11 Annex 1 – Methods

This Annex gives the methods applied to data for assessments of marine regions, and briefly describes the Water Framework Directive (WFD) methods used for the phytoplankton, macrophytes, zoobenthos and fish indicators. Details of WFD methods are given in reports under the UK Technical Advisory Group (TAG, www.wfduk.org) and reports by Competent Monitoring Authorities (CMAs). Some methods vary between devolved administrations (DAs). Classifications of coastal and other water bodies under the WFD are also given in reports by the DAs.

11.1 Nutrient enrichment

11.1.1 Analysis of RID Data

Total loads of nitrogen (N) and phosphorus (P)

Trends in the total loads of N and P (both unadjusted and flow adjusted) were assessed by fitting a smoother to the log loads assuming the errors were normally distributed and correlated with an AR1 structure. There was no evidence of nonlinearity except for N in the North Sea North; i.e. in most cases the underlying trend was linear (or log-linear on the untransformed scale). The trends in each time series were summarised by the estimated yearly percentage change in loadings between 1990 and 2014. For the linear trends, these estimates were given by

$$\%\,\text{yearlychange} = 100 * \exp(\hat{b} - 1)$$

where $\hat{b}$ is the estimated slope of the linear relationship, with significance determined by the significance of the linear relationship. Where there is evidence of nonlinearity, the yearly percentage change is estimated by taking the fitted log loads in 1990 and 2014, $\hat{y}_{1990}$ and $\hat{y}_{2014}$ respectively, and calculating:

$$\%\,\text{yearlychange} = 100 * \exp\left(\frac{\hat{y}_{2014} - \hat{y}_{1990}}{2014 - 1990} - 1\right)$$

with significance determined by a Wald test using the covariance matrix of the fitted values.

Loads per area and input type

RID data are recorded by PARCOM area (Figure A1.1). For each area / input type / nutrient, Mann-Kendall tests were used to analyse trends. This test is appropriate for detecting any type of monotonic trend (linear or nonlinear), assuming the data each year are independently distributed about the underlying trend. It is robust in the sense that outliers don't matter, but it will give erroneous results if the data are auto-correlated. The results are given as tau (test statistic) and significance (p-value), with a significance of 0 equivalent to p < 0.0001. If the trend is linear, then the Sen estimator (given as sen.slope) is a robust estimator of the trend. The sen.lbound and sen.ubound give 95% confidence intervals on the trend. The value of Sen can be converted to the % yearly change in load = 100 (exp(Sen) – 1). When Sen is less than 0.1, the % yearly change is approximately 100 Sen.

If the data are auto-correlated and the trend is linear, then Zhang's method can be used to get a more appropriate estimate of trend and a better test of significance.

