	0.372	0.087	13
GURA	**-0.042**	**-0.379**	**0.001**	**36**
HARV	**-0.030**	**-0.502**	**0.000**	**38**
HEBI	0.000	0.267	0.221	10
HIND	-0.001	-0.046	0.711	34
JAND	**-0.013**	**-0.567**	**0.000**	**39**
JASP	**-0.013**	**-0.323**	**0.010**	**32**
JERD	0.003	0.016	0.900	38
JOON	**-0.014**	**-0.421**	**0.000**	**39**
KARA	0.010	0.333	0.356	7
KENT	0.000	-0.119	0.395	23
KOND	0.054	0.282	0.198	13
KWOB	0.012	0.128	0.577	13
KWOR	-0.005	-0.198	0.091	36
LITT	-0.012	-0.219	0.070	34
LOGU	**-0.016**	**-0.316**	**0.004**	**39**
MARI	0.000	-0.022	0.910	22
MART	**-0.019**	**-0.330**	**0.006**	**34**
MCLA	**-0.029**	**-0.403**	**0.008**	**23**
MEAR	-0.014	-0.173	0.154	34
METT	0.011	0.159	0.177	36
MOAT	-0.001	-0.099	0.394	37
MORT	**-0.080**	**-0.444**	**0.011**	**18**
STRE	0.019	0.282	0.198	13
TAAN	0.007	0.154	0.476	14
TAAR	-0.001	-0.166	0.128	39
THOM	**-0.013**	**-0.319**	**0.004**	**40**
TOOL	**0.000**	**-0.293**	**0.003**	**38**
TORD	**-0.042**	**-0.599**	**0.000**	**38**
TOWE	0.008	0.151	0.186	38
TWIN	0.018	0.733	0.060	6
UNIC	**-0.019**	**-0.232**	**0.042**	**38**
VARL	-0.002	-0.229	0.082	29

Site	η m/a	τ	p	n	Site	η m/a	τ	p	n
NOON	**-0.016**	**-0.332**	**0.006**	**34**	**WALB**	**-0.014**	**-0.302**	**0.006**	**39**
NPAR	0.046	0.242	0.173	18	**WALY**	**-0.009**	**-0.246**	**0.045**	**33**
OWIN	**-0.014**	**-0.375**	**0.008**	**26**	WANN	-0.004	-0.158	0.160	39
PABE	**0.000**	**0.000**	**0.000**	**14**	WARD	0.019	0.183	0.107	38
PALL	0.000	0.018	1.000	11	WARG	0.017	0.167	0.463	13
PARK	-0.010	-0.134	0.273	34	WARR	0.002	0.066	0.573	37
PILL	-0.019	-0.209	0.312	14	WEST	-0.006	-0.169	0.172	33
PINJ	-0.062	-0.205	0.360	13	WHEA	-0.010	-0.150	0.404	18
PLAN	0.009	0.286	0.448	7	WHIA	-0.004	-0.267	0.566	6
PLEA	-0.004	-0.064	0.580	38	**WHIN**	**-0.004**	**-0.363**	**0.010**	**25**
POOR	**-0.007**	**-0.232**	**0.039**	**39**	**WHIW**	**-0.004**	**-0.308**	**0.013**	**32**
POWE	0.005	0.202	0.086	36	WILS	0.004	0.258	0.067	26
QUEE	**0.288**	**0.714**	**0.035**	**7**	**YAAL**	**-0.040**	**-0.303**	**0.009**	**36**
RANG	0.000	-0.098	0.569	18	**YARN**	**-0.007**	**-0.260**	**0.020**	**39**
REDB	-0.001	-0.134	0.388	22	YARR	-0.001	-0.127	0.396	24
REDM	0.032	0.288	0.216	12	YEAG	0.005	0.095	0.879	7
RONN	-0.012	-0.320	0.068	18	YEAS	0.018	0.143	0.764	7
SHAR	-0.003	-0.128	0.263	38	YEAL	-0.014	-0.157	0.164	39
SHAS	0.028	0.197	0.409	12	**YELL**	**-0.106**	**-0.469**	**0.000**	**31**
STAT	**0.001**	**0.252**	**0.025**	**38**	**YURI**	**-0.027**	**-0.325**	**0.036**	**22**

Table 11: Means of water depths and salinities for September and November observations pre- and post-2000. Bold values indicate a significant difference in the means between pre- and post-2000 (p<0.05). Blue values are deeper or fresher, while red values are shallower or more saline.

	Depth (m)				$\log_{10}$ Salinity			
	September		November		September		November	
Site	Pre	Post	Pre	Post	Pre	Post	Pre	Post
ALB1	0.66	0.73	0.62	0.74	-0.01	-0.16	0.12	-0.10
ALTH	0.46	0.16	0.63	0.26	1.83	2.09	1.66	1.95
ANDE	1.14	0.86	1.02	0.80	2.03	2.21	2.10	2.24
BAMB	2.49	2.54	**2.33**	**2.40**	-0.02	-0.03	0.02	-0.01
BENN	0.73	1.18	0.79	1.07	1.53	1.47	1.54	1.51
BEVE	1.35	1.09	1.26	0.95	1.62	1.76	1.74	1.88
BOA1	1.11	0.98	1.03	0.94	**-0.23**	**-0.10**	-0.17	-0.05
BOYU	0.24	0.16	0.22	0.15	-0.50	-0.59	-0.31	-0.34
BROA	0.91	0.89	0.71	0.77	0.14	0.28	0.38	0.47
BROW	0.96	0.65	0.99	0.90	1.29	1.68	1.34	1.49
BRYD	1.08	0.80	1.28	0.62	-0.02	0.40	-0.05	0.62
BYEN	**2.30**	**2.02**	2.26	2.00	**0.54**	**0.79**	**0.53**	**0.79**
CAMP	0.62	0.50	0.68	0.42	2.16	2.35	2.15	2.35
CASU	1.15	0.89	0.87	0.82	**1.14**	**1.55**	**1.29**	**1.69**
CHAN	0.93	0.91	0.77	0.79	-0.12	-0.10	0.08	0.08

	Depth (m)				log_{10} Salinity			
	September		November		September		November	
Site	Pre	Post	Pre	Post	Pre	Post	Pre	Post
CLIF	**4.40**	**4.19**	**4.31**	**4.11**	**1.30**	**1.58**	**1.32**	**1.57**
COOM	0.90	0.88	0.89	0.77	1.42	1.73	**1.36**	**1.86**
CORR	1.04	1.04	0.84	0.98	-0.63	-0.38	-0.43	-0.26
COYR	1.44	0.94	1.40	0.98	**1.06**	**1.60**	**1.08**	**1.65**
CRAC	1.08	1.09	0.96	0.97	**-0.13**	**0.13**	**0.00**	**0.24**
DAVI	4.69	4.64	4.48	4.46	**0.23**	**0.38**	**0.25**	**0.40**
DOBA	**0.55**	**0.36**	0.43	0.27	-1.29	-1.08	-1.05	-0.97
DULB	0.85	0.74	0.67	0.69	0.56	0.69	0.88	0.98
DUMB	1.76	0.87	1.67	0.77	1.76	2.14	1.84	2.19
EGAN	2.17	1.58	1.89	1.57	1.37	1.72	1.53	1.73
EGRE	0.41	0.38	0.42	0.27	**-0.23**	**0.29**	**-0.08**	**0.32**
ENEM	1.77	0.76	1.60	1.27	-0.44	-0.05	-0.30	-0.31
ESP1	0.87	1.35	1.06	1.37	**0.17**	**0.72**	**0.06**	**0.82**
ESP3	0.11	0.10	0.05	0.05	2.09	2.08	2.50	2.25
FLAG	0.72	0.53	0.67	0.46	1.74	1.93	1.83	2.04
FORR	**0.71**	**0.33**	**0.71**	**0.29**	0.18	0.26	0.32	0.42
GIBB	0.67	0.66	0.46	0.58	-0.87	-0.84	-0.68	-0.74
GORE	1.48	1.57	1.44	1.55	1.59	1.58	1.66	1.60
GURA	1.54	1.12	1.53	1.28	0.84	1.03	0.99	1.12
HARV	**1.32**	**0.67**	**1.24**	**0.72**	**-0.40**	**-0.14**	**-0.36**	**-0.04**
HIND	1.00	1.02	0.87	0.99	2.14	2.17	2.17	2.20
JAND	**1.24**	**0.98**	**1.16**	**0.86**	-0.58	-0.60	-0.52	-0.53
JASP	**9.62**	**9.35**	**9.55**	**9.32**	**-0.70**	**-0.57**	**-0.67**	**-0.56**
JERD	1.73	1.73	1.76	1.70	1.46	1.63	1.50	1.64
JOON	**3.05**	**2.66**	**3.01**	**2.65**	-0.21	-0.13	-0.13	-0.06
KWOR	0.50	0.31	0.47	0.28	1.26	1.34	1.41	1.62
LITT	0.73	0.40	0.64	0.47	1.36	1.68	1.45	1.71
LOGU	1.15	0.69	1.33	0.76	0.25	0.21	0.39	0.61
MART	**0.87**	**0.40**	**0.86**	**0.36**	1.29	1.53	**1.28**	**1.66**
MEAR	1.05	0.86	0.96	0.81	1.43	1.64	1.48	1.73
METT	0.58	0.84	0.56	0.88	-0.62	-0.63	-0.56	-0.54
MOAT	4.55	4.48	4.35	4.31	-0.37	-0.29	-0.33	-0.26
MUIR	**0.83**	**0.67**	**0.87**	**0.60**	0.65	1.01	0.95	1.28
NINA	1.40	0.96	1.27	0.88	1.82	2.14	1.97	2.20
NINE	**1.38**	**0.48**	**1.36**	**0.49**	-0.47	-0.54	-0.42	-0.45
NOON	**0.83**	**0.28**	0.88	0.55	**1.24**	**1.91**	1.16	1.64
OWIN	**1.68**	**1.45**	1.27	1.27	-0.56	-0.49	-0.13	-0.17
PARK	1.05	0.70	0.90	0.60	**1.48**	**1.87**	1.62	1.99
PLEA	0.98	0.82	1.02	0.84	-0.34	-0.40	-0.32	-0.30
POOR	**0.55**	**0.34**	**0.52**	**0.37**	-0.61	-0.44	-0.56	-0.45
POWE	0.57	0.68	0.83	0.76	**-0.34**	**-0.13**	**-0.16**	**0.11**
SHAR	2.14	2.21	2.14	2.17	0.11	0.18	0.12	0.20
STAT	0.69	0.73	0.60	0.64	1.09	1.15	1.28	1.27

	Depth (m)				log10 Salinity			
	September		November		September		November	
Site	Pre	Post	Pre	Post	Pre	Post	Pre	Post
TAAR	0.48	0.43	0.44	0.55	1.03	1.10	1.30	1.24
THOM	**1.06**	**0.68**	**1.01**	**0.54**	0.10	0.06	0.18	0.29
TOOL	1.30	1.49	1.29	1.36	0.56	-0.15	0.64	-0.07
TORD	**2.49**	**1.60**	**2.53**	**1.75**	**0.06**	**0.43**	**0.06**	**0.42**
TOWE	2.75	3.09	2.61	2.99	0.95	0.86	1.01	0.89
UNIC	1.18	0.75	1.16	0.78	**0.59**	**0.91**	0.69	0.98
VARL	0.09	0.15	0.04	0.22	2.08	2.03	2.48	1.87
WALB	0.66	0.43	0.62	0.52	0.40	0.27	0.54	0.08
WALY	0.67	0.30	0.50	0.15	1.16	1.14	1.54	1.54
WANN	1.48	1.25	1.25	1.07	**0.80**	**1.02**	**0.89**	**1.20**
WARD	1.26	1.87	1.26	1.82	1.70	1.78	1.74	1.84
WARR	0.42	0.41	0.37	0.46	**-0.91**	**-0.66**	**-0.82**	**-0.54**
WEST	0.66	0.47	0.71	0.57	0.99	1.14	1.00	1.14
WHIN	0.54	0.05	0.73	0.24	1.28	1.46	1.42	1.21
WHIW	0.56	0.36	0.62	1.05	1.33	1.48	1.44	1.05
WILS	3.79	3.87	**3.64**	**3.79**	**-0.87**	**-0.78**	**-0.84**	**-0.76**
YAAL	1.62	0.94	1.71	1.12	-0.09	-0.11	-0.18	-0.25
YARN	**1.05**	**0.81**	0.93	0.78	**0.12**	**0.64**	**0.20**	**0.73**
YARR	0.33	0.19	0.24	0.12	2.21	2.38	2.35	2.26
YEAL	1.68	1.24	1.49	1.31	**1.25**	**1.69**	**1.36**	**1.66**
YELL	**3.43**	**1.69**	**3.22**	**1.61**	**0.50**	**1.46**	**0.53**	**1.50**
YURI	1.44	0.84	1.37	0.82	**-0.01**	**-0.43**	0.12	-0.25

Salinity and depth data by site

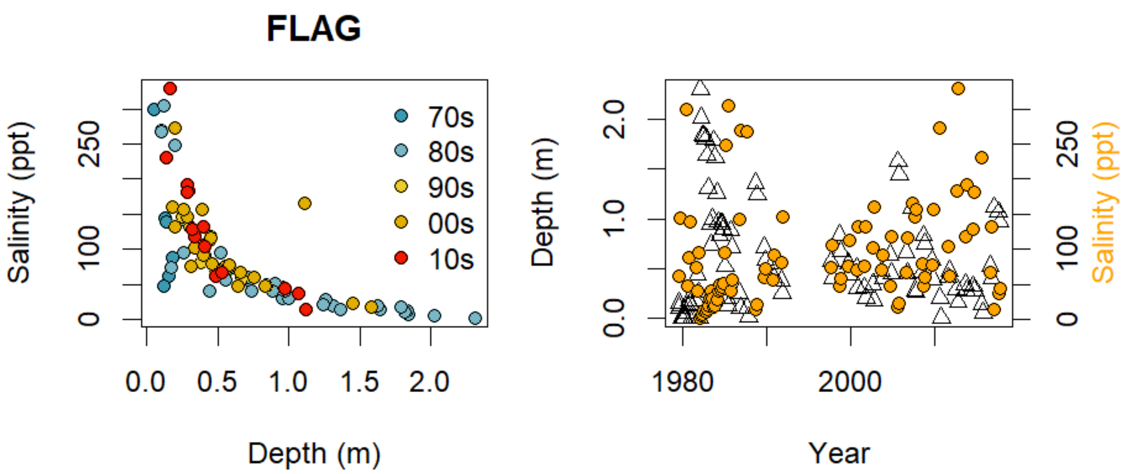
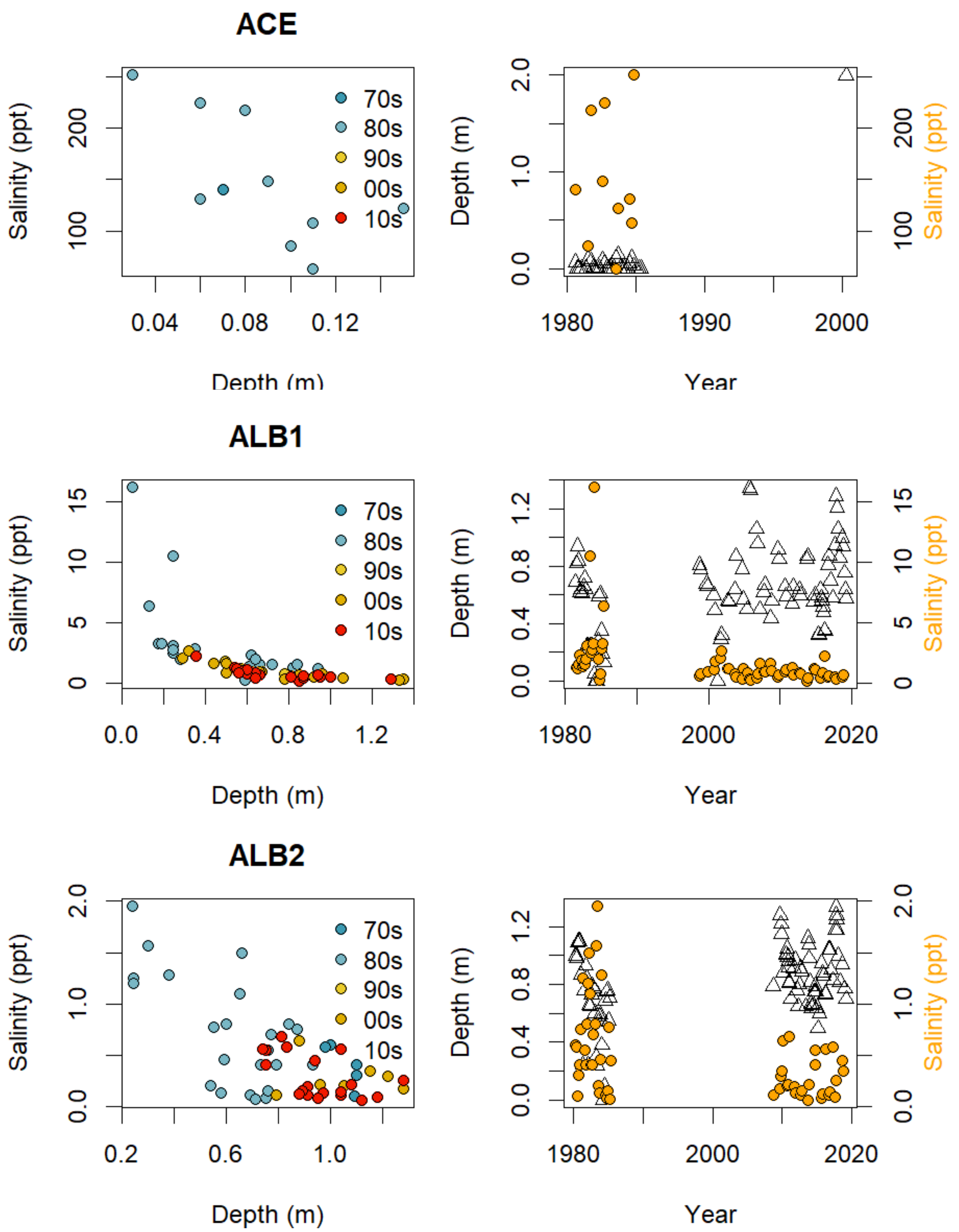
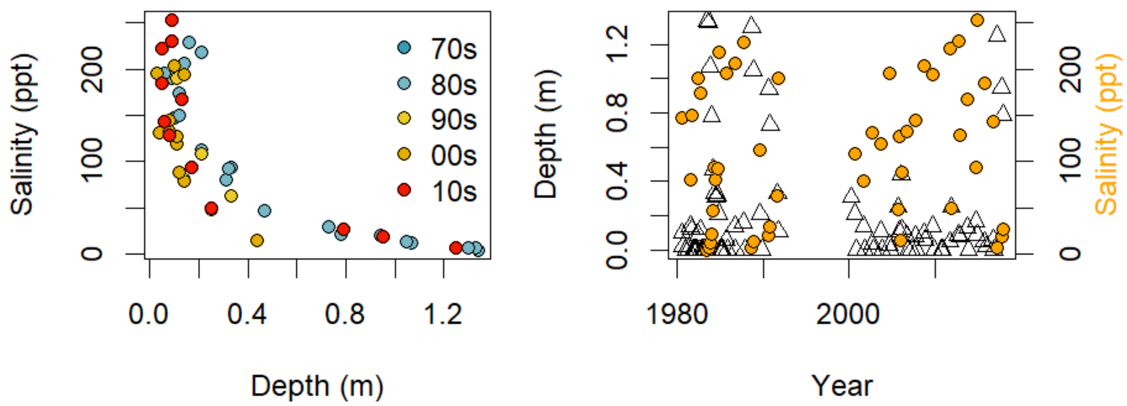


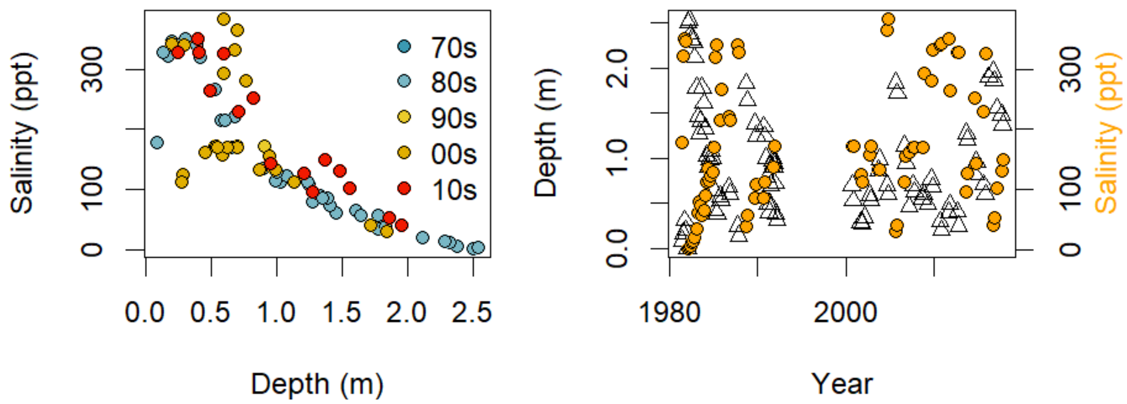
Figure 22: Key to data figures in Appendix 3. Left: Salinity vs water depth with colours used to distinguish the decade a sample was collected. Right: Time series of the same data with salinity (circles) and water levels (triangles).


ACE
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Year
ALB1
ALB2

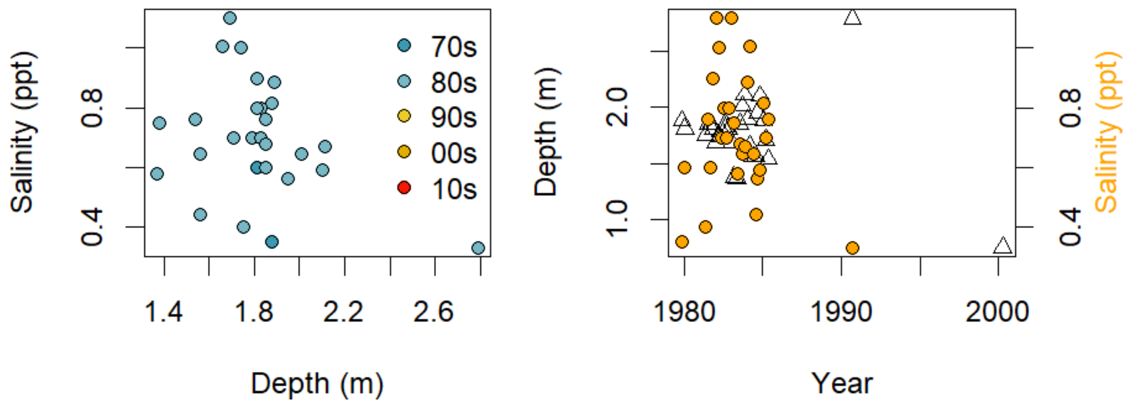
ALTH

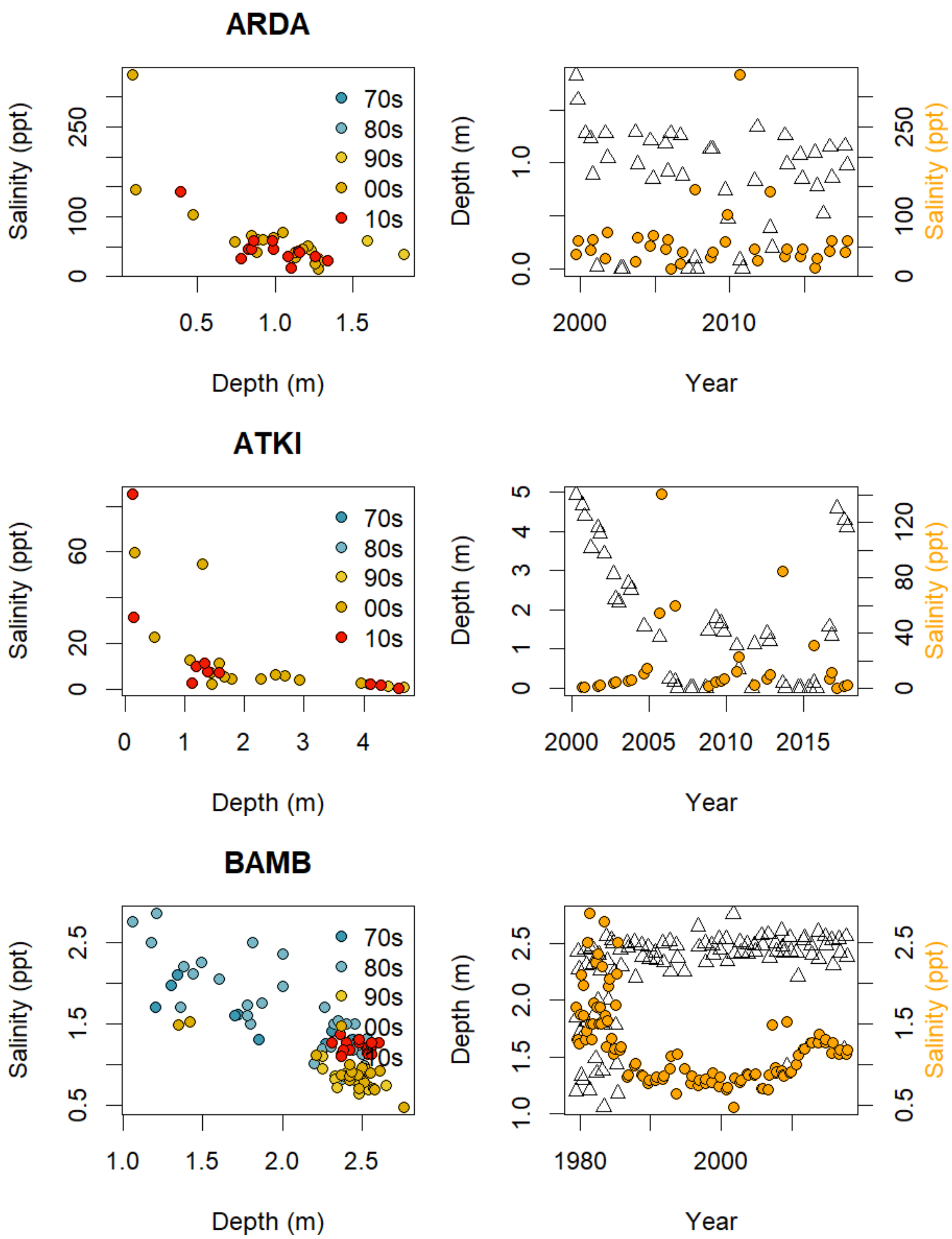


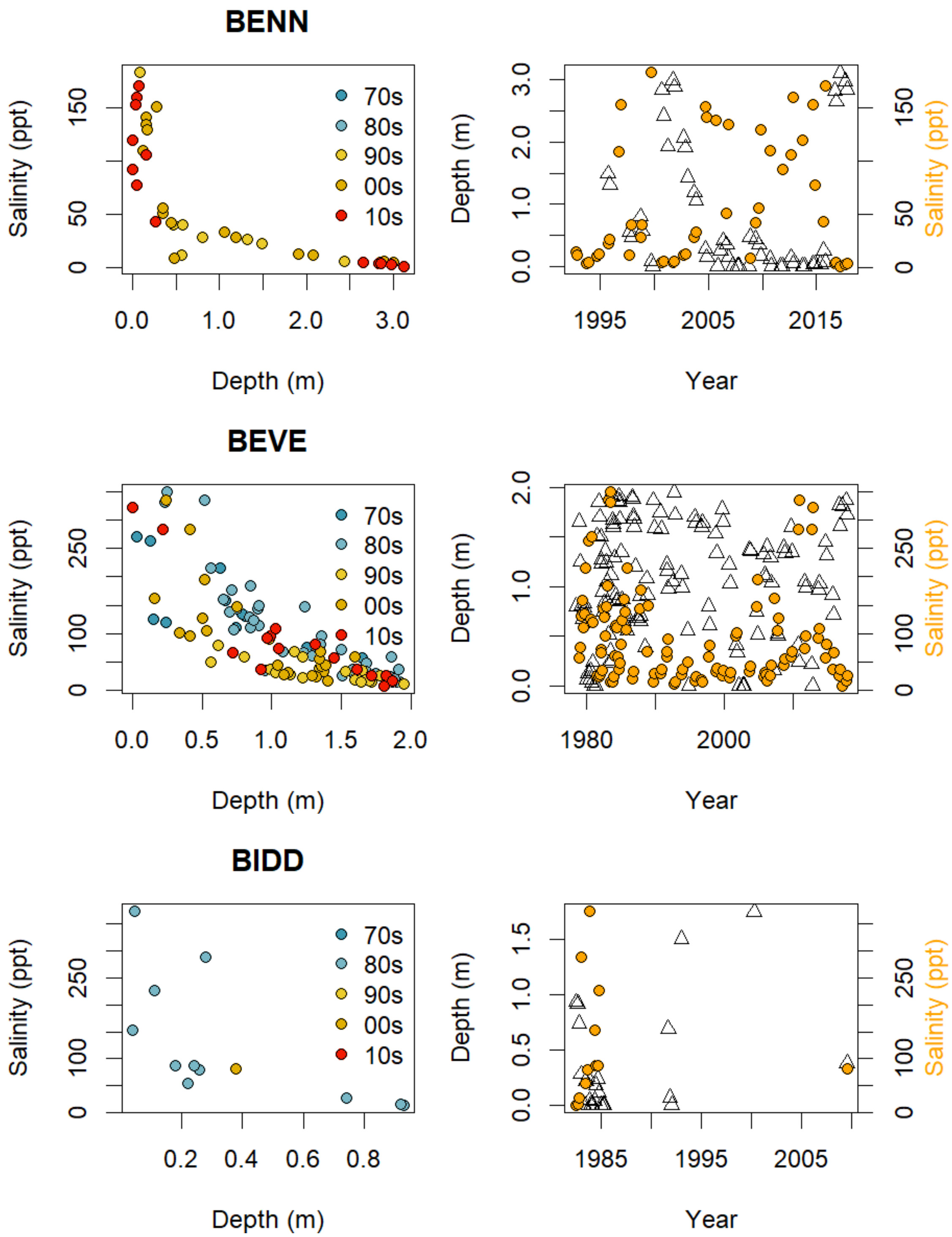
ANDE

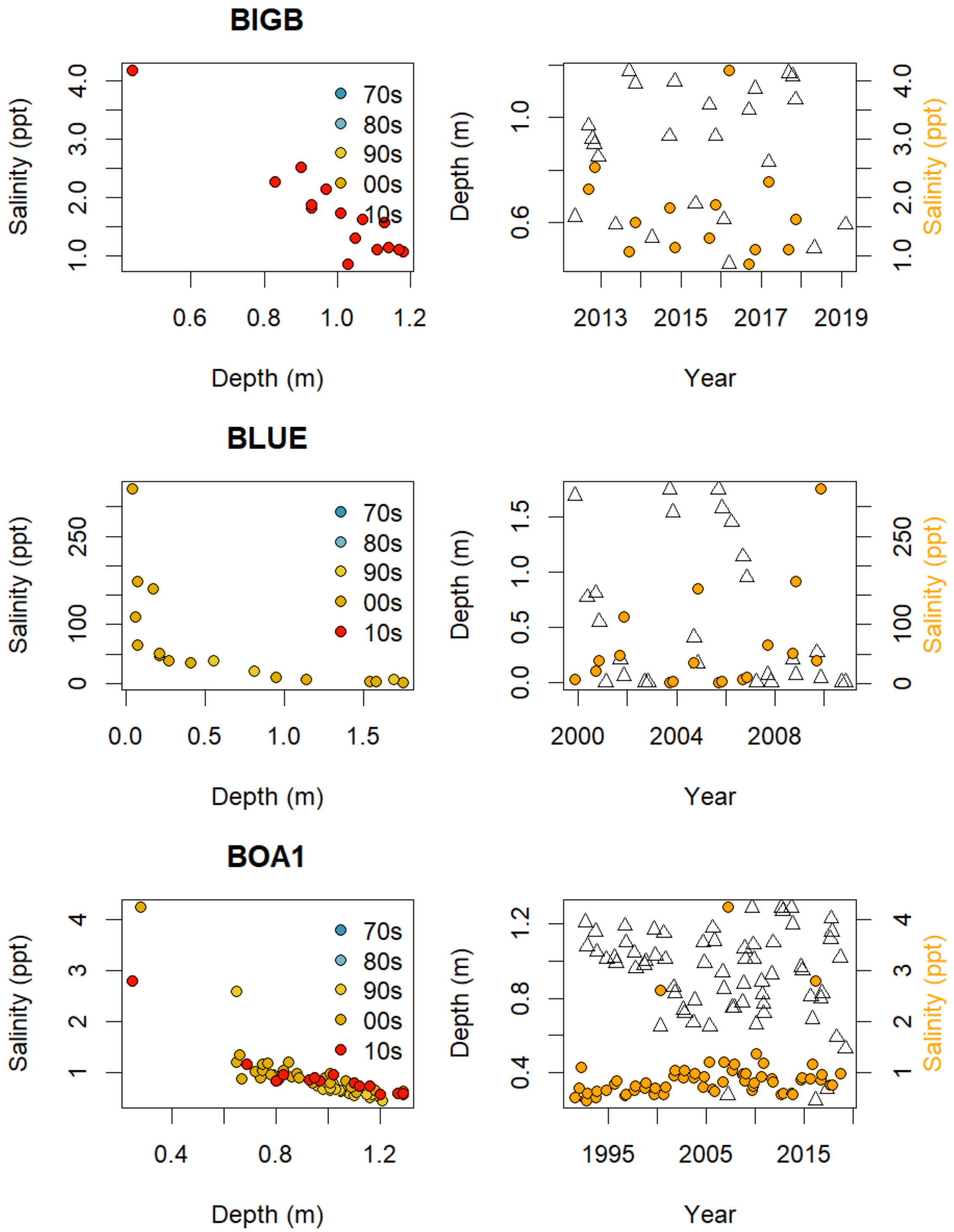


ANGO

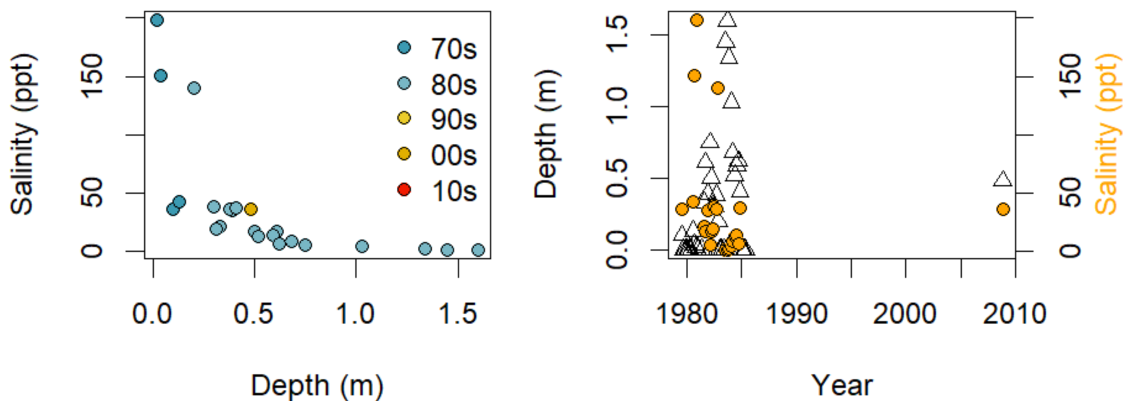



ARDA
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Year
ATKI
BAMB

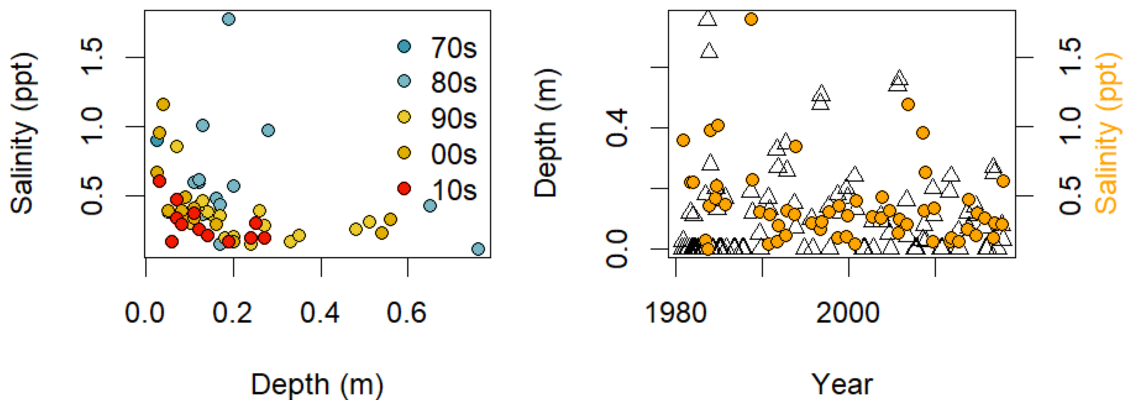

BENN
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Year
BEVE
BIDD


BIGB
Salinity (ppt)
1.0
2.0
3.0
4.0
70s
80s
90s
00s
10s
0.6
0.8
1.0
1.2
Depth (m)
Depth (m)
0.6
1.0
Salinity (ppt)
2013
2015
2017
2019
Year
BLUE
Salinity (ppt)
0
100
250
0.0
0.5
1.0
1.5
Depth (m)
Depth (m)
2000
2004
2008
Year
BOA1
Salinity (ppt)
1
2
3
4
0.4
0.8
1.2
Depth (m)
Depth (m)
1995
2005
2015
Year

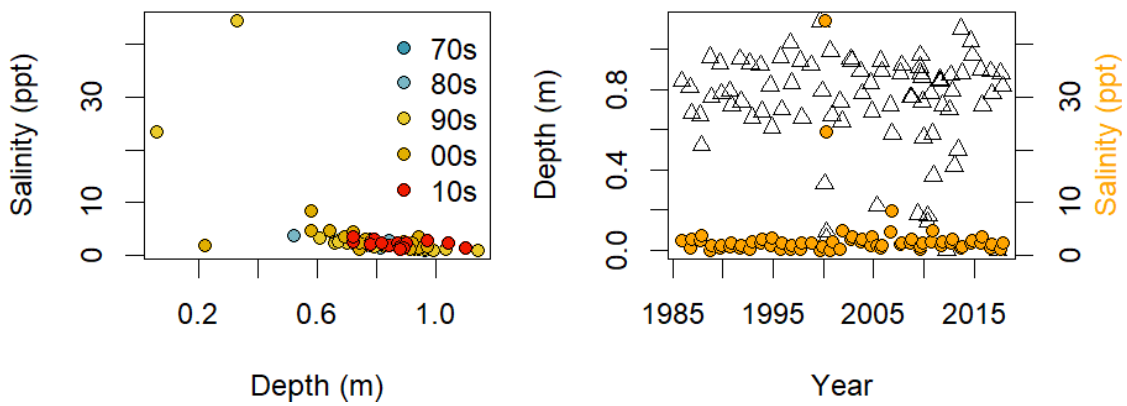
BOKA

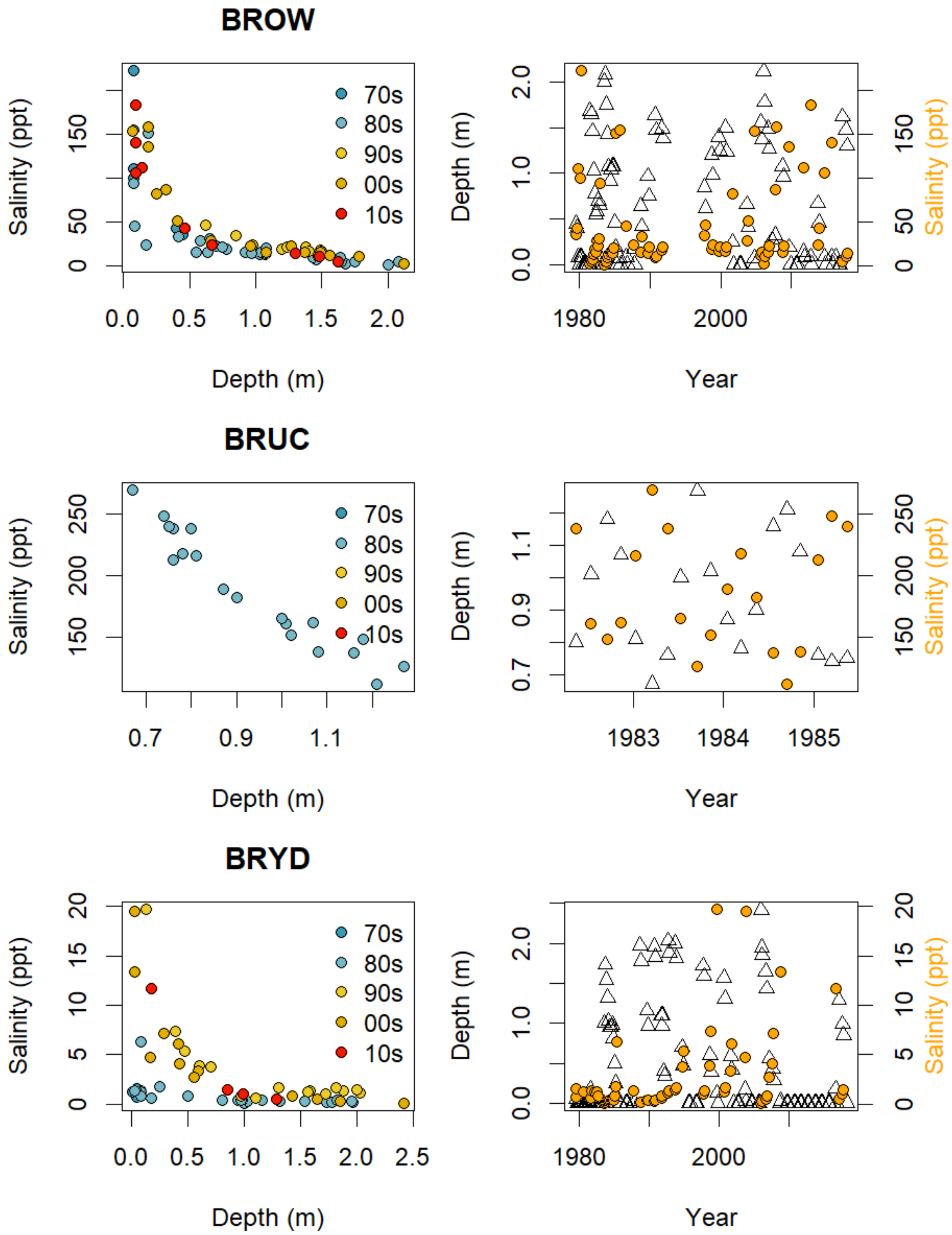


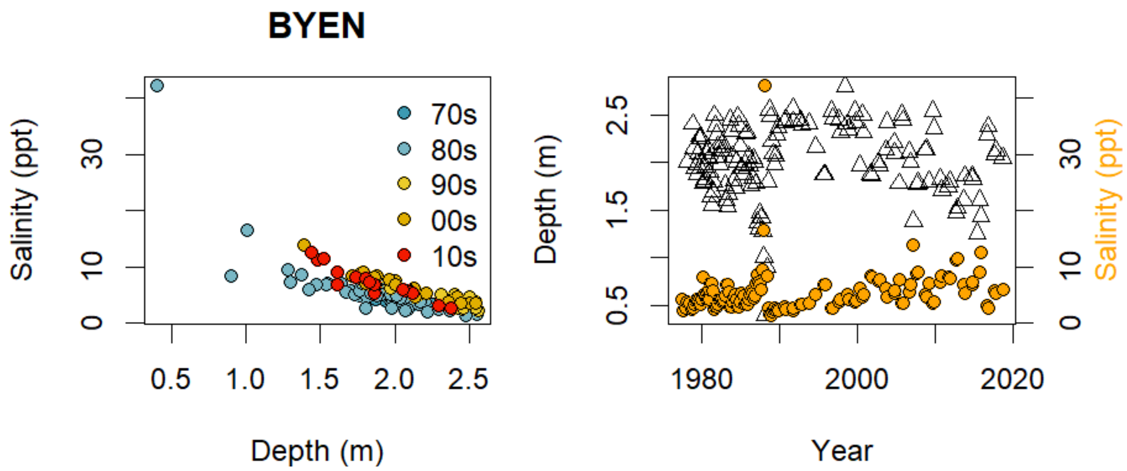
BOYU

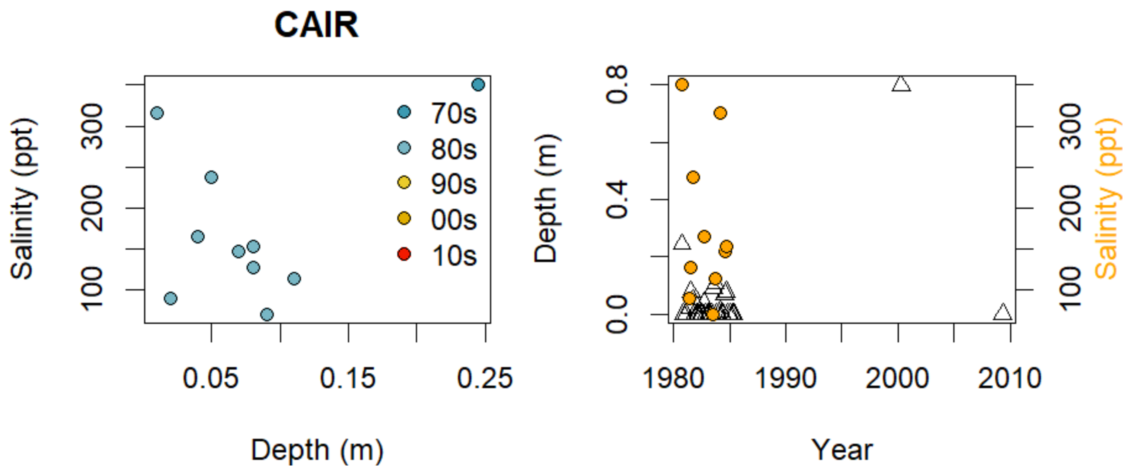


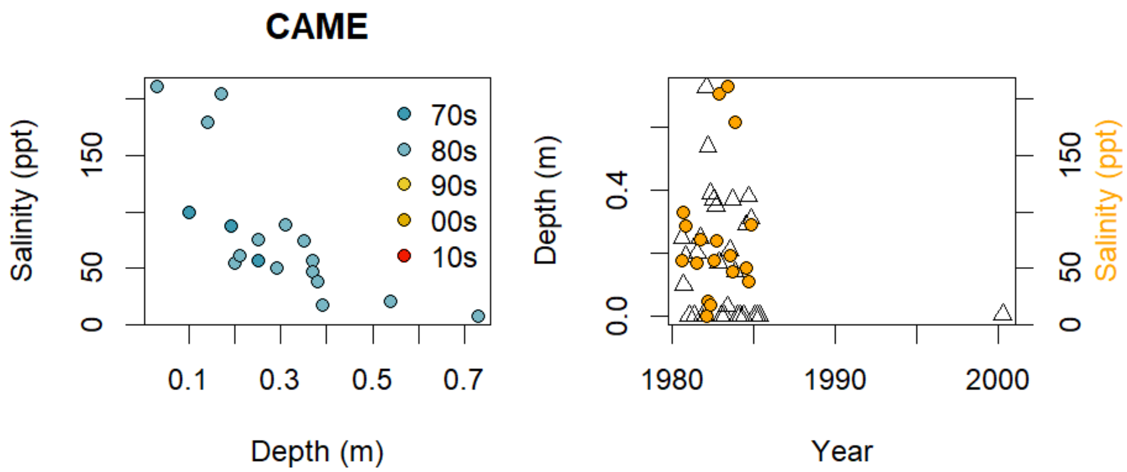
BROA

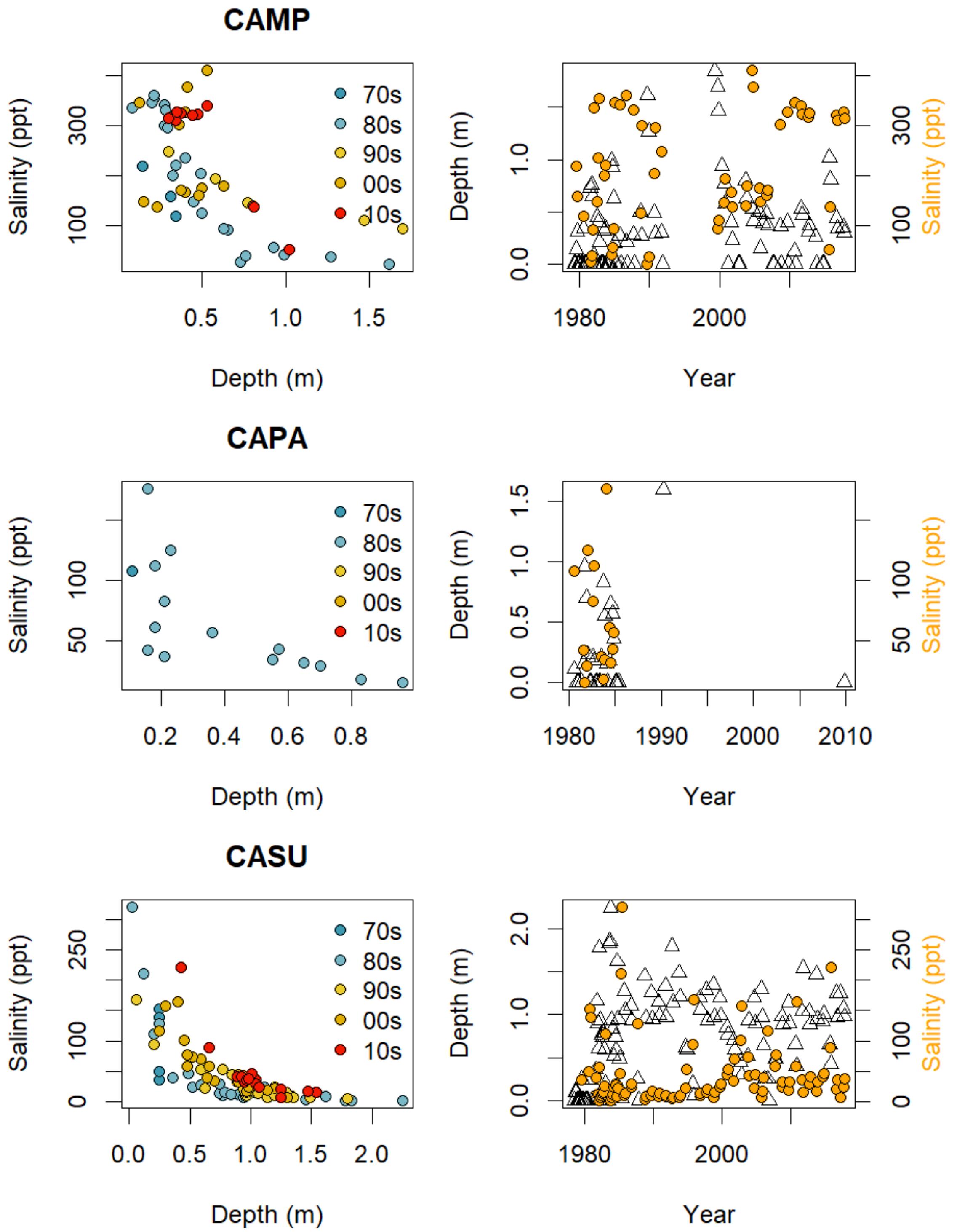


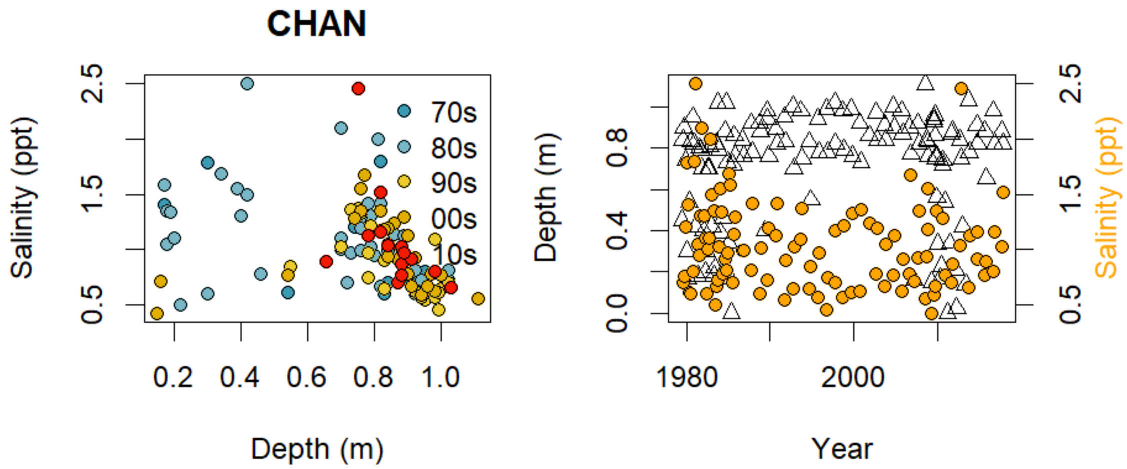

BROW
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)
BRUC
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)
BRYD
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)