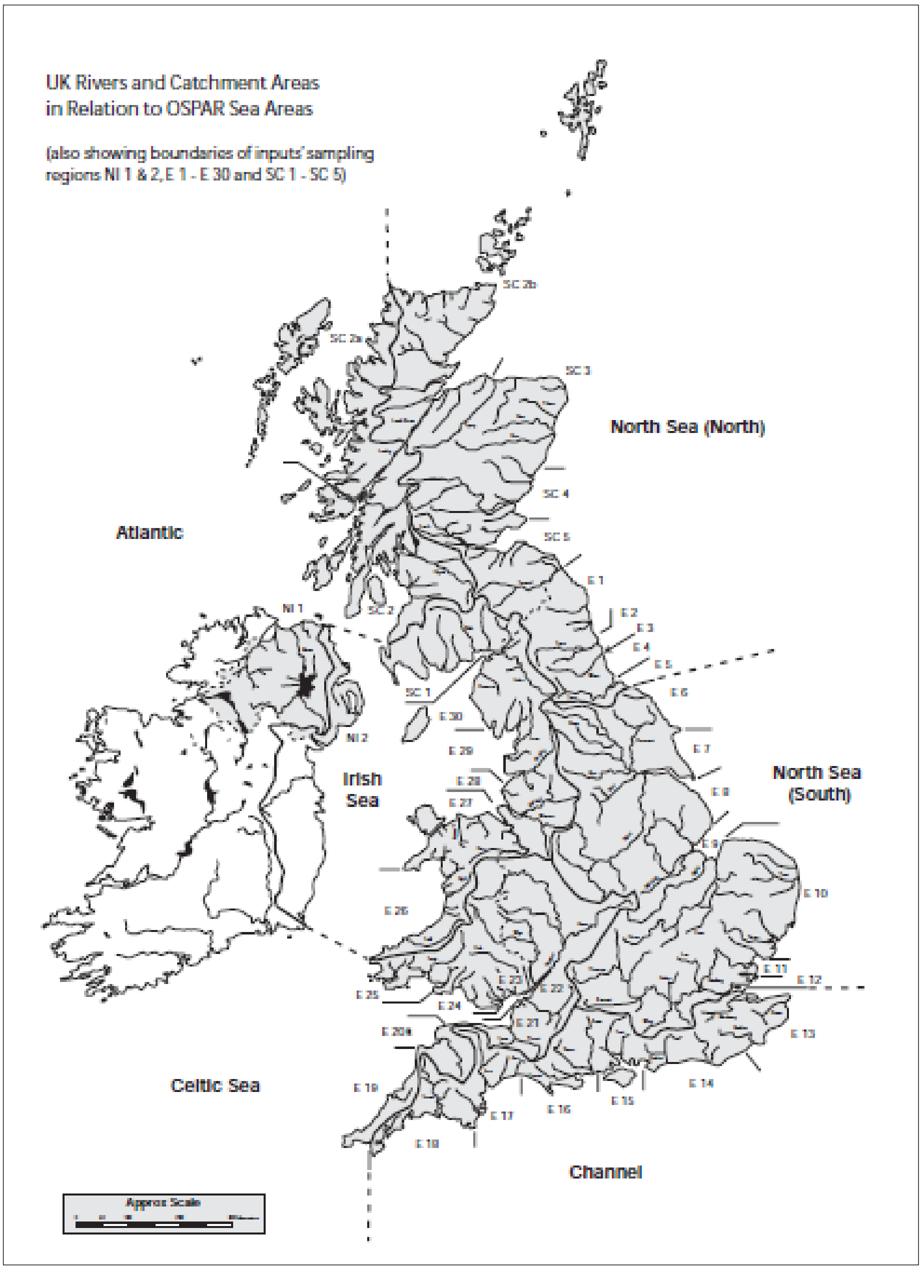


Figure A1.1: PARCOM areas (NI1 & 2, E1-E30, SC1-SC5) in relation to UK assessment regions.

Both sets of p-values were calculated for Riverine and Sewage loads; time series where there is clear evidence of nonlinearity are shown (e.g. Riverine E 1, both N and P). For industrial loads, the ordinary Mann-Kendall significance levels are recommended. Where there is evidence of step-changes in load, for example due to changes in discharges or reporting practices, the Mann-Kendall significance levels are likely to be more appropriate than the Zhang significance levels.

11.1.2 Nutrient concentrations

Nutrient data were obtained using a variety of sampling platforms, and samples were generally analysed following standard oceanographic procedures (e.g. see Greenwood et al 2010; Smith et al 2014). Approaches used to determine the reference values and thresholds used for winter concentrations of dissolved inorganic nitrogen (DIN), and ratios of DIN to dissolved inorganic phosphorus (DIP) are described in Foden et al (2011).

For WFD assessments, Devlin et al (2007b) developed an approach for using nutrients to support ecological assessments taking account of both nutrient concentrations and turbidity.

11.2 Direct effects

11.2.1 Chlorophyll

Chlorophyll data were obtained from a number of platforms; samples were analysed by a number of methods including fluorometry, spectrophotometry and pigment analysis (e.g. see Baretta-Bekker et al 2015; Walsham et al 2015). The 90th percentile was calculated over the growing season (March through October, inclusive). Determination of the reference values and thresholds used for chlorophyll in coastal and offshore waters is described in Foden et al (2011).

11.2.2 Phytoplankton indicators

The UK Technical Advisory Group (TAG) have developed tools for assessing WFD ecological quality elements, including a phytoplankton tool. The phytoplankton tool considers composition, abundance, biomass and planktonic blooms. For the second application of the OSPAR Common Procedure, the approach described in Devlin et al (2007a) was used for assessing phytoplankton in transitional and coastal waters. For the third application of the Common Procedure, WFD assessments have used the revised phytoplankton tool (UK TAG 2014a; UK TAG 2014b), which combines indices for Chlorophyll (90th percentile), elevated counts, and seasonal succession. The elevated count metric is based on the number of occasions that phytoplankton counts exceed an established threshold over the reporting period. The seasonal succession metric works on the measurement of the two main taxonomic groupings (diatoms and dinoflagellates) falling within a seasonal reference growth curve. The three indices are averaged to provide an overall phytoplankton assessment. An assessment can be made from one, or any combination, of the indices, if required.

11.2.3 Macrophytes

The OSPAR Commission (2008) states in particular the shift from long-lived to short-lived nuisance species like Ulva spp. is a relevant assessment of macrophytes for coastal areas. This was interpreted as the existence of excessive blooms of these opportunistic macroalgae. It is not a relevant parameter for offshore regions with no coast. Under the WFD, UK TAG have developed tools for assessing ecological quality elements, including macroalgae and other macrophytes. For the second application of the OSPAR Common Procedure, WFD thresholds and assessment results from the macroalgal tool developed by Scanlan et al (2007) were used for assessing macroalgae. For the third application of the Common Procedure, WFD assessments based on the revised macroalgal tool (UK TAG 2014c; UK TAG 2014d) were used, which includes composition, macroalgal cover, abundance and disturbance-sensitive taxa.

11.3 Indirect effects during growing season

11.3.1 Oxygen deficiency

Data on dissolved oxygen concentrations were obtained using a variety of sampling platforms, and samples were analysed following standard oceanographic procedures (e.g. Greenwood et al 2010; Queste et al 2012). Approaches used to determine reference values, thresholds and other assessment criteria include empirical studies (see Foden et al 2011), modelling studies (e.g. Große et al 2015) and expert groups (e.g. Baretta-Bekker et al 2014; OSPAR 2015). For marine waters, we have followed the assessment method used for the common assessment of common indicators (OSPAR 2015), i.e. to present the mean of the lowest quartile of near-bed oxygen concentrations and percentage saturation. WFD and OSPAR thresholds range from 4 to 6 mg l^{-1} and 50 to 75 % saturation (Best et al 2007). For marine waters, we have used 6 mg l^{-1} and 60 % saturation for the assessments. Data were filtered by season (stratification period, July to October, inclusive) and depth (deepest sample within 10 m of the seabed, where the water column depth was <500 m).

11.3.2 Zoobenthos and fish

UK TAG have developed tools for assessing WFD ecological quality elements for zoobenthos and fish. These include the infaunal quality index (IQI) for zoobenthos ("benthic invertebrate fauna") (UK TAG 2014e) and fish fauna in transitional waters (UK TAG 2014f).

The IQI enables an assessment of the ecological health of the biological quality element, "benthic invertebrate fauna" (zoobenthos), and considers abundance, diversity and the presence and/or absence of pollution-tolerant and disturbance-sensitive taxa. The IQI is a multimetric index composed of three individual components: the AZTI Marine Biotic Index (AMBI), Simpson's Evenness (1-'), and the number of taxa (S).

The transitional fish classification index (TFCI) enables an assessment of the ecological health of the biological quality element, "fish fauna", and considers composition, abundance, and the presence and/or absence of disturbance-sensitive taxa. The TFCI is a multimetric index composed of ten individual components which include measures of species diversity and composition, species abundance, nursery function, and trophic integrity.

11.4 Representativeness in space and time

The representativeness of the available data in space and time over the assessment period (2006-2014) was calculated using a method similar to that described by Brockmann and Topcu (2014).