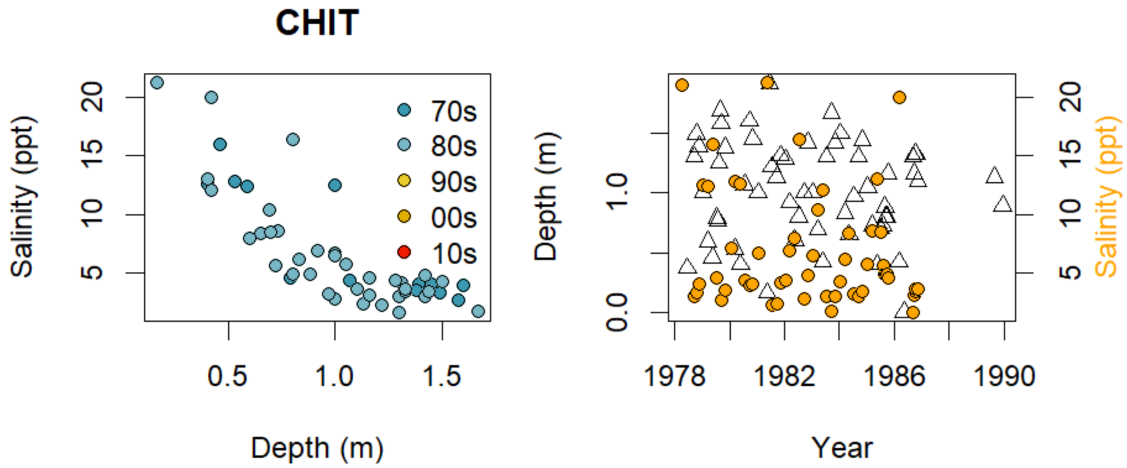

BYEN
Salinity (ppt)
0
10
30
70s
80s
90s
00s
10s
0.5
1.0
1.5
2.0
2.5
Depth (m)
Depth (m)
0.5
1.5
2.5
1980
2000
2020
Year
Salinity (ppt)

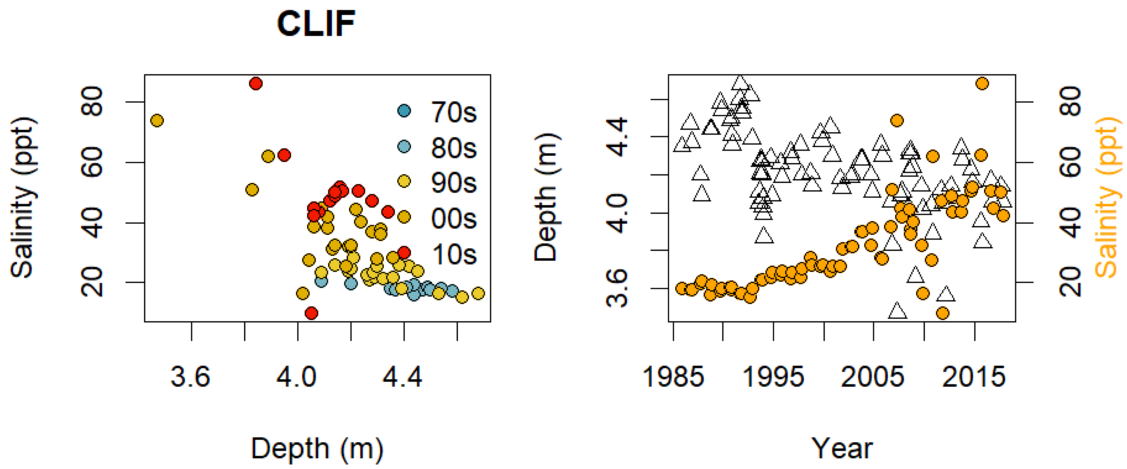

CAIR
Salinity (ppt)
100
200
300
70s
80s
90s
00s
10s
0.05
0.15
0.25
Depth (m)
Depth (m)
0.0
0.4
0.8
1980
1990
2000
2010
Year
Salinity (ppt)

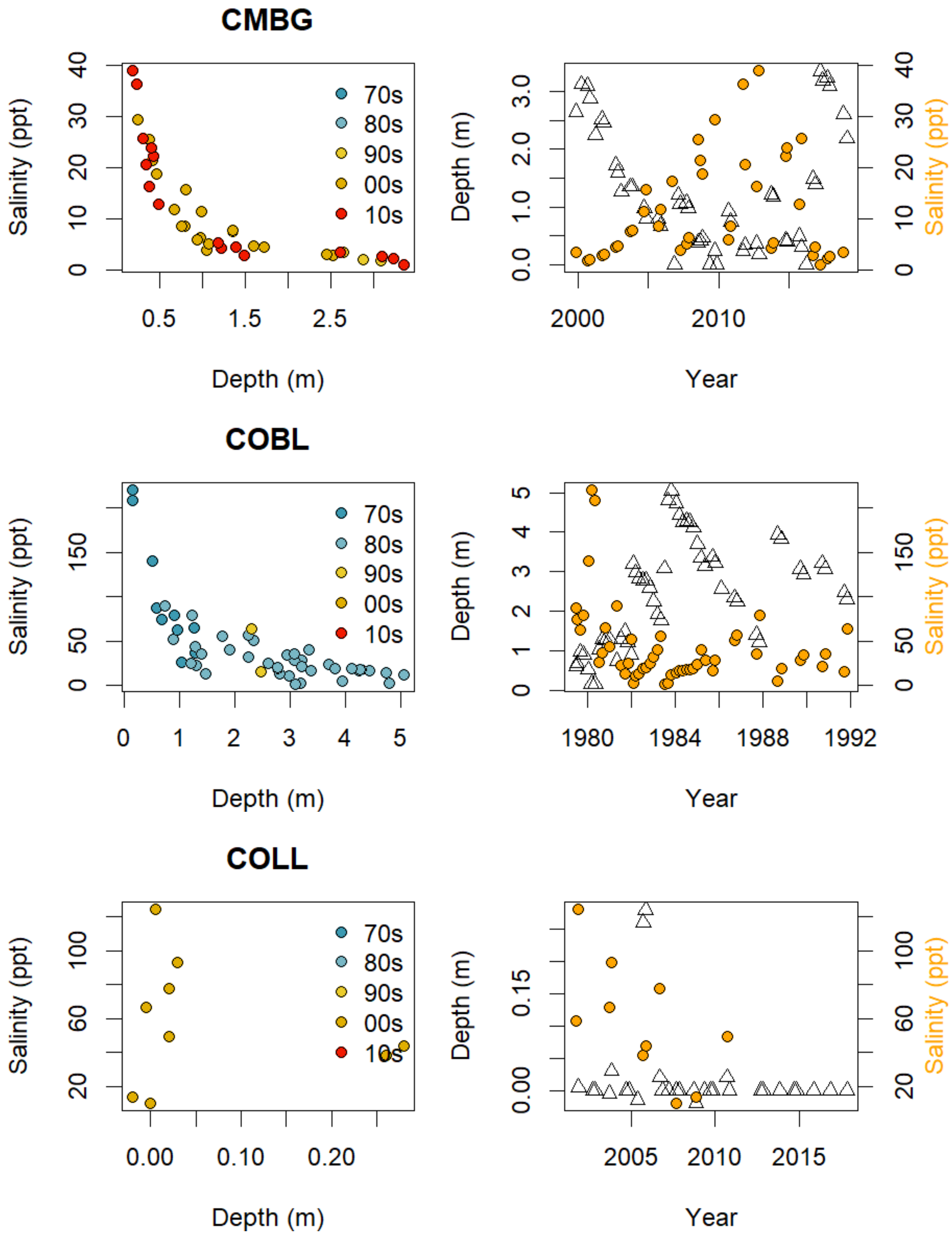

CAME
Salinity (ppt)
0
50
150
70s
80s
90s
00s
10s
0.1
0.3
0.5
0.7
Depth (m)
Depth (m)
0.0
0.4
1980
1990
2000
Year
Salinity (ppt)

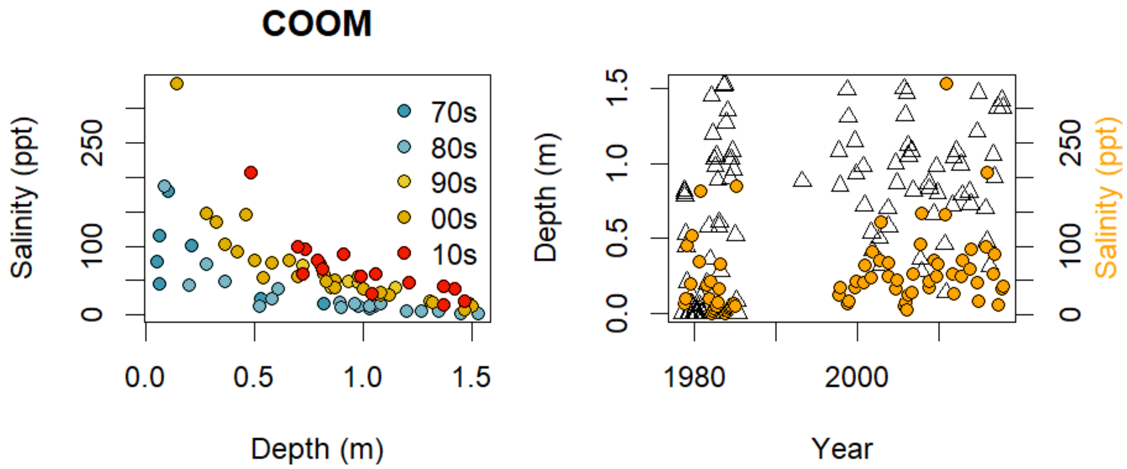

CAMP
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)
CAPA
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)
CASU
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)

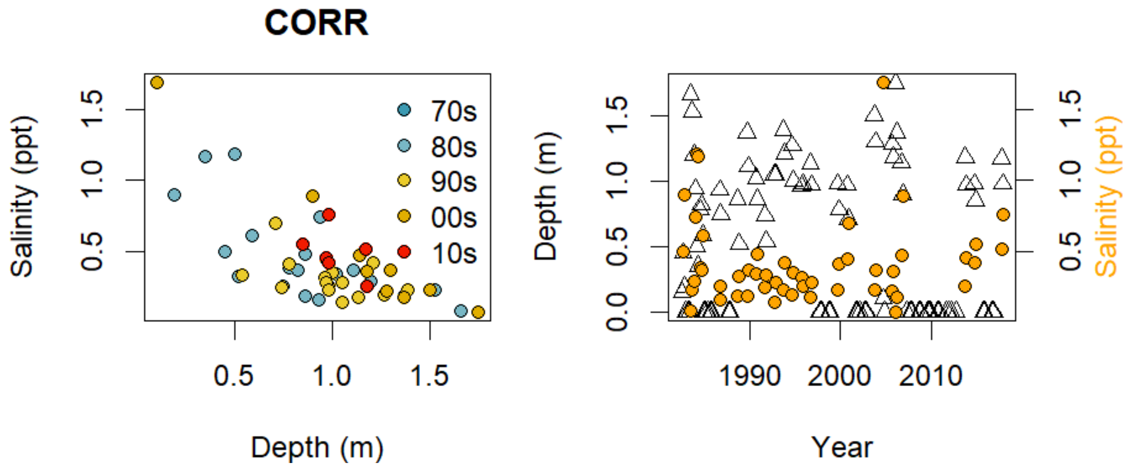

CHAN
Salinity (ppt)
0.5
1.5
2.5
70s
80s
90s
00s
10s
0.2
0.4
0.6
0.8
1.0
Depth (m)
Depth (m)
0.0
0.4
0.8
1980
2000
Year
Salinity (ppt)

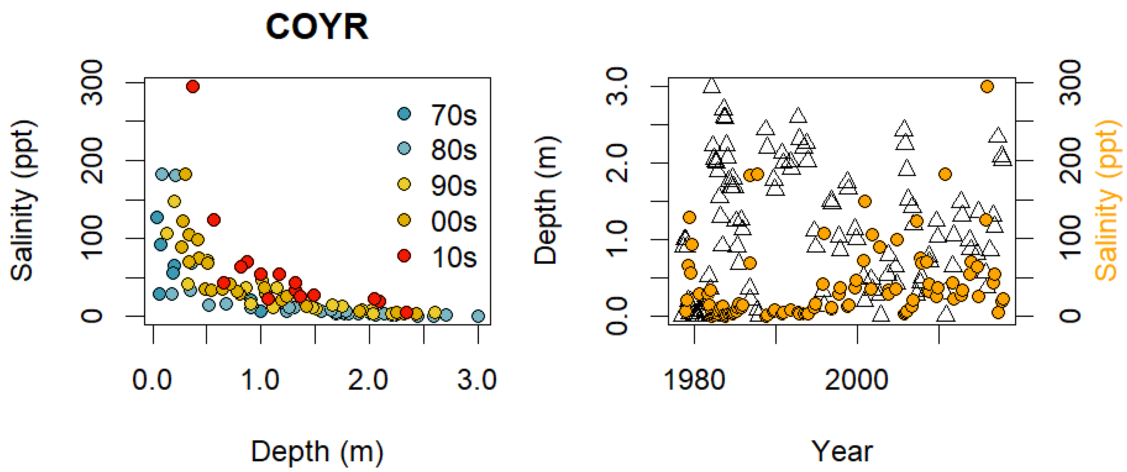

CHIT
Salinity (ppt)
5
10
15
20
70s
80s
90s
00s
10s
0.5
1.0
1.5
Depth (m)
Depth (m)
0.0
1.0
1978
1982
1986
1990
Year
Salinity (ppt)

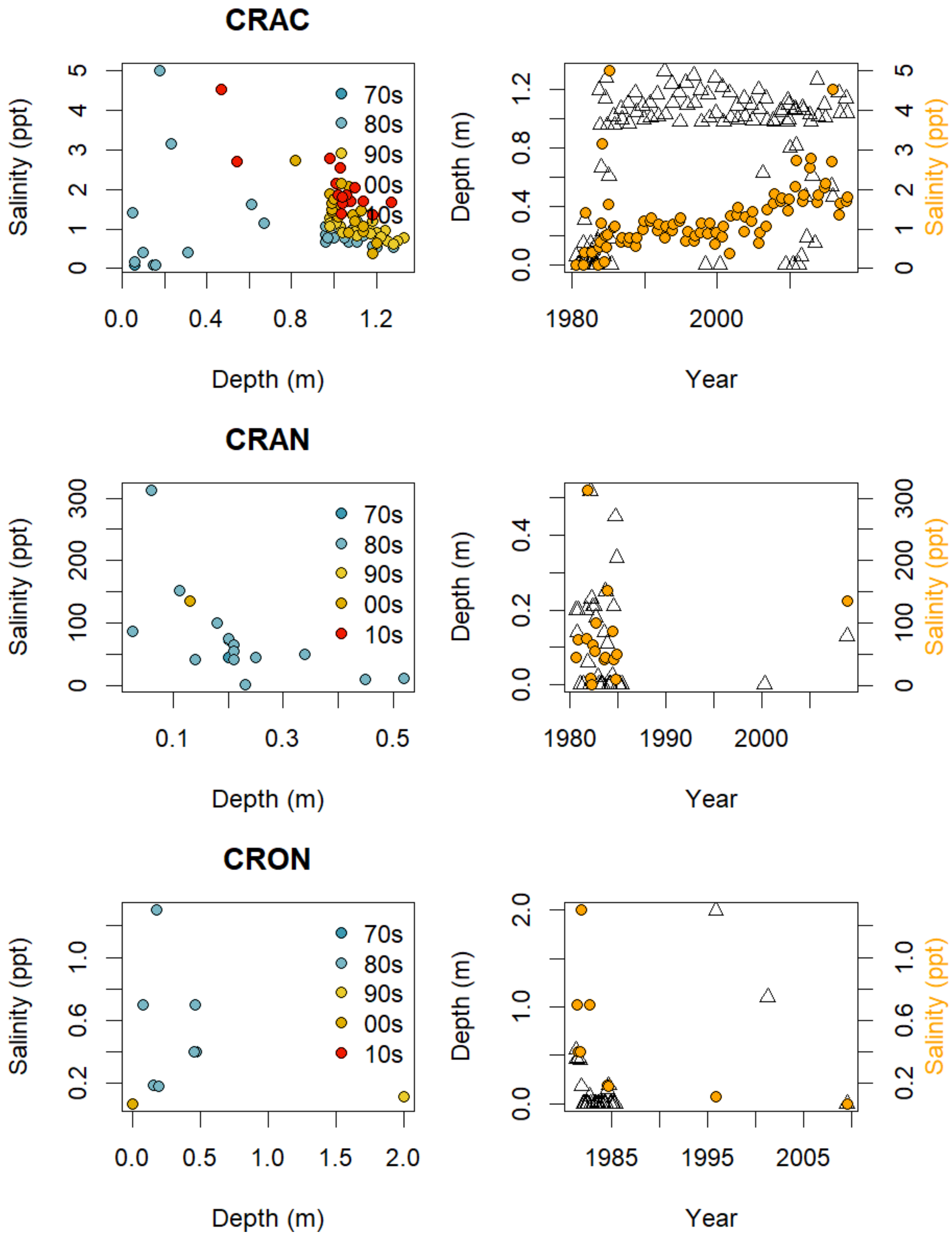

CLIF
Salinity (ppt)
20
40
60
80
70s
80s
90s
00s
10s
3.6
4.0
4.4
Depth (m)
Depth (m)
3.6
4.0
4.4
1985
1995
2005
2015
Year
Salinity (ppt)


CMBG
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
0.5
1.5
2.5
Depth (m)
Year
2000
2010
Salinity (ppt)
COBL
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
0
1
2
3
4
5
Depth (m)
Year
1980
1984
1988
1992
Salinity (ppt)
COLL
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
0.00
0.10
0.20
Depth (m)
Year
2005
2010
2015
Salinity (ppt)

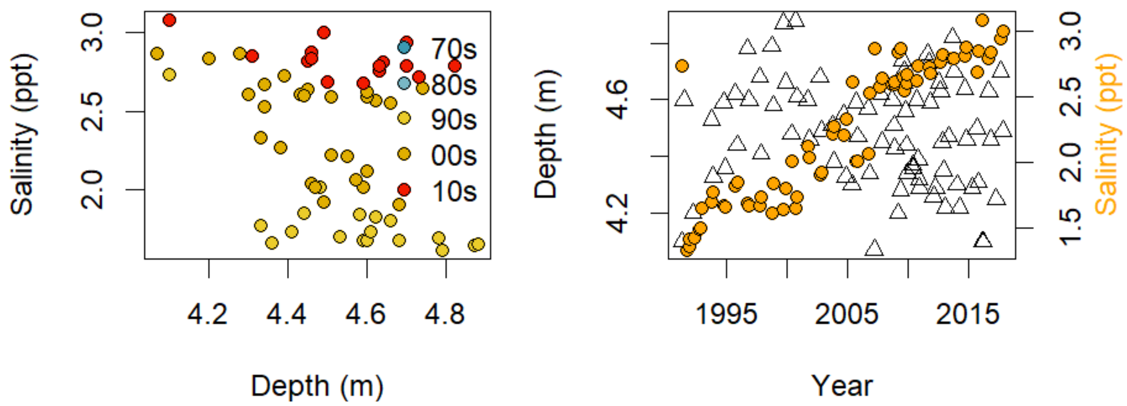

COOM
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Year
Salinity (ppt)


CORR
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Year
Salinity (ppt)

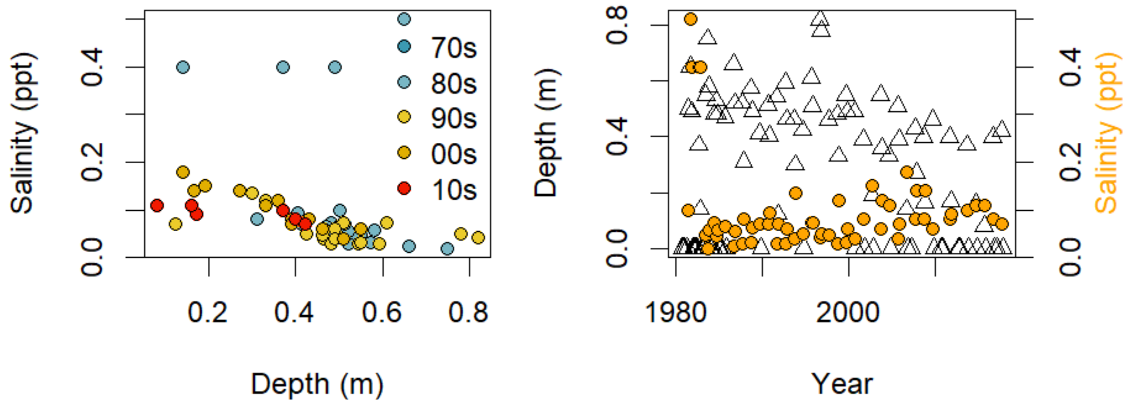

COYR
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Year
Salinity (ppt)


CRAC
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Year
Salinity (ppt)
CRAN
CRON

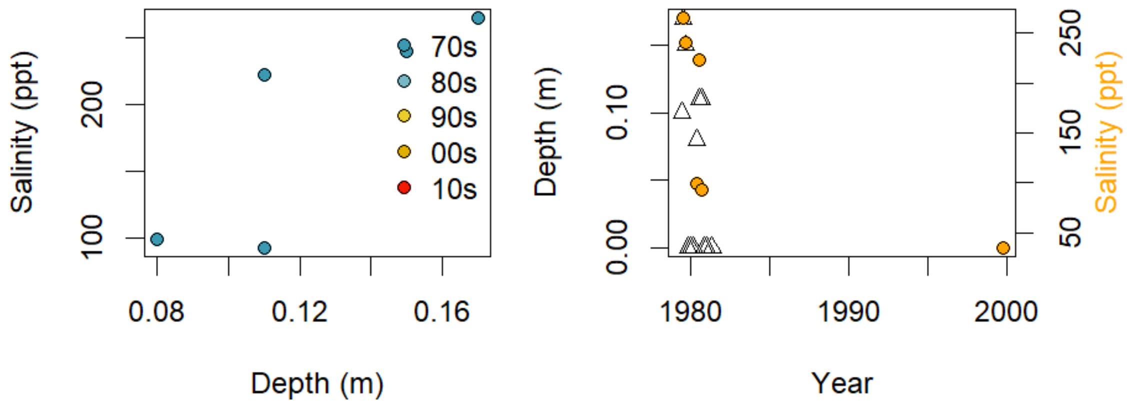
DAVI

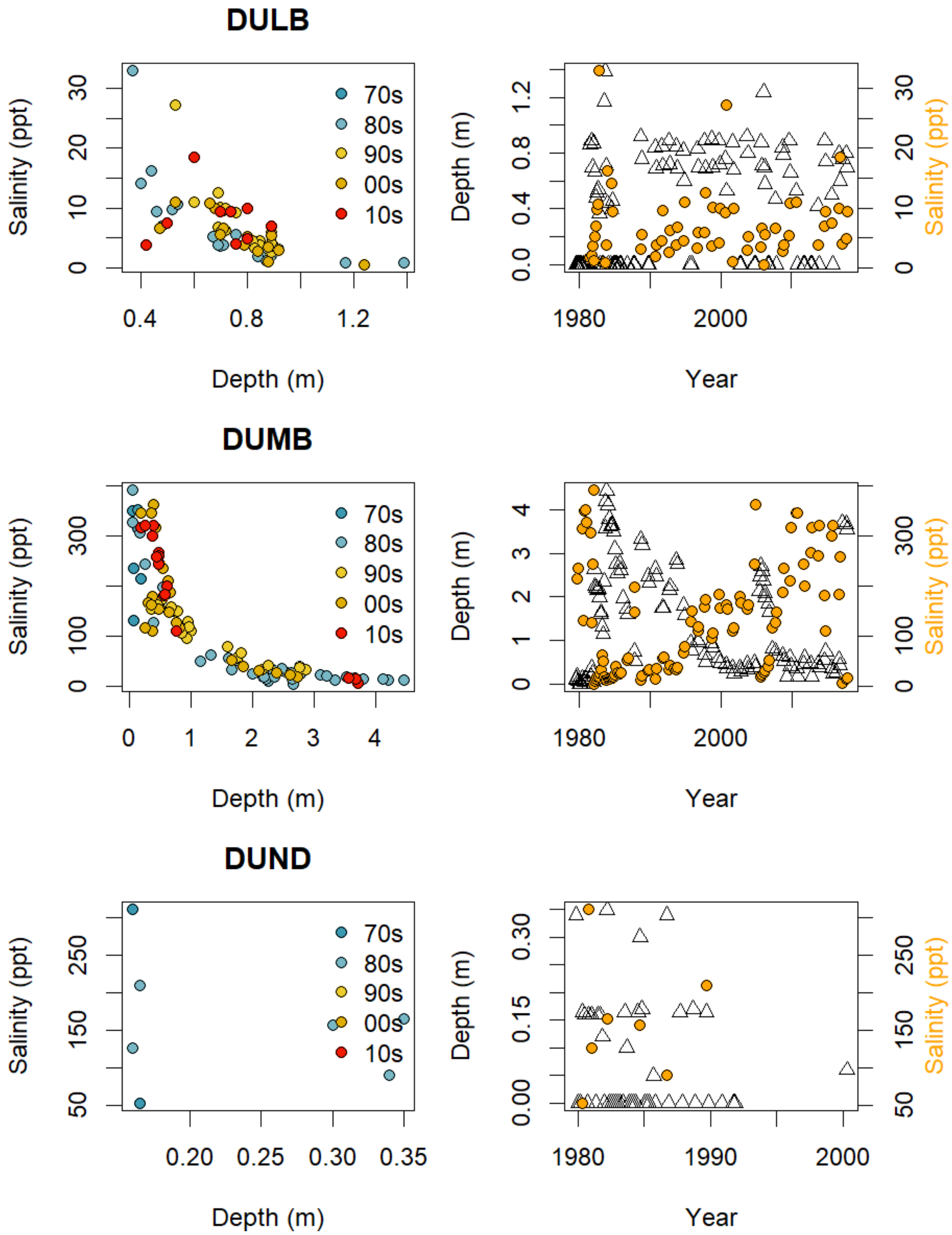


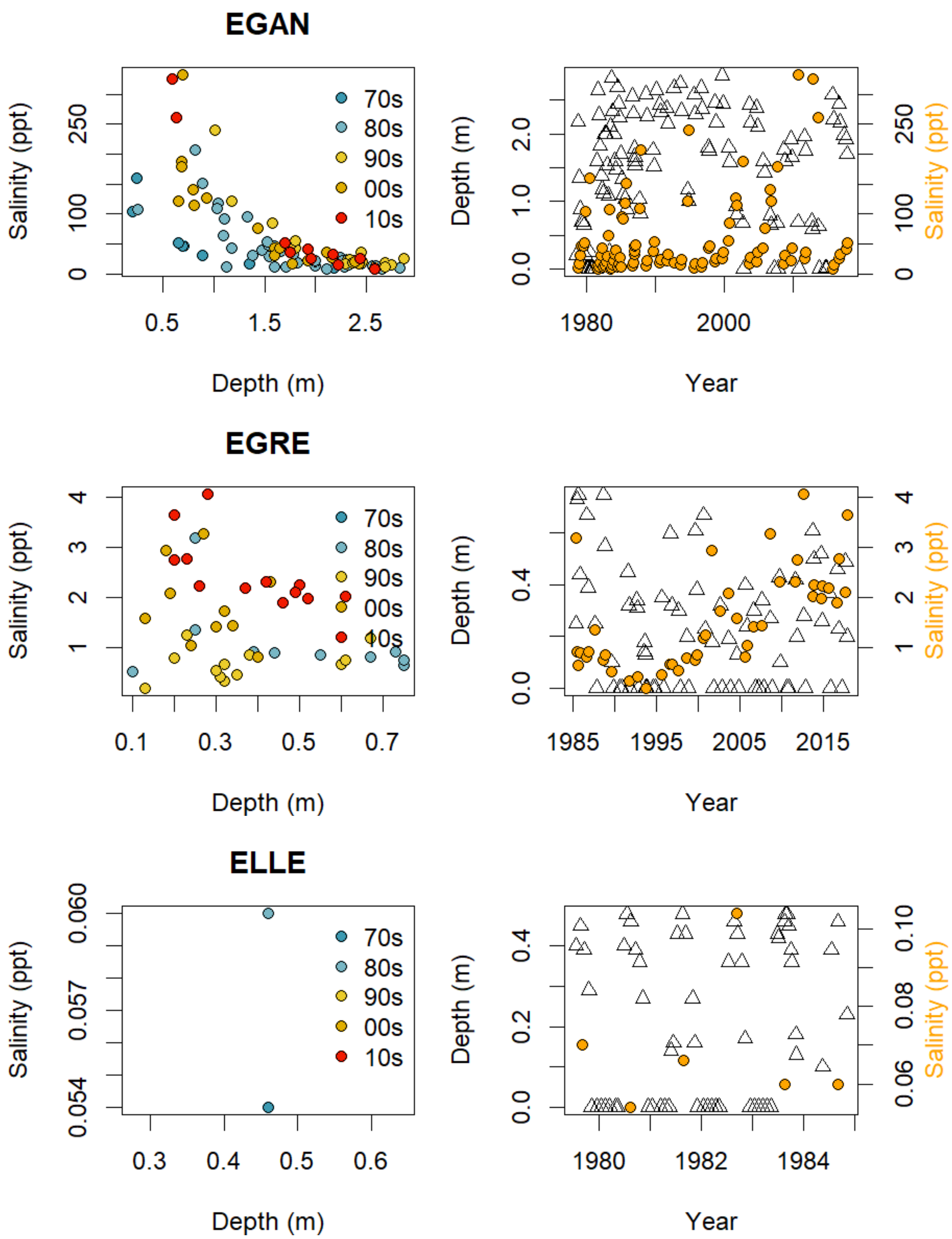
DOBA

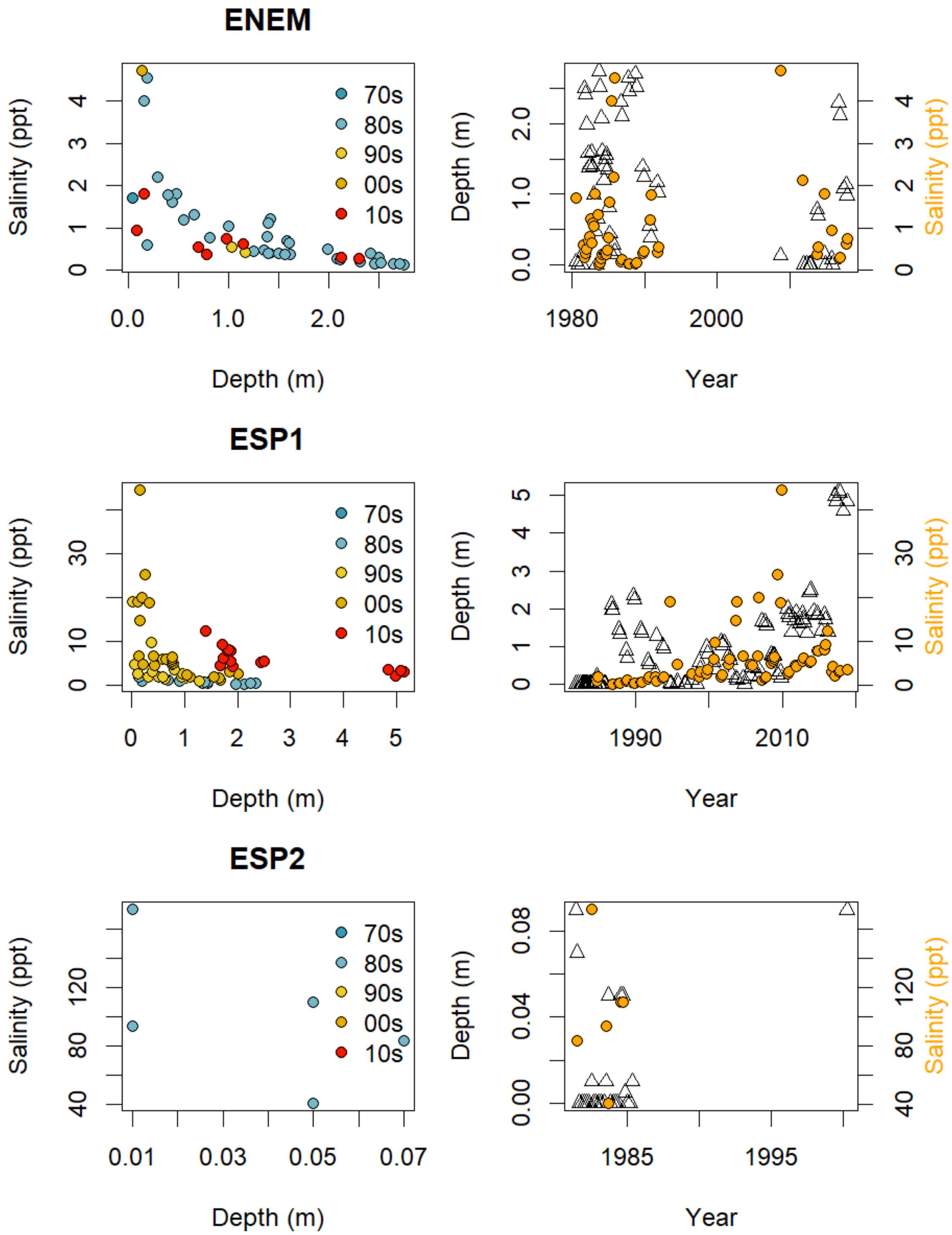


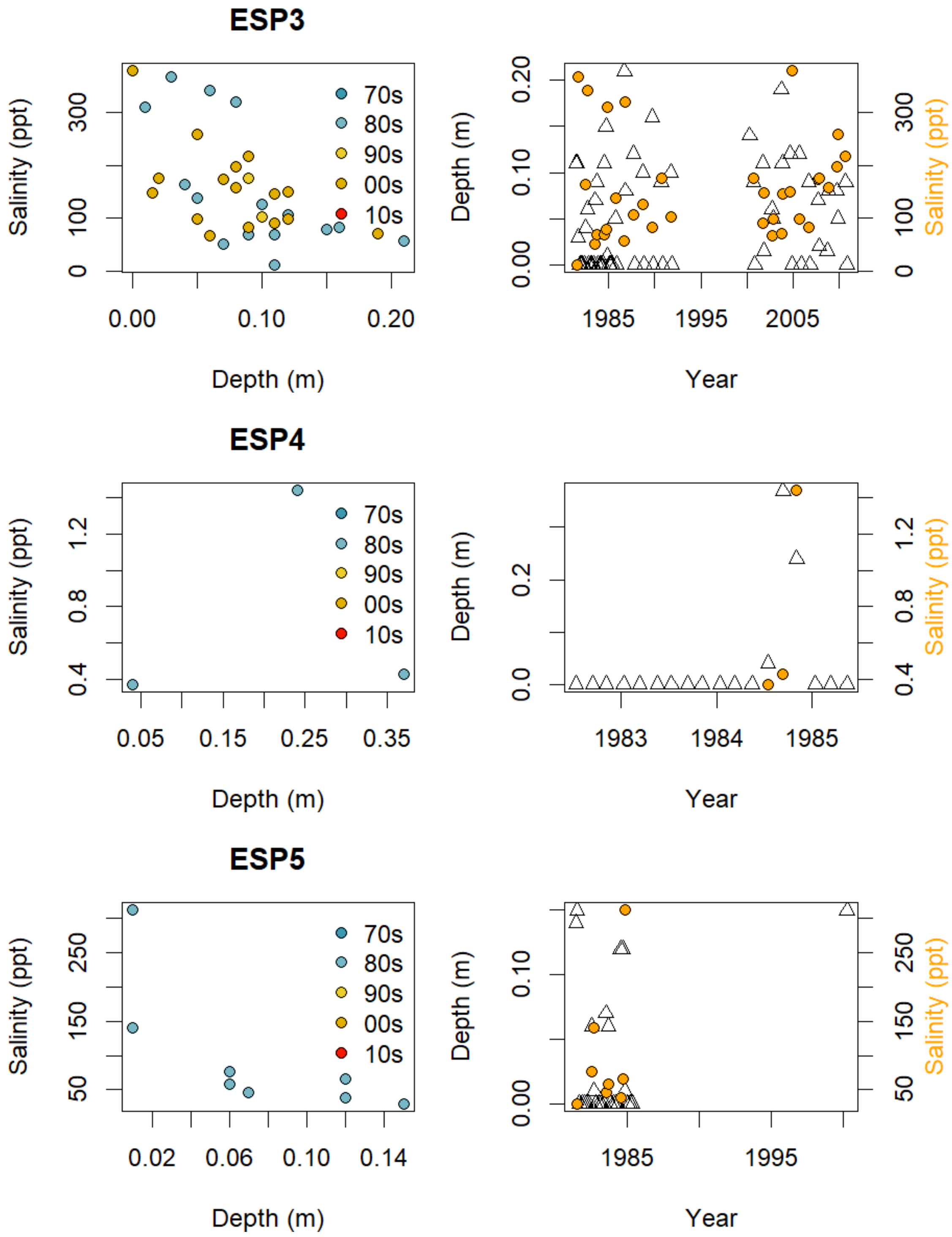
DOWE

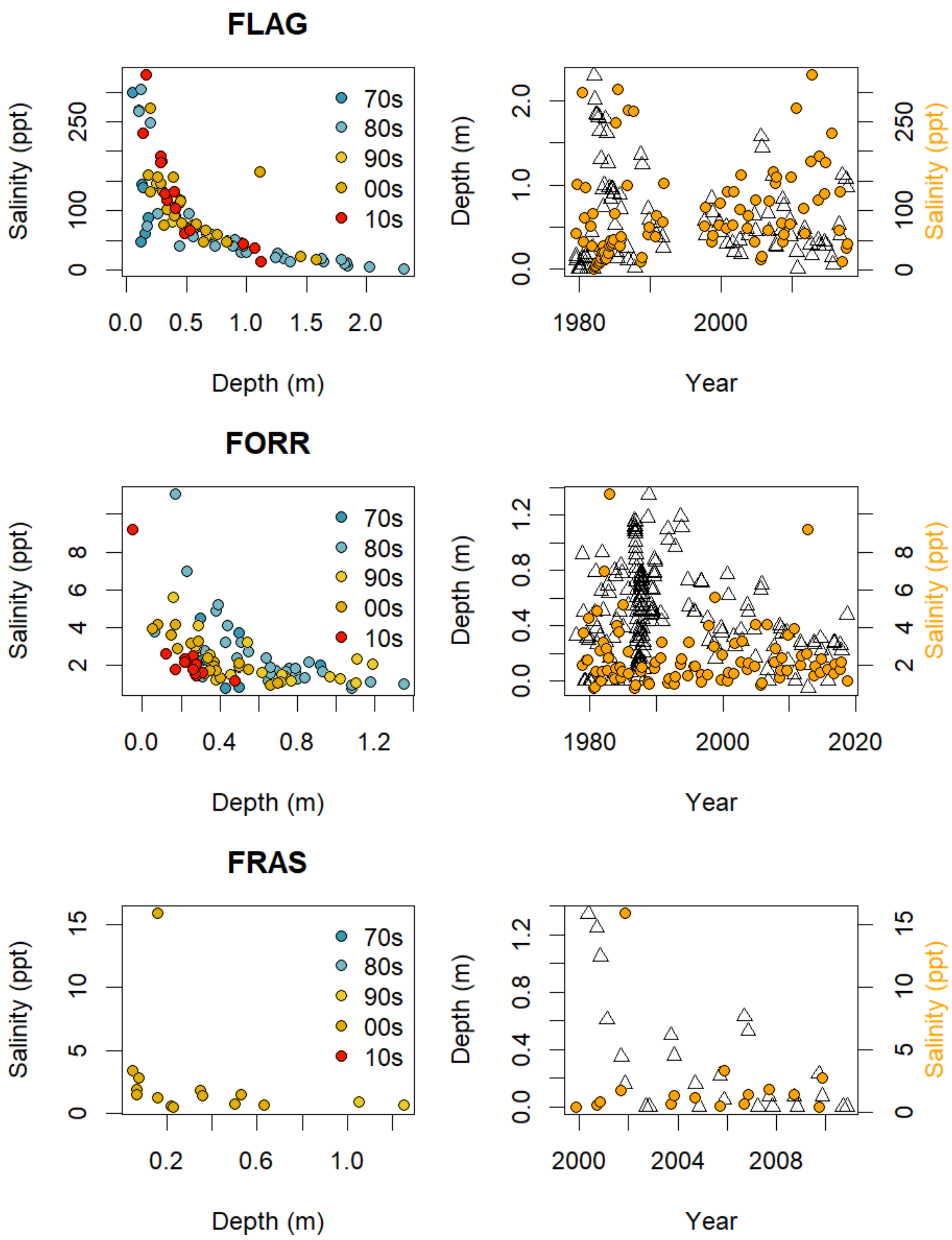



DULB
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)
DUMB
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)
DUND
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)

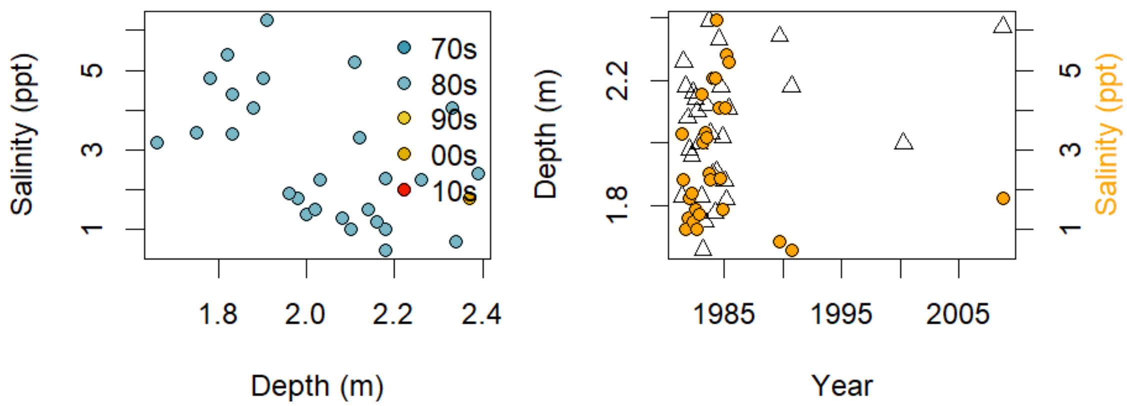

EGAN
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Year
EGRE
ELLE


ENEM
Salinity (ppt)
0 1 2 3 4
70s
80s
90s
00s
10s
0.0 1.0 2.0
Depth (m)
Depth (m)
0.0 1.0 2.0
1980 2000
Year
Salinity (ppt)
0 1 2 3 4
ESP1
Salinity (ppt)
0 10 30
70s
80s
90s
00s
10s
0 1 2 3 4 5
Depth (m)
Depth (m)
0 1 2 3 4 5
1990 2010
Year
Salinity (ppt)
0 10 30
ESP2
Salinity (ppt)
40 80 120
70s
80s
90s
00s
10s
0.01 0.03 0.05 0.07
Depth (m)
Depth (m)
0.00 0.04 0.08
1985 1995
Year
Salinity (ppt)
40 80 120

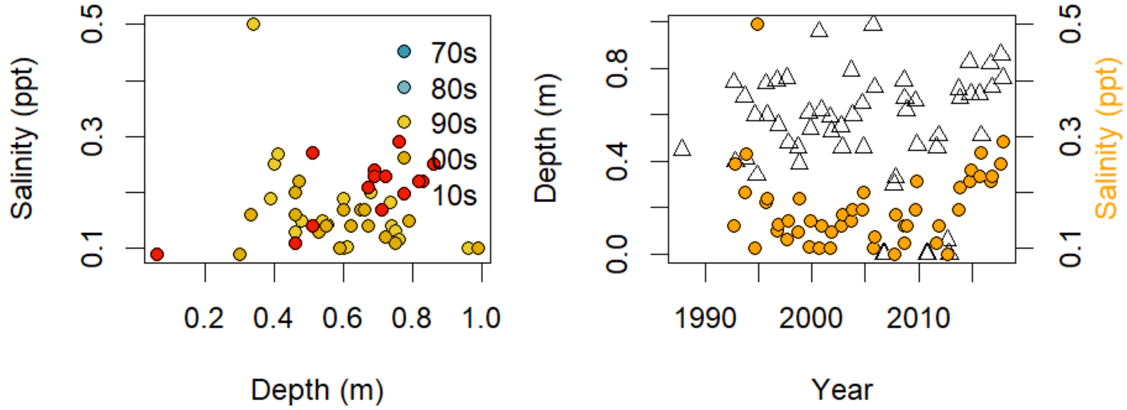

ESP3
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Year
Salinity (ppt)
ESP4
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Year
Salinity (ppt)
ESP5
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Year
Salinity (ppt)