The spatial representativeness was assessed by analysing the representativeness in longitude and latitude separately. In this way, these dimensions were treated independently. Since we wanted all the UK assessment regions to have the same width for the spatial and temporal intervals (3/25 degrees for the latitude and longitude transects, which is approximately 13 km in latitude and 7-10 km in longitude, depending on the latitude, and 1 month for the temporal intervals), all the regions had a different number of equally-spaced intervals. This was due to differences in the sizes of the assessment regions.

If an interval is sampled, it gets the full confidence of 100/N, with N the number of intervals in which a transect/time series has been divided. Thus, if all the intervals have been sampled, the representativeness is 100%.

If an interval is not sampled, it gets a reduced score that depends on the difference in gradient between the next sampled cells (calculated as a percentage of the overall gradient) and the number of connected empty cells. In general, the representativeness of an empty interval is given by (see Brockmann and Topcu 2014):

$$R = OR - G * n * OR/100 \qquad (1)$$

with R is the representativeness of the empty interval (%), OR is the full representativeness of the interval (%), *n* is the number of empty intervals, and G is the maximum difference between min-max values of the closest sampled cells divided by the overall difference in min-max (in %). Notice that this is a slight modification of G with respect to Brockmann and Topcu (2014), and follows

Annex 8 of the guidance (sections B1 and B2, OSPAR 2013b). If R is negative, it is assigned a score of 0, since it is not contributing to the overall representativeness.

The overall confidence of the representativeness in space and time was taken as the worst score in either space or time (see OSPAR 2013b Annex 8, Section B3).

12 Annex 2 - Inventory of available marine data

Datasets used – UK (see Table A2.1):

1. MERMAN (BODC). Discrete samples for chlorophyll (by fluorometry), dissolved oxygen, salinity and temperature, and nutrients (including nitrate, nitrite, total oxidised nitrogen, ammonium, phosphate and silicate). From 1999 to 2014. MERMAN data did not include water column depth so this was extracted from GEBCO bathymetry.
2. NODB (BODC). Discrete bottle samples and calibrated profile data for where bottles were fired. Chlorophyll (variety of methods, only relevant ones used and maximum chlorophyll value taken where more than one method was used simultaneously), oxygen, salinity and temperature, nutrients (including nitrite, total oxidised nitrogen, ammonium, phosphate and silicate). From 1990 to 2014.
3. Sapphire (Cefas). Discrete samples of chlorophyll, dissolved oxygen, salinity and temperature, and nutrients (including nitrate, nitrite, total oxidised nitrogen, ammonium, phosphate and silicate). From 1990 to 2012. Sapphire data did not always include water column depth so this was extracted from GEBCO bathymetry where missing. Some degree of overlapping between the MERMAN and the Sapphire dataset is possible, especially after 2010. Future versions of this report will try to minimise the overlapped data.
4. SmartBuoy (Cefas). Weekly averages of calibrated continuous data from Smartbuoys and landers for chlorophyll, dissolved oxygen, salinity and temperature, and nutrients (including nitrite, total oxidised nitrogen, and silicate). From 2000 to 2014.
5. Scottish monitoring stations (MSS). Weekly samples from four coastal monitoring stations for chlorophyll, dissolved oxygen, salinity and temperature, and nutrients (including nitrate, nitrite, total oxidised nitrogen, ammonium, phosphate and silicate). From 1997 to 2013.

All datasets were averaged by station, datetime and sample depth to average replicates, and then combined into a UK dataset.

To incorporate data collected in UK waters by other countries, and data that was submitted directly to ICES and not via BODC, we also incorporated data from ICES OCEAN. This included bottle data and profiles aggregated to standard depths, for chlorophyll, dissolved oxygen, salinity and temperature, and nutrients (including nitrate, nitrite, ammonium, phosphate and silicate) from 1990 to 2014. Total oxidised nitrogen was calculated by summing nitrate and nitrite. Water column depth was normally included, but where it was not it was obtained from GEBCO bathymetry.

There were some replicates between the UK dataset and the ICES dataset. In order to remove these, they were matched based on spatial and temporal location. By rounding latitude and longitude to 2 decimal places, sample depth to the nearest 5 m and datetime to the nearest minute. This was used to create a spatiotemporal ID and each dataset was averaged based on this ID. Samples were removed from the ICES dataset where they were also present in the UK dataset, and then the two datasets were combined to produce a final dataset for the assessment.

The dataset was then separated into nutrients, chlorophyll, and oxygen, and filters applied to extract the relevant season and portion of the water column.

For nutrients:

- Between November and February. November and December are classified as belonging to the following year as the winter covers two years but affect growth in the following spring
- DIN calculated by summing total oxidised nitrogen and ammonium.
- Ratios calculated: DIN:DIP and TOXN:DIP.

- Data averaged over the whole water column for each cruise station and day, with the exception of MERMAN data where datetime was used instead of day as there were multiple records in different locations (along transects) for the same station and day.

For chlorophyll:

- Between March and October (inclusive).
- Data averaged over the whole water column for each cruise station and day, with the exception of MERMAN data where datetime was used instead of day as there were multiple records in different locations (along transects) for the same station and day.

For oxygen:

- Only the deepest sample at each cruise/station using the day and station number. If there were two samples on the same day at the same depth, both were retained.
- Only samples within 10 m of the seabed.
- Between July and October (inclusive).
- Oxygen saturation was calculated from oxygen concentration, temperature and salinity.

In this report, “raw data” refers to the dataset that results from applying all the filters above. The “assessed data” refers to results from statistical techniques per year/ per season/ per variable/ per region applied to the raw data. Data were included in assessments only where five or more data points were available.

SmartBuoy Data

SmartBuoys have been deployed in marine waters at sites where risks from anthropogenic nutrient inputs were considered to be greatest (Table A2.2). Some SmartBuoys are still active, but some have been discontinued. SmartBuoy moorings and instruments were also deployed for one to two years for a research programme in 2007/2008: one north of the Dogger Bank (North Dogger) in the northern North Sea (NNS), and one at the Sean Gas Fields in the southern North Sea (SNS). At North Dogger, the mooring included a surface buoy, a mid-water tether, and a benthic lander. In the Sean Gas Fields, a benthic lander was deployed. SmartBuoy instuments are used to monitor physical and chemical parameters at high frequency using sensors calibrated against *in situ* measurements (see Greenwood et al. 2010), and to collect samples for subsequent analyses.

Table A2.1: Summary of available data (raw data) in each of the UK regional seas for assessments, for the period 2006-2014. The 'source' shows the database from which data were obtained. The 'count' shows the number of data points available after filtering (see Figure 2) by salinity (>30), season (for winter nutrients, growing season chlorophyll and stratified season DO) and after removal of replicates. In the case of vertical profiles, the count is shown as one per vertical profile, which is independent of the resolution of the profile. This is because a depth averaged value is provided for all the variables, except oxygen, for which the deepest value (as long as it belongs to the deepest 10 m of the water column) is selected. DIN = dissolved inorganic nitrogen (nitrite+nitrate+ammonium), DIP = dissolved inorganic phosphorus, TOxN = total oxidised nitrogen (nitrite+nitrate), DO = dissolved oxygen, x = no data.

		DIN (µM)	**DIN:DIP**	**TOxN (µM)**	**Chlorophyll (µgl-1)**	**Near bed DO**
CP2	**Source**	**Count**	**Count**	**Count**	**Count**	**Count**
1	BODC	x	X	x	x	x
	ICES	52	15	1022	755	181
	MERMAN	2093	1964	3780	306	157
	SAPPHIRE	85	85	311	93	11
	SMARTBUOY	x	X	17	45	17
	MSS	36	X	209	230	X
2	BODC	x	X	x	x	X
	ICES	22	22	519	40	55
	MERMAN	275	275	372	207	17
	SAPPHIRE	395	395	1873	314	30
	SMARTBUOY	x	X	380	444	7
3	BODC	x		x	X	X
	ICES	3	3	73	1	3
	MERMAN	46	46	61	7	1
	SAPPHIRE	76	75	272	16	X
	SMARTBUOY	x	X	x	X	X
4	BODC	x	X	x		X
	ICES	13	13	161	18	16
	MERMAN	81	81	90	40	X
	SAPPHIRE	115	114	457	40	X
	SMARTBUOY	x	X	x	0	X
5	BODC	x	X	x	x	X
	ICES	37	24	291	31	8
	MERMAN	423	355	527	270	104
	SAPPHIRE	246	245	x	529	X
	SMARTBUOY	x	X	123	175	X
6	BODC	x	X	x	x	X
	ICES	14	6	21	433	47
	MERMAN	1204	1172	2239	85	49
	SAPPHIRE	x	X	12	x	X
	SMARTBUOY	x	X	x	x	X
	MSS	56	X	160	250	X
7	BODC	x	X	24	x	X
	ICES	8	2	115	517	55
	MERMAN	645	615	1240	87	35
	SAPPHIRE	x	X	x	0	X
	SMARTBUOY	x	X	x	x	X
	MSS	46	X	256	x	X
8	ICES				111	