FLAG
70s
80s
90s
00s
10s
Salinity (ppt)
Depth (m)
Year
FORR
FRAS

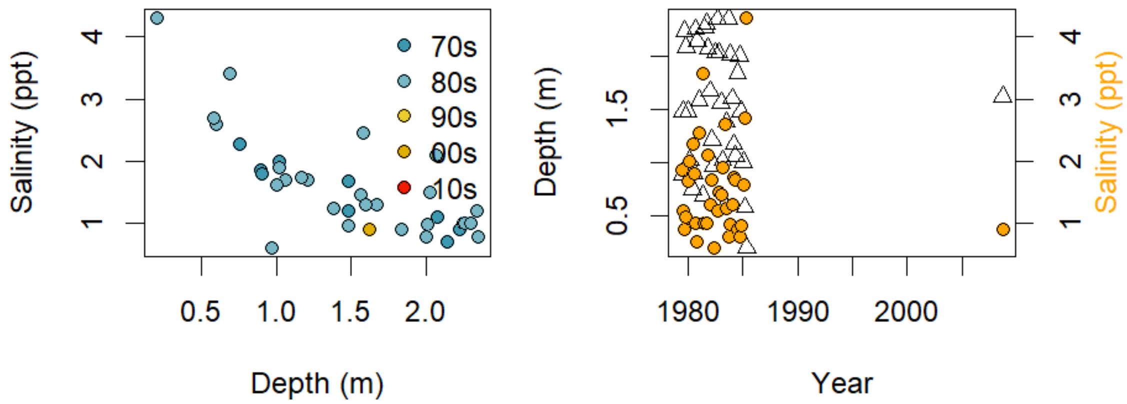
GARD

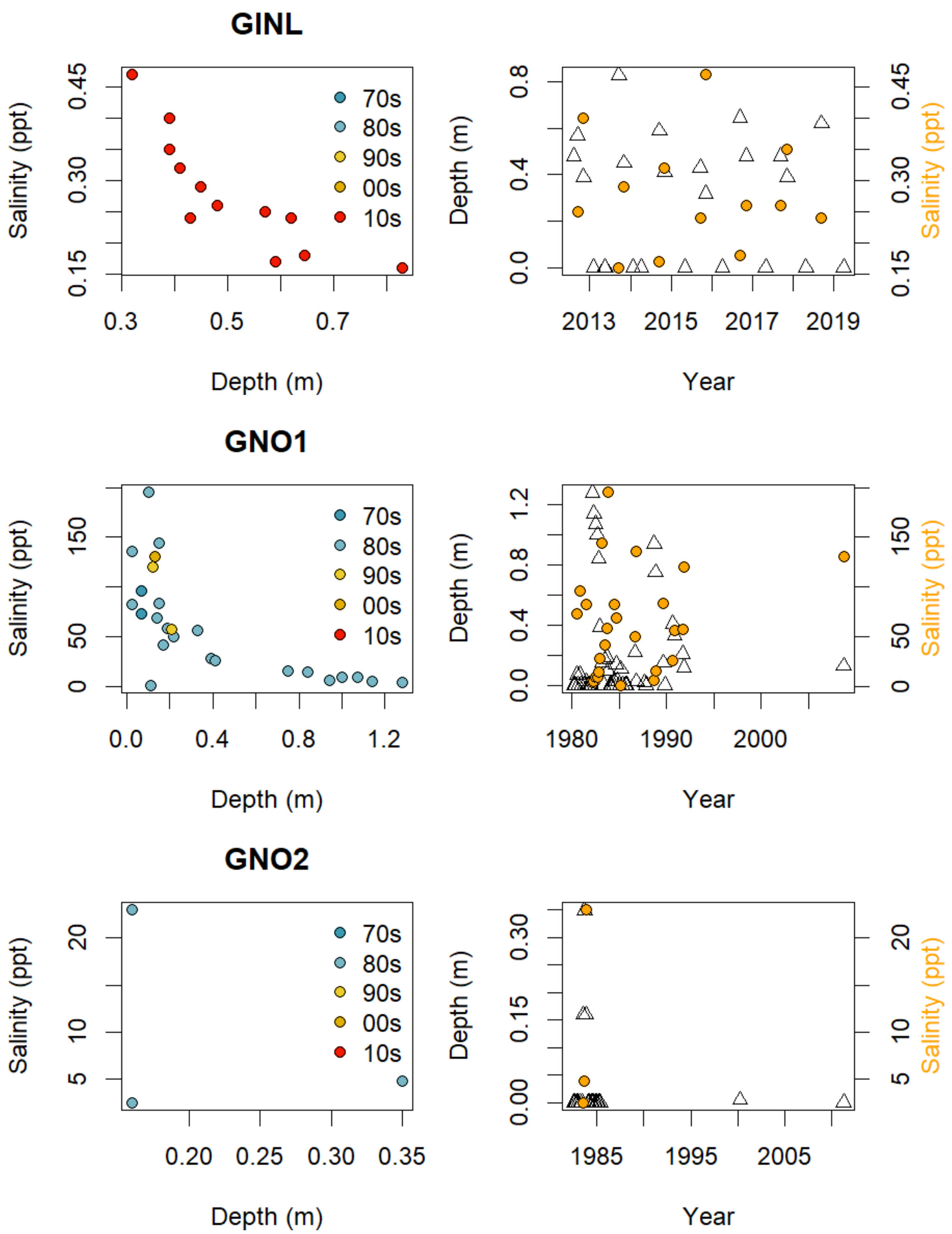


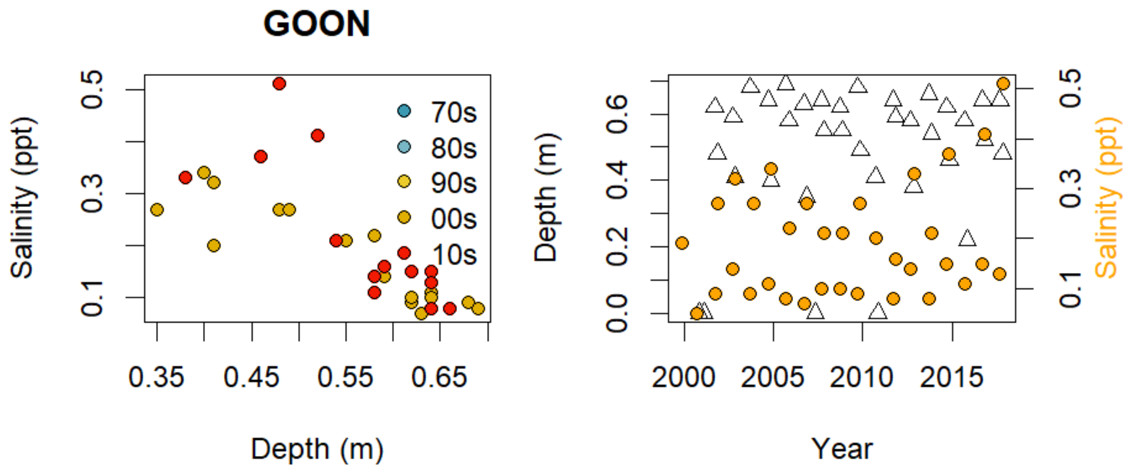
GIBB

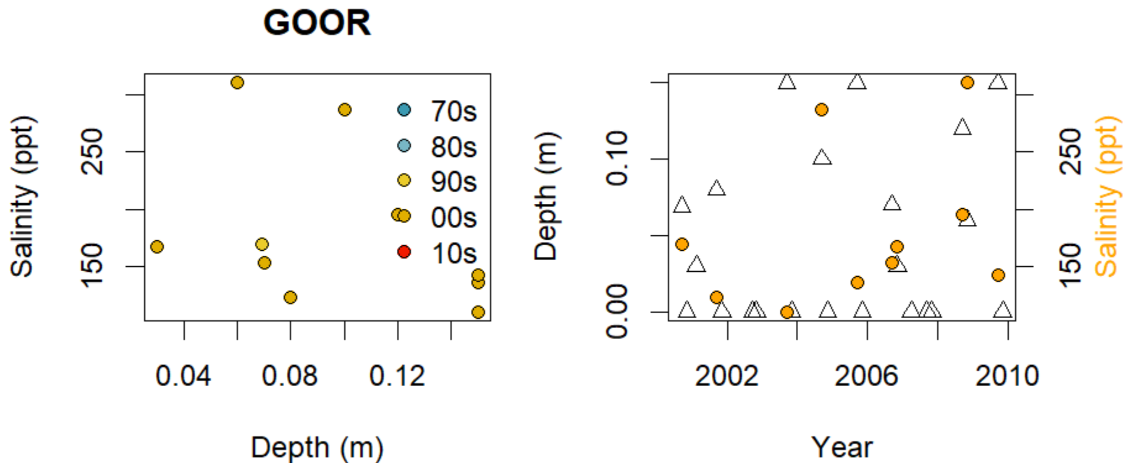


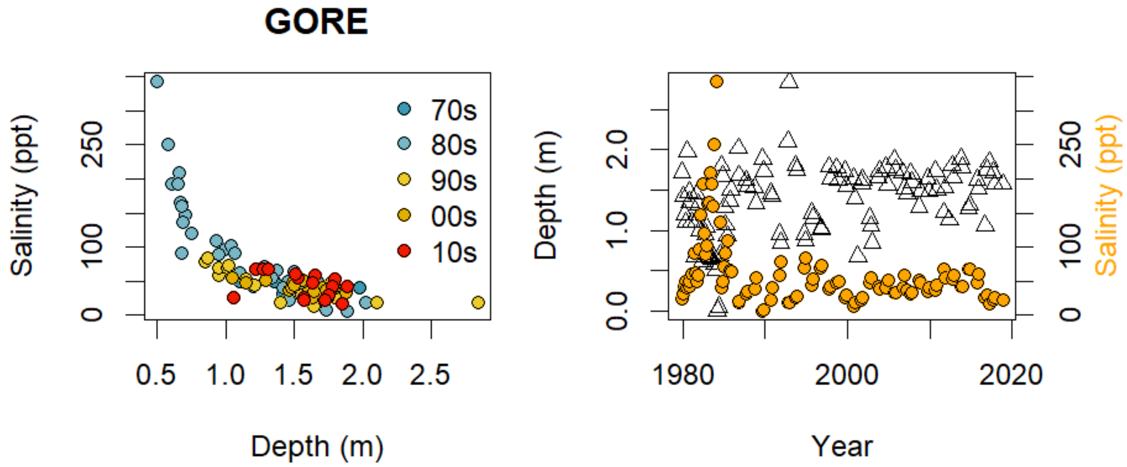
GING

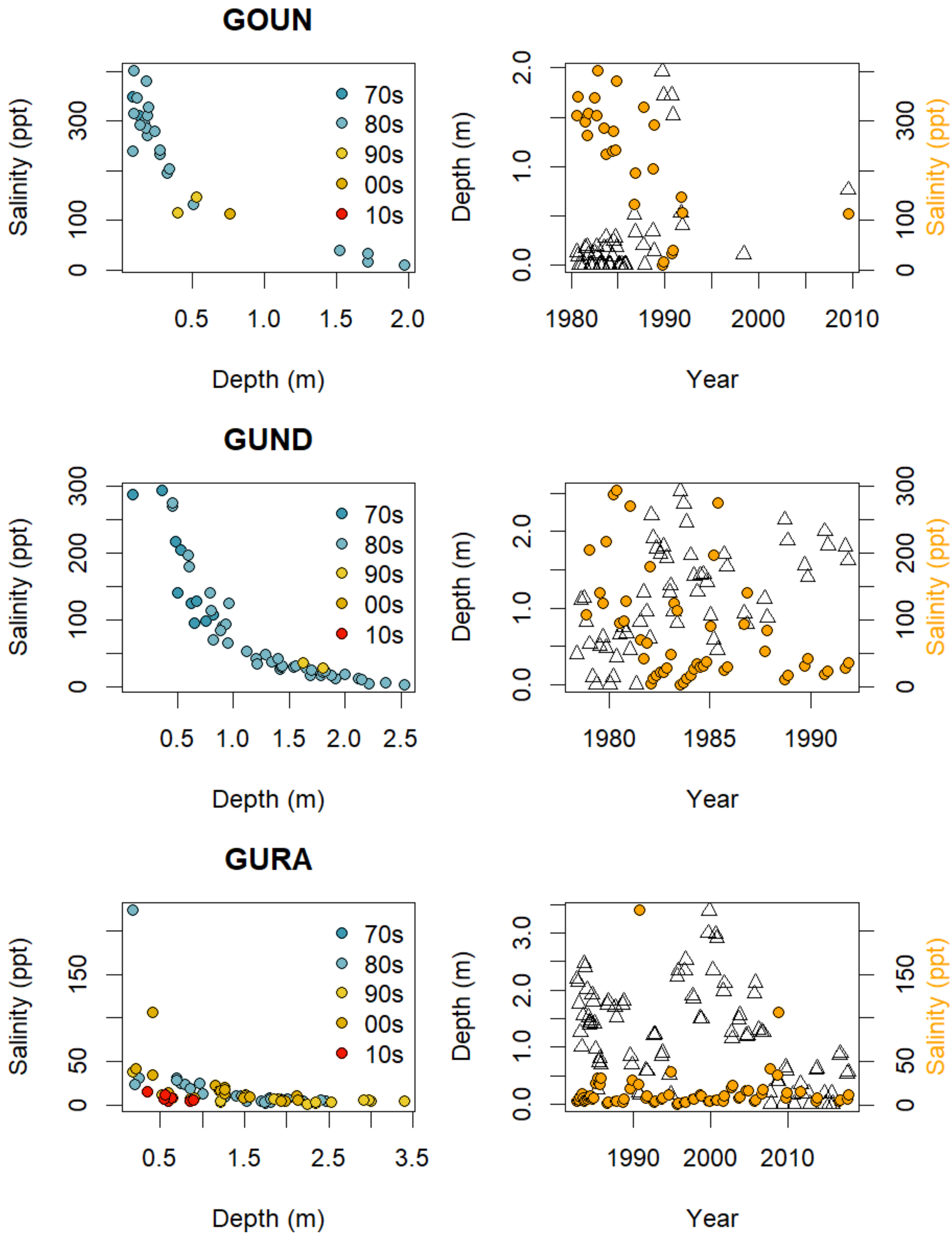


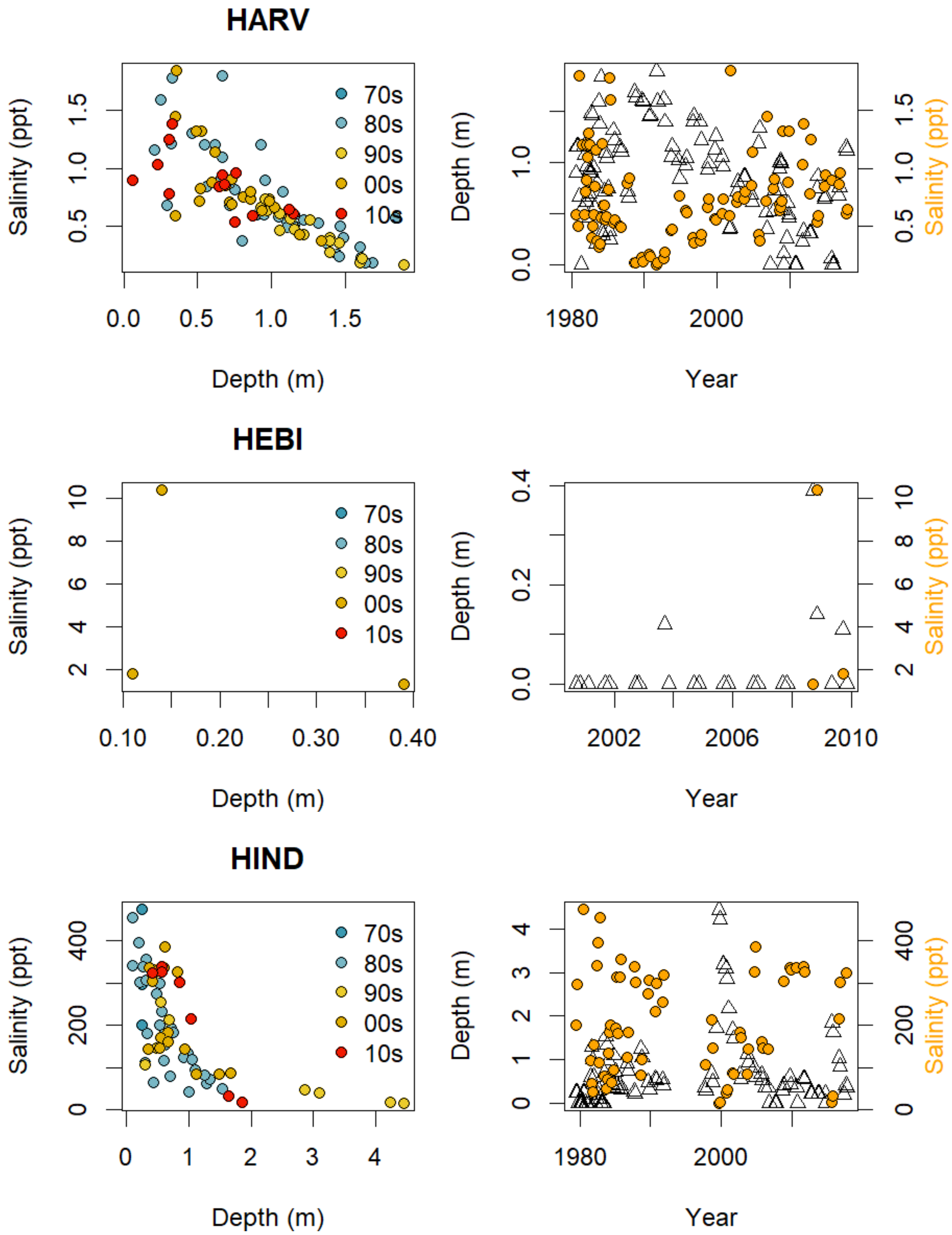

GINL
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)
GNO1
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)
GNO2
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)

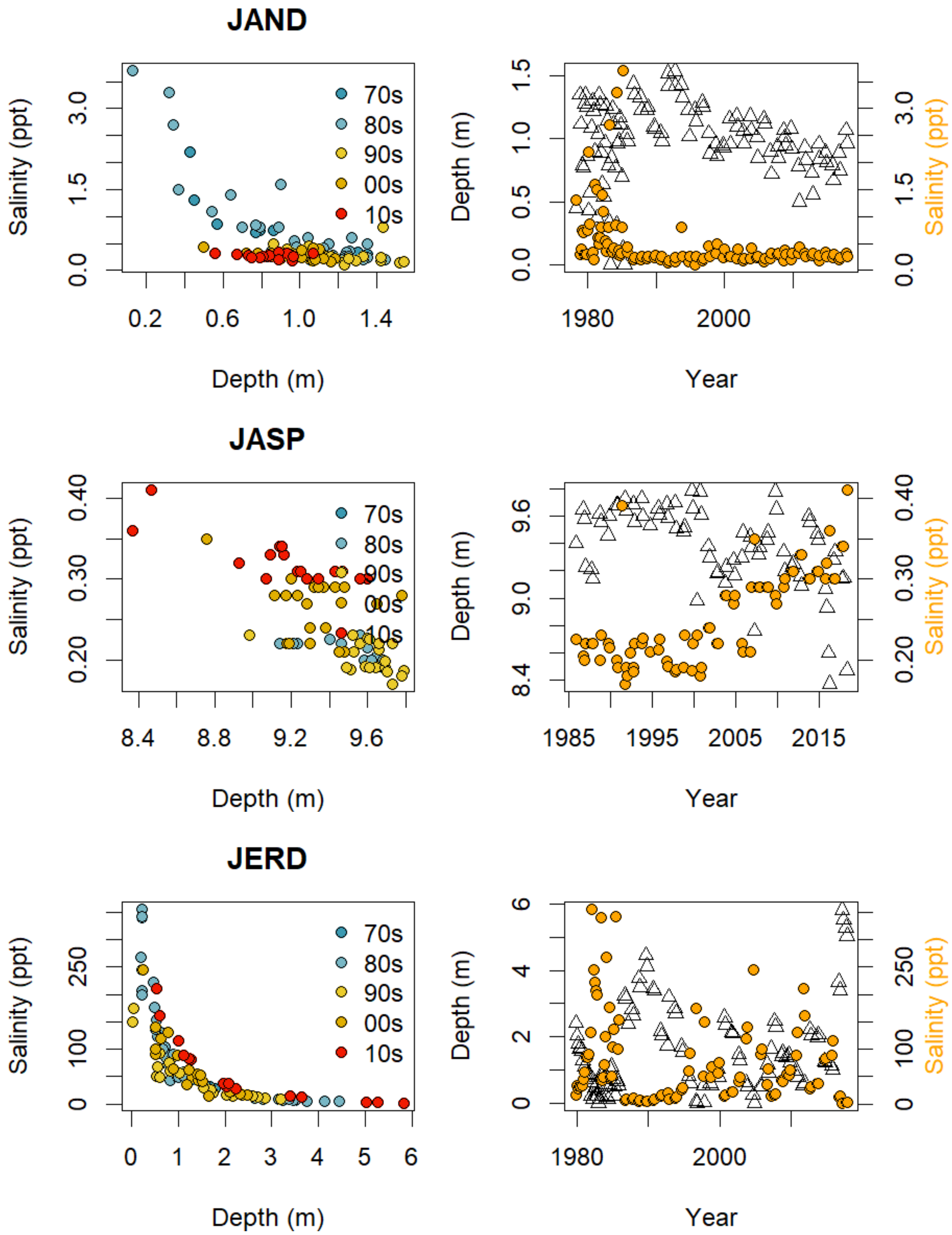

GOON
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)

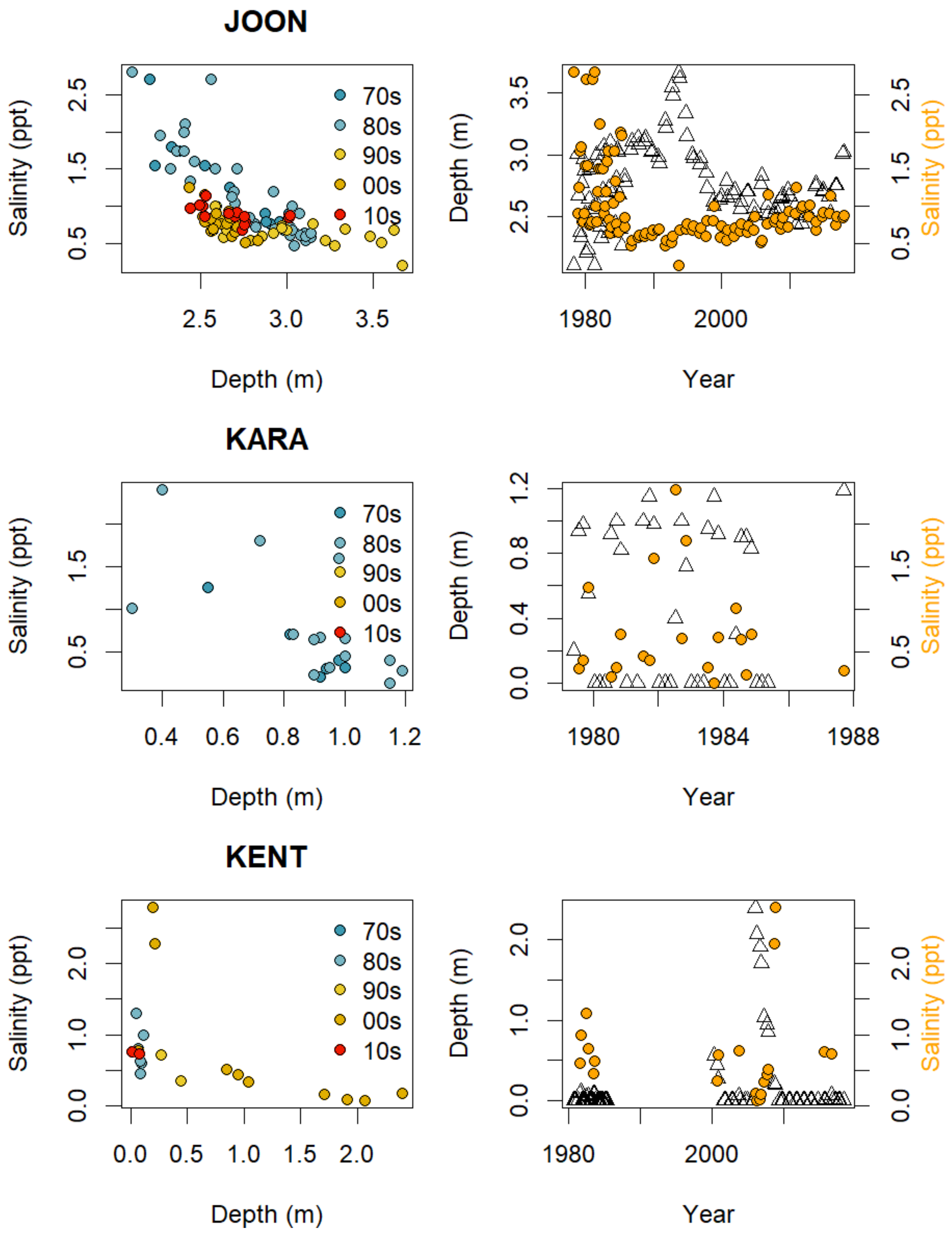

GOOR
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)

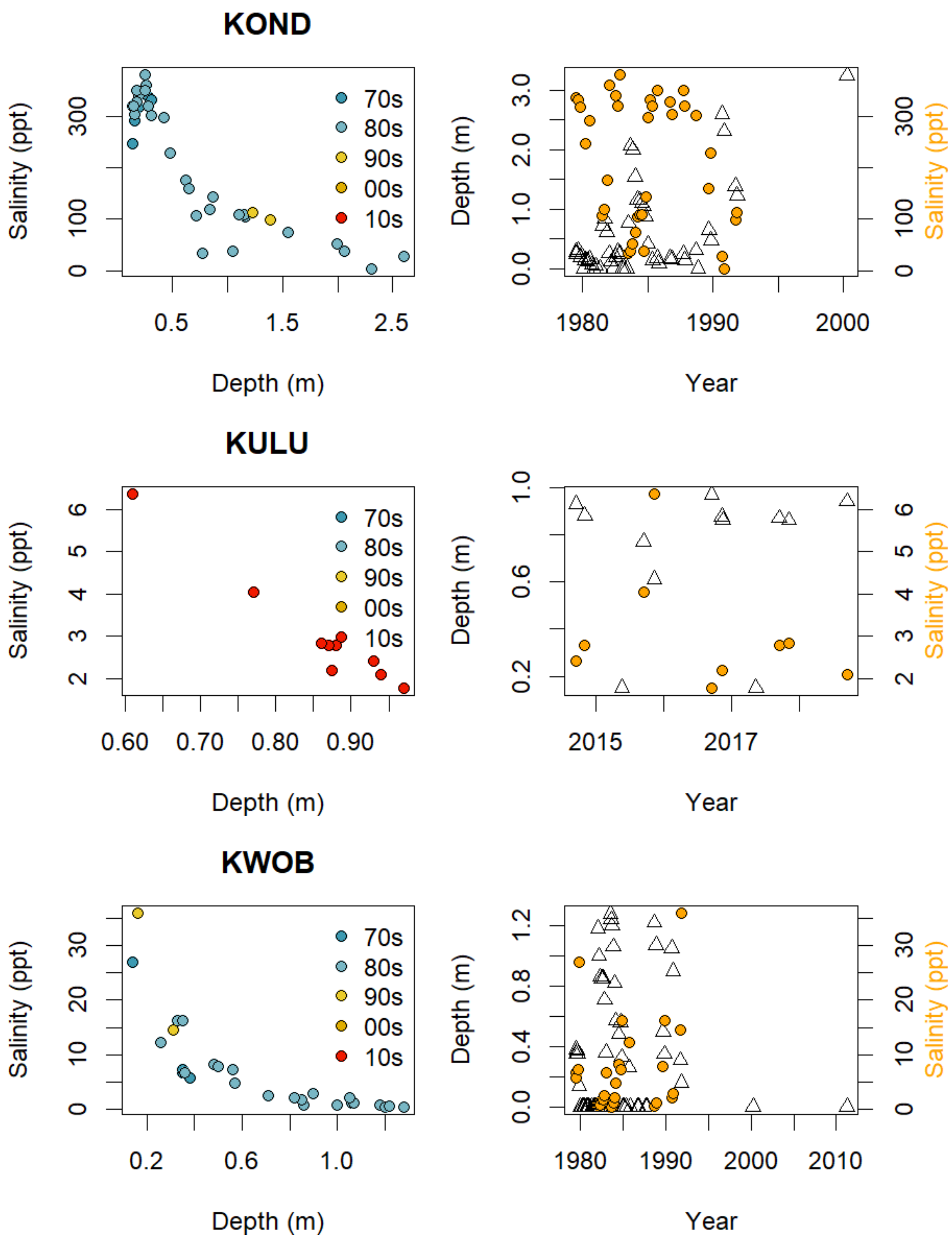

GORE
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)

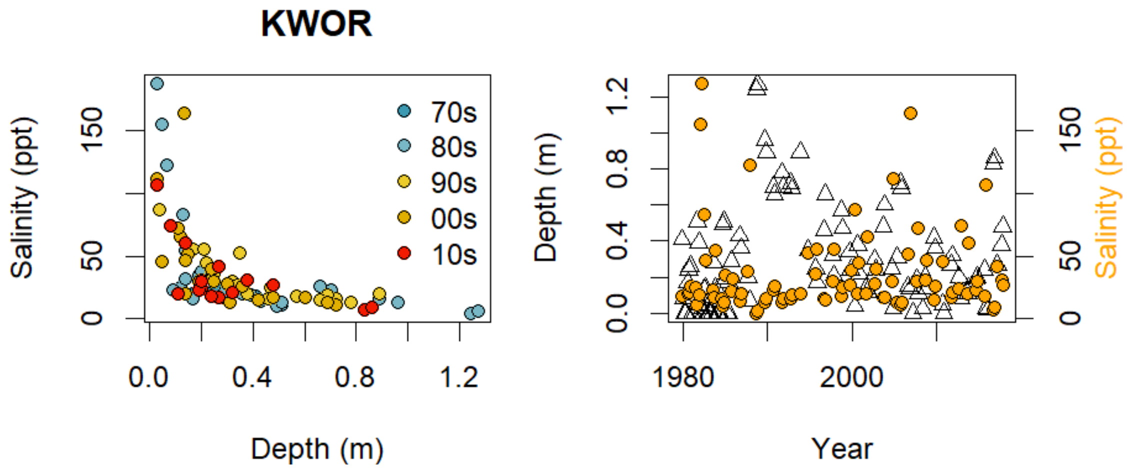

GOUN
Salinity (ppt)
70s
80s
90s
00s
10s
Depth (m)
Depth (m)
Year
Salinity (ppt)
GUND
Salinity (ppt)
70s
80s
90s
00s
10s
Depth (m)
Depth (m)
Year
Salinity (ppt)
GURA
Salinity (ppt)
70s
80s
90s
00s
10s
Depth (m)
Depth (m)
Year
Salinity (ppt)

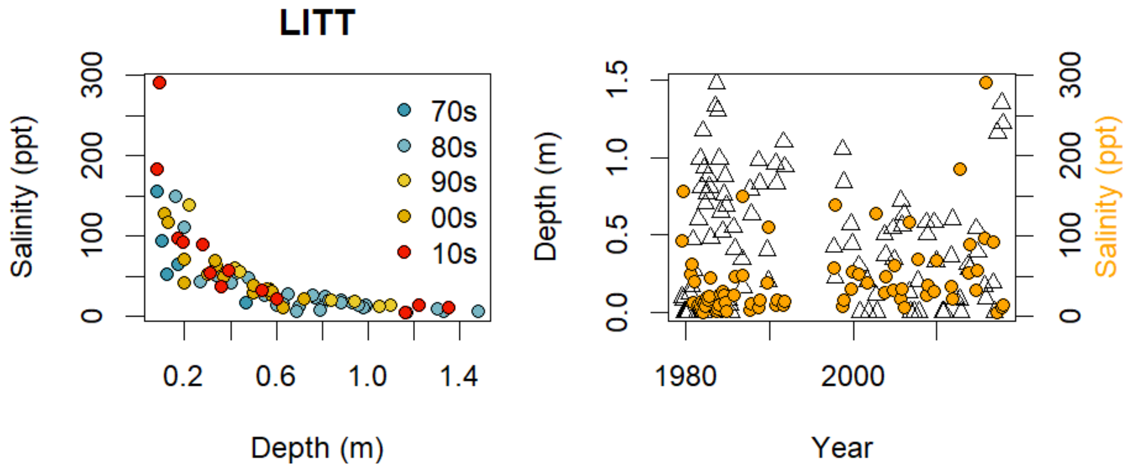

HARV
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)
HEBI
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)
HIND
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)

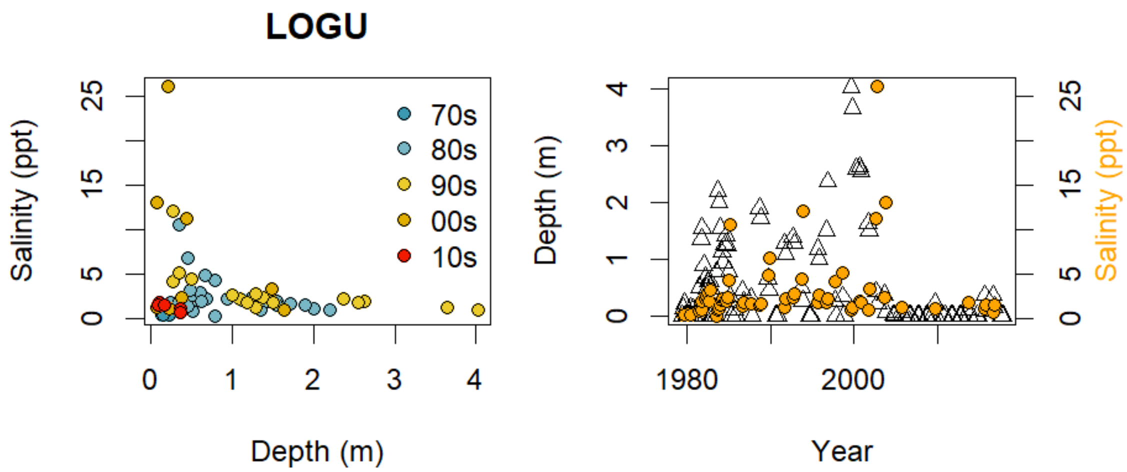

JAND
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)
JASP
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)
JERD
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)

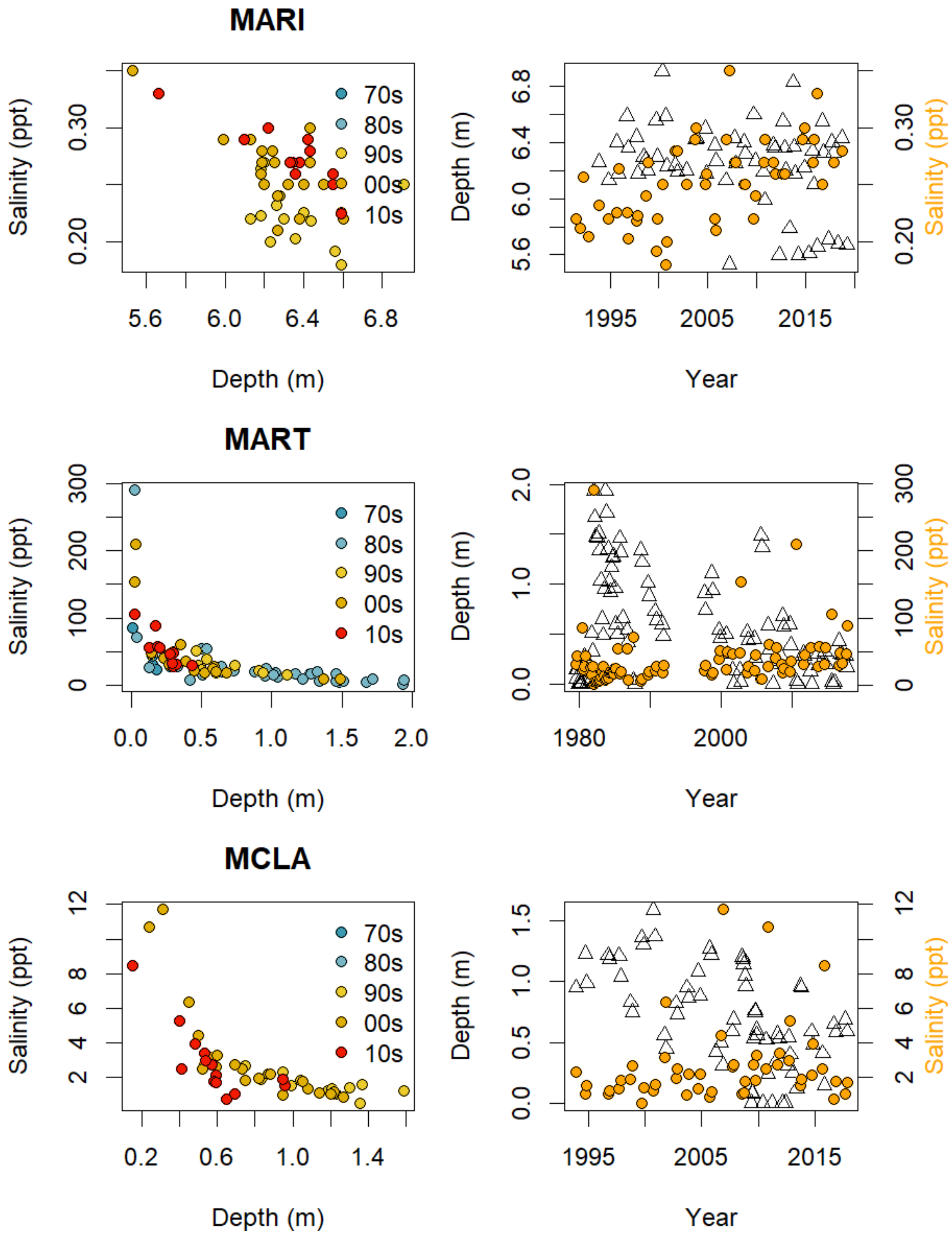

JOON
KARA
KENT
Salinity (ppt)
Depth (m)
Year
Salinity (ppt)
70s
80s
90s
00s
10s
2.5
3.0
3.5
1980
2000
0.4
0.6
0.8
1.0
1.2
1984
1988
0.0
0.5
1.5
2.0

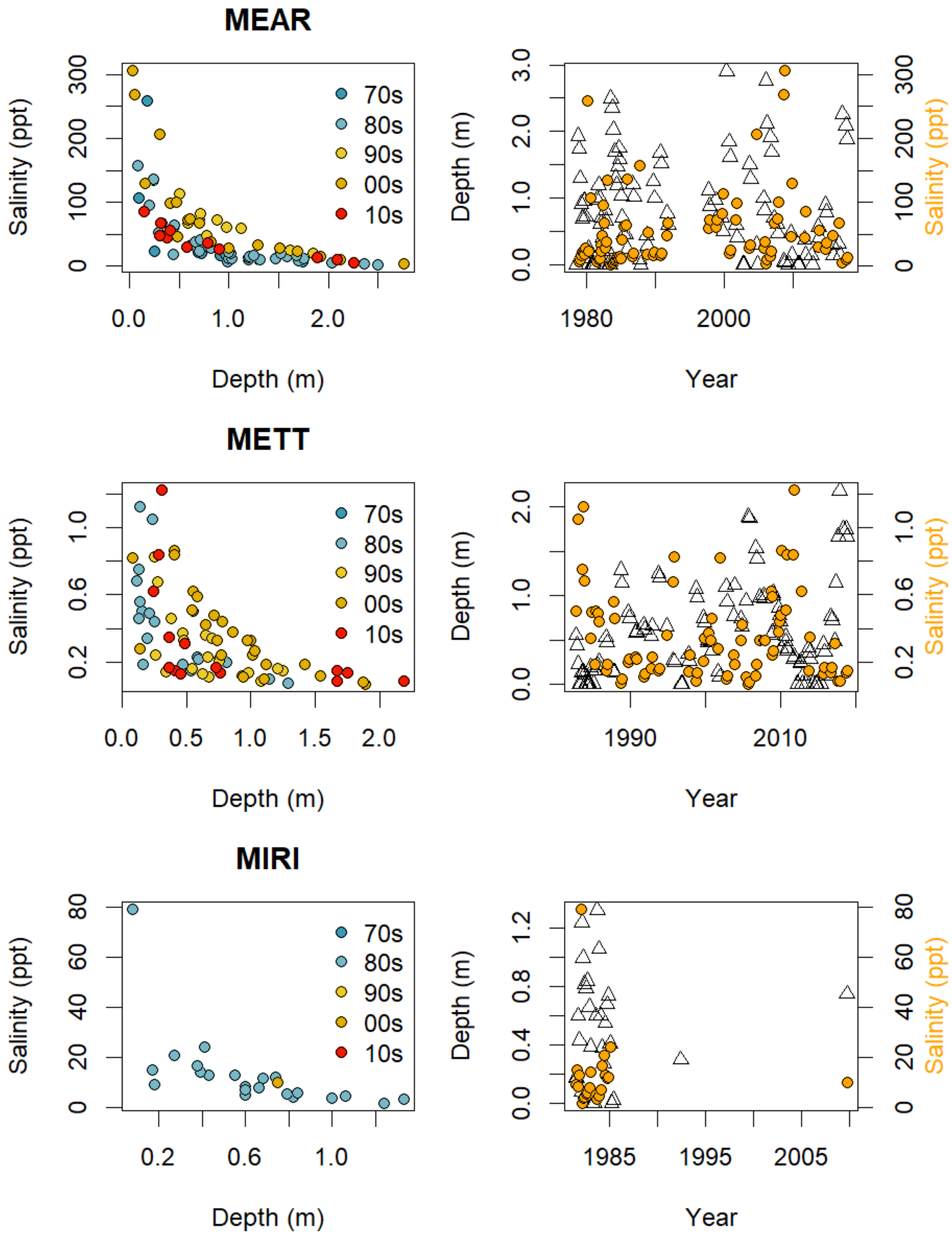

KOND
Salinity (ppt)
0
100
300
70s
80s
90s
00s
10s
0.5
1.5
2.5
Depth (m)
Depth (m)
0.0
1.0
2.0
3.0
1980
1990
2000
Year
Salinity (ppt)
KULU
Salinity (ppt)
2
3
4
5
6
70s
80s
90s
00s
10s
0.60
0.70
0.80
0.90
Depth (m)
Depth (m)
0.2
0.6
1.0
2015
2017
Year
Salinity (ppt)
KWOB
Salinity (ppt)
0
10
20
30
70s
80s
90s
00s
10s
0.2
0.6
1.0
Depth (m)
Depth (m)
0.0
0.4
0.8
1.2
1980
1990
2000
2010
Year
Salinity (ppt)

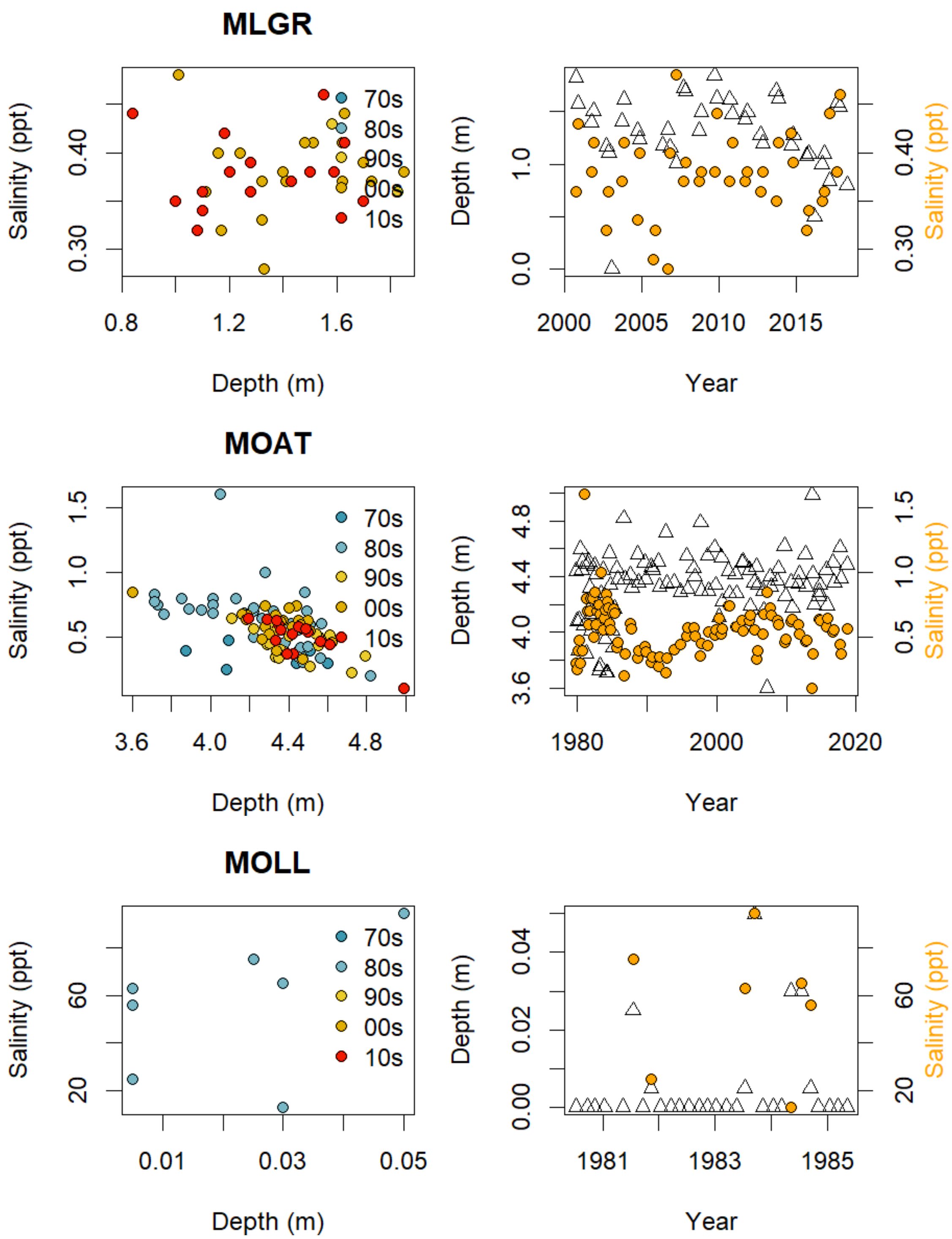

KWOR
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)

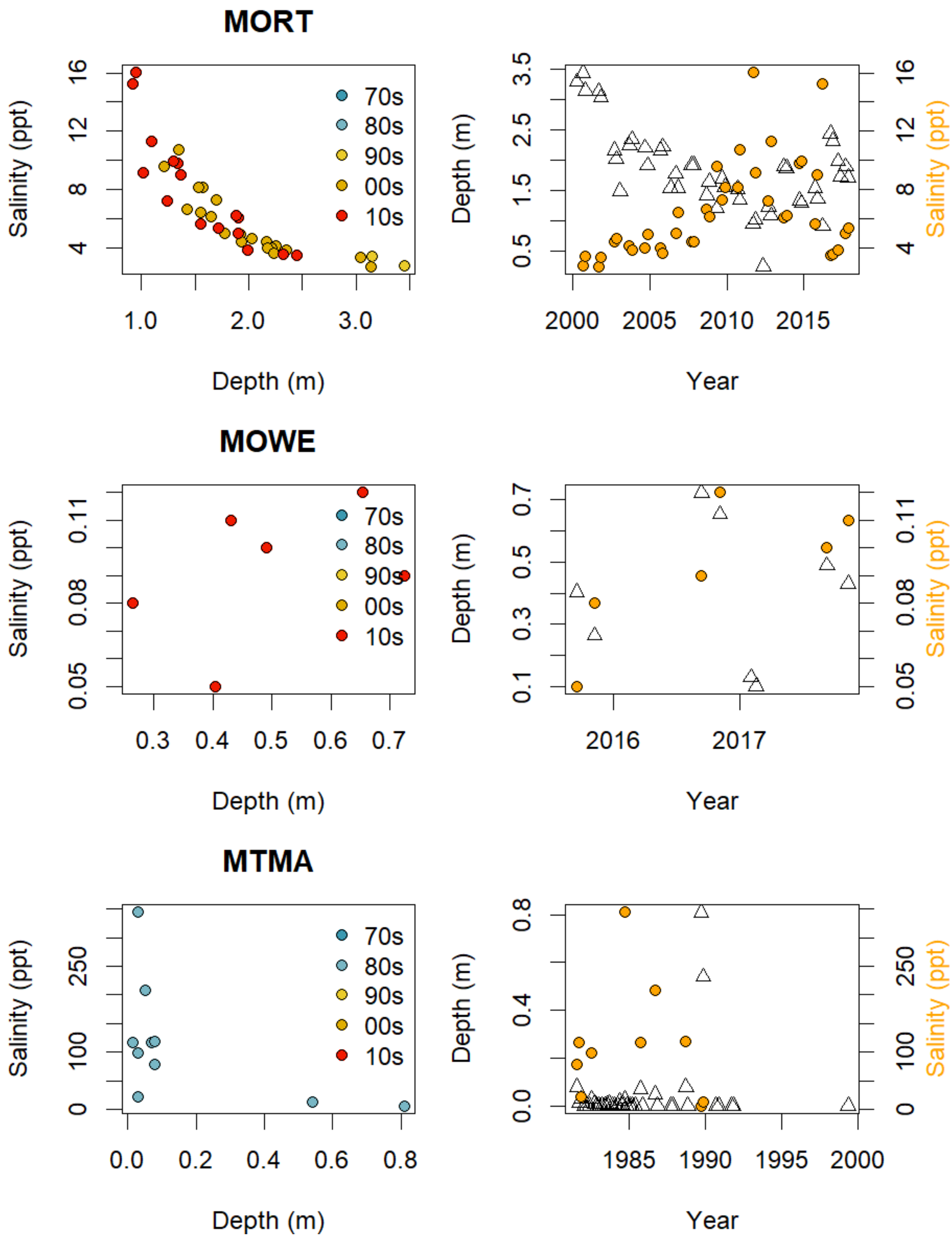

LITT
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)

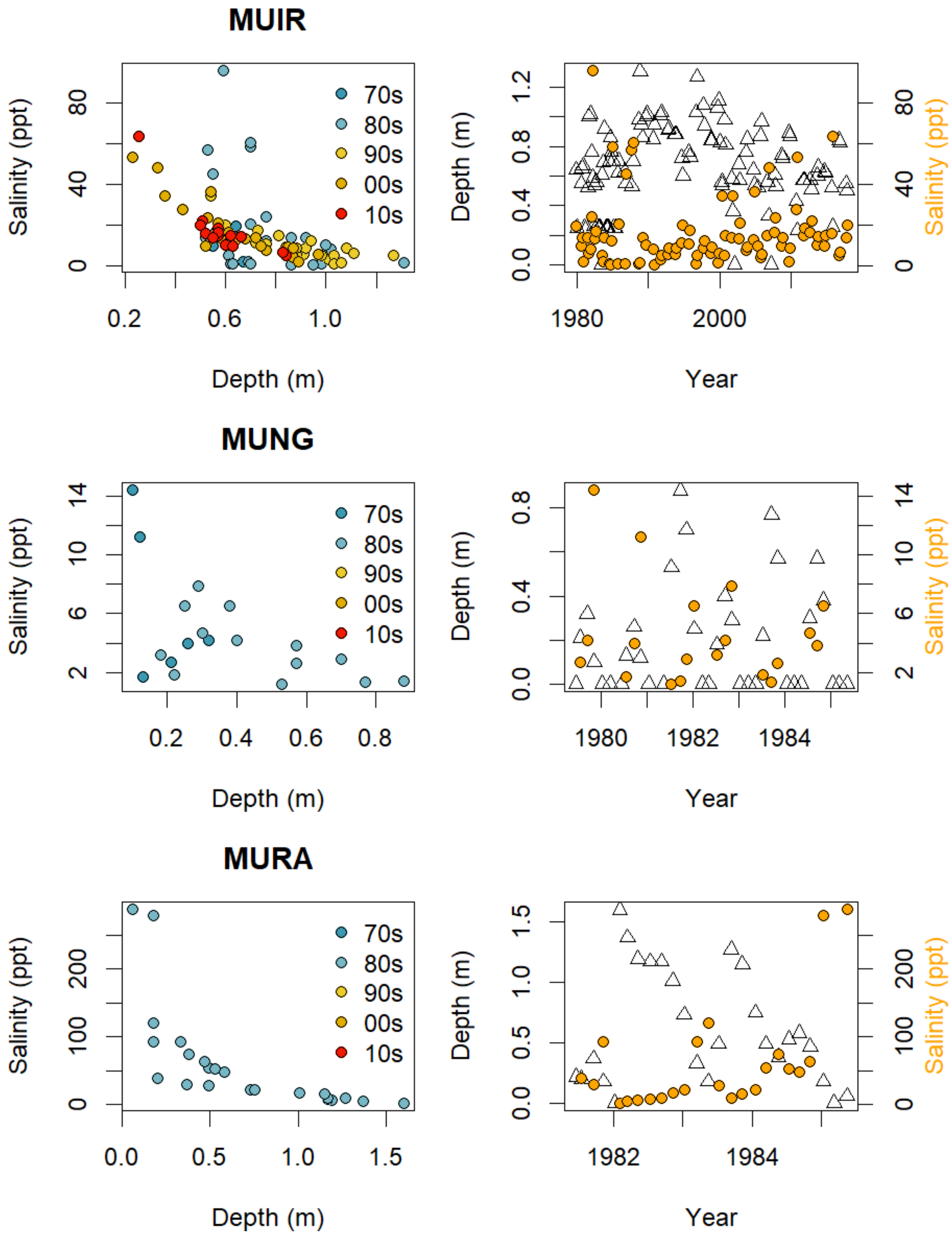

LOGU
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)

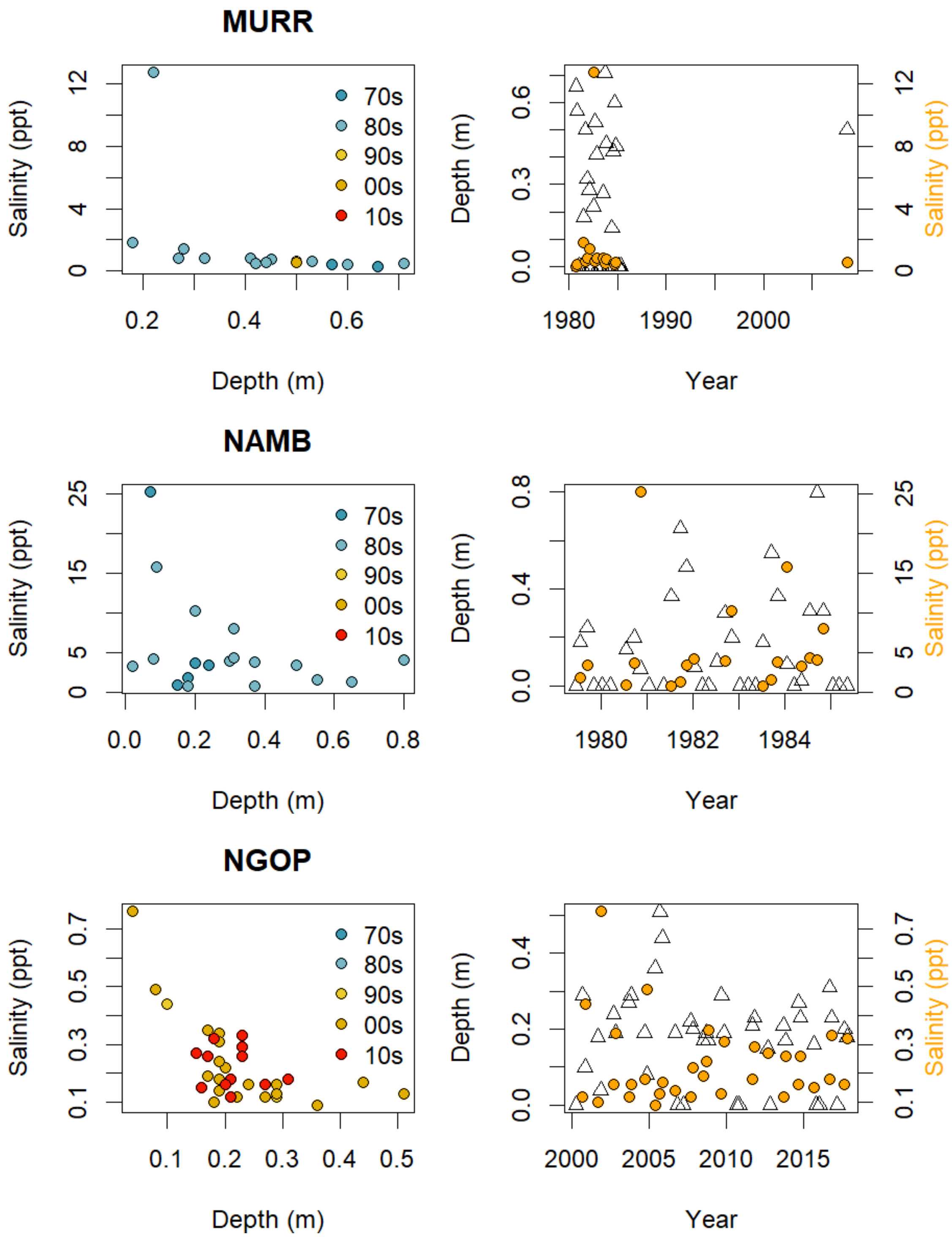

MARI
Salinity (ppt)
Depth (m)
Year
70s
80s
90s
00s
10s
MART
Salinity (ppt)
Depth (m)
Year
70s
80s
90s
00s
10s
MCLA
Salinity (ppt)
Depth (m)
Year
70s
80s
90s
00s
10s

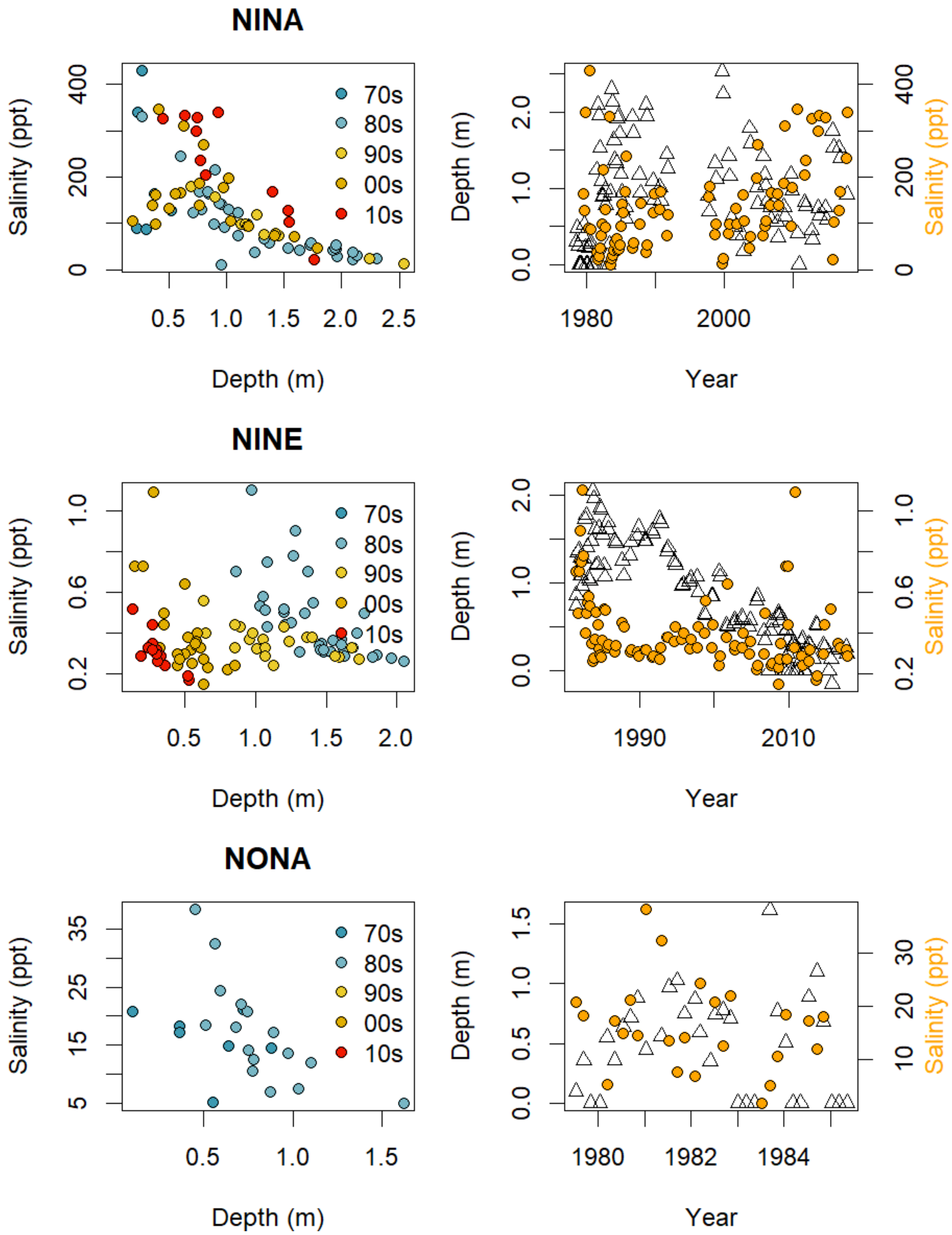

MEAR
Salinity (ppt)
0
100
200
300
70s
80s
90s
00s
10s
0.0
1.0
2.0
Depth (m)
Depth (m)
0.0
1.0
2.0
3.0
1980
2000
Year
Salinity (ppt)
METT
Salinity (ppt)
0.2
0.6
1.0
0.0
0.5
1.0
1.5
2.0
Depth (m)
Depth (m)
0.0
1.0
2.0
1990
2010
Year
MIRI
Salinity (ppt)
0
20
40
60
80
0.2
0.6
1.0
Depth (m)
Depth (m)
0.0
0.4
0.8
1.2
1985
1995
2005
Year


MLGR
Salinity (ppt)
0.30
0.40
0.8
1.2
1.6
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
0.0
1.0
2000
2005
2010
2015
Year
Salinity (ppt)
MOAT
Salinity (ppt)
0.5
1.0
1.5
3.6
4.0
4.4
4.8
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
3.6
4.0
4.4
4.8
1980
2000
2020
Year
Salinity (ppt)
MOLL
Salinity (ppt)
20
60
0.01
0.03
0.05
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
0.00
0.02
0.04
1981
1983
1985
Year
Salinity (ppt)


MORT
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)
MOWE
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)
MTMA
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)

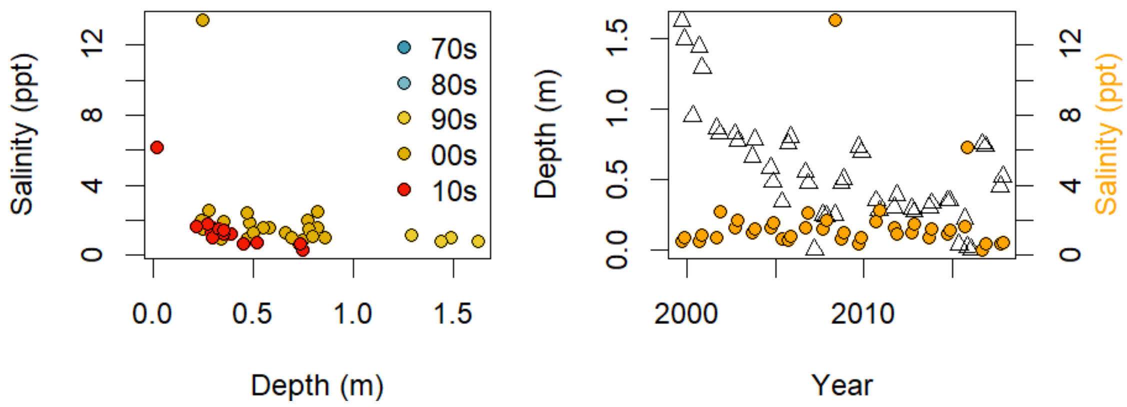

MUIR
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Year
MUNG
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Year
MURA
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Year


MURR
Salinity (ppt)
0
4
8
12
70s
80s
90s
00s
10s
0.2
0.4
0.6
Depth (m)
Depth (m)
0.0
0.3
0.6
1980
1990
2000
Year
Salinity (ppt)
NAMB
Salinity (ppt)
0
5
15
25
0.0
0.2
0.4
0.6
0.8
Depth (m)
Depth (m)
0.0
0.4
0.8
1980
1982
1984
Year
NGOP
Salinity (ppt)
0.1
0.3
0.5
0.7
0.1
0.2
0.3
0.4
0.5
Depth (m)
Depth (m)
0.0
0.2
0.4
2000
2005
2010
2015
Year

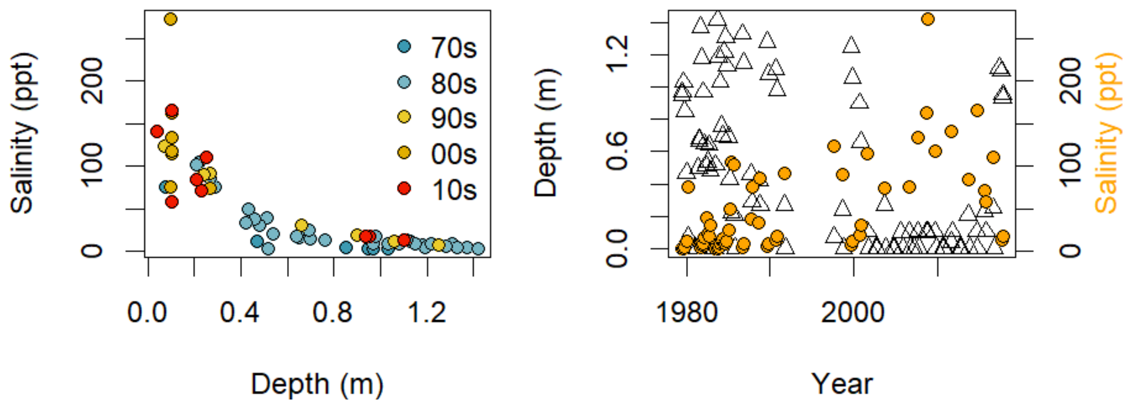


NINA
Salinity (ppt)
0
200
400
0.5
1.0
1.5
2.0
2.5
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
0.0
1.0
2.0
1980
2000
Year
Salinity (ppt)
0
200
400
NINE
Salinity (ppt)
0.2
0.6
1.0
0.5
1.0
1.5
2.0
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
0.0
1.0
2.0
1990
2010
Year
Salinity (ppt)
0.2
0.6
1.0
NONA
Salinity (ppt)
5
15
25
35
0.5
1.0
1.5
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
0.0
0.5
1.0
1.5
1980
1982
1984
Year
Salinity (ppt)
10
20
30

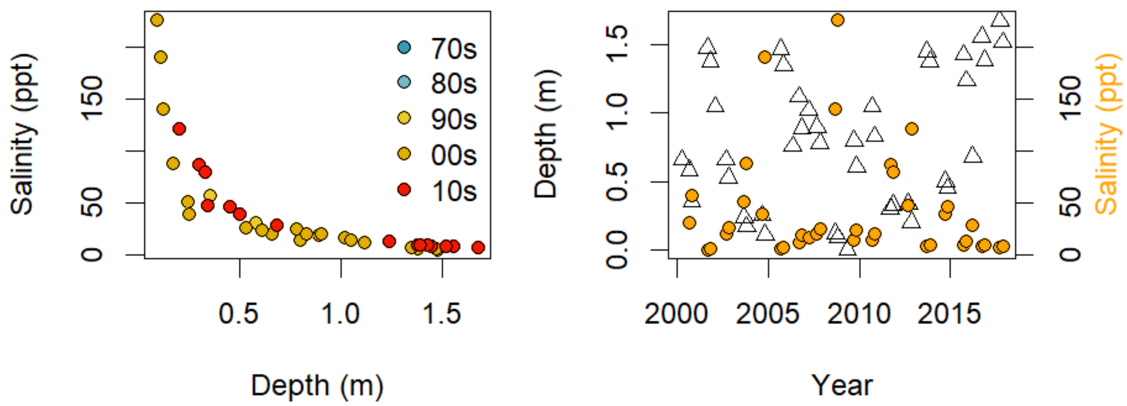
NOOB

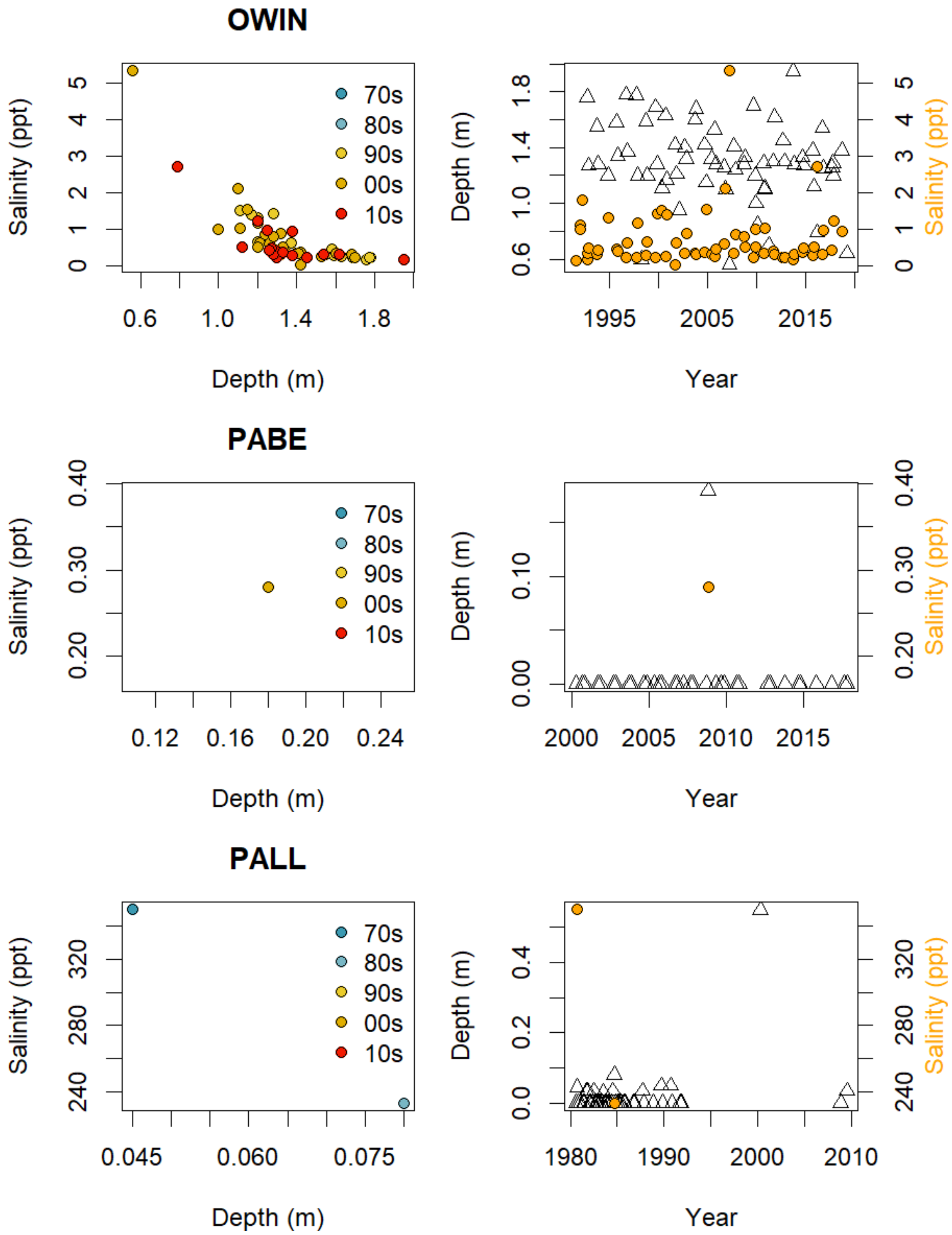


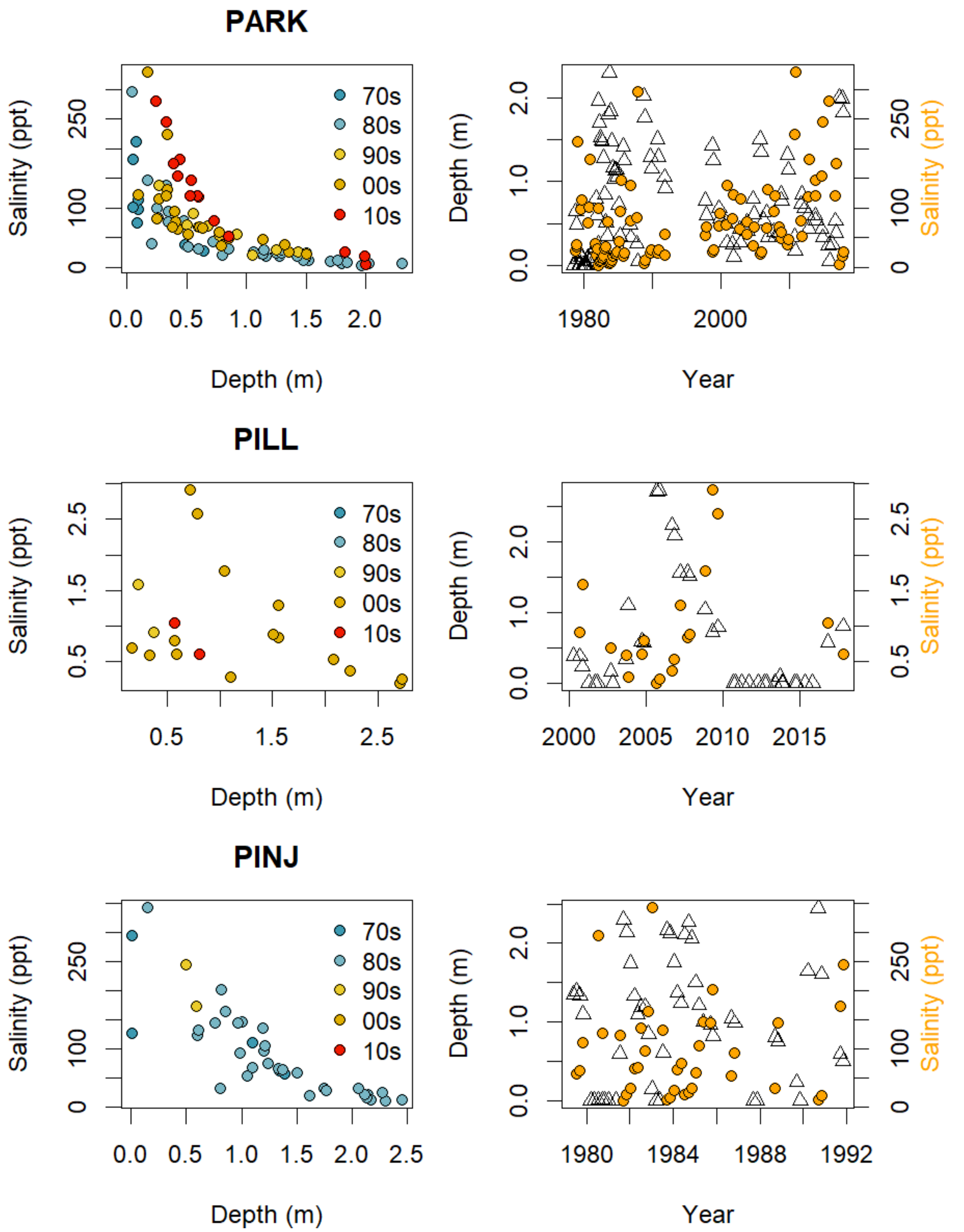
NOON

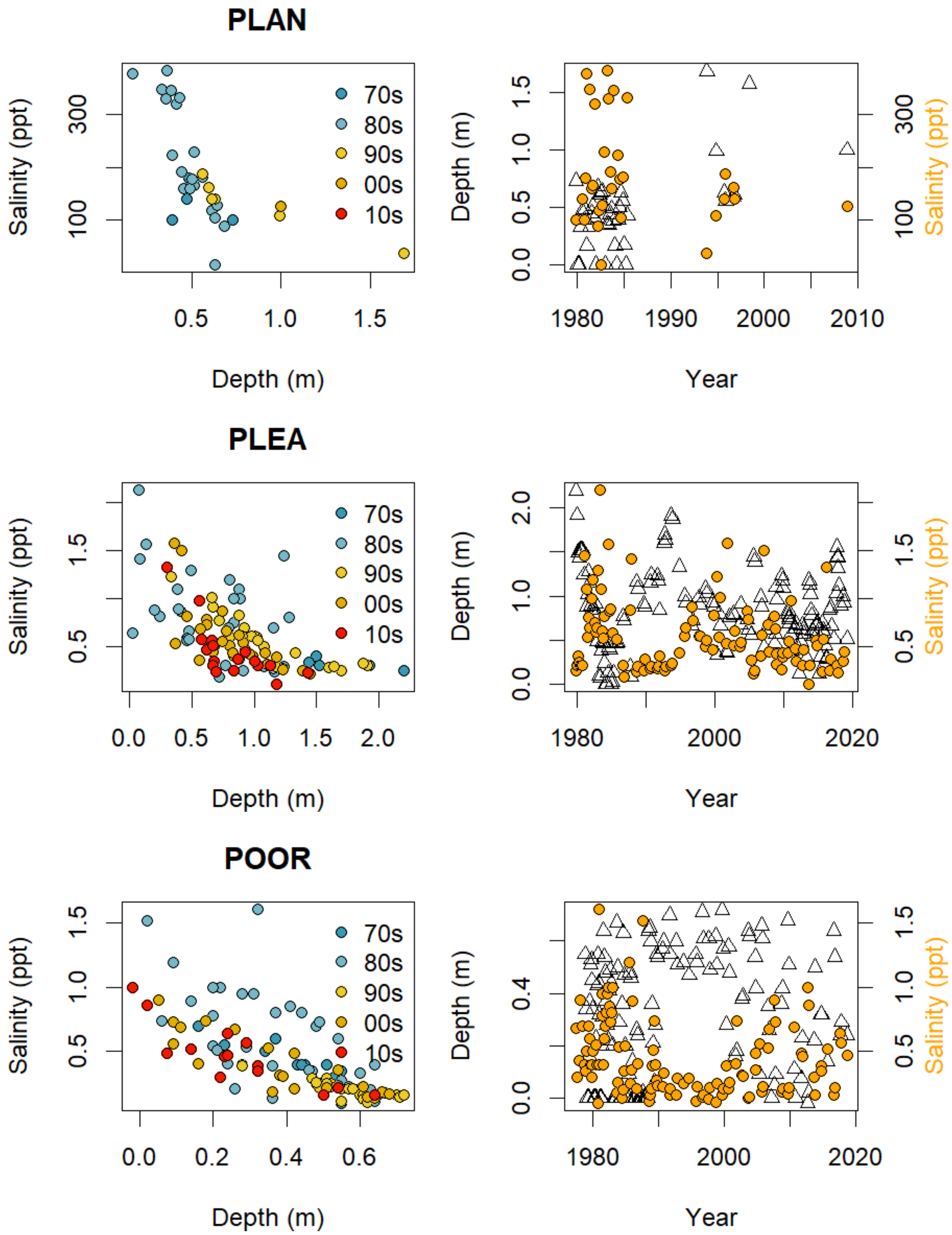


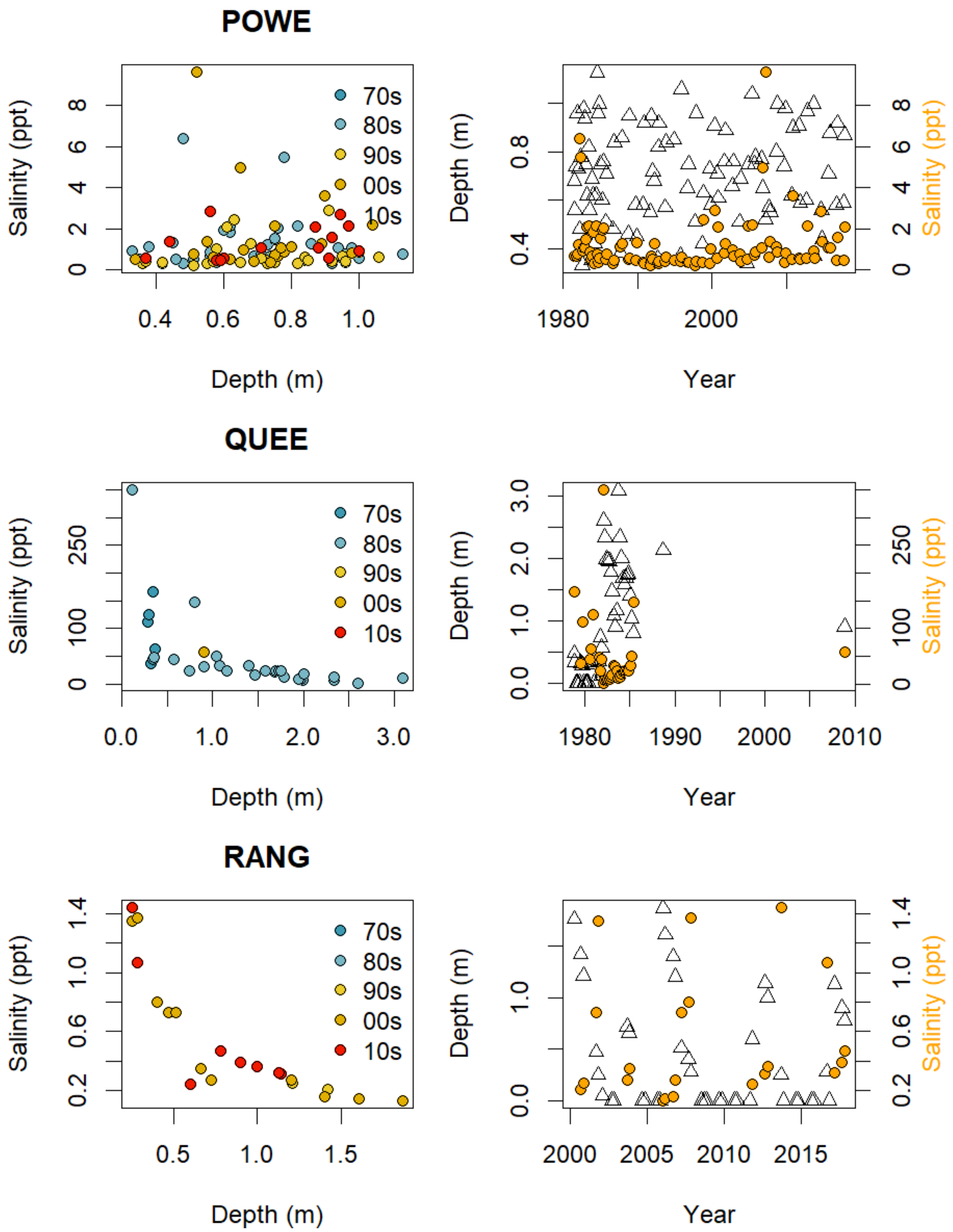
NPAR

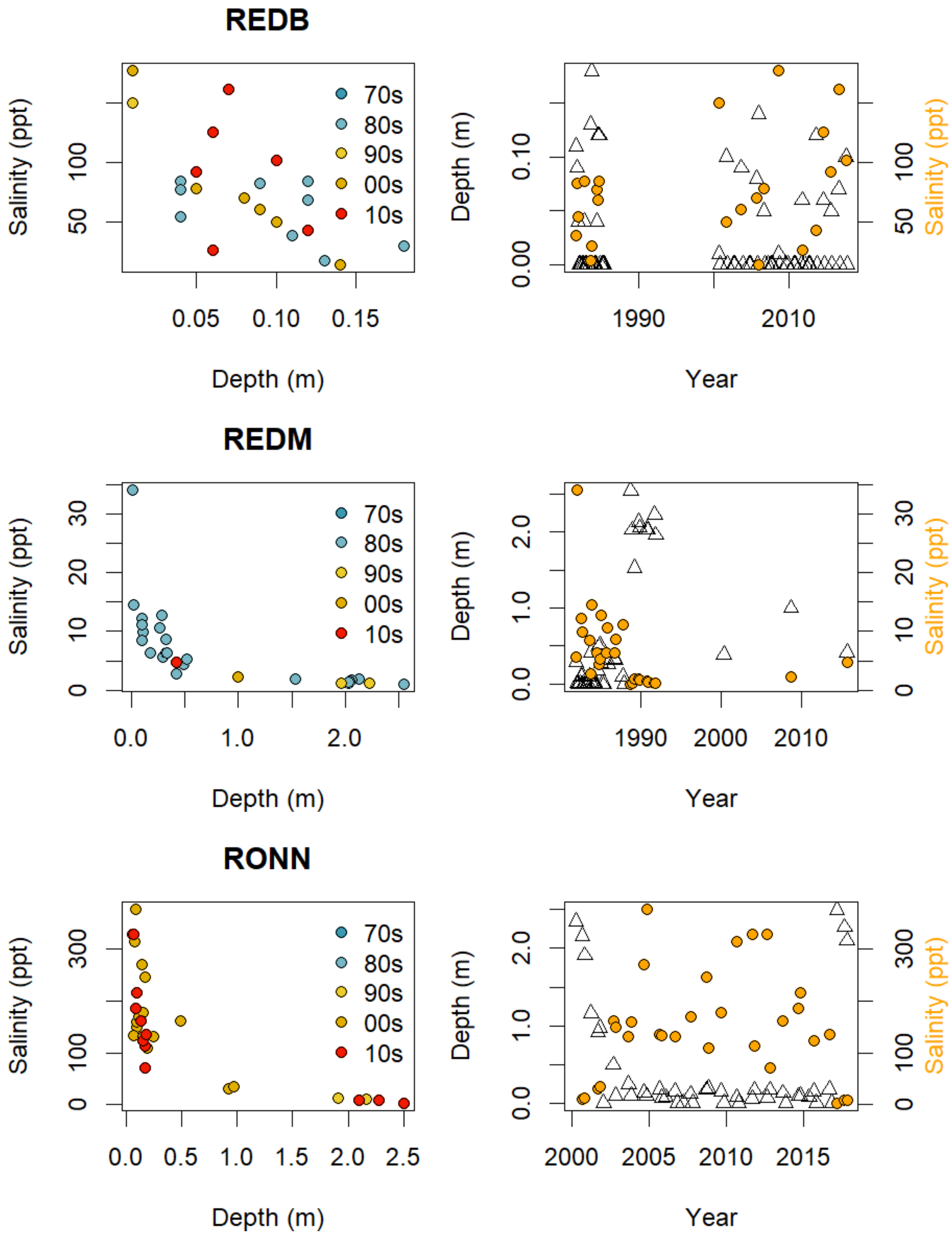



OWIN
Salinity (ppt)
0 1 2 3 4 5
70s
80s
90s
00s
10s
0.6 1.0 1.4 1.8
Depth (m)
Depth (m)
0.6 1.0 1.4 1.8
1995 2005 2015
Year
Salinity (ppt)
PABE
Salinity (ppt)
0.20 0.30 0.40
70s
80s
90s
00s
10s
0.12 0.16 0.20 0.24
Depth (m)
Depth (m)
0.00 0.10
2000 2005 2010 2015
Year
Salinity (ppt)
PALL
Salinity (ppt)
240 280 320
70s
80s
90s
00s
10s
0.045 0.060 0.075
Depth (m)
Depth (m)
0.0 0.2 0.4
1980 1990 2000 2010
Year
Salinity (ppt)

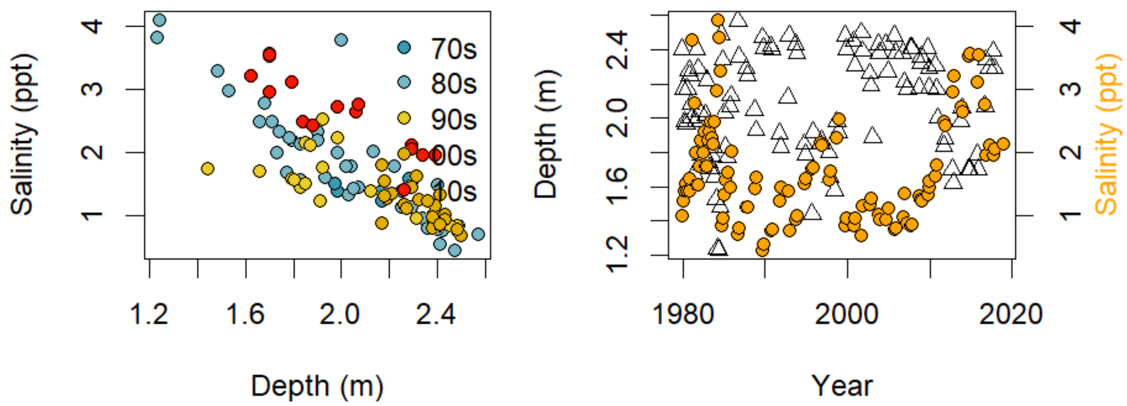

PARK
Salinity (ppt)
0
100
250
70s
80s
90s
00s
10s
0.0
0.5
1.0
1.5
2.0
Depth (m)
Depth (m)
0.0
1.0
2.0
1980
2000
Year
Salinity (ppt)
0
100
250
PILL
Salinity (ppt)
0.5
1.5
2.5
70s
80s
90s
00s
10s
0.5
1.5
2.5
Depth (m)
Depth (m)
0.0
1.0
2.0
2000
2005
2010
2015
Year
Salinity (ppt)
0.5
1.5
2.5
PINJ
Salinity (ppt)
0
100
250
70s
80s
90s
00s
10s
0.0
0.5
1.0
1.5
2.0
2.5
Depth (m)
Depth (m)
0.0
1.0
2.0
1980
1984
1988
1992
Year
Salinity (ppt)
0
100
250


PLAN
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Year
Salinity (ppt)
PLEA
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Year
Salinity (ppt)
POOR
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Year
Salinity (ppt)

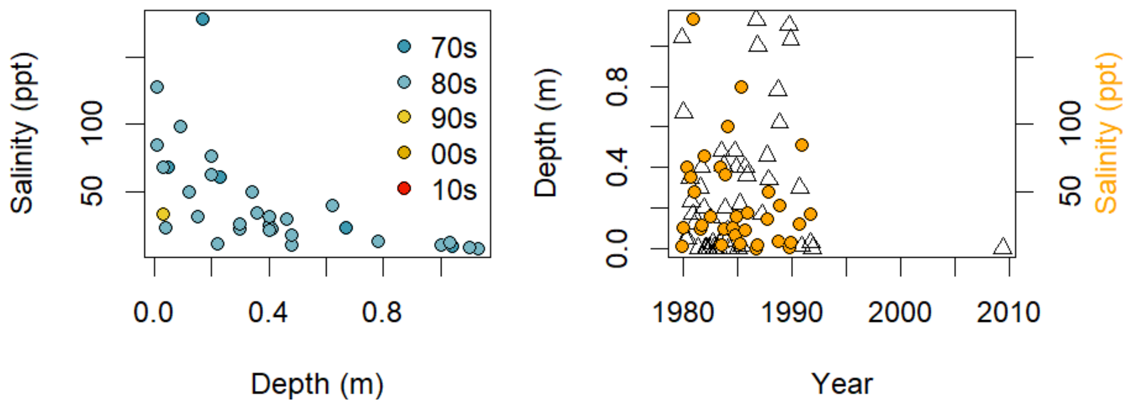

POWE
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)
QUEE
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)
RANG
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)


REDB
Salinity (ppt)
50
100
70s
80s
90s
00s
10s
0.05
0.10
0.15
Depth (m)
Depth (m)
0.00
0.10
1990
2010
Year
Salinity (ppt)
REDM
Salinity (ppt)
0
10
20
30
0.0
1.0
2.0
Depth (m)
Depth (m)
1990
2000
2010
Year
RONN
Salinity (ppt)
0
100
300
0.0
0.5
1.0
1.5
2.0
2.5
Depth (m)
Depth (m)
2000
2005
2010
2015
Year

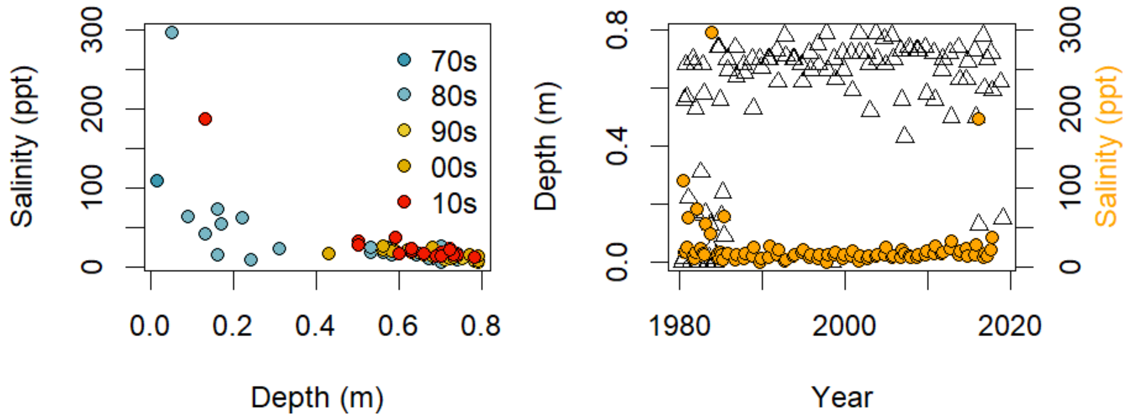
SHAR

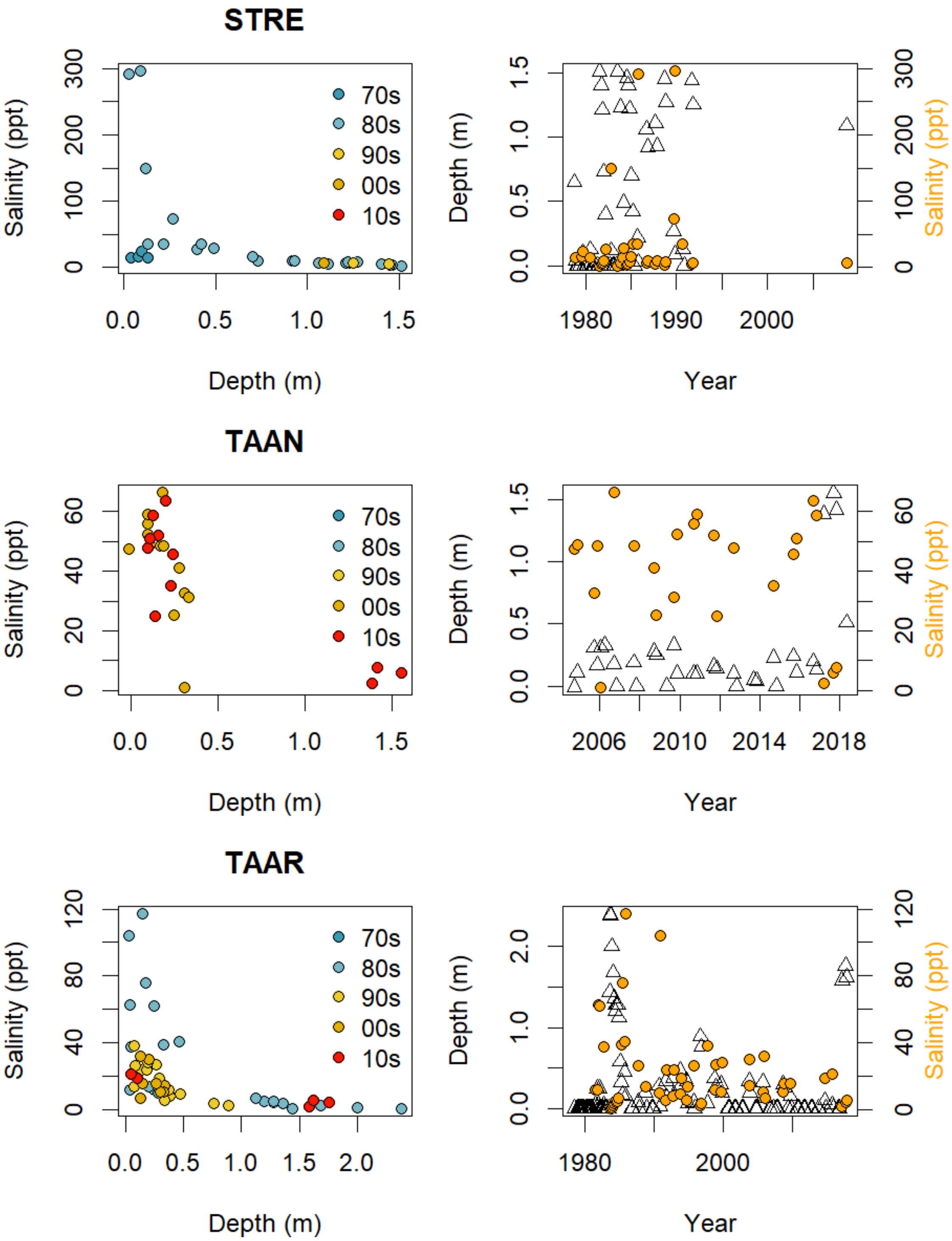


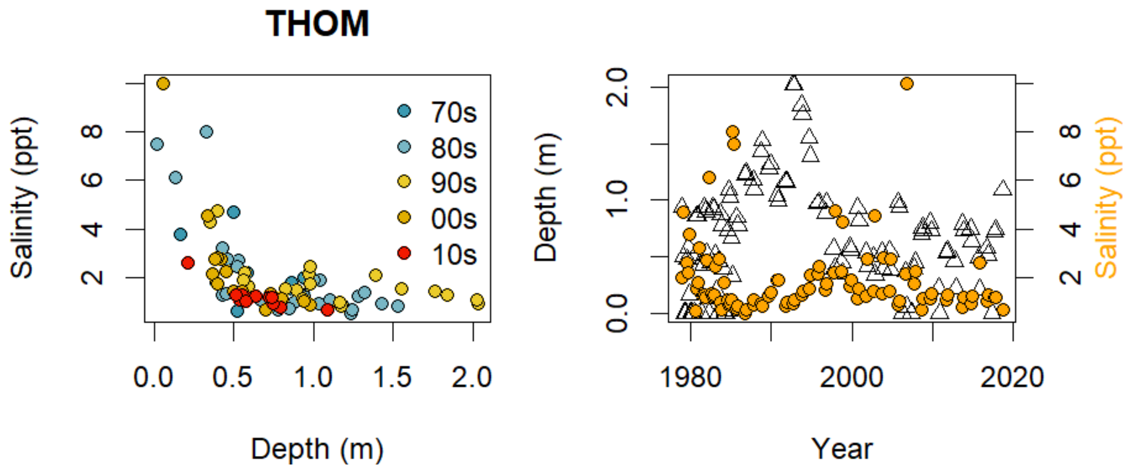
SHAS

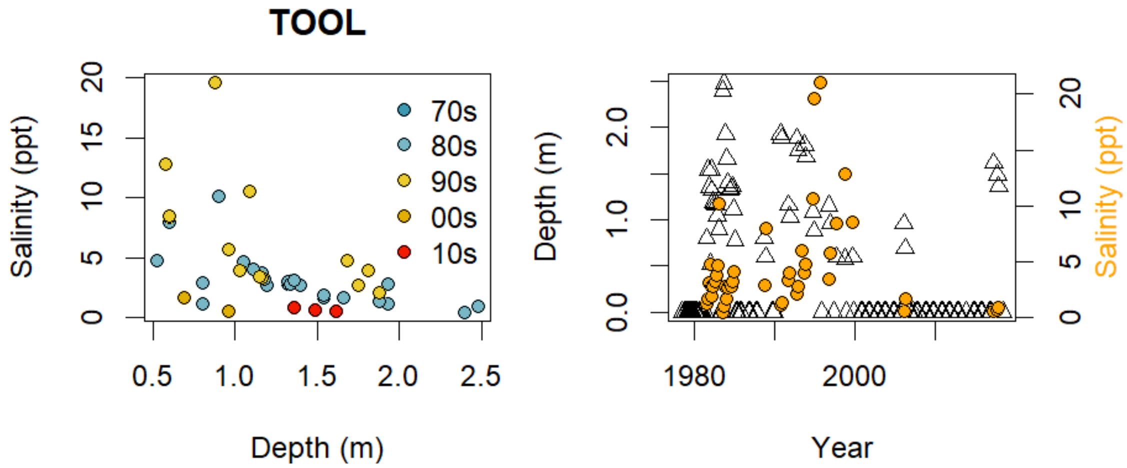


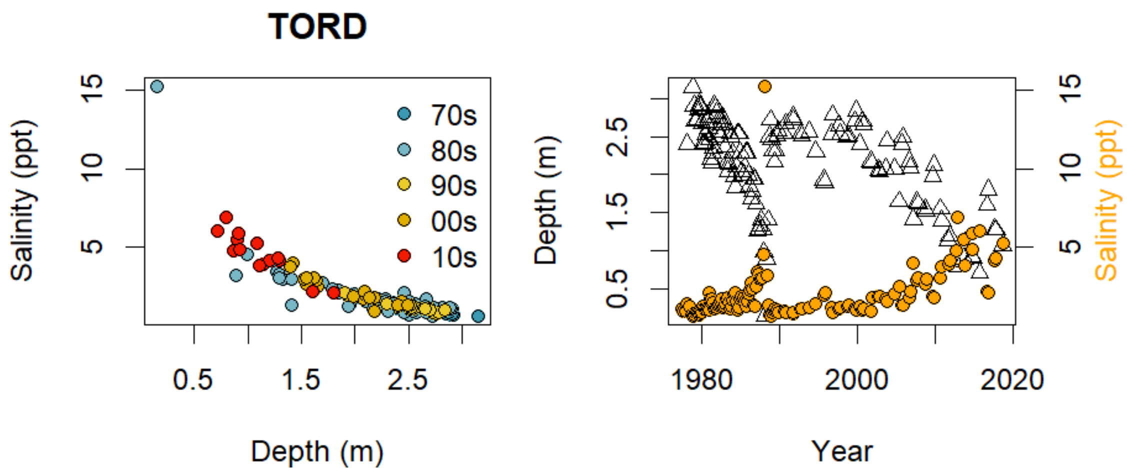
STAT

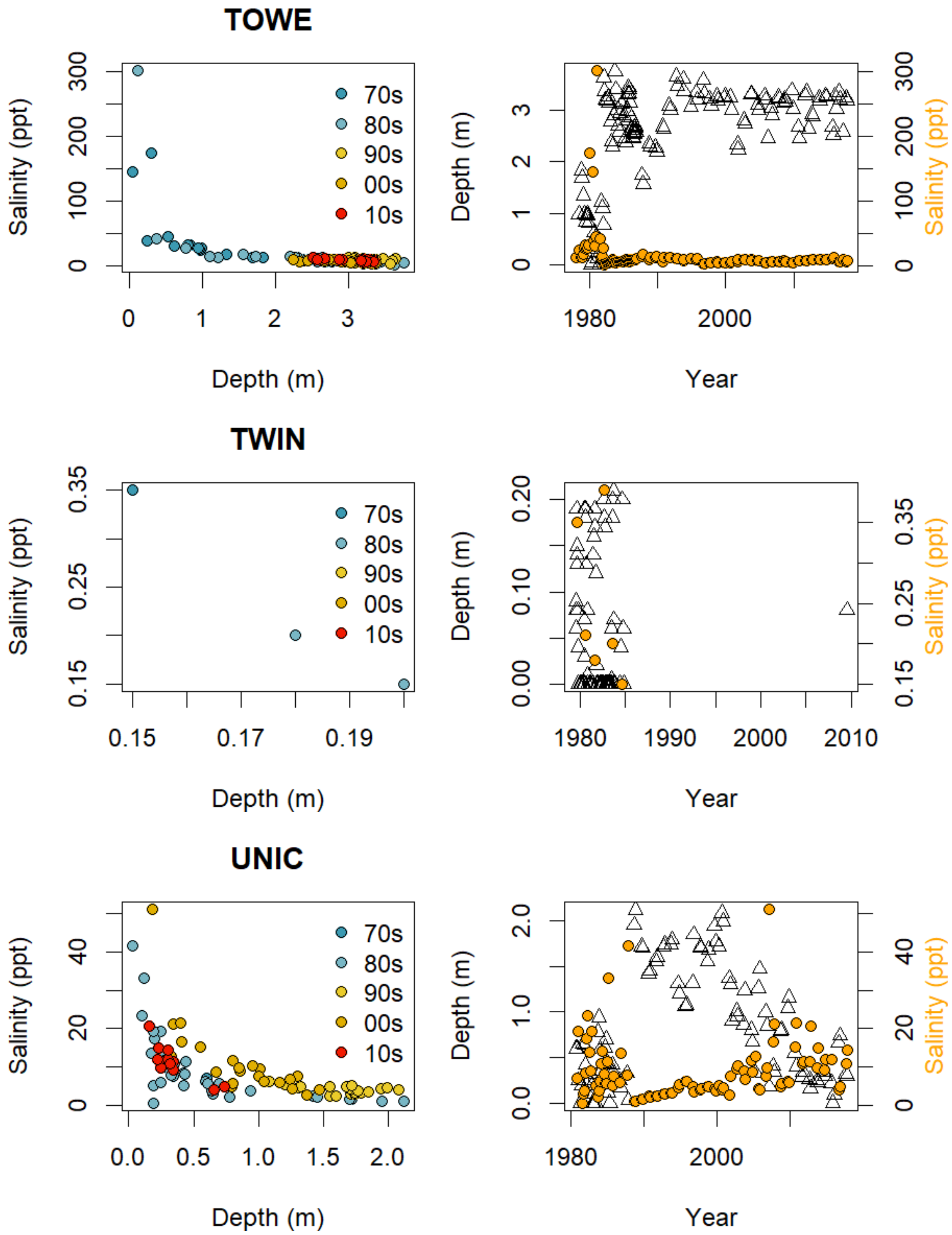


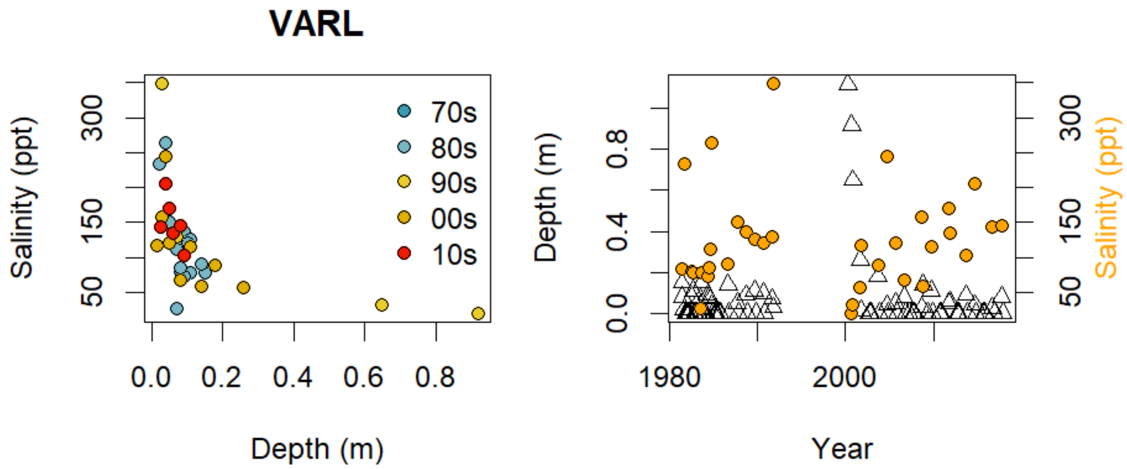

STRE
TAAN
TAAR
Salinity (ppt)
Depth (m)
Year
70s
80s
90s
00s
10s

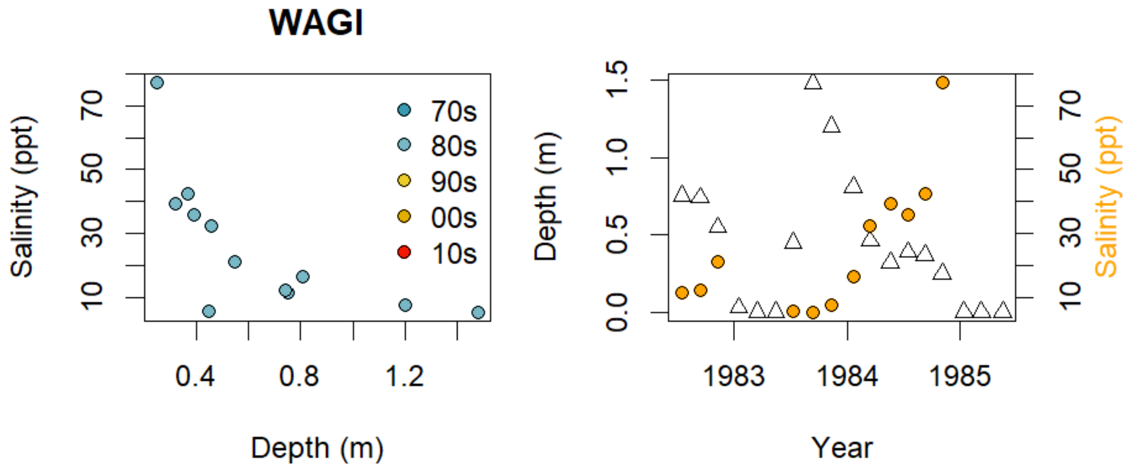

THOM
Salinity (ppt)
70s
80s
90s
00s
10s
Depth (m)
Year
Depth (m)
Salinity (ppt)
0.0 0.5 1.0 1.5 2.0
1980 2000 2020

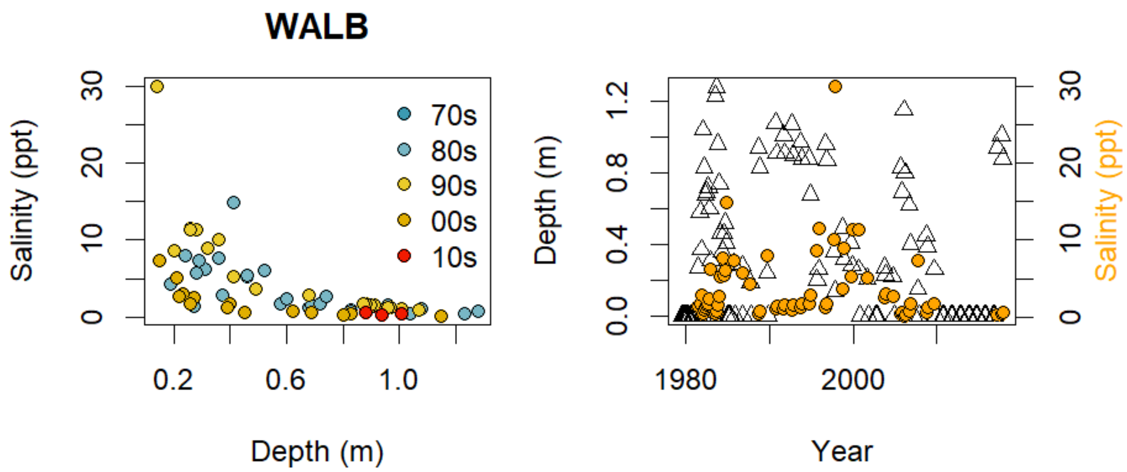

TOOL
Salinity (ppt)
70s
80s
90s
00s
10s
Depth (m)
Year
Depth (m)
Salinity (ppt)
0.5 1.0 1.5 2.0 2.5
1980 2000

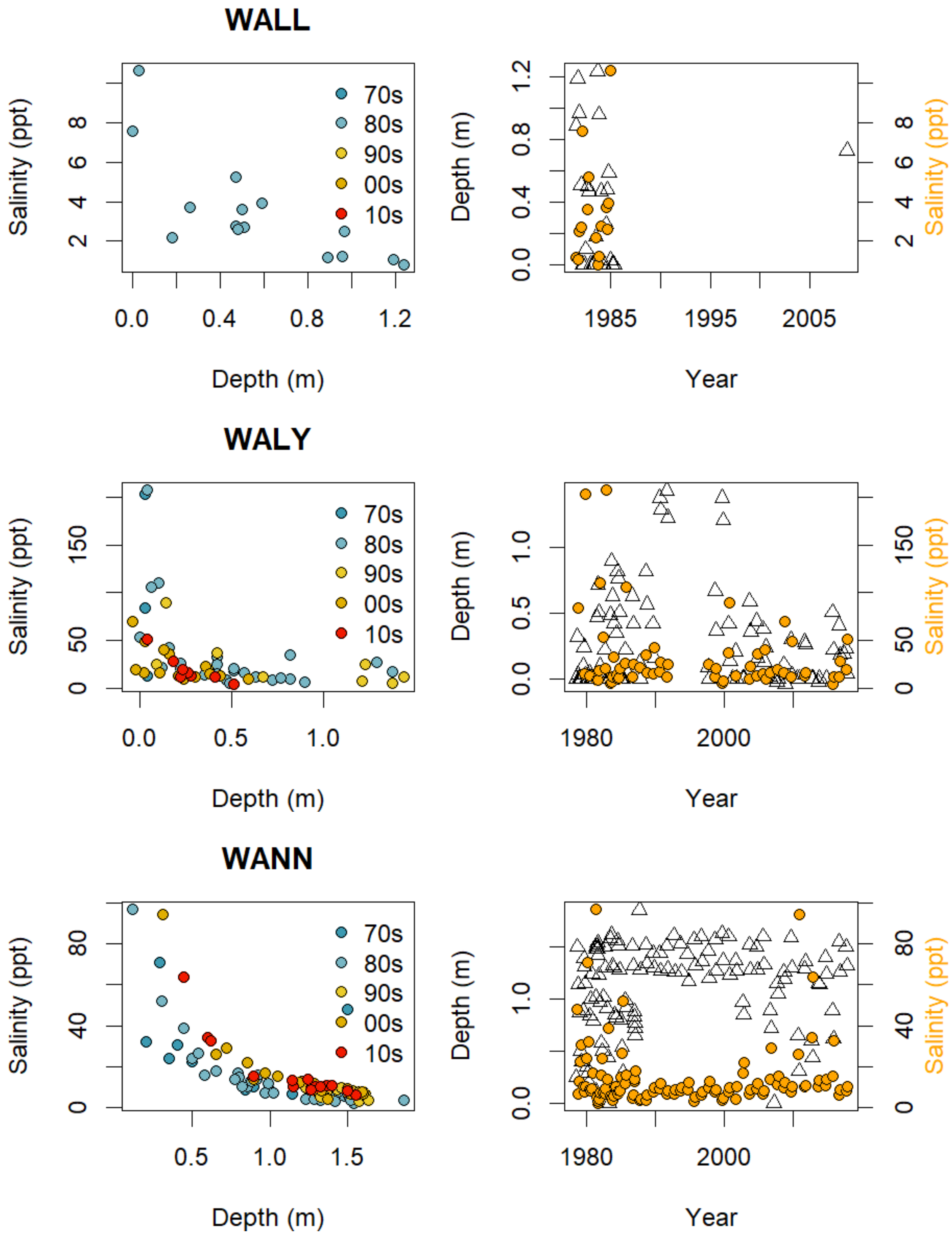

TORD
Salinity (ppt)
70s
80s
90s
00s
10s
Depth (m)
Year
Depth (m)
Salinity (ppt)
0.5 1.5 2.5
1980 2000 2020

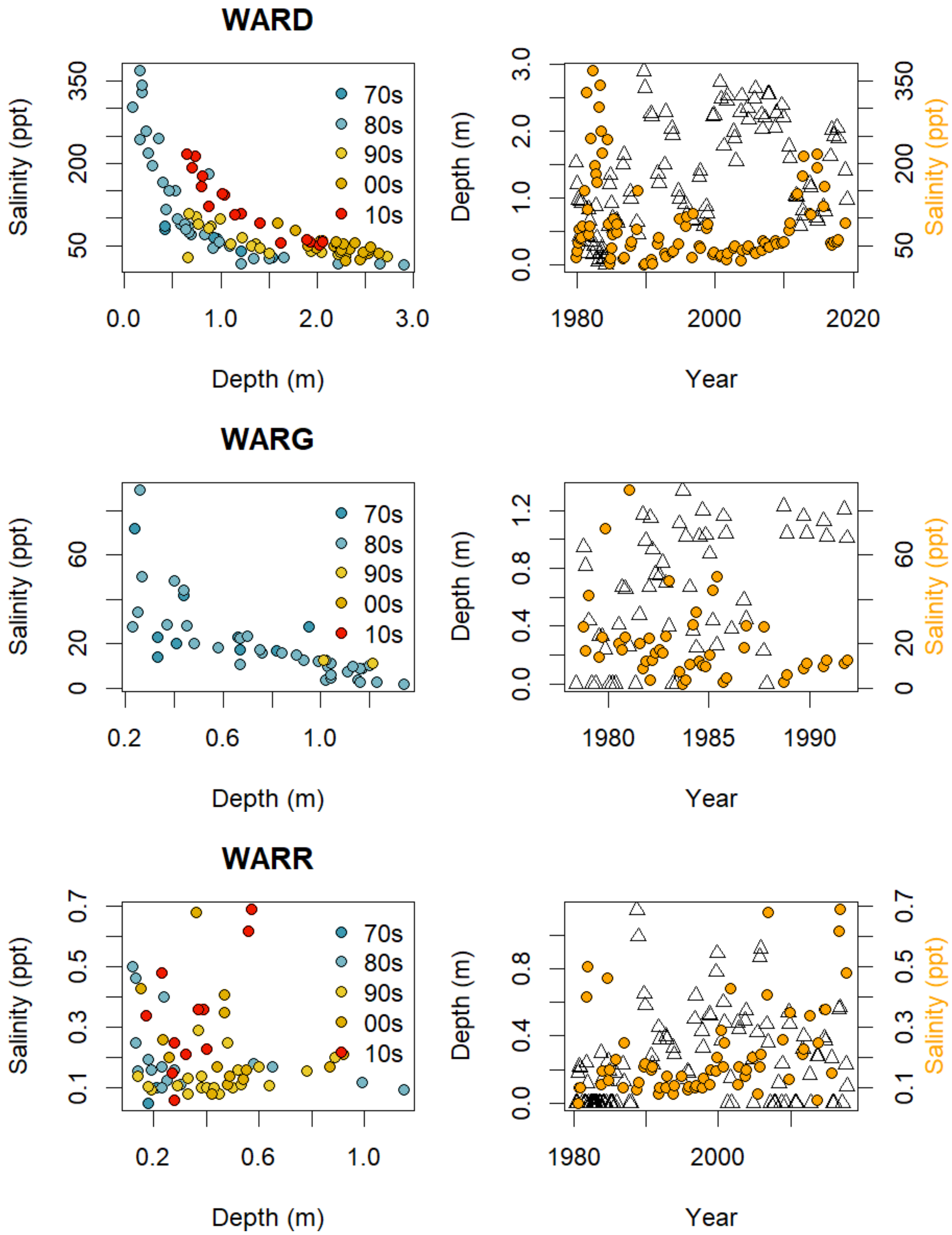

TOWE
TWIN
UNIC
70s
80s
90s
00s
10s
Salinity (ppt)
Depth (m)
Year
0
100
200
300
1
2
3
1980
2000
0.15
0.25
0.35
0.17
0.19
0.00
0.10
0.20
1990
2010
20
40
0.0
0.5
1.0
1.5
2.0

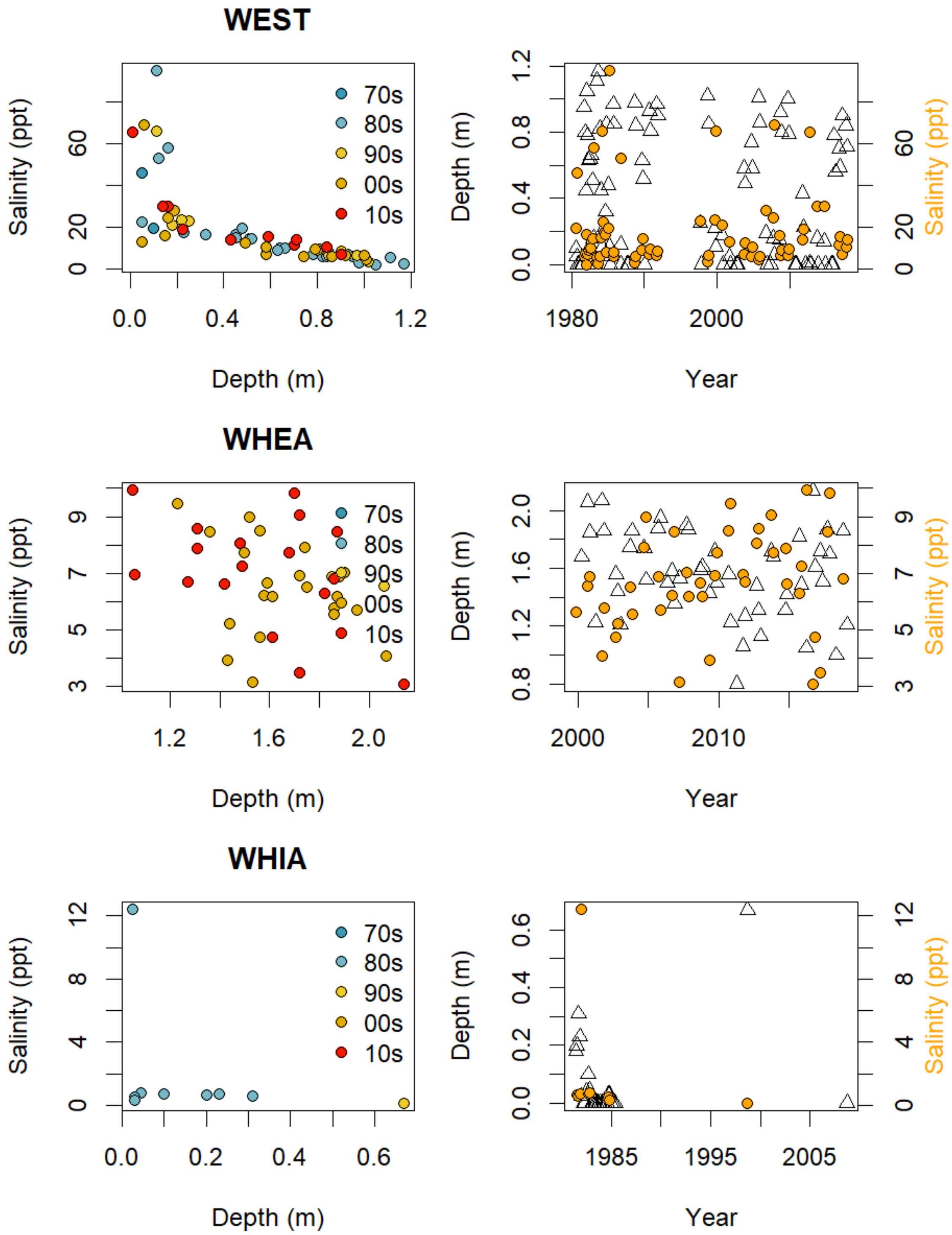

VARL
Salinity (ppt)
50
150
300
70s
80s
90s
00s
10s
0.0
0.2
0.4
0.6
0.8
Depth (m)
Depth (m)
0.0
0.4
0.8
1980
2000
Year
Salinity (ppt)

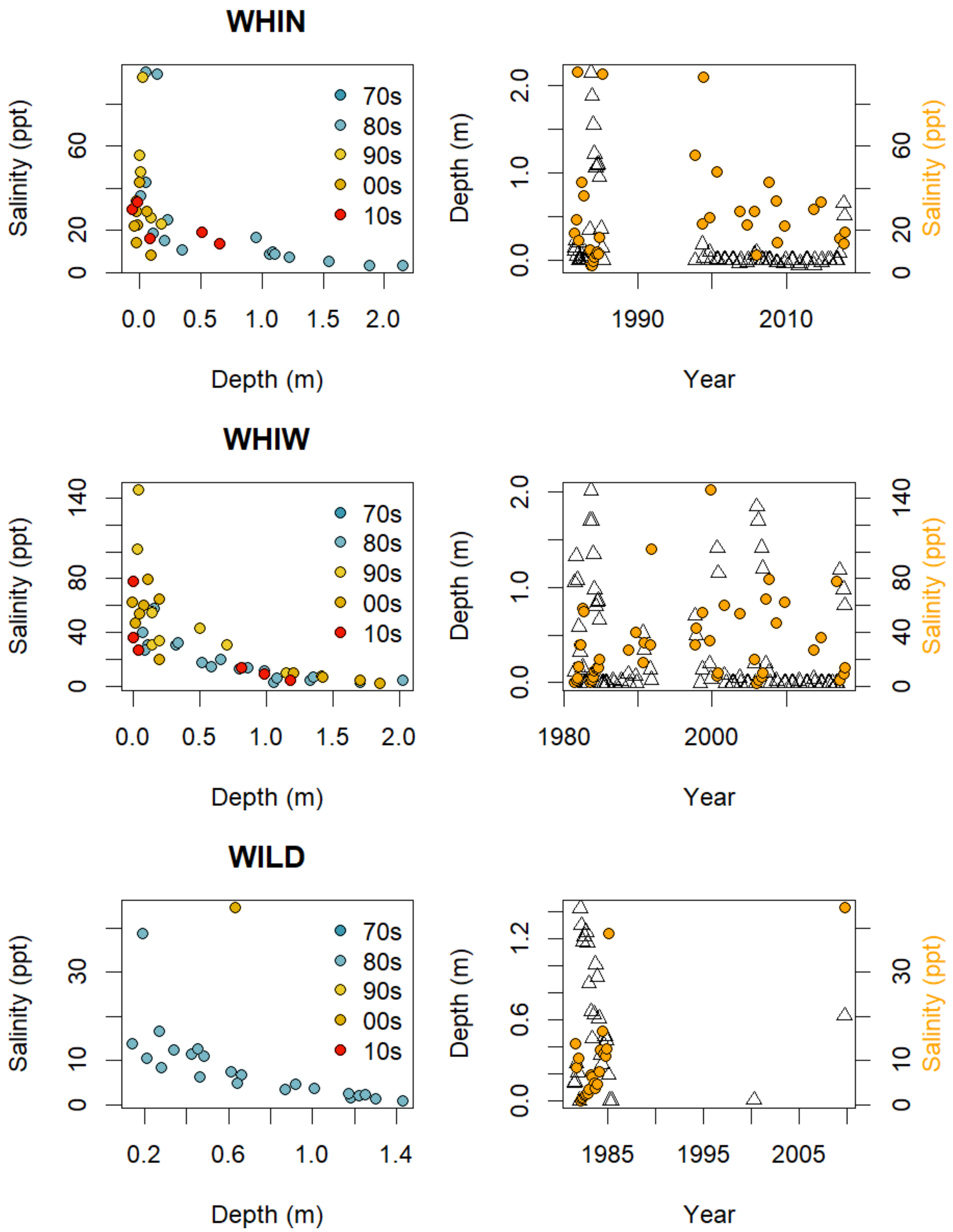

WAGI
Salinity (ppt)
10
30
50
70
70s
80s
90s
00s
10s
0.4
0.8
1.2
Depth (m)
Depth (m)
0.0
0.5
1.0
1.5
1983
1984
1985
Year
Salinity (ppt)

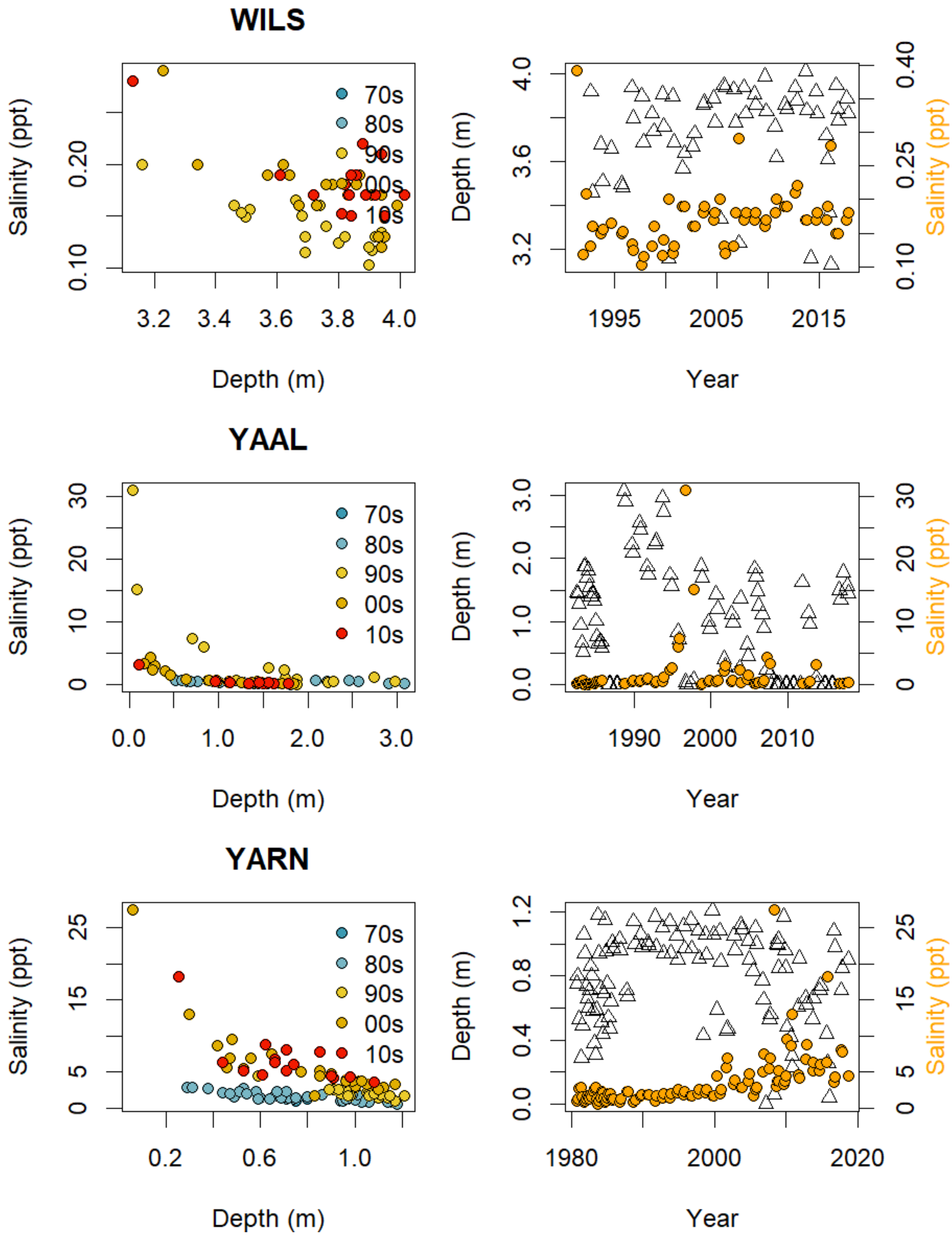

WALB
Salinity (ppt)
0
10
20
30
70s
80s
90s
00s
10s
0.2
0.6
1.0
Depth (m)
Depth (m)
0.0
0.4
0.8
1.2
1980
2000
Year
Salinity (ppt)

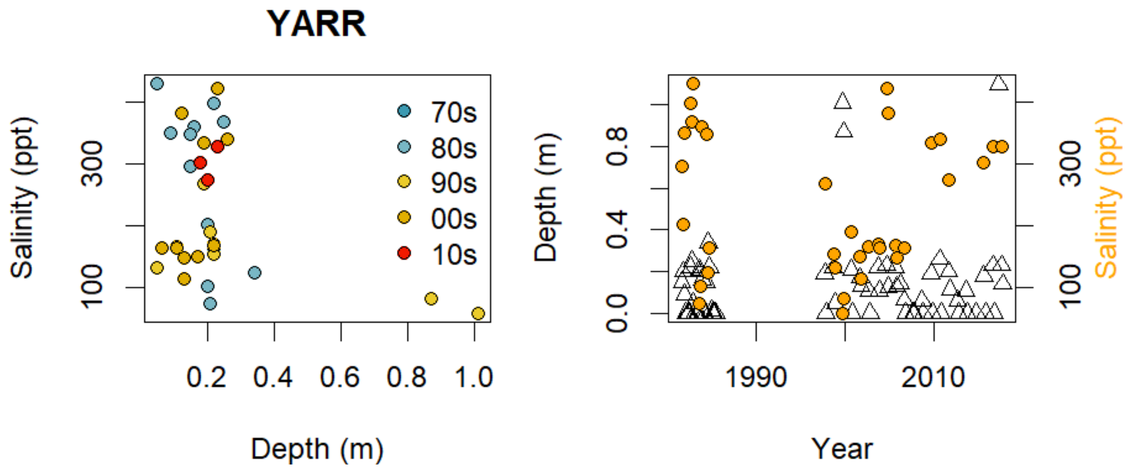

WALL
Salinity (ppt)
2 4 6 8
0.0 0.4 0.8 1.2
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
0.0 0.4 0.8 1.2
1985 1995 2005
Year
Salinity (ppt)
2 4 6 8
WALY
Salinity (ppt)
0 50 150
0.0 0.5 1.0
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
0.0 0.5 1.0
1980 2000
Year
Salinity (ppt)
0 50 150
WANN
Salinity (ppt)
0 40 80
0.5 1.0 1.5
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
0.0 1.0
1980 2000
Year
Salinity (ppt)
0 40 80

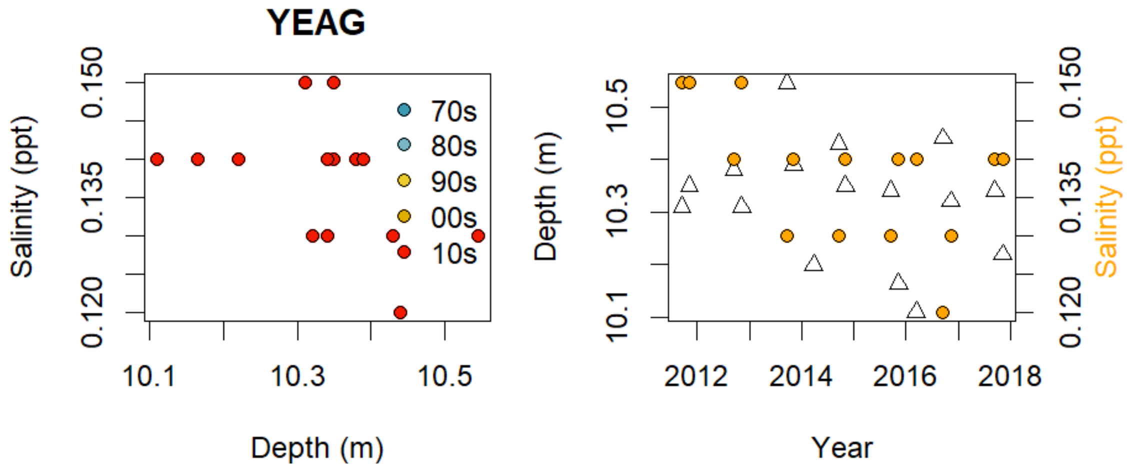

WARD
Salinity (ppt)
Depth (m)
Year
70s
80s
90s
00s
10s
WARG
Salinity (ppt)
Depth (m)
Year
70s
80s
90s
00s
10s
WARR
Salinity (ppt)
Depth (m)
Year
70s
80s
90s
00s
10s

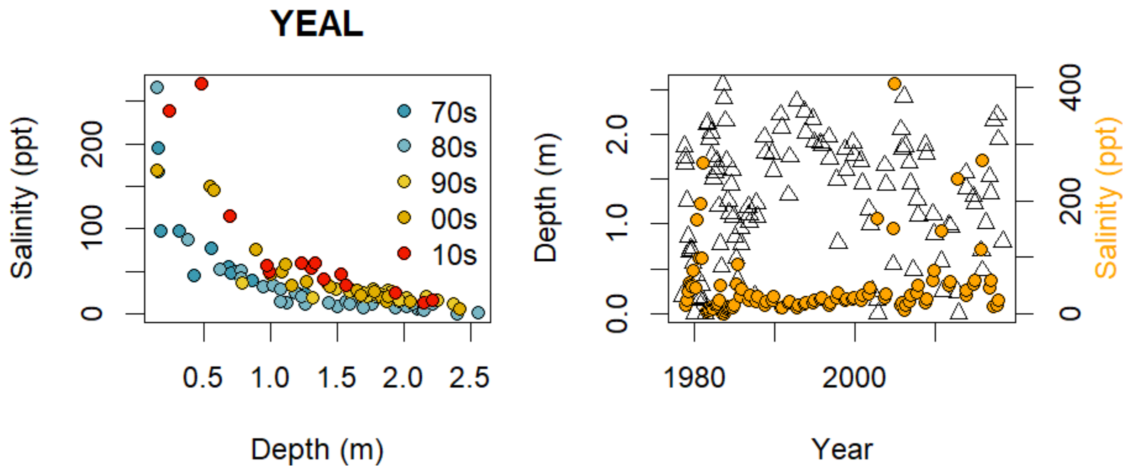

WEST
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Salinity (ppt)
Year
WHEA
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Salinity (ppt)
Year
WHIA
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Salinity (ppt)
Year

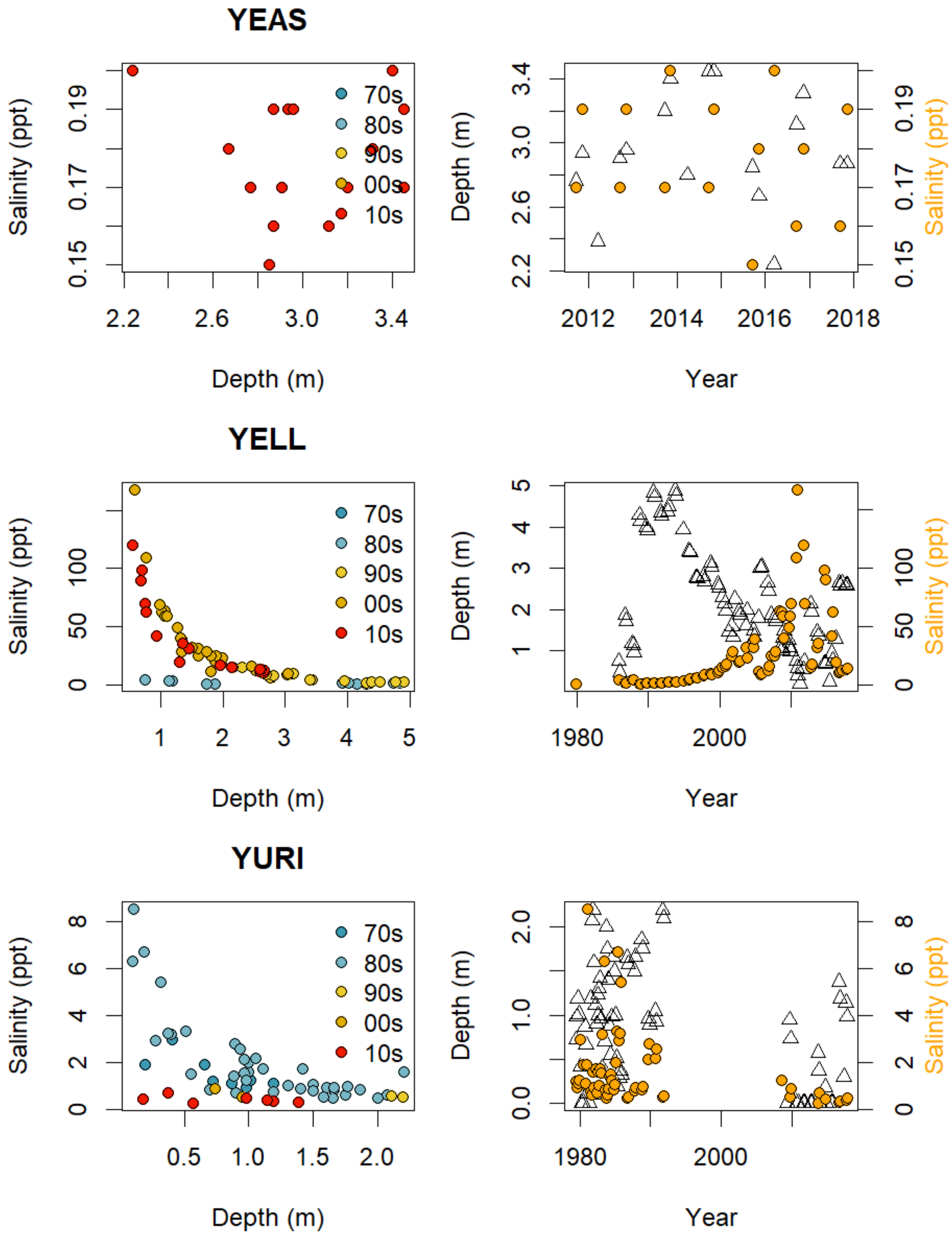

WHIN
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)
WHIW
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)
WILD
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)


WILS
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)
YAAL
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)
YARN
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)

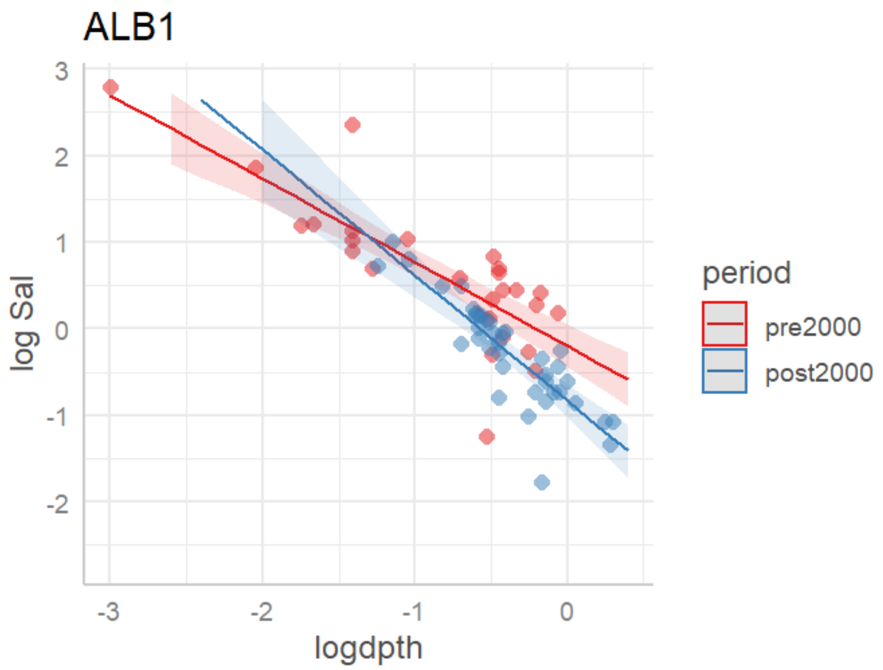

YARR
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)

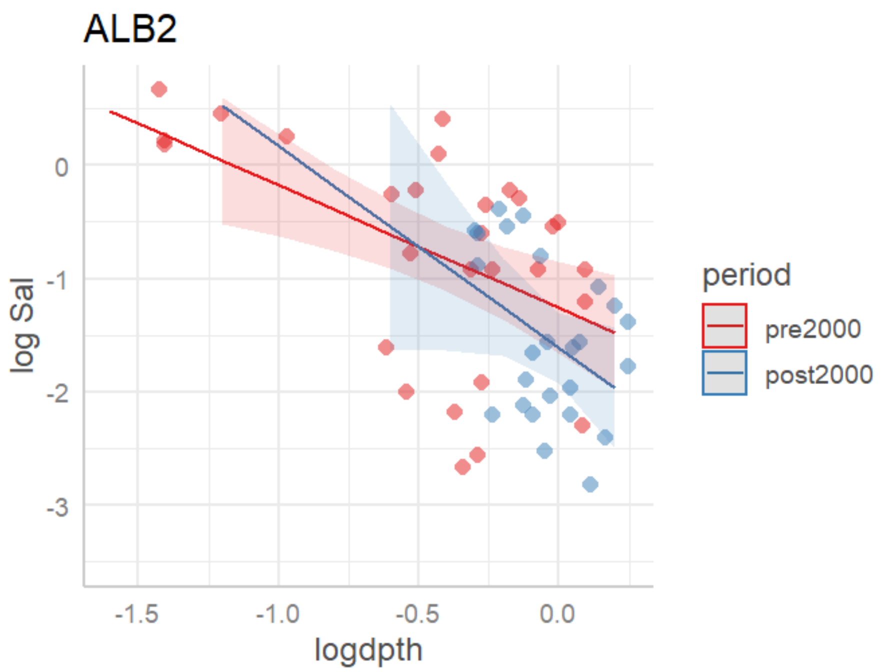

YEAG
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)

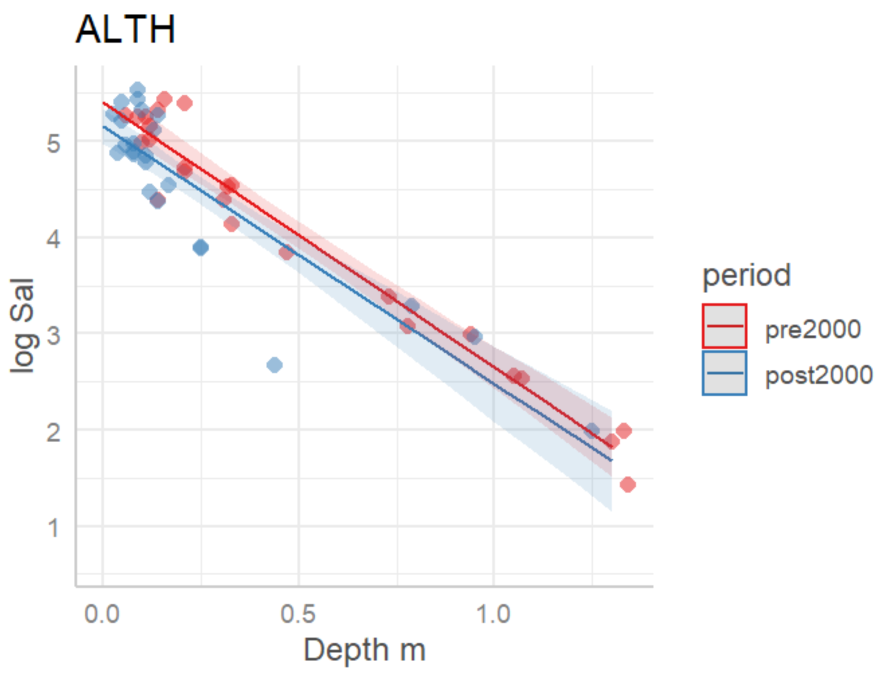

YEAL
Salinity (ppt)
Depth (m)
70s
80s
90s
00s
10s
Depth (m)
Year
Salinity (ppt)

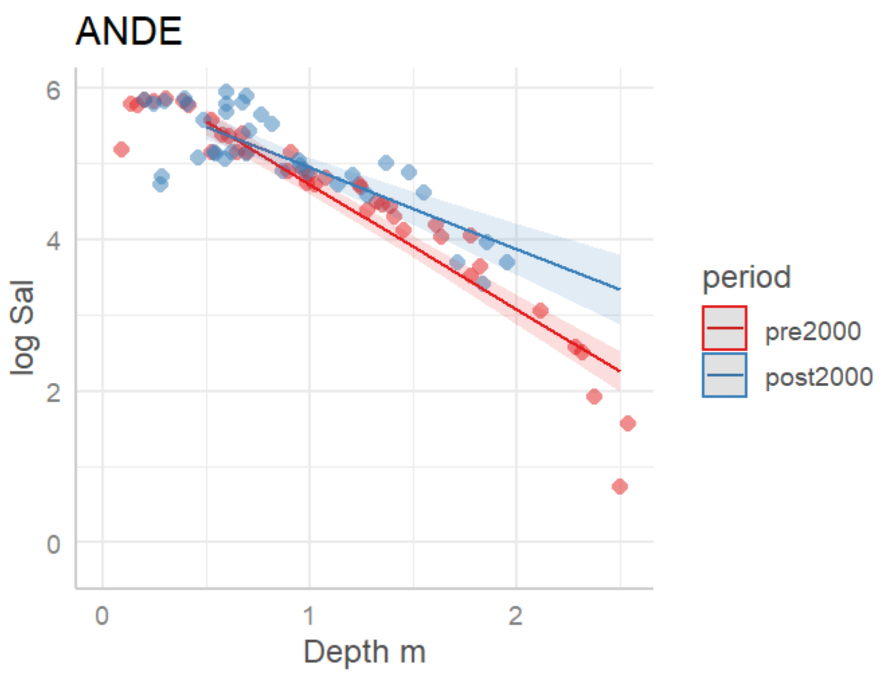

YEAS
Salinity (ppt)
0.15
0.17
0.19
70s
80s
90s
00s
10s
2.2
2.6
3.0
3.4
Depth (m)
Depth (m)
2.2
2.6
3.0
3.4
2012
2014
2016
2018
Year
Salinity (ppt)
0.15
0.17
0.19
YELL
Salinity (ppt)
0
50
100
70s
80s
90s
00s
10s
1
2
3
4
5
Depth (m)
Depth (m)
1
2
3
4
5
1980
2000
Year
Salinity (ppt)
0
50
100
YURI
Salinity (ppt)
0
2
4
6
8
70s
80s
90s
00s
10s
0.5
1.0
1.5
2.0
Depth (m)
Depth (m)
0.0
1.0
2.0
1980
2000
Year
Salinity (ppt)
0
2
4
6
8

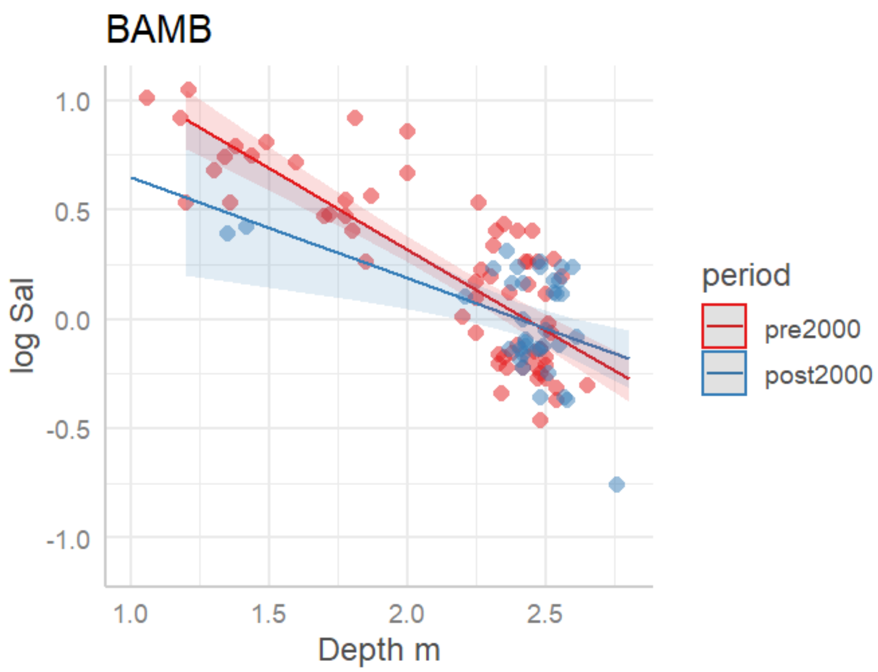
Salinity – depth regressions by site

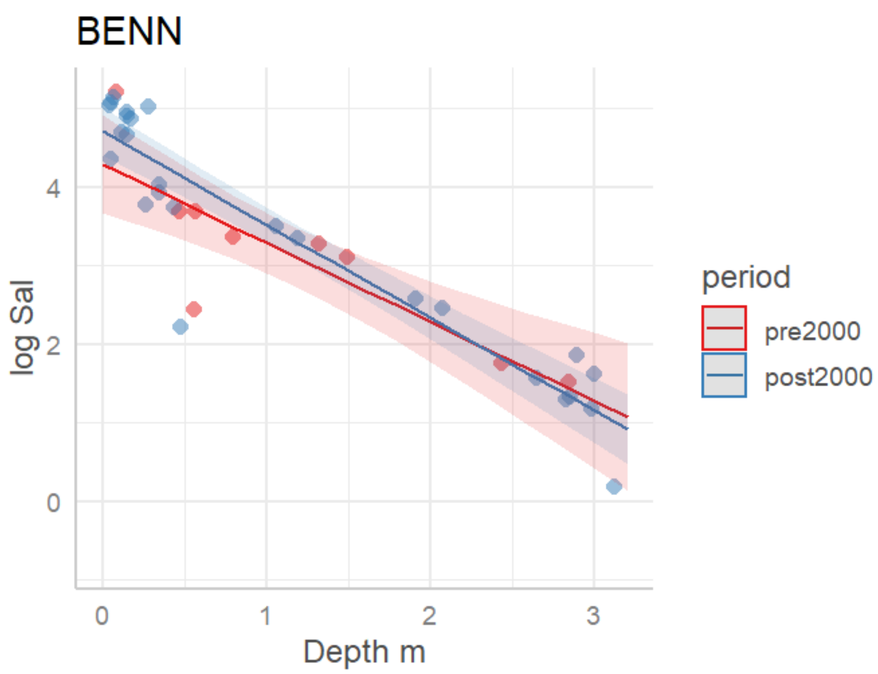


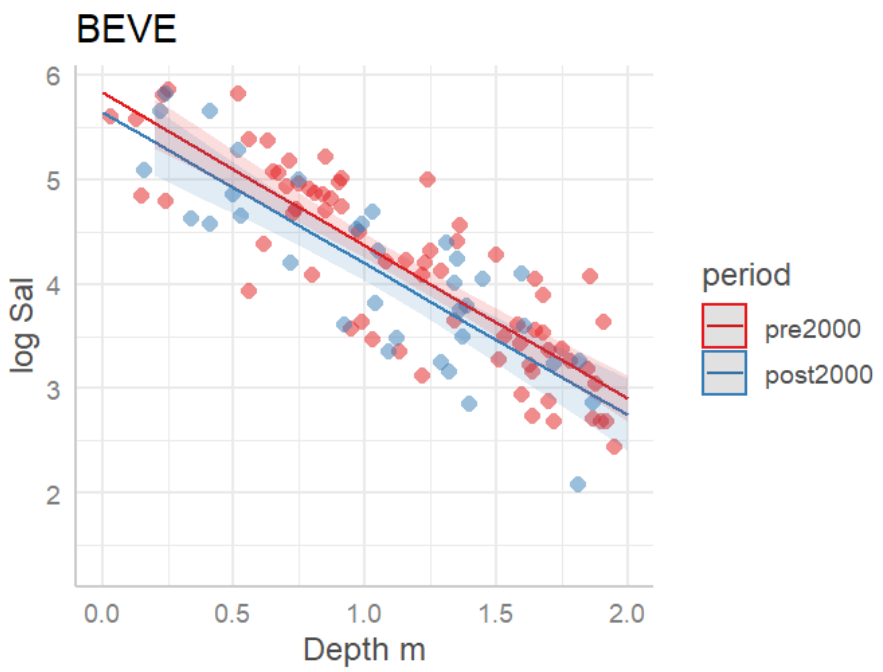


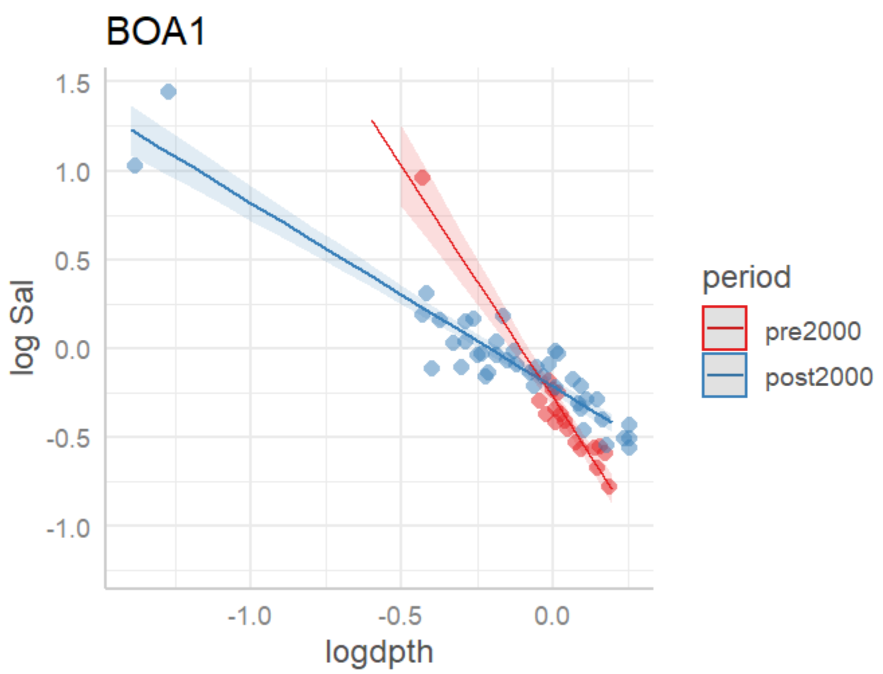

ALTH
log Sal
5
4
3
2
1
0.0
0.5
1.0
Depth m
period
pre2000
post2000

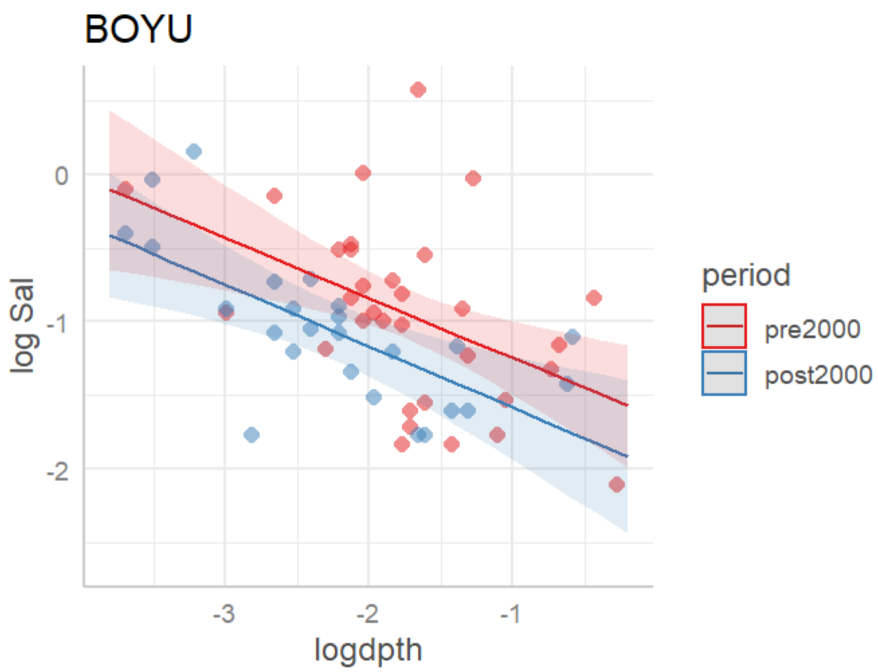

ANDE
log Sal
6
4
2
0
0
1
2
Depth m
period
pre2000
post2000


BAMB
log Sal
1.0
0.5
0.0
-0.5
-1.0
1.0
1.5
2.0
2.5
Depth m
period
pre2000
post2000

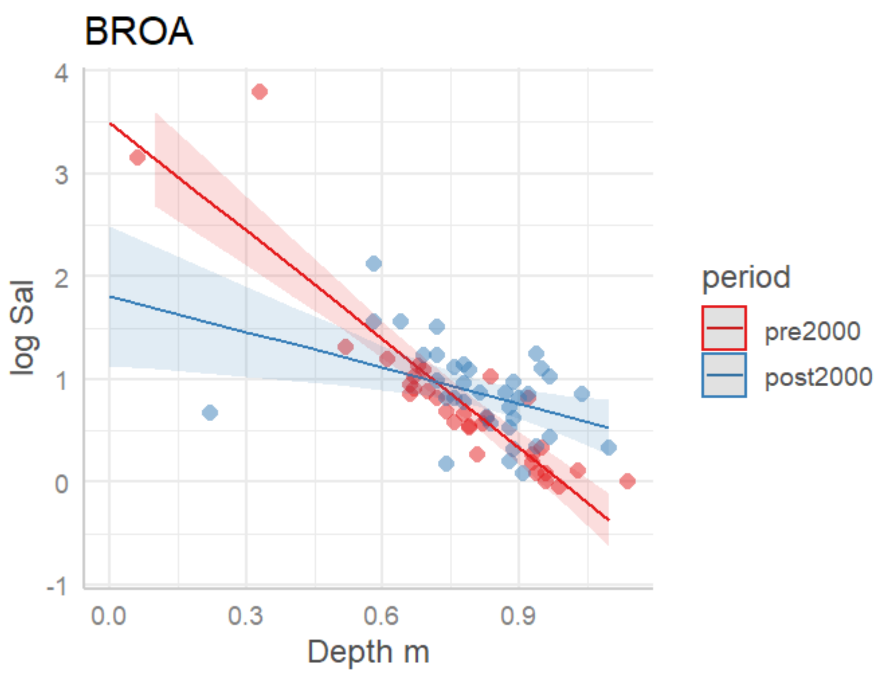

BENN
log Sal
4
2
0
0
1
2
3
Depth m
period
pre2000
post2000


BEVE
log Sal
6
5
4
3
2
0.0
0.5
1.0
1.5
2.0
Depth m
period
pre2000
post2000

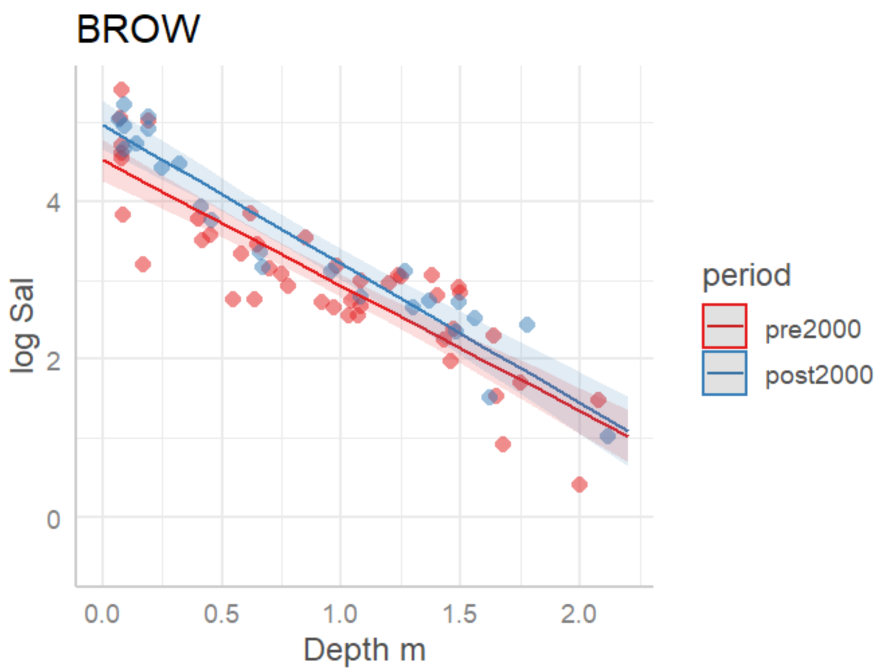

BOA1
log Sal
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.0
-0.5
0.0
logdpth
period
pre2000
post2000

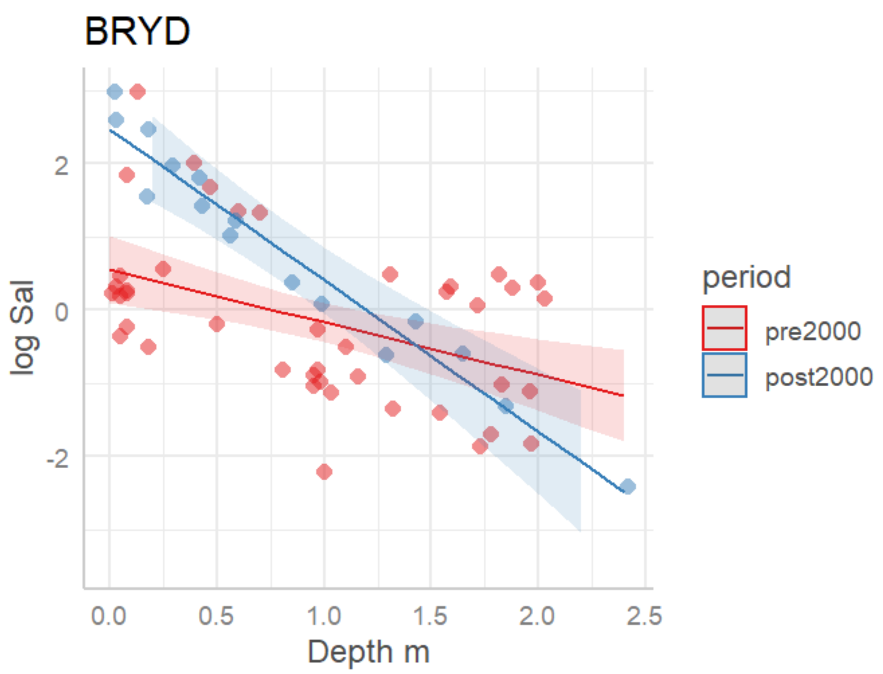


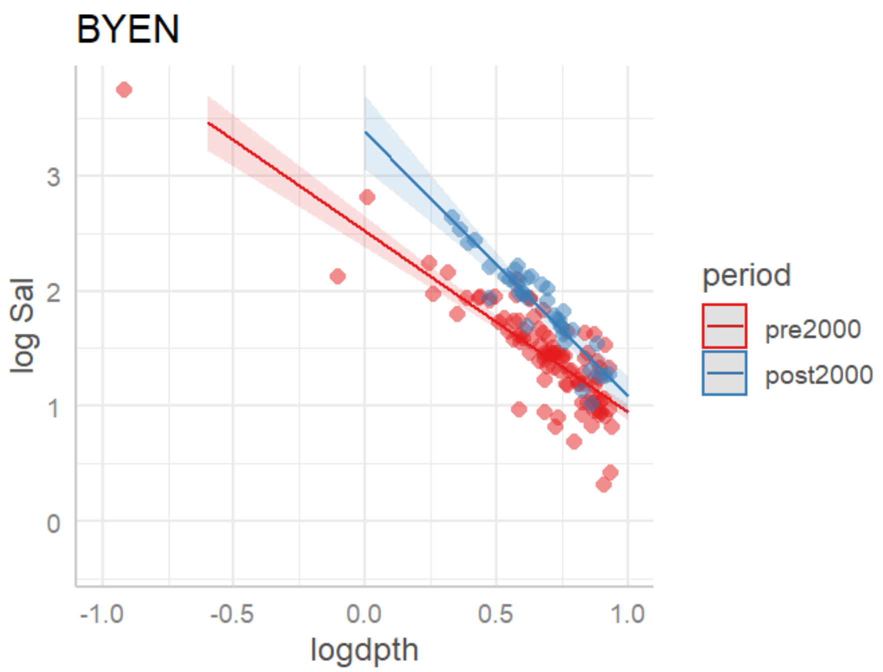
BOYU
log Sal
0
-1
-2
-3
-2
-1
logdpth
period
pre2000
post2000

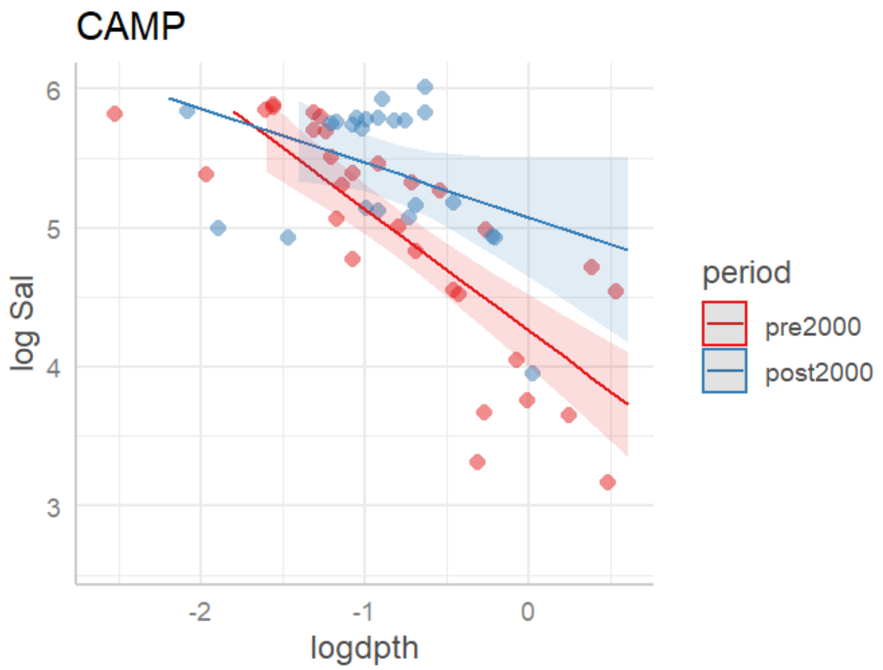


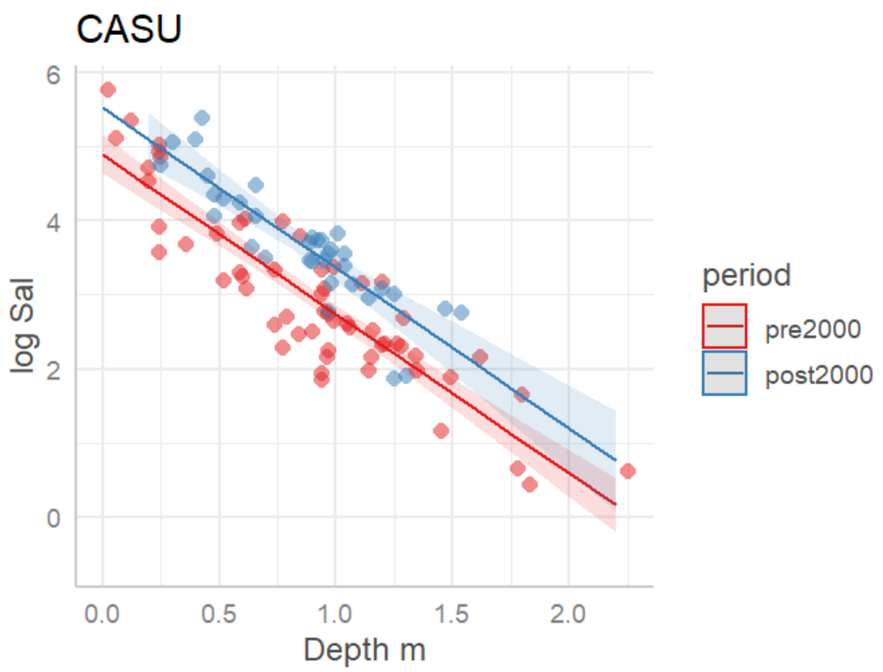
BROA
log Sal
4
3
2
1
0
-1
0.0
0.3
0.6
0.9
Depth m
period
pre2000
post2000

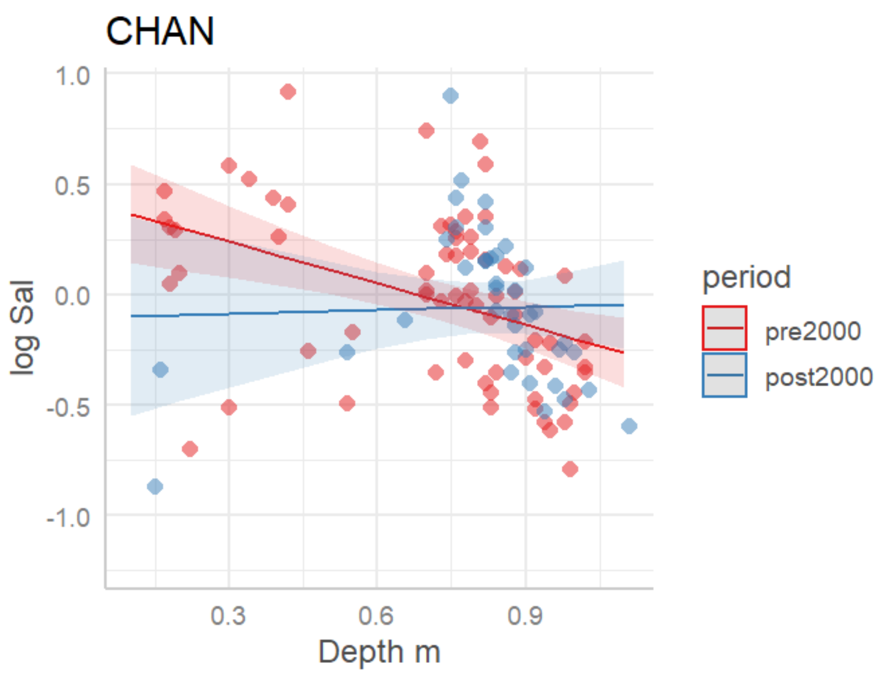

BROW
log Sal
4
2
0
0.0
0.5
1.0
1.5
2.0
Depth m
period
pre2000
post2000

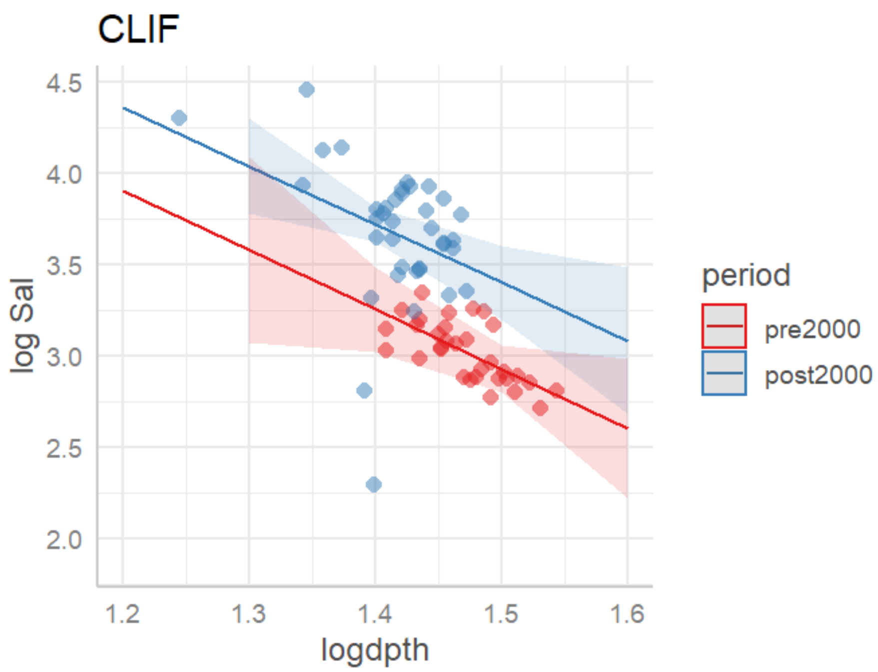

BRYD
log Sal
2
0
-2
0.0
0.5
1.0
1.5
2.0
2.5
Depth m
period
pre2000
post2000

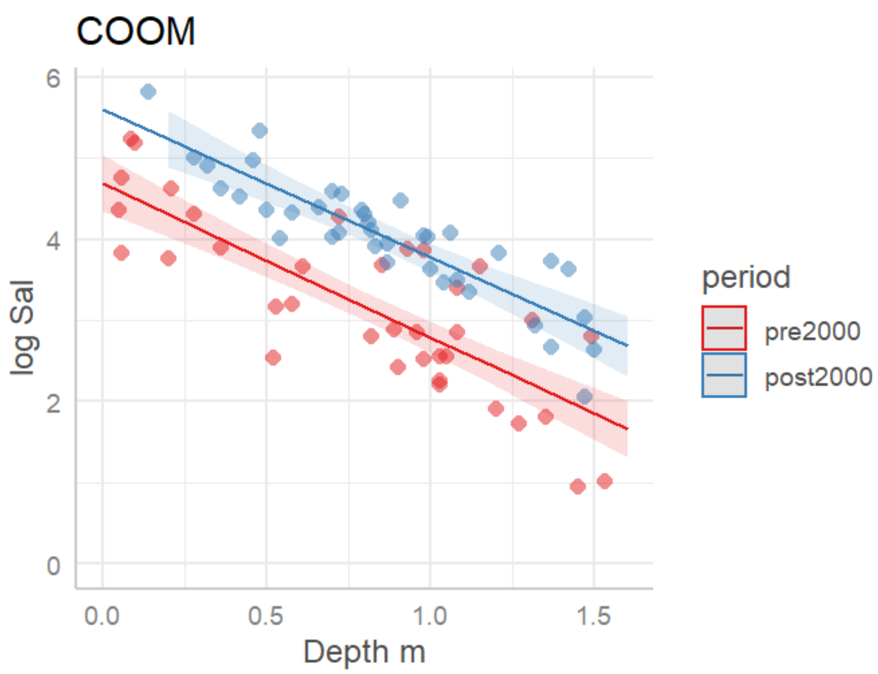

BYEN
log Sal
0
1
2
3
-1.0
-0.5
0.0
0.5
1.0
logdpth
period
pre2000
post2000

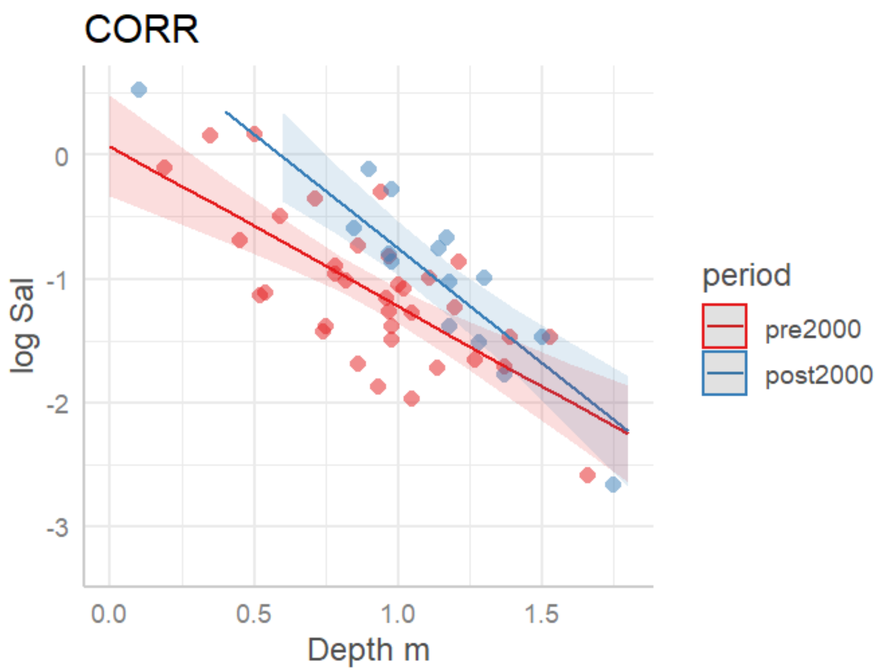

CAMP
log Sal
3
4
5
6
-2
-1
0
logdpth
period
pre2000
post2000

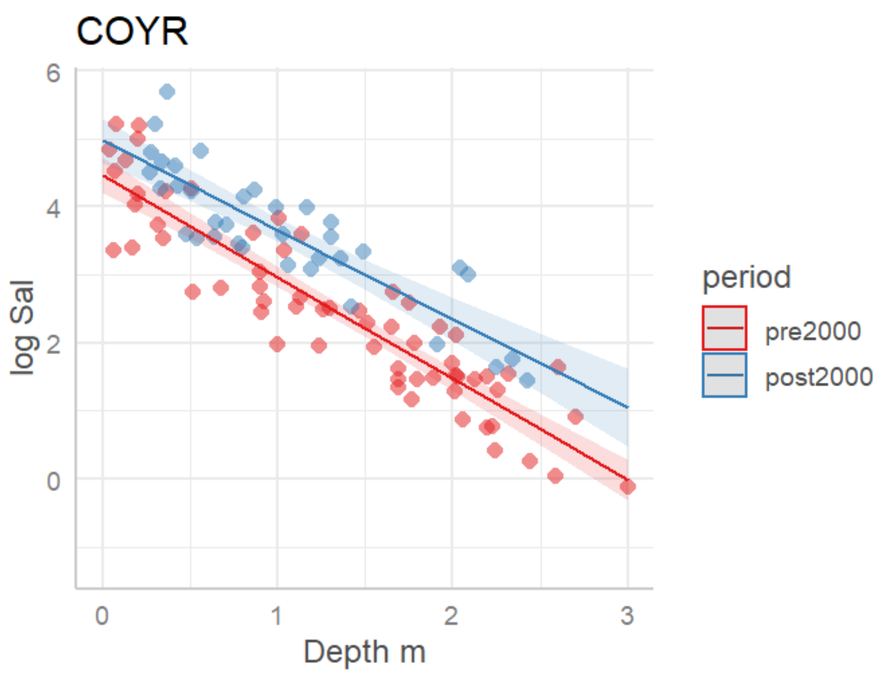

CASU
6
4
2
0
log Sal
0.0
0.5
1.0
1.5
2.0
Depth m
period
pre2000
post2000

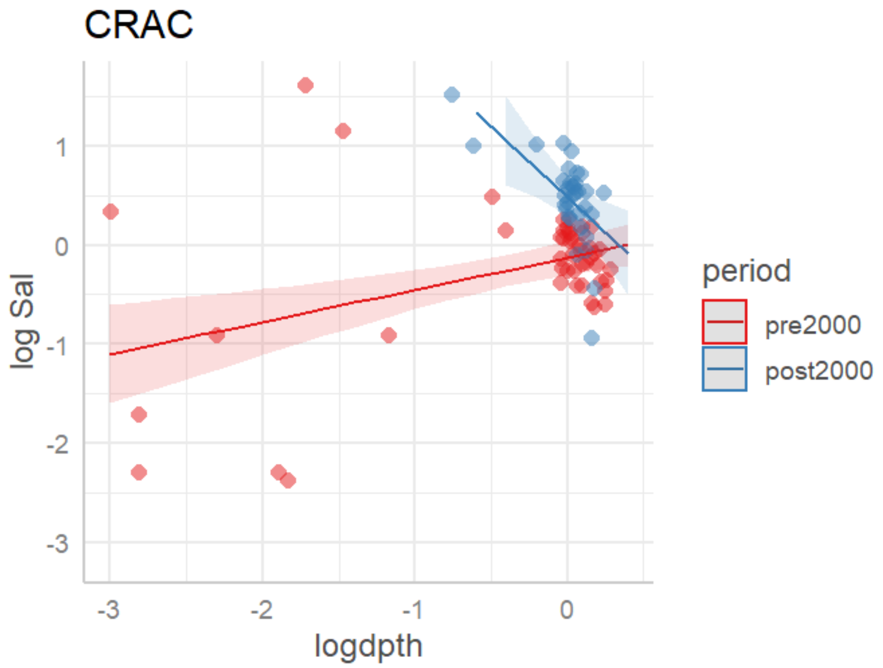

CHAN
1.0
0.5
0.0
-0.5
-1.0
log Sal
0.3
0.6
0.9
Depth m
period
pre2000
post2000

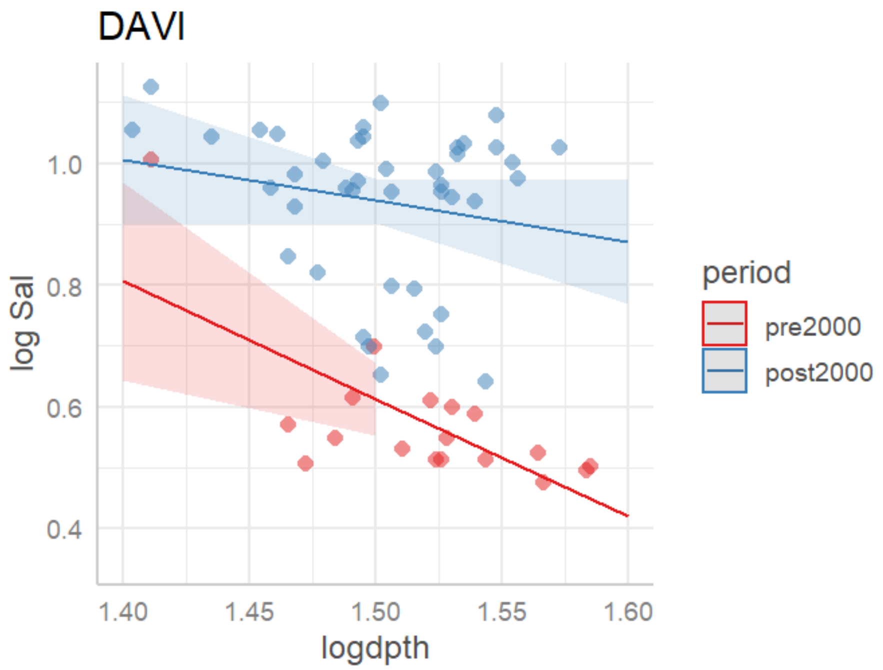

CLIF
4.5
4.0
3.5
3.0
2.5
2.0
log Sal
1.2
1.3
1.4
1.5
1.6
logdpth
period
pre2000
post2000

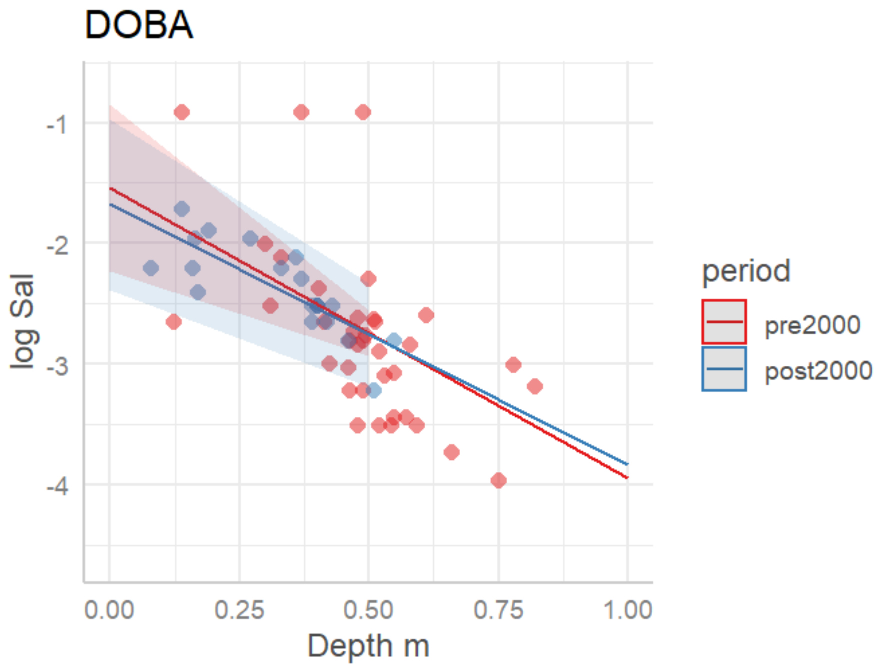

COOM
6
4
2
0
log Sal
0.0
0.5
1.0
1.5
Depth m
period
pre2000
post2000

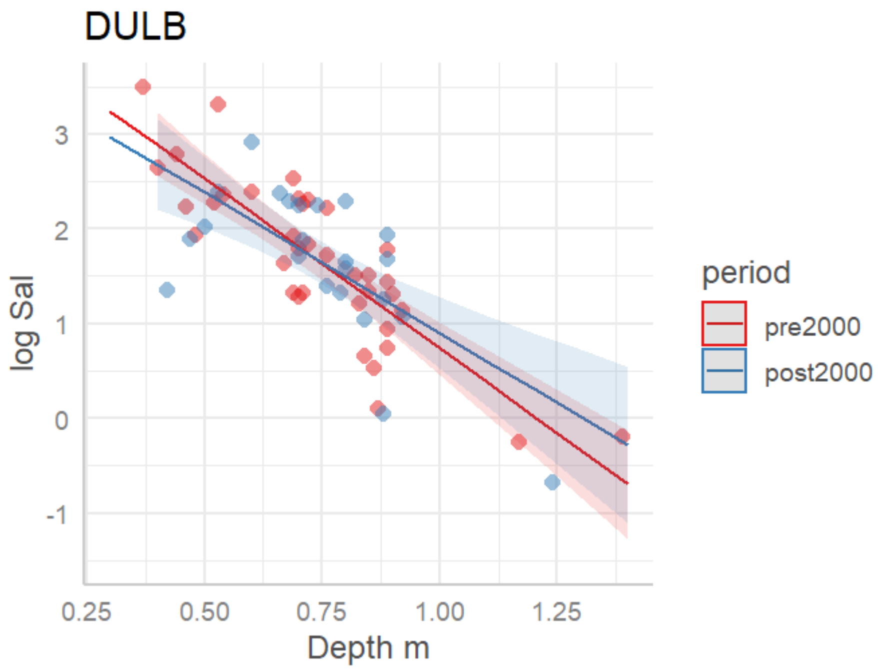

CORR
log Sal
0
-1
-2
-3
0.0
0.5
1.0
1.5
Depth m
period
pre2000
post2000

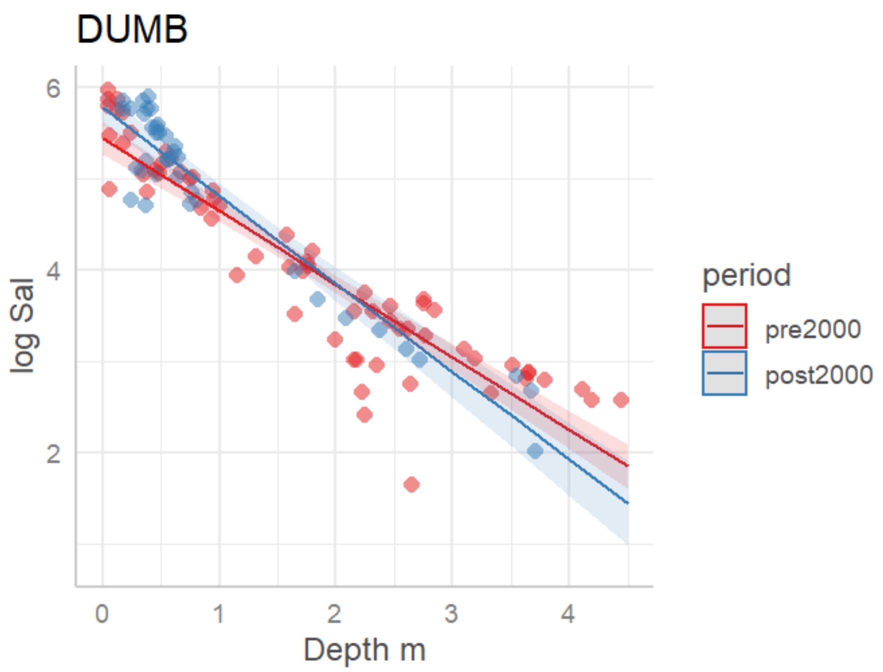

COYR
log Sal
6
4
2
0
0
1
2
3
Depth m
period
pre2000
post2000

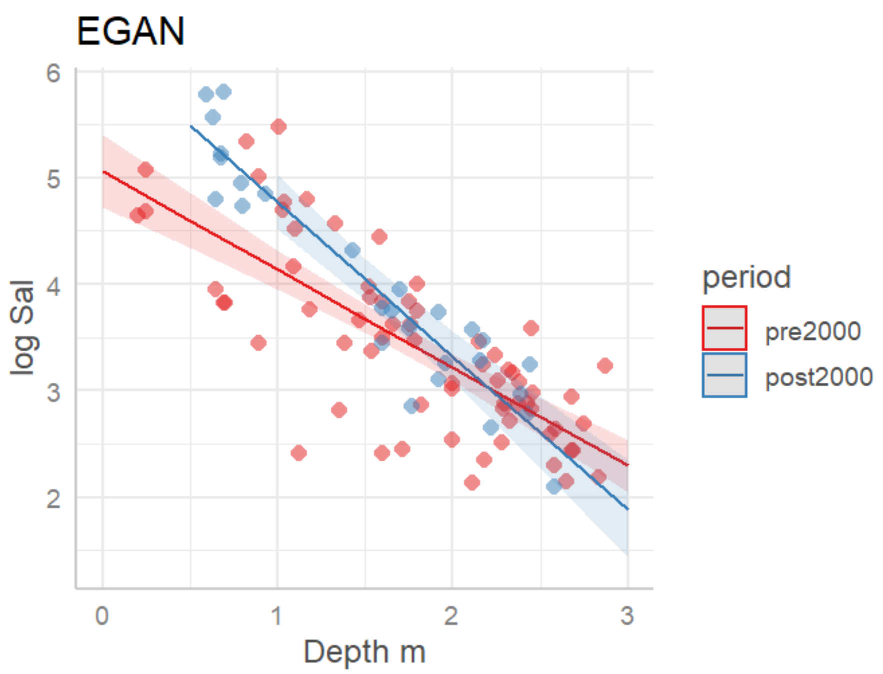

CRAC
log Sal
1
0
-1
-2
-3
-3
-2
-1
0
logdpth
period
pre2000
post2000

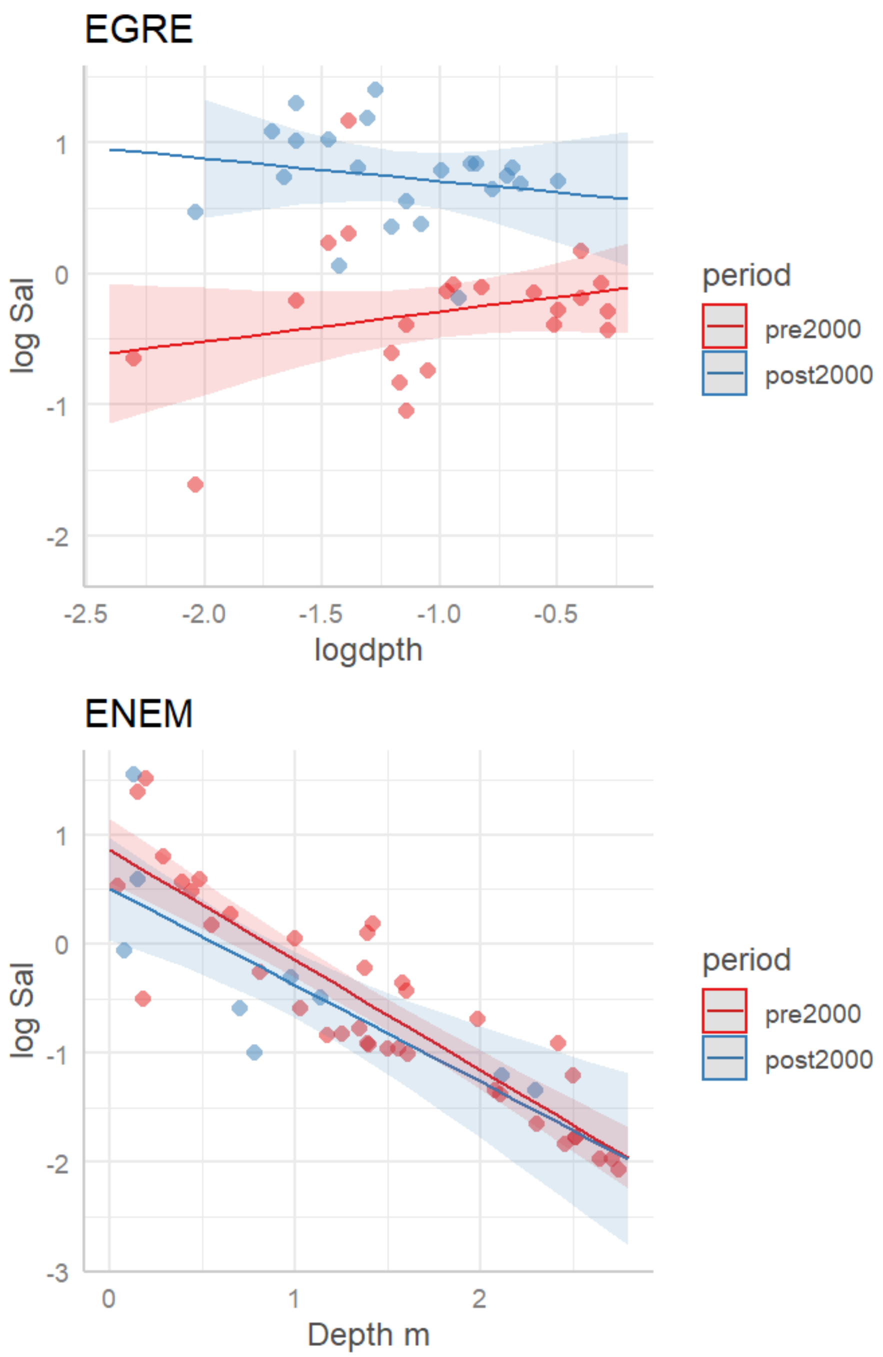

DAVI
log Sal
1.0
0.8
0.6
0.4
1.40
1.45
1.50
1.55
1.60
logdpth
period
pre2000
post2000

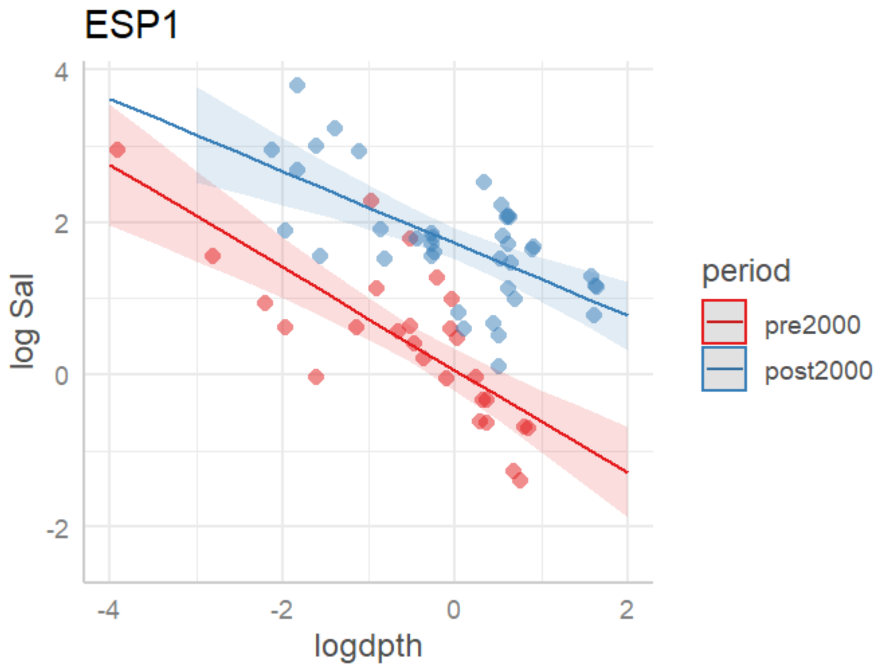

DOBA
log Sal
-1
-2
-3
-4
0.00
0.25
0.50
0.75
1.00
Depth m
period
pre2000
post2000

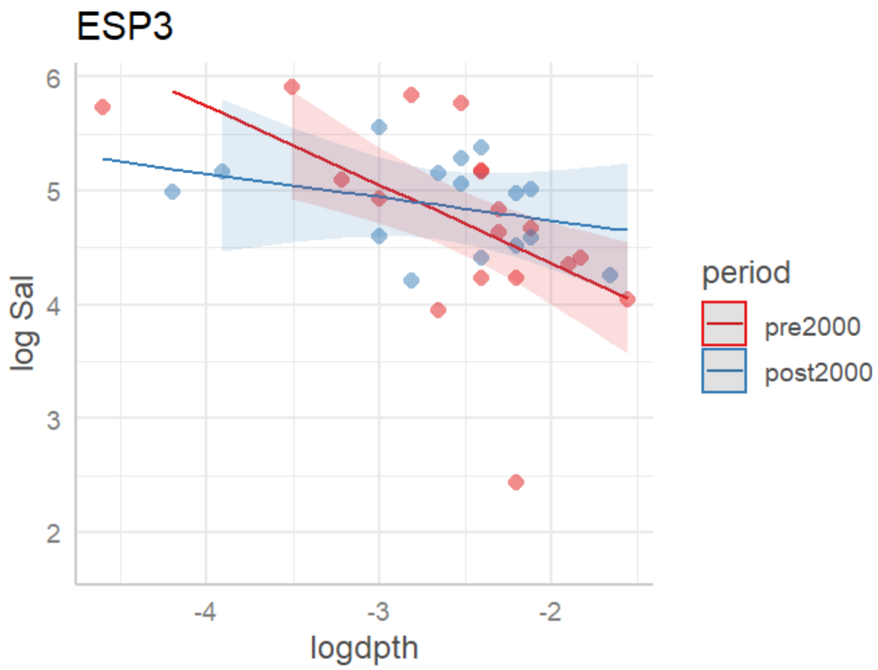

DULB
log Sal
3
2
1
0
-1
0.25
0.50
0.75
1.00
1.25
Depth m
period
pre2000
post2000

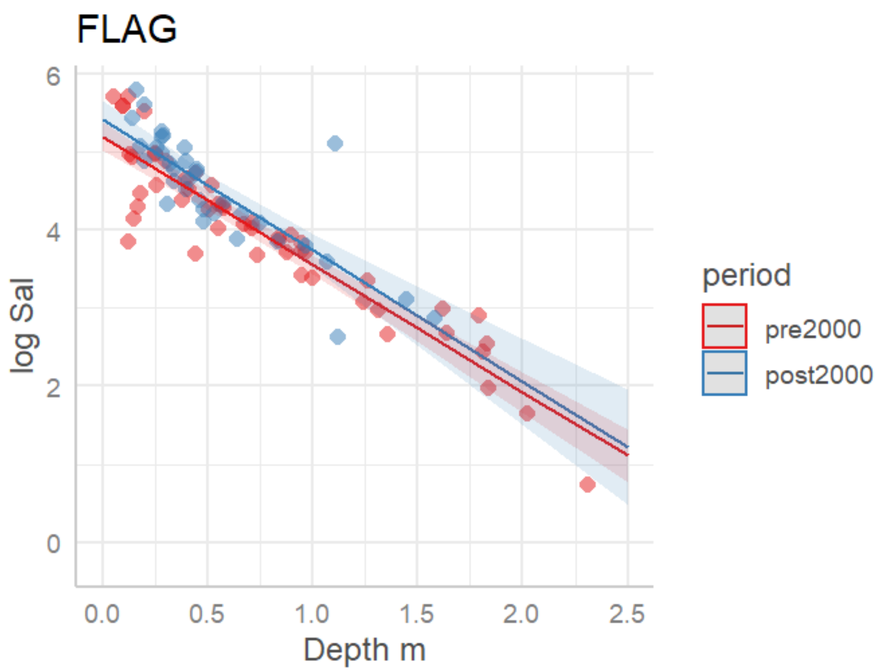

DUMB
log Sal
6
4
2
0
1
2
3
4
Depth m
period
pre2000
post2000

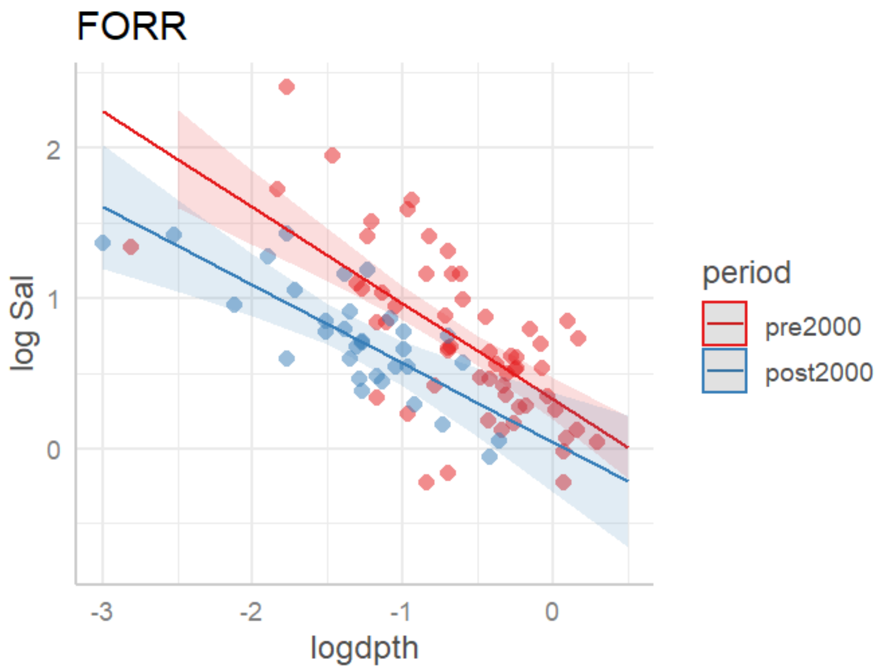

EGAN
log Sal
6
5
4
3
2
0
1
2
3
Depth m
period
pre2000
post2000

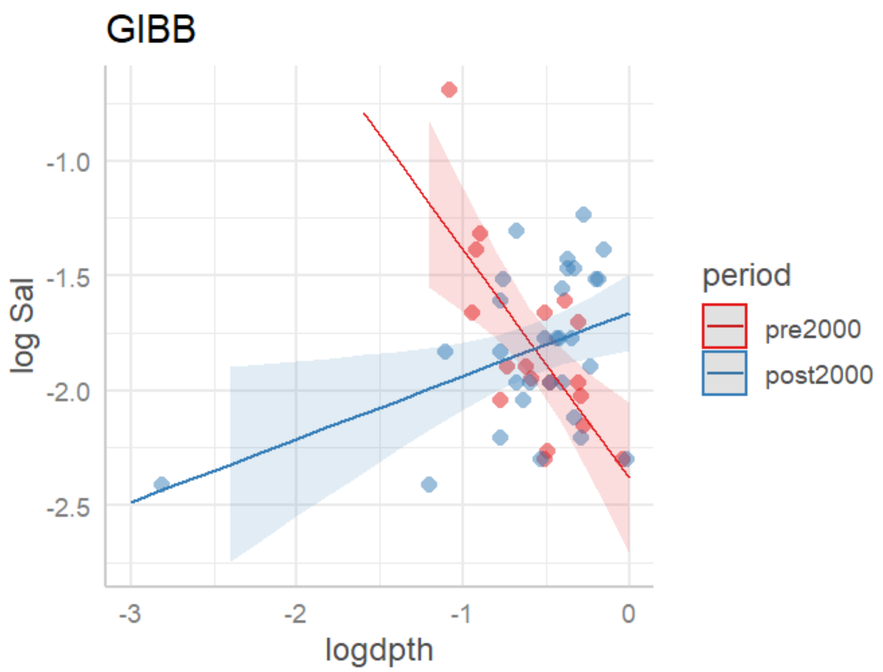

EGRE
log Sal
1
0
-1
-2
-2.5
-2.0
-1.5
-1.0
-0.5
logdpth
period
pre2000
post2000
ENEM
log Sal
1
0
-1
-2
-3
0
1
2
Depth m
period
pre2000
post2000

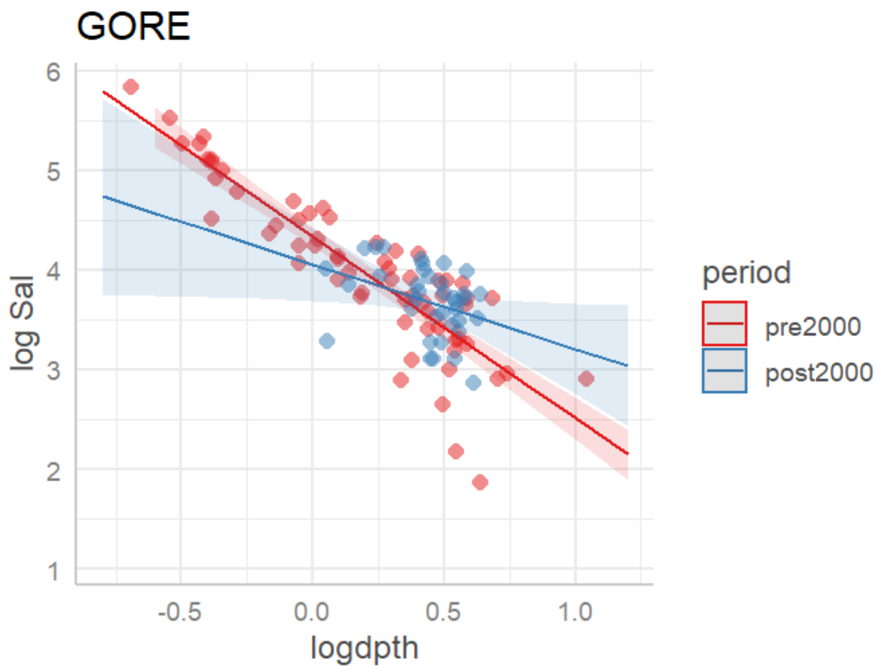

ESP1
log Sal
4
2
0
-2
-4
-2
0
2
logdpth
period
pre2000
post2000

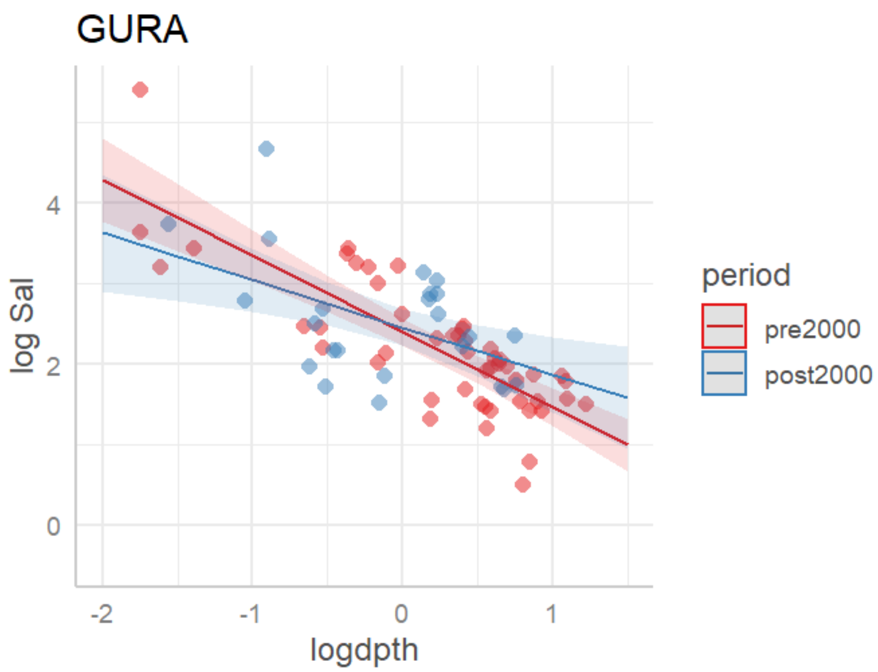

ESP3
log Sal
6
5
4
3
2
-4
-3
-2
logdpth
period
pre2000
post2000

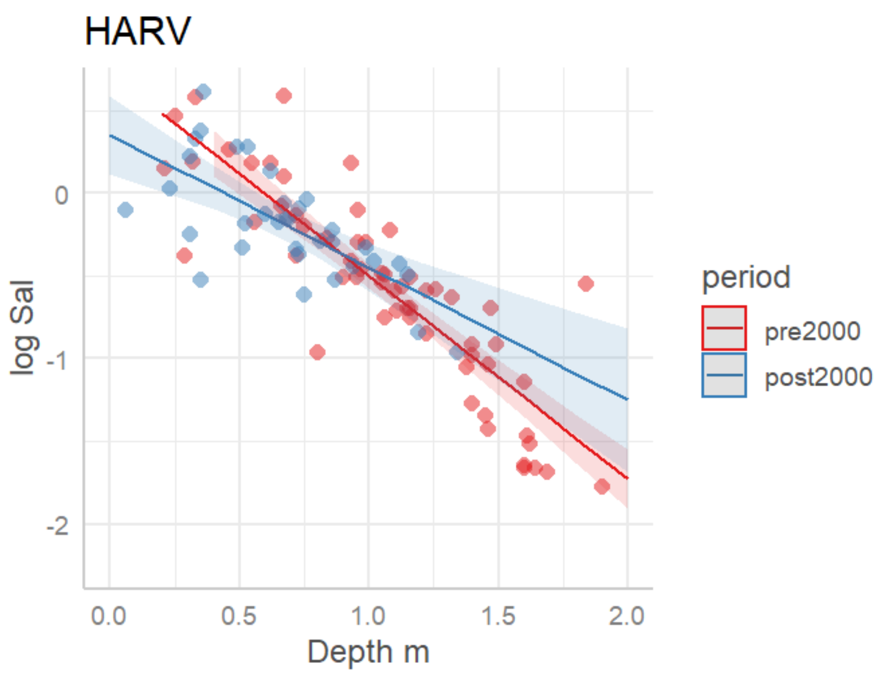

FLAG
log Sal
0
2
4
6
0.0
0.5
1.0
1.5
2.0
2.5
Depth m
period
pre2000
post2000


FORR
log Sal
0
1
2
-3
-2
-1
0
logdpth
period
pre2000
post2000


GIBB
log Sal
-1.0
-1.5
-2.0
-2.5
-3
-2
-1
0
logdpth
period
pre2000
post2000


GORE
log Sal
6
5
4
3
2
1
-0.5
0.0
0.5
1.0
logdpth
period
pre2000
post2000


GURA
log Sal
4
2
0
-2
-1
0
1
logdpth
period
pre2000
post2000


HARV
log Sal
0
-1
-2
0.0
0.5
1.0
1.5
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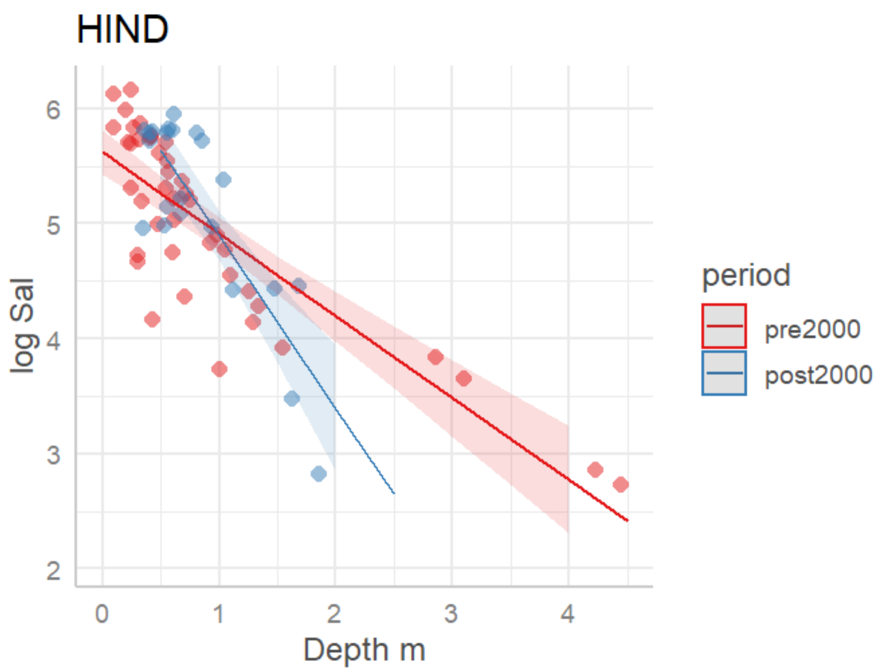
Depth m
period
pre2000
post2000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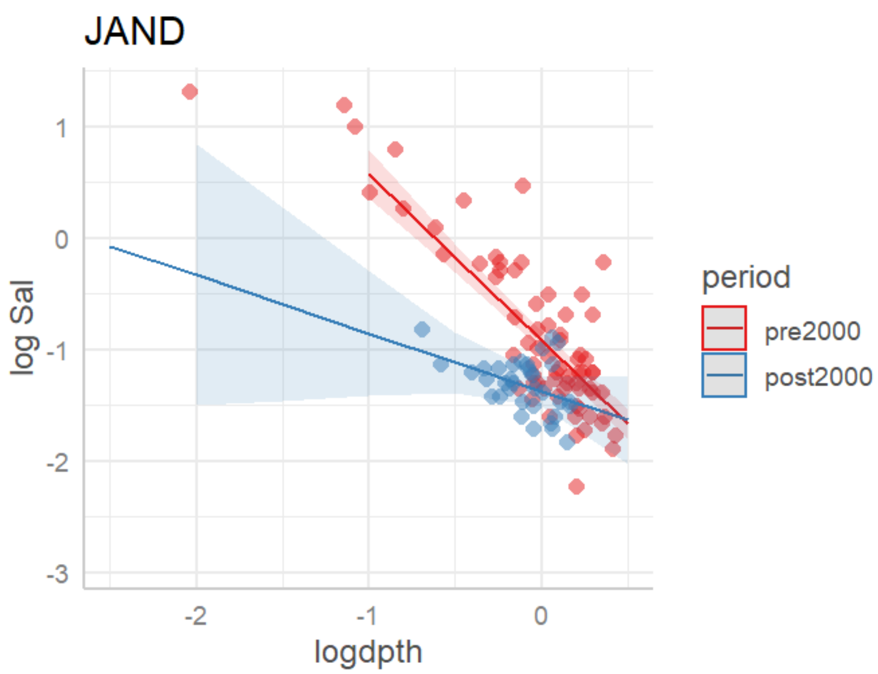
post2000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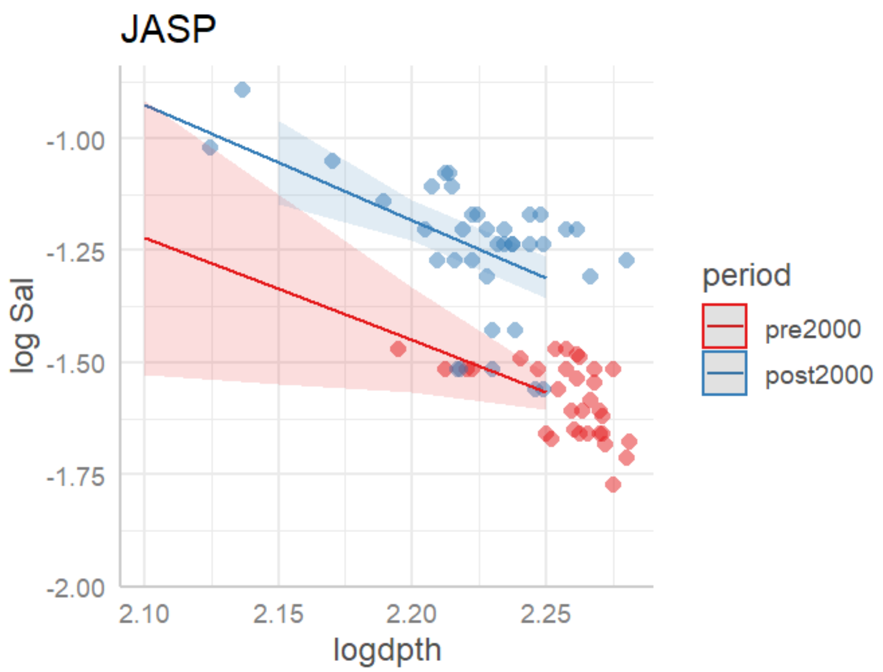
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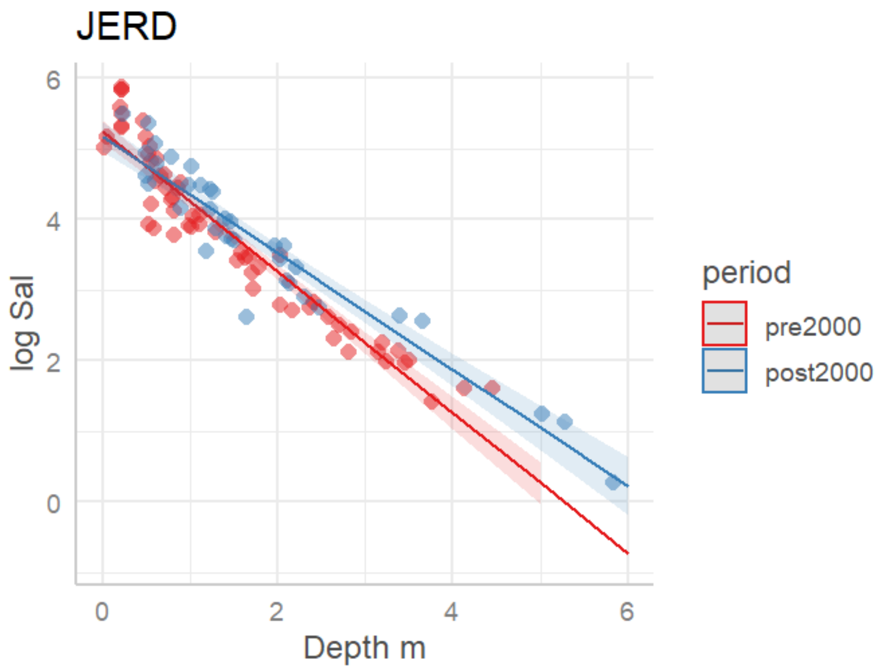
post2000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2
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Depth m
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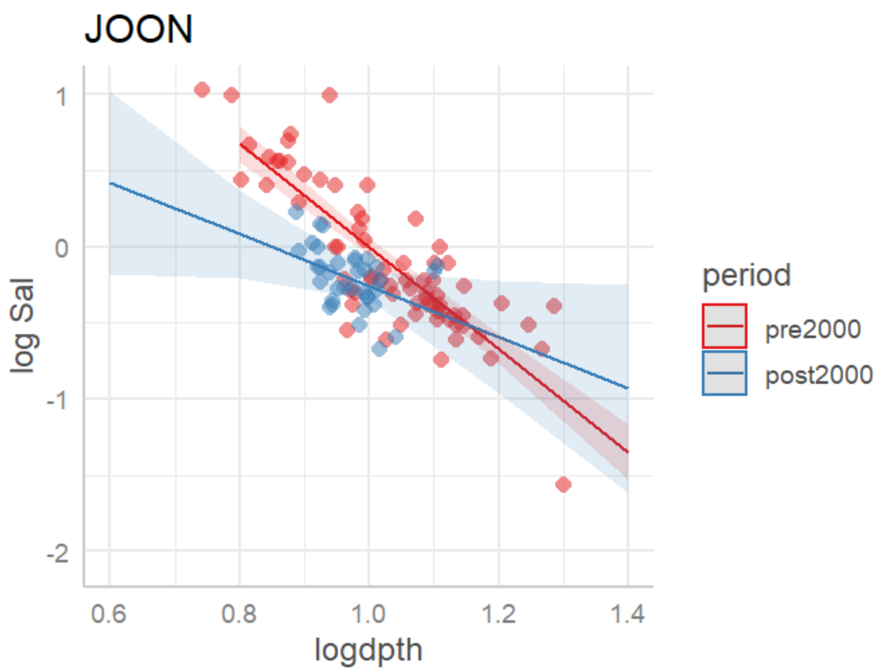
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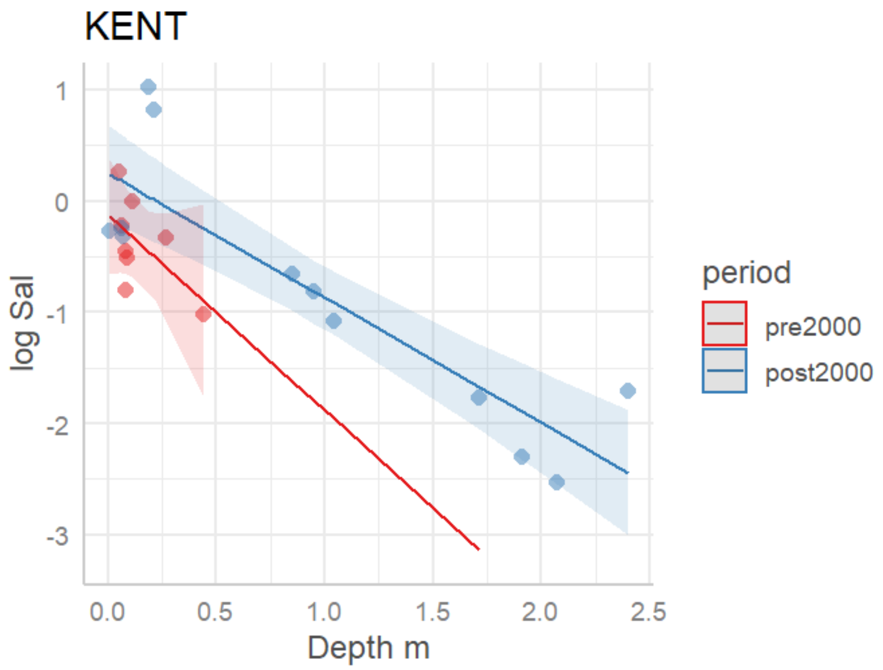
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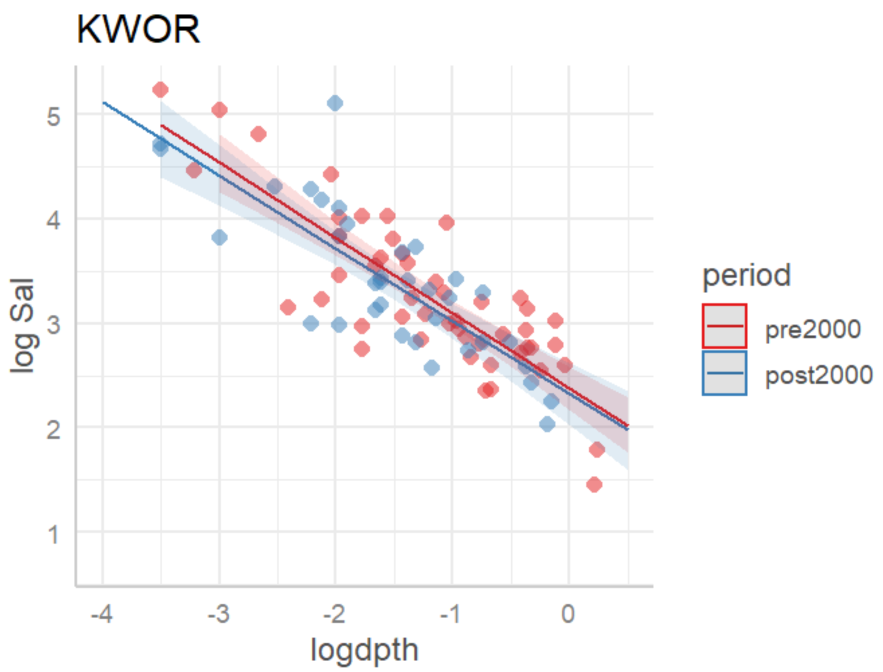
post2000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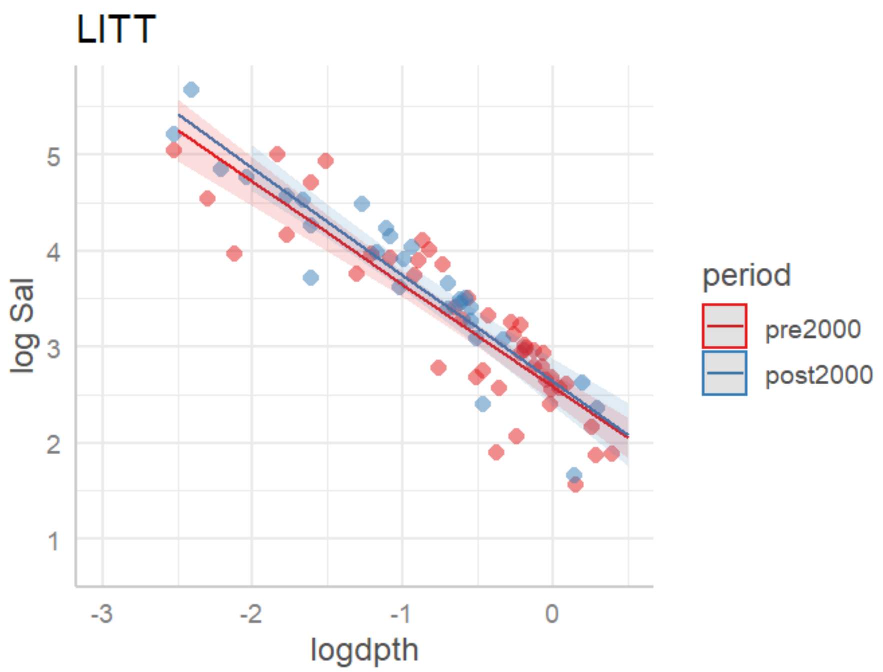
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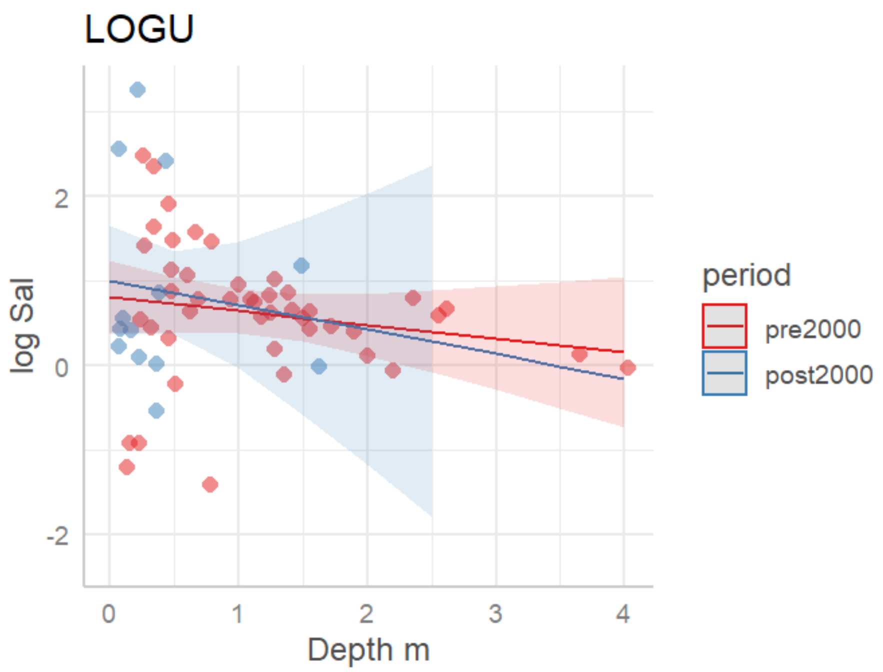
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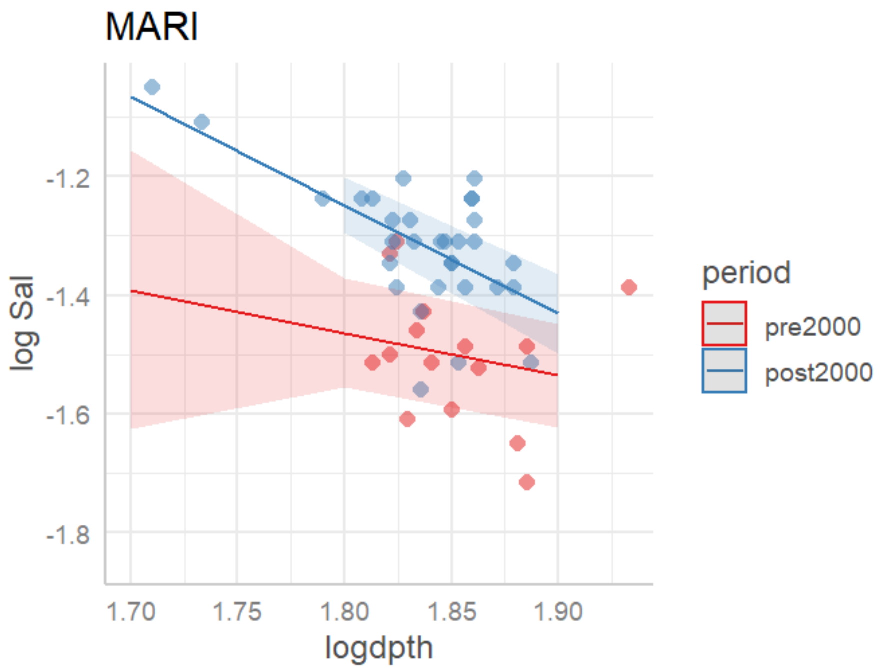
MARI
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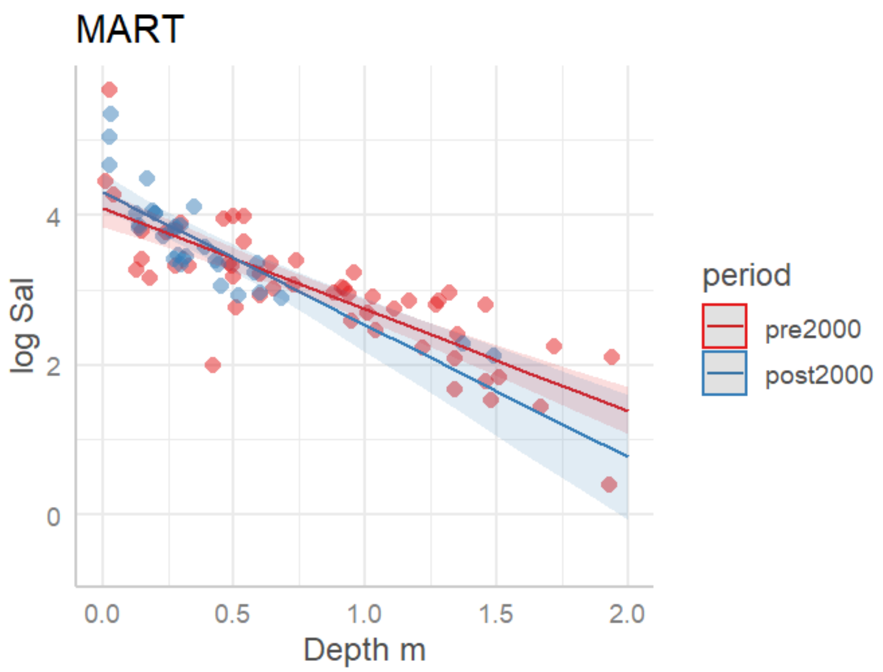
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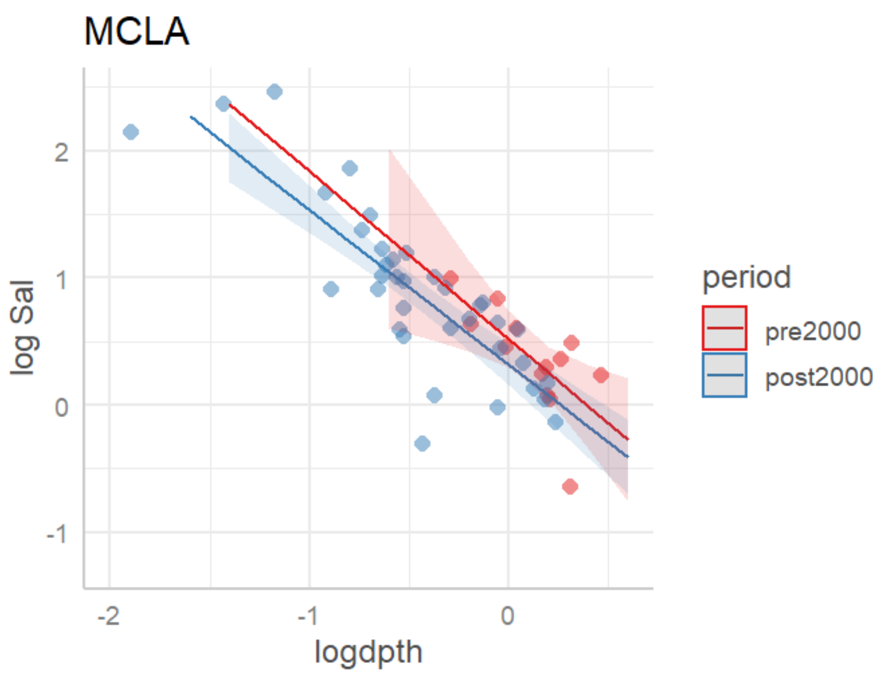
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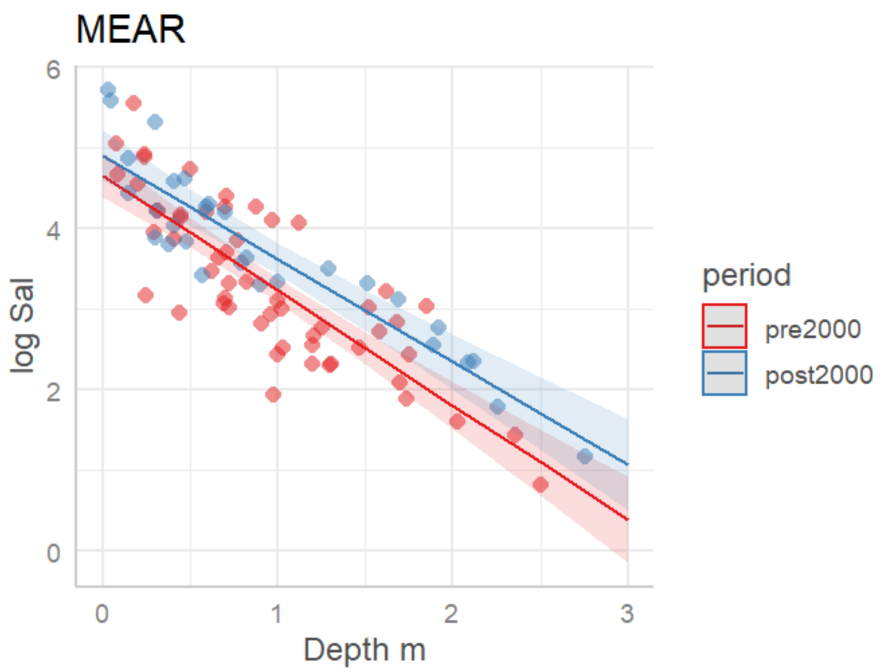
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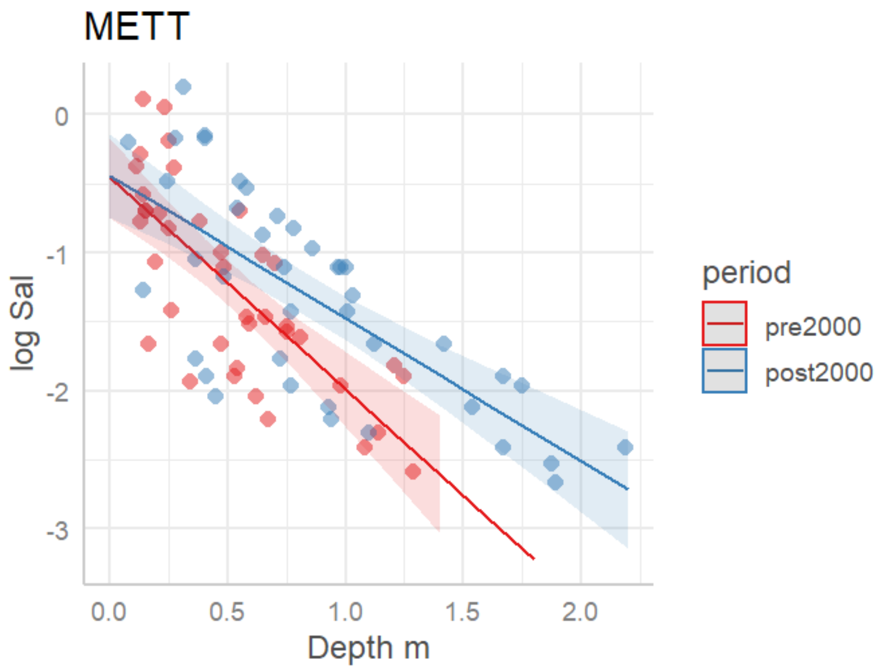
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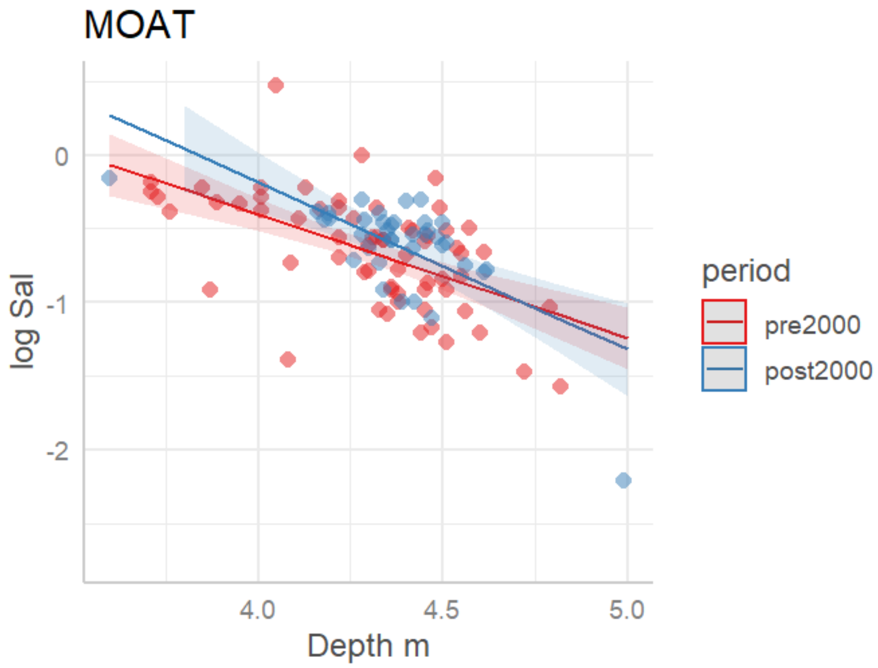
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Depth m
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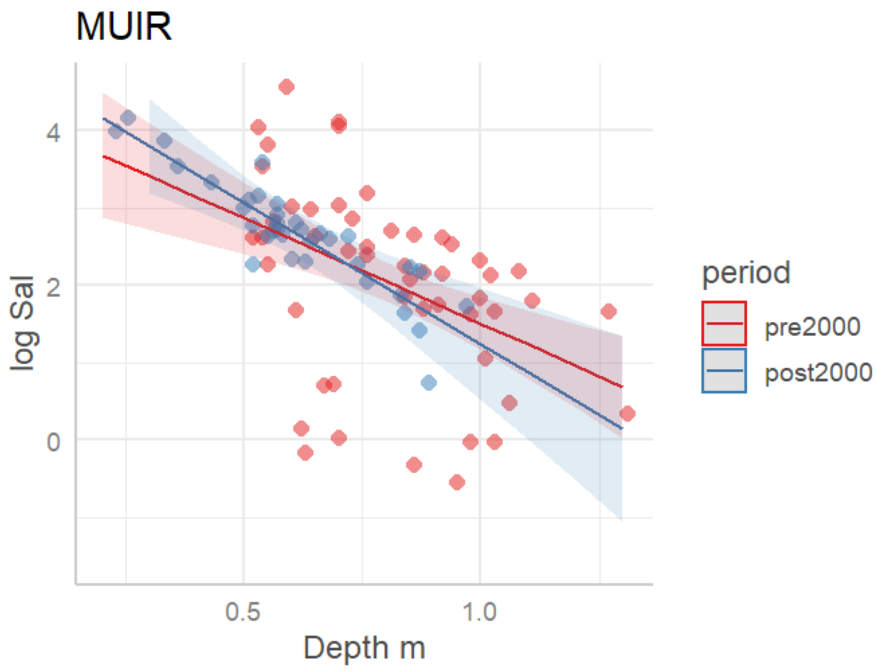
post2000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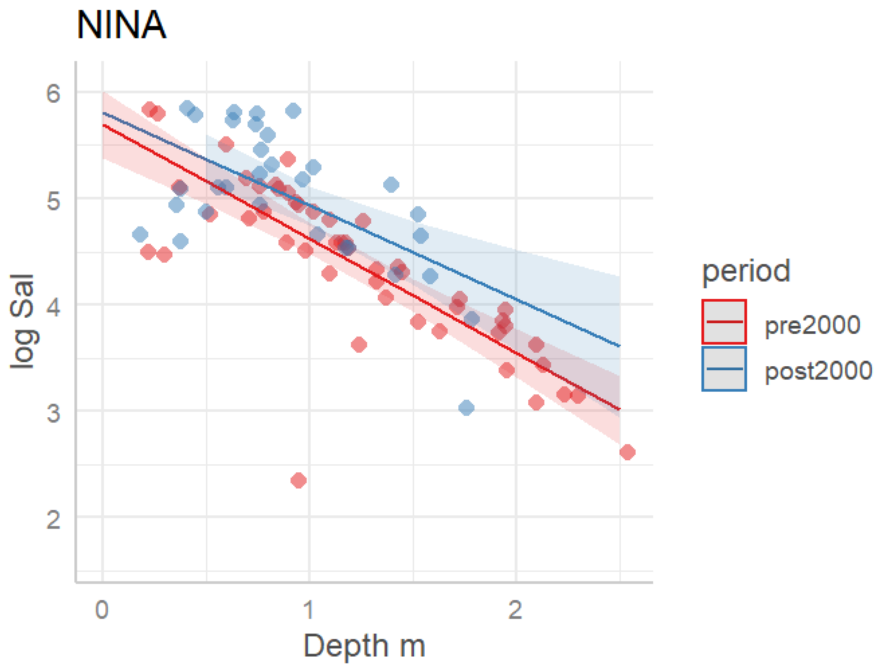
post2000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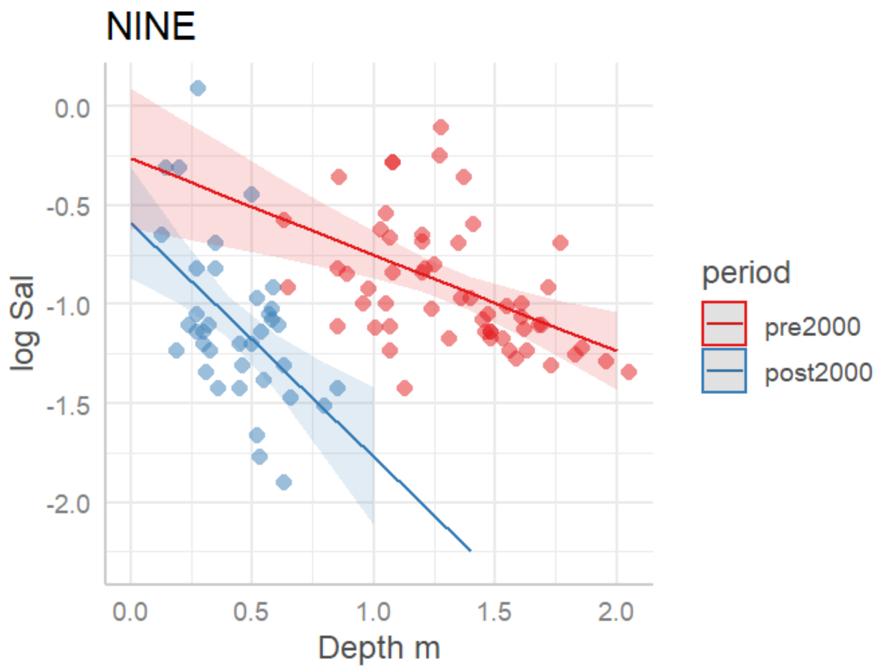
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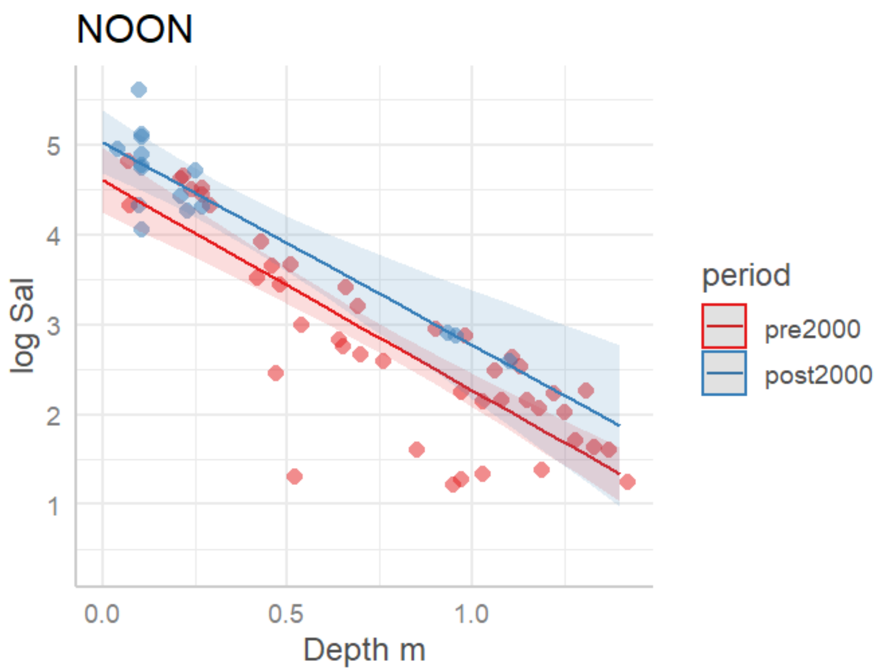
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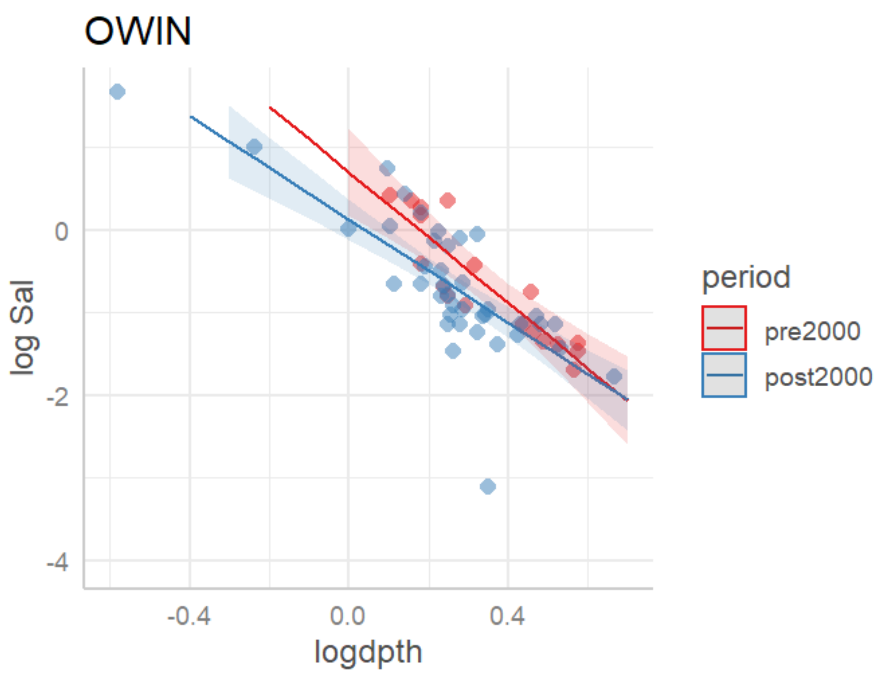
pre2000
post2000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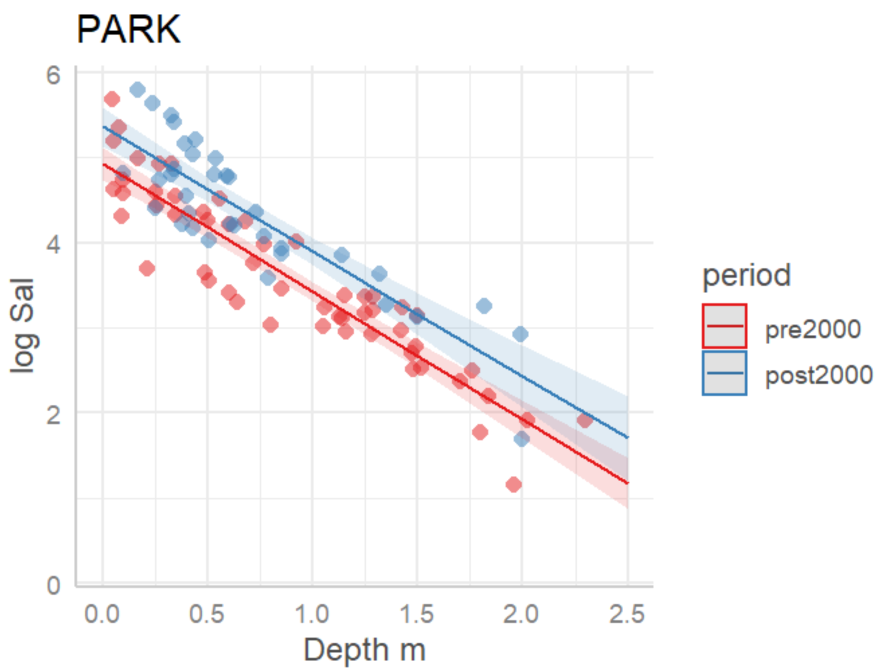
period
pre2000
post2000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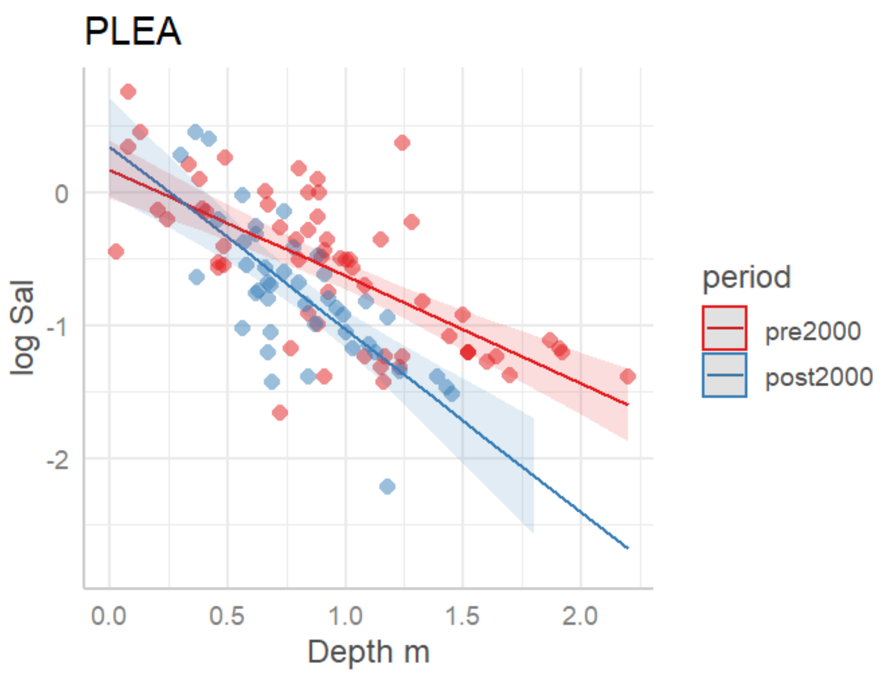
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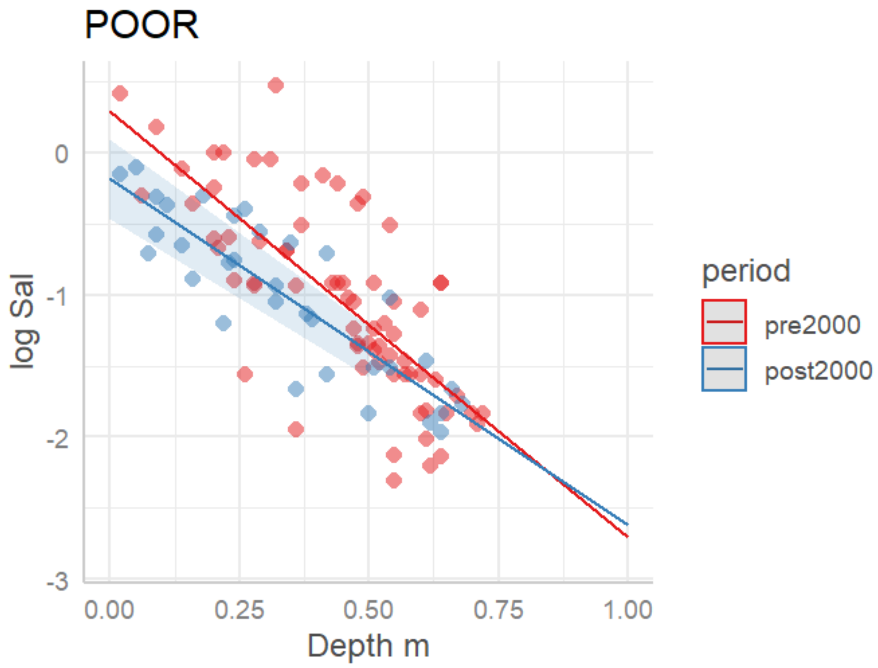
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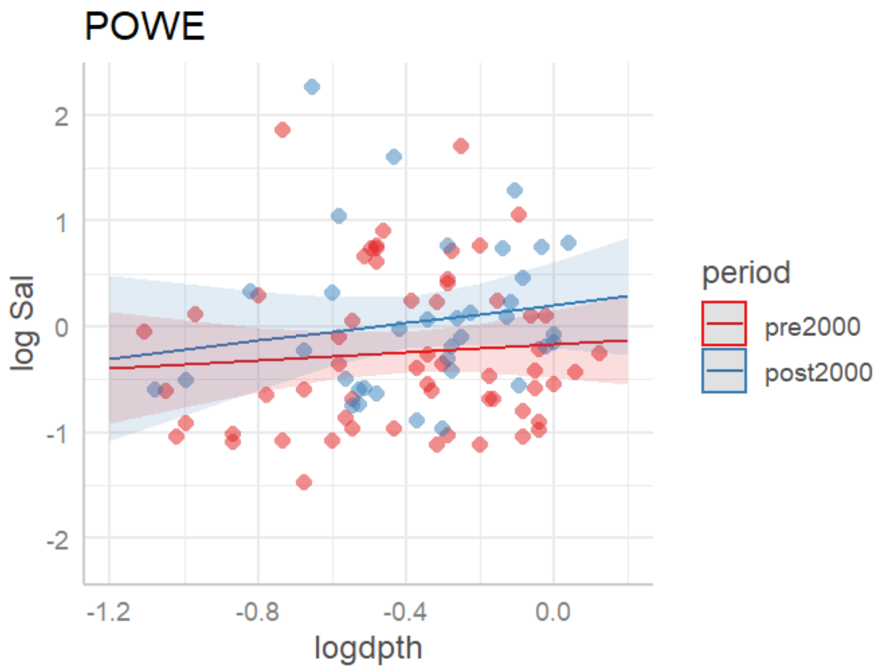
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logdpth
period
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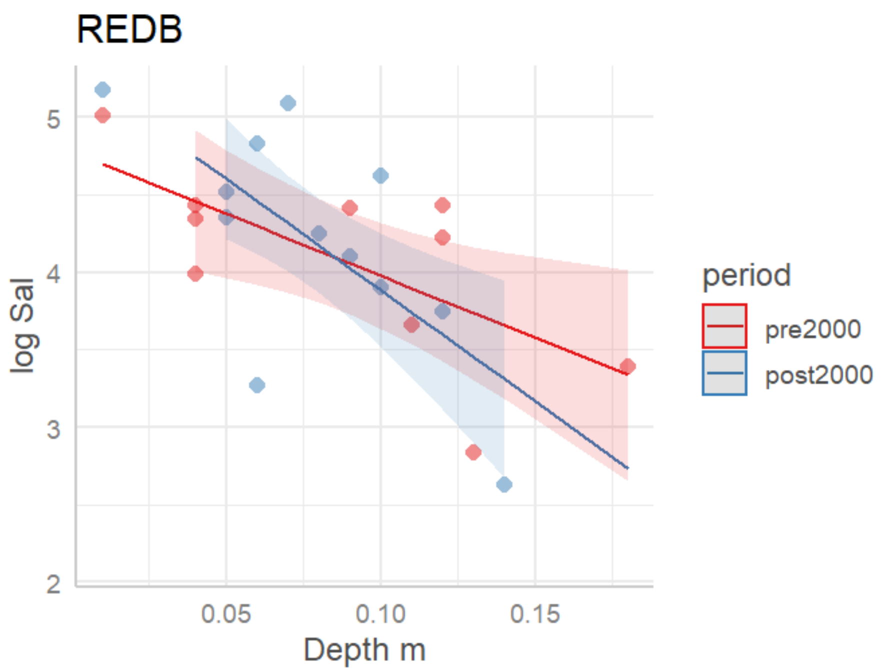
post2000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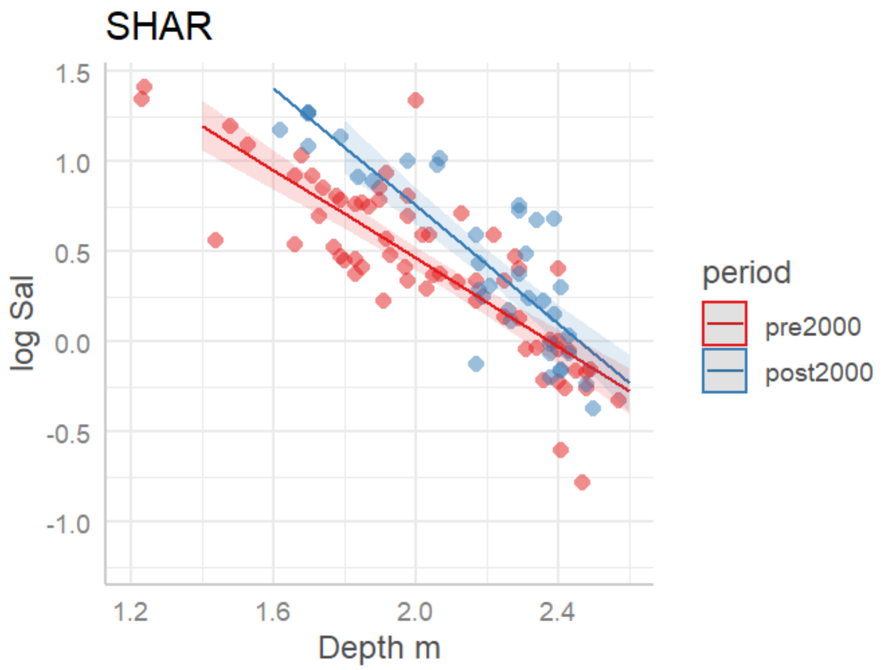
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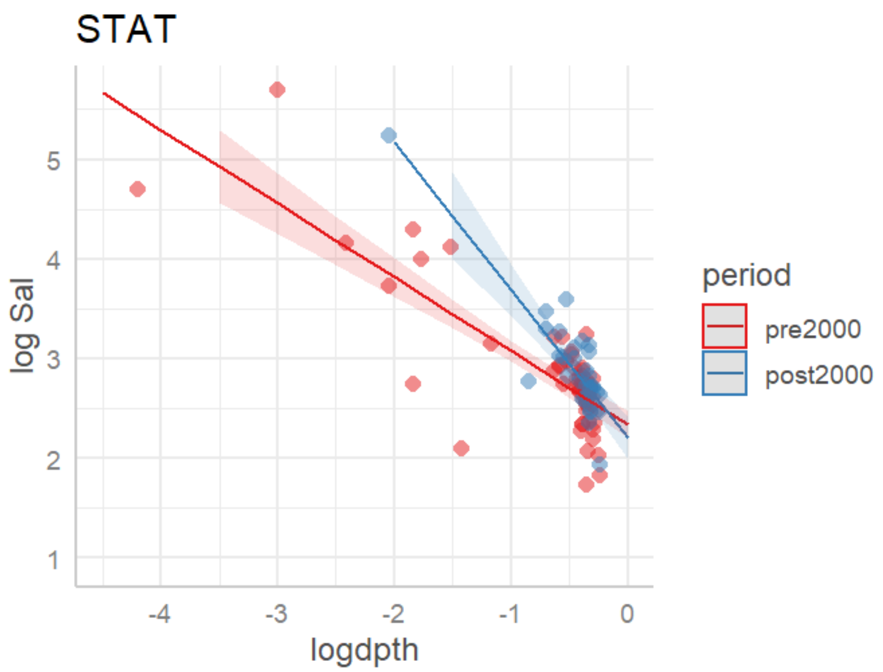
Depth m
period
pre2000
post2000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period
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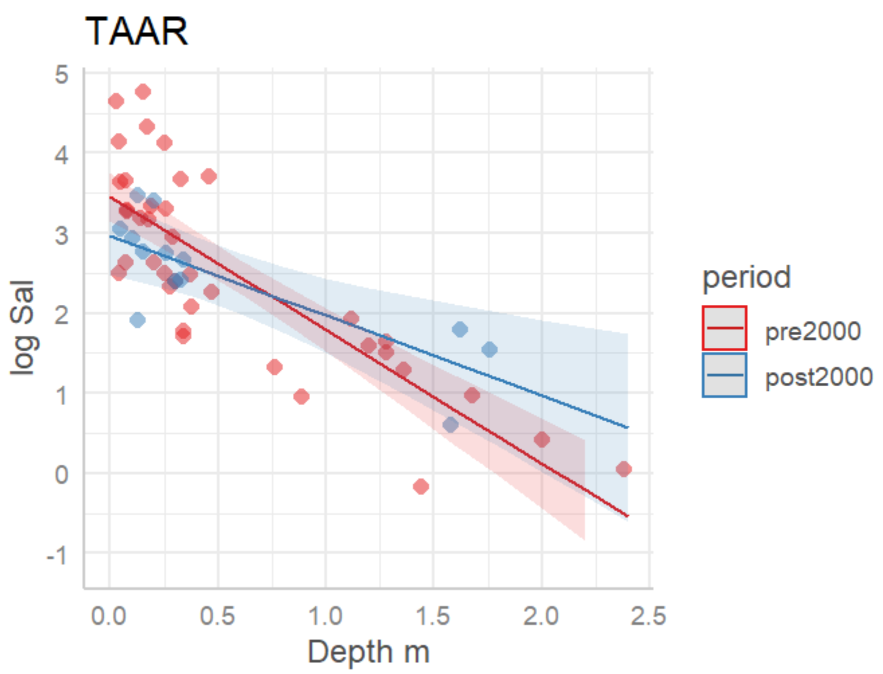
post2000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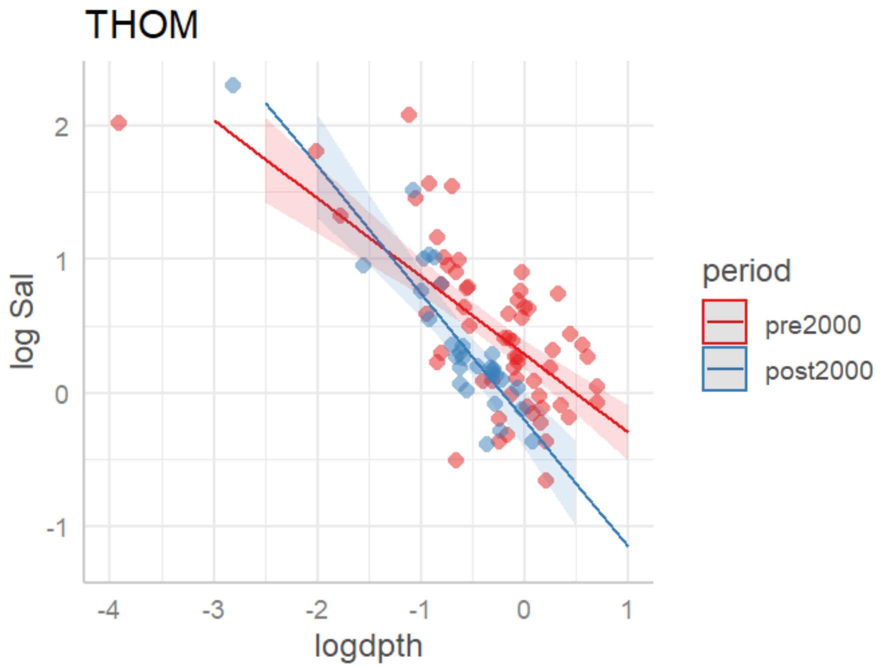
period
pre2000
post2000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1
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period
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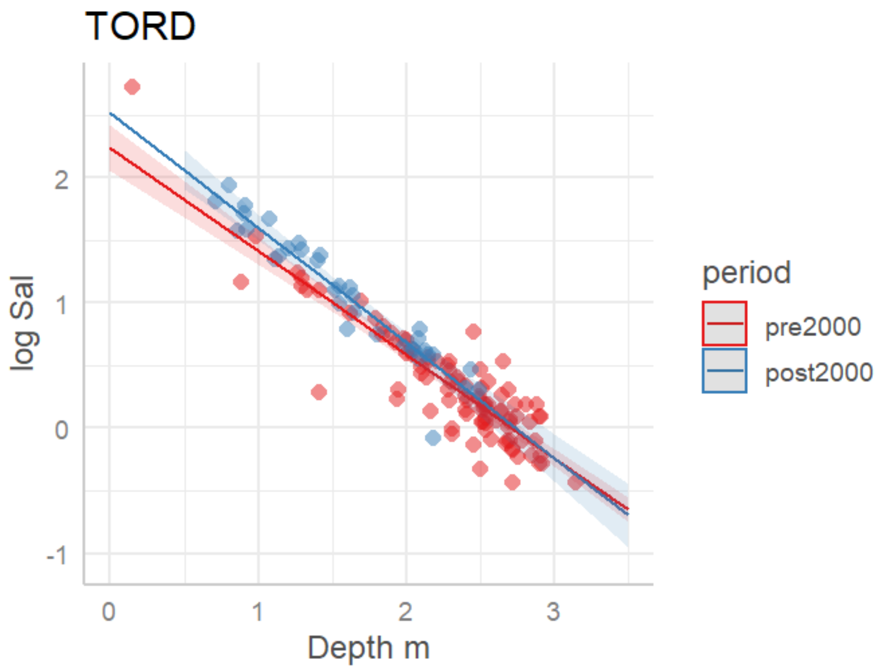
post2000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period
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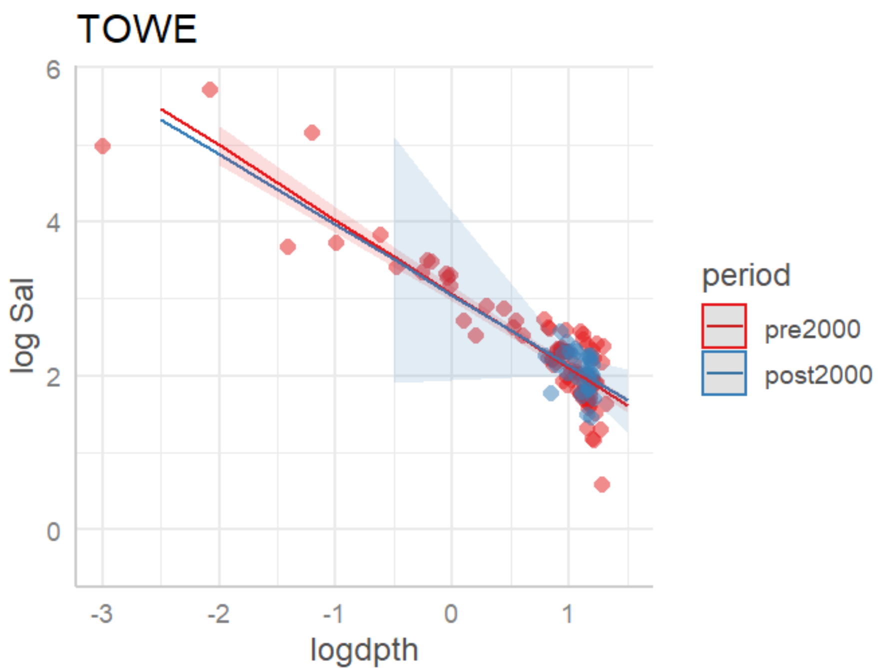
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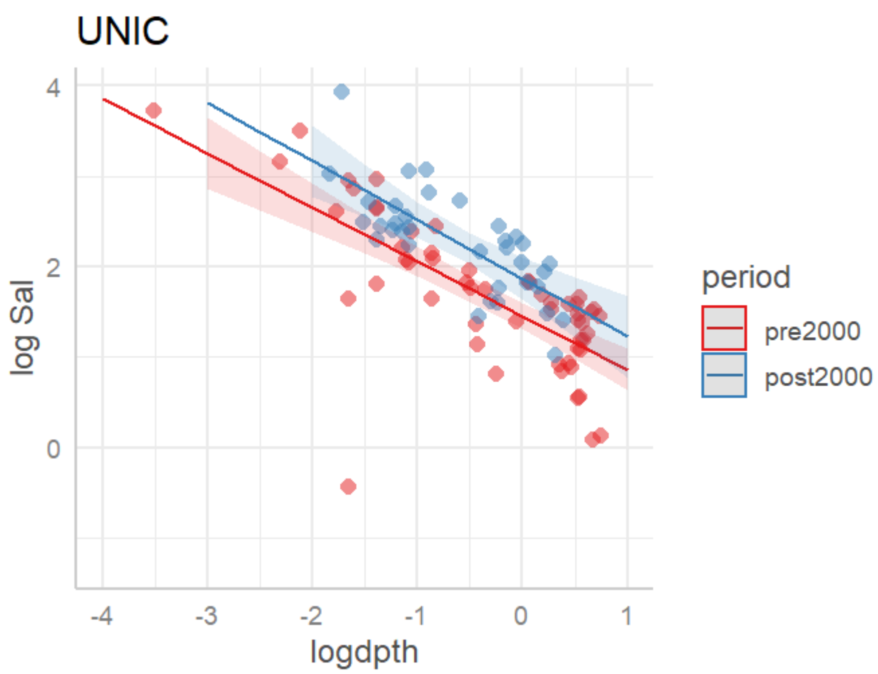
logdpth
period
pre2000
post2000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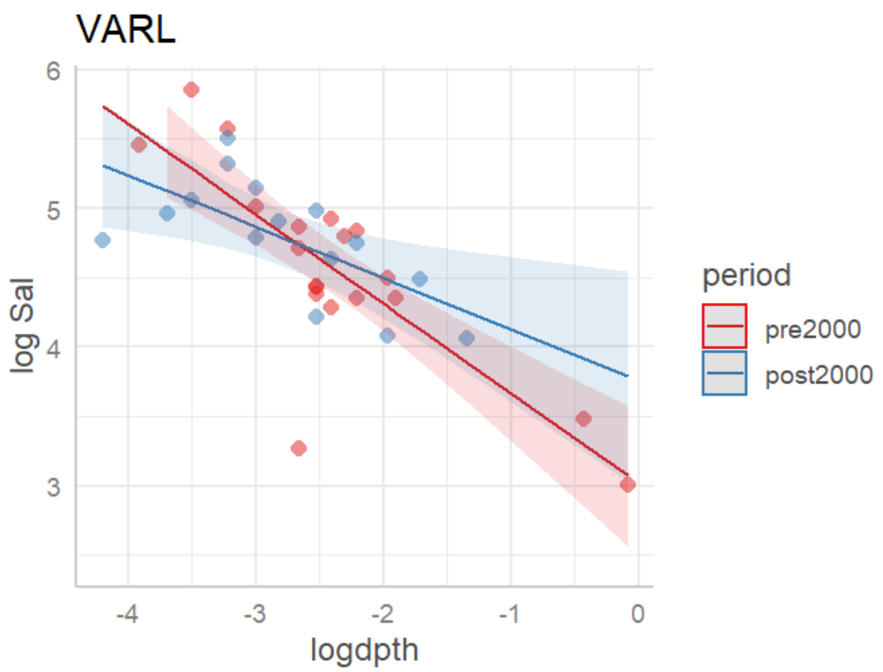
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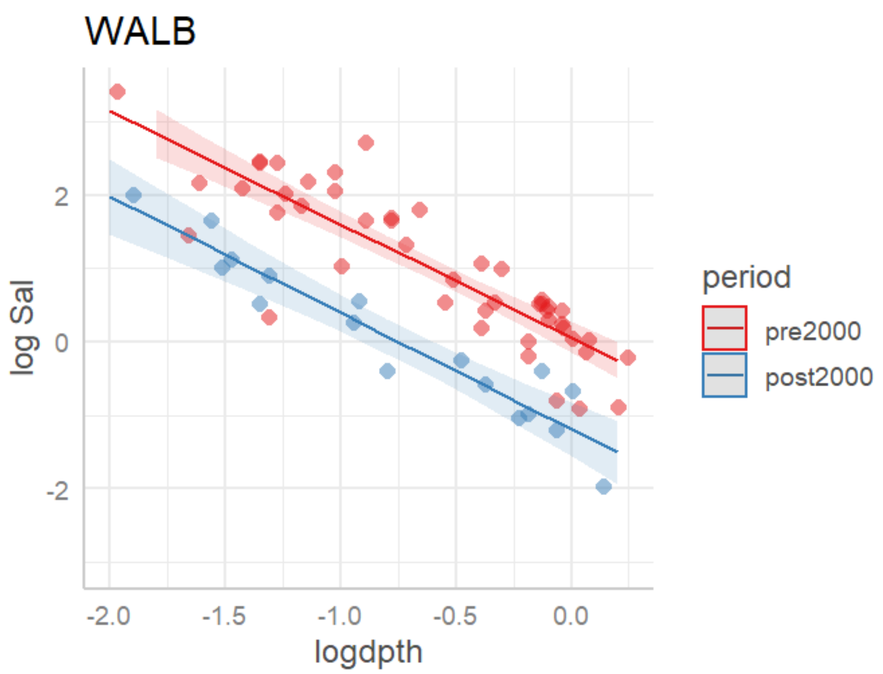
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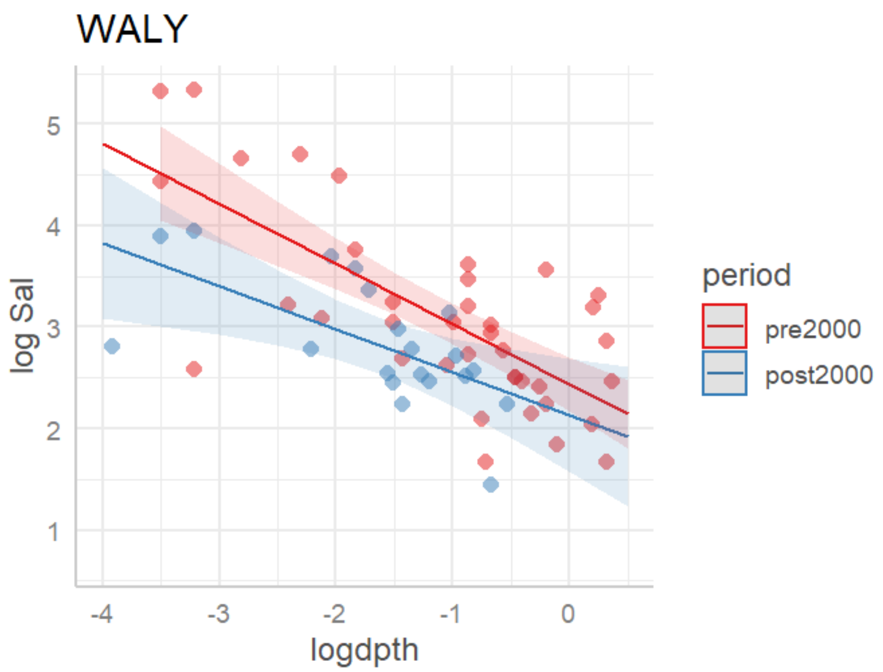
logdpth
period
pre2000
post2000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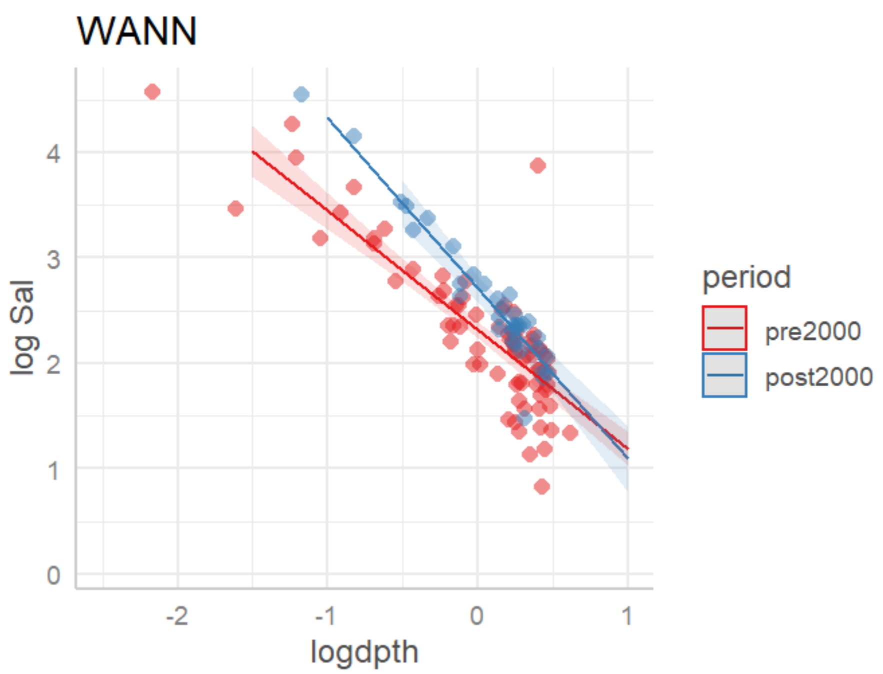
post2000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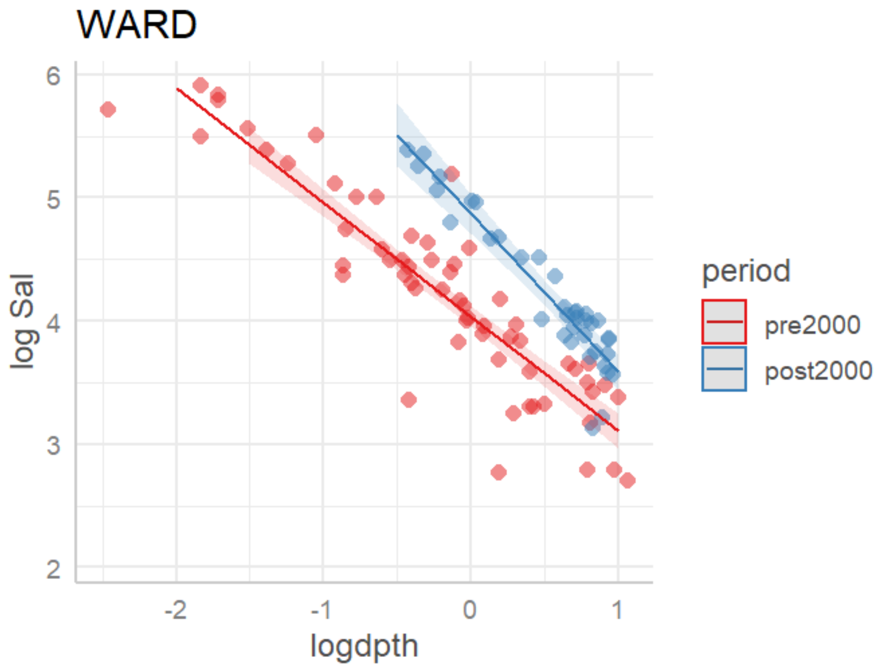
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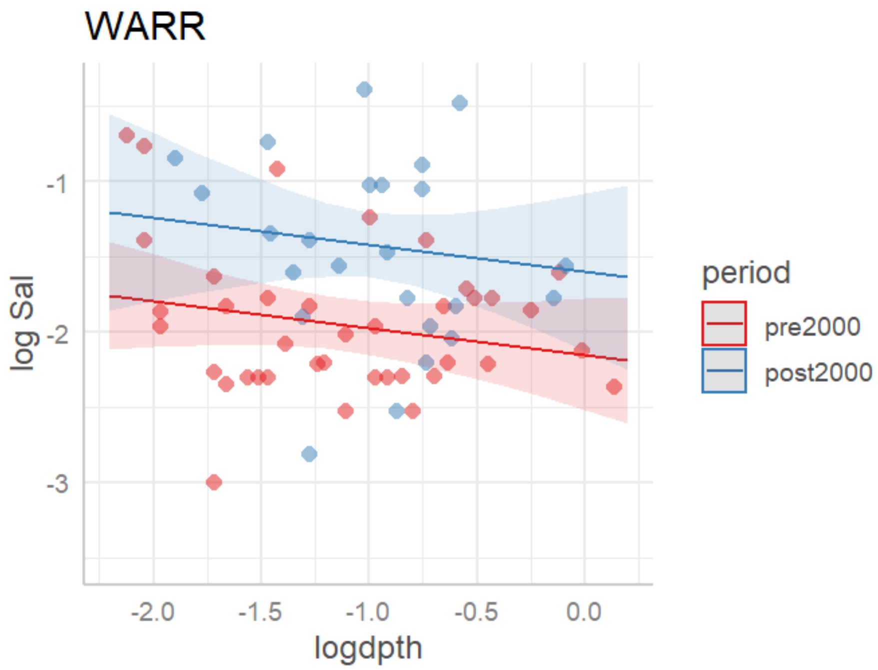
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period
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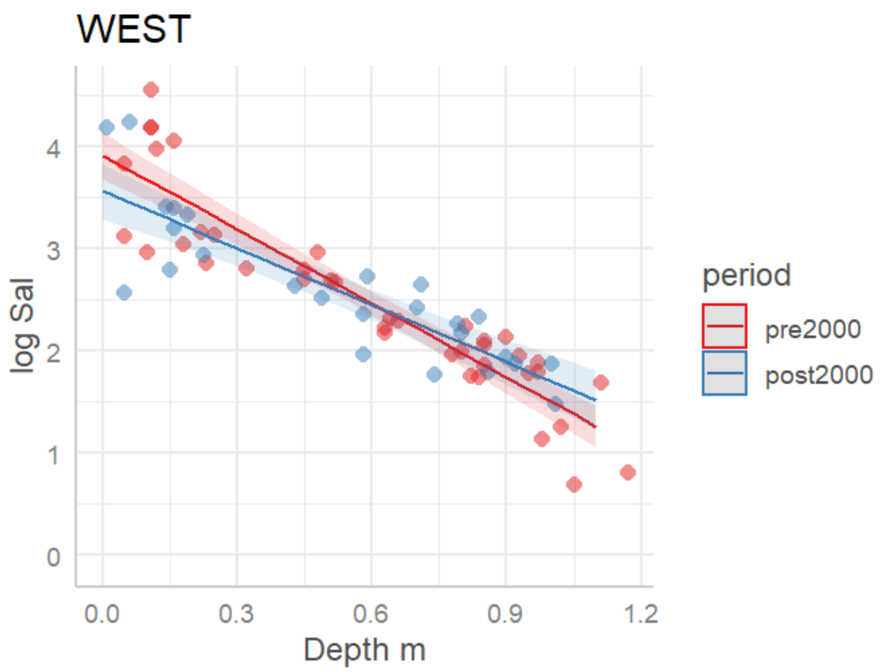
post2000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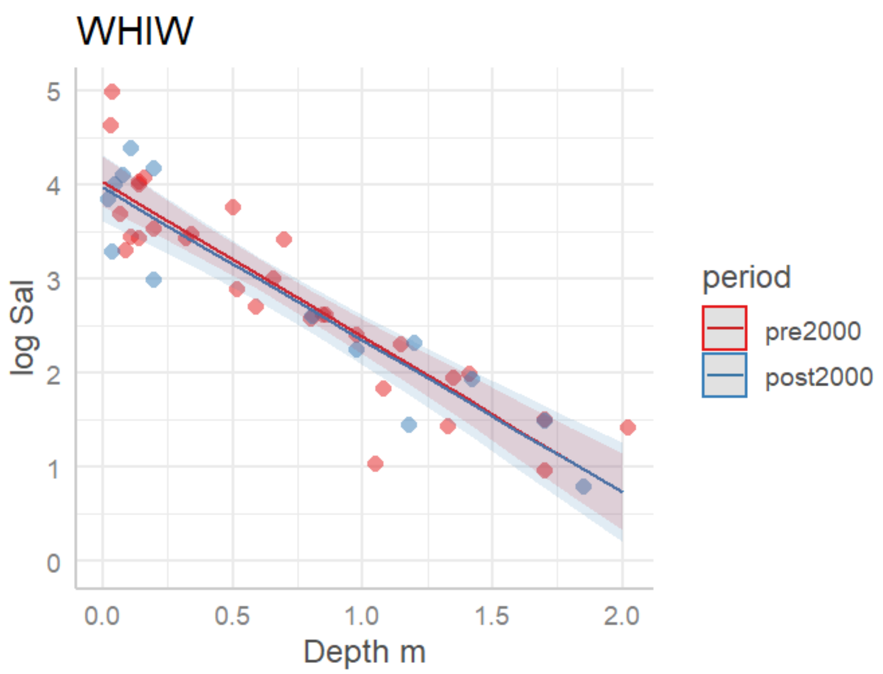
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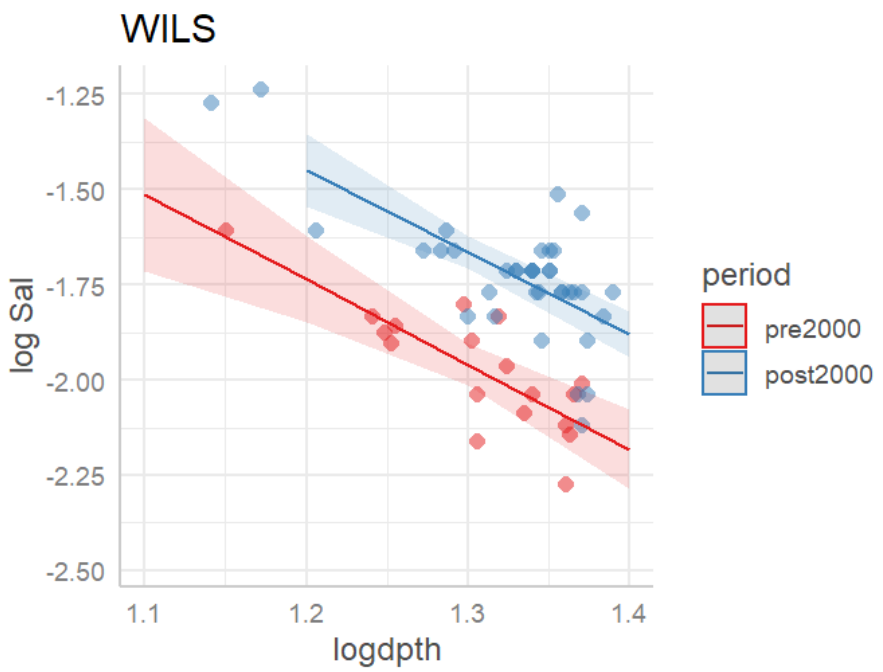
pre2000
post2000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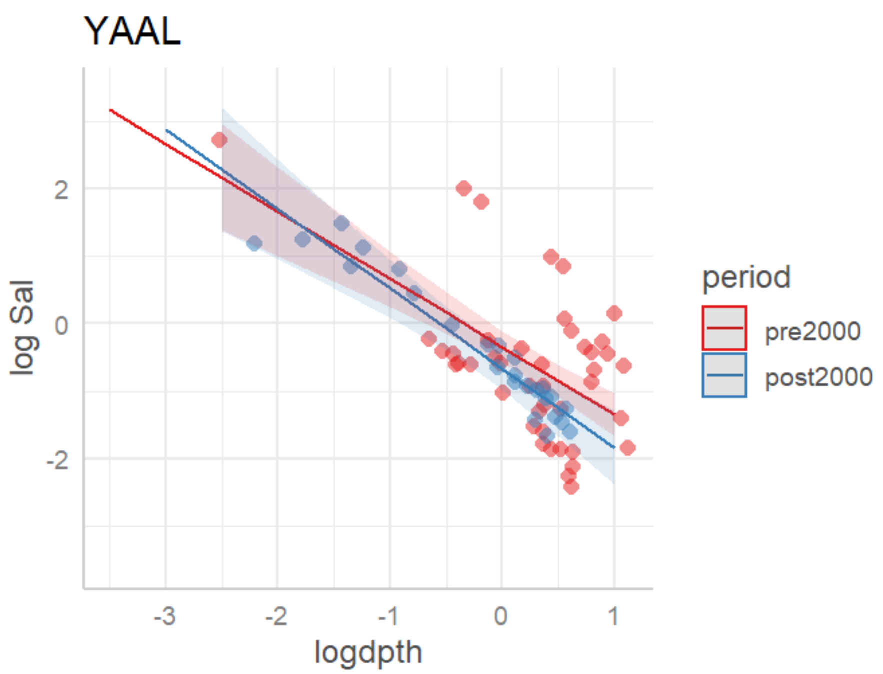
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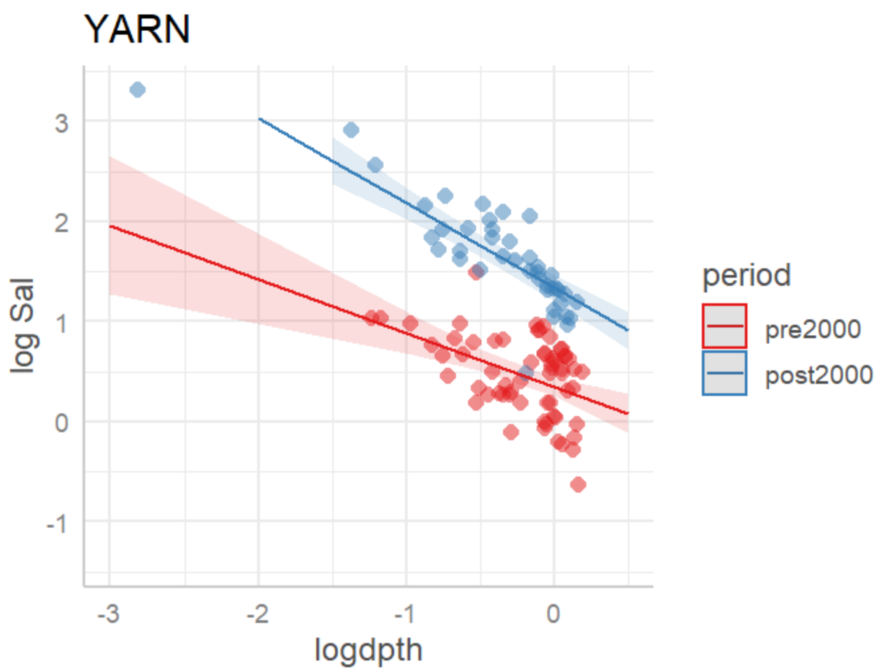
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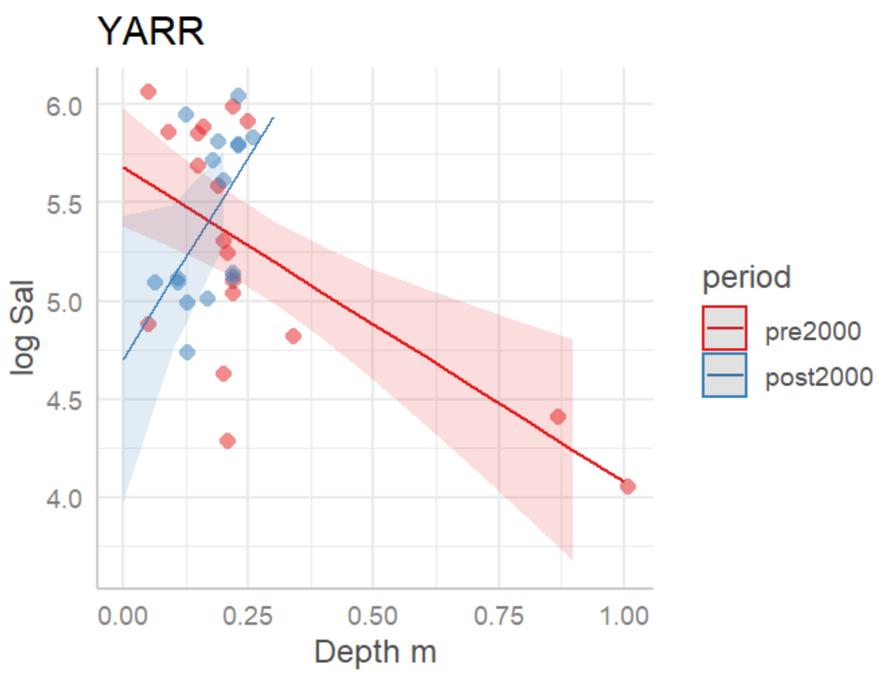
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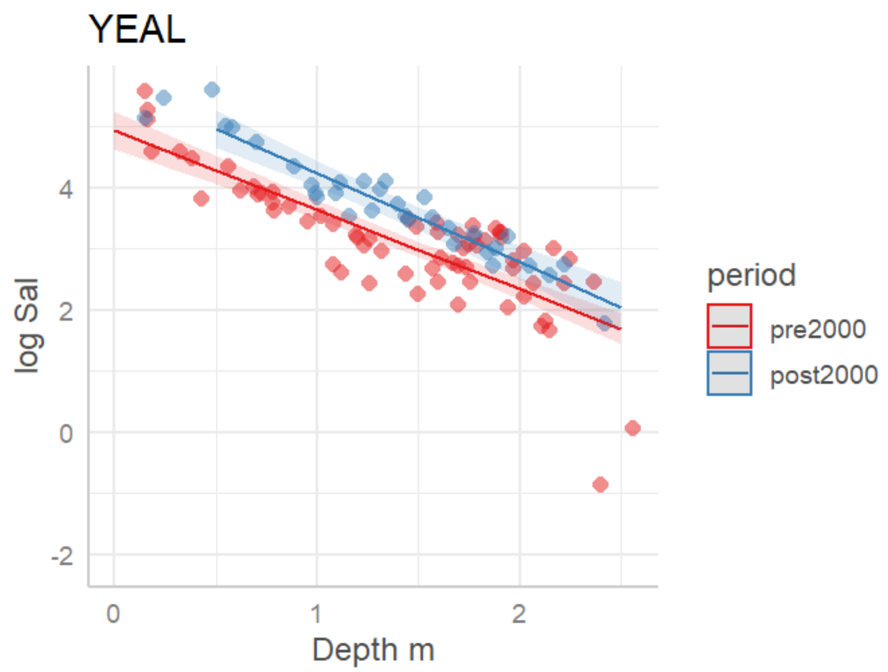
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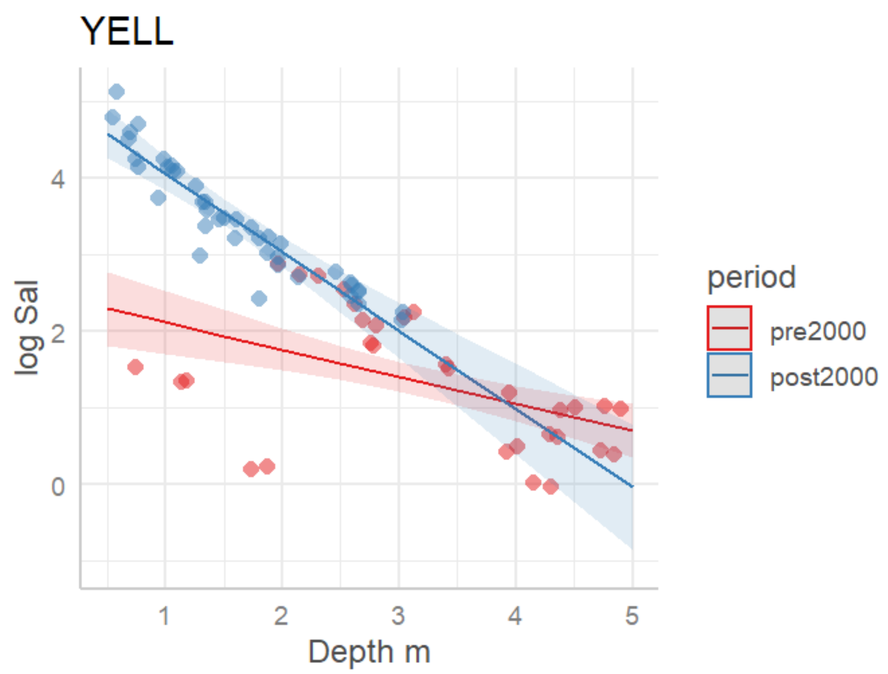
2
Depth m
period
pre2000
post2000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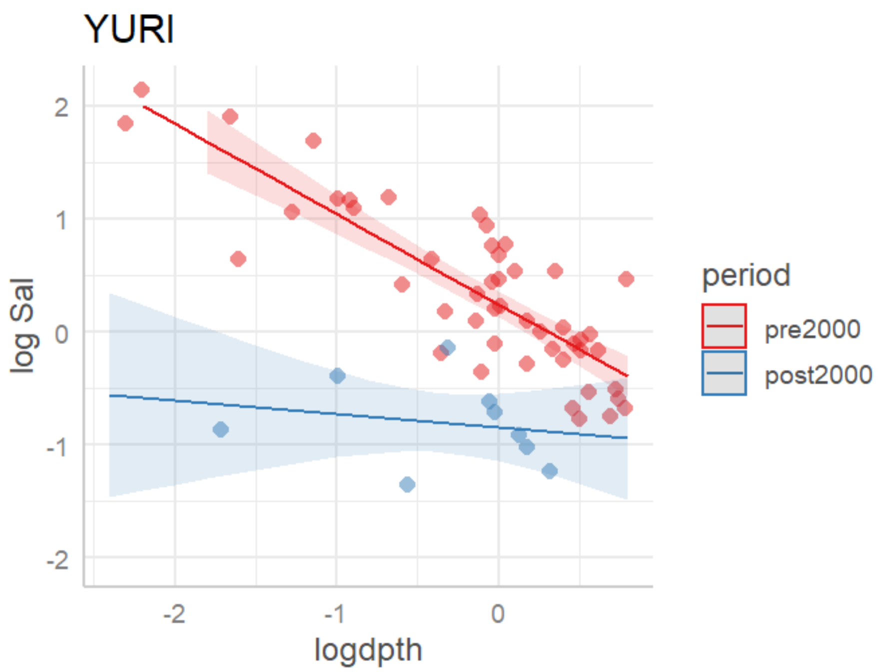
YURI
log Sal
2
1
0
-1
-2
-2
-1
0
logdpth
period
pre2000
post2000

Glossary

Ephemeral wetland	A wetland that is usually dry and fills only on rare occasions.
Groundwater	Water that has filled cracks or pores in soil and rocks.
Groundwater flow-through wetlandt	A wetland which exchanges water with (i.e. receives from and discharges to) groundwater.
Hydrology	The science of the water cycle.
Intermittent wetland	A wetland that dries completely each year but usually contains water at the end of each winter.
Ordinary differential equation	In mathematics it is an equation relating a function of one variable usually to the variable's rate of change.
Playa	Usually a terminal ephemeral lake developed from aeolian deflation in semi-arid conditions resulting in flat and shallow filling.
Power-law	An equation relating one variable (y) to another (x) raised to a power, i.e. $y=a\,x^{b}$, where a and b are numerical coefficients.
Salinity	The amount of salt dissolved in a body of water
Salinization	The process of increasing salt concentrations.
SWWMP	South-West Wetland Monitoring Program, 1977 - 2019
Terminal wetland/lake	A wetland without any surface water outlet.
Wetland	An ecosystem that has water on or near the surface, either permanently, seasonally, or intermittently.
Ephemeral wetland	A wetland that is usually dry and fills only on rare occasions.

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