Table A2.2: Summary of time series of data available from SmartBuoy moorings. Physical and chemical parameters are monitored at high frequency using sensors calibrated against in situ measurements (see Greenwood et al. 2010). Phytoplankton samples are collected at various time intervals. n = total number of samples collected.

Location	**First deployment**	**Active?**	**End date**	**Data on physical and chemical parameters (**e.g. temperature, salinity, nutrients, chlorophyll)	**Phytoplankton samples (sampling period)**
NNS					
North Dogger	Feb-07	No	Sep-08	Near-continuous	Feb-07 to Nov-07, n = 10
SNS					
Warp (Thames)	Nov-00	Yes		Near-continuous	Apr-01 to Dec-13, n = 105
West Gabbard	Nov-00	Yes		Near-continuous	Mar-03 to Oct-14, n = 147
Gabbard	May-01	No	2002	Near-continuous	May-01 to Aug-02, n = 13
Dowsing	Jan-09	Yes		Near-continuous	Mar-10 to Oct-14, n = 67
Sean Gas Fields	Jul-2007	No	May-08	Near-continuous	
Irish Sea					
Liverpool Bay	Nov-00	Yes		Near-continuous	Nov-02 to Oct-14, n = 110
Liverpool Bay 2	Jan-05	No	2011	Near-continuous	
Celtic Sea					
Celtic Deep	May-09	No		Near-continuous	Jun-10 to Jan-13, n = 29

13 Annex 3 - Modelling studies: ecohydrodynamics and nutrient transport

Assessment areas used in recent OSPAR assessments and for CP2 (Figure 2) are broadly similar to the ‘ecohydrodynamic types’ identified by Tett et al (2007), defined by key ecosystem characteristics. This approach was taken further in recent modelling studies, which were able to better define these regions. Results from a modelling study using the coupled hydrodynamics-ecosystem model, GETM-ERSEM-BFM, in a 51-year hindcast simulation (1958–2008, van Leeuwen et al. 2015) are shown in Figure A3.1. The analysis was based on the number of days of continuous density stratification and the number of days of continuous mixed conditions in each spatial grid point of the model for each year. Model results, averaged over the 51-year period, show areas of the North Sea which may be clearly identified as being permanently stratified, seasonally stratified, intermittently stratified or permanently mixed, and coastal regions which are strongly influenced by the input of freshwater (‘regions of freshwater influence ‘, or ROFIs). However, model results also show that many parts of the North Sea are subject to high inter-annual variability and not easily defined in terms of stable conditions (mixed or stratified) for biological activity. This has implications for the definition of marine areas as required by the MSFD which should take into account the high inter-annual variability that some areas experience in terms of hydrodynamic conditions.

The modelling work with GETM-ERSEM-BFM has also been extended to the whole of the UK shelf (Figure A3.2). This map, based on the first results of this new model domain spanning only 1996-2010, depicts similar regions to the North Sea map (Figure A3.1). The higher resolution of the shelf wide domain (3 nm versus 6 nm for the North Sea domain) means more features are visible, leading to an increase of the ROFI region in the German Bight. Furthermore, this map provides a first indication of ecohydrodynamic regions in the Irish Sea, Celtic Sea and off-shelf regions.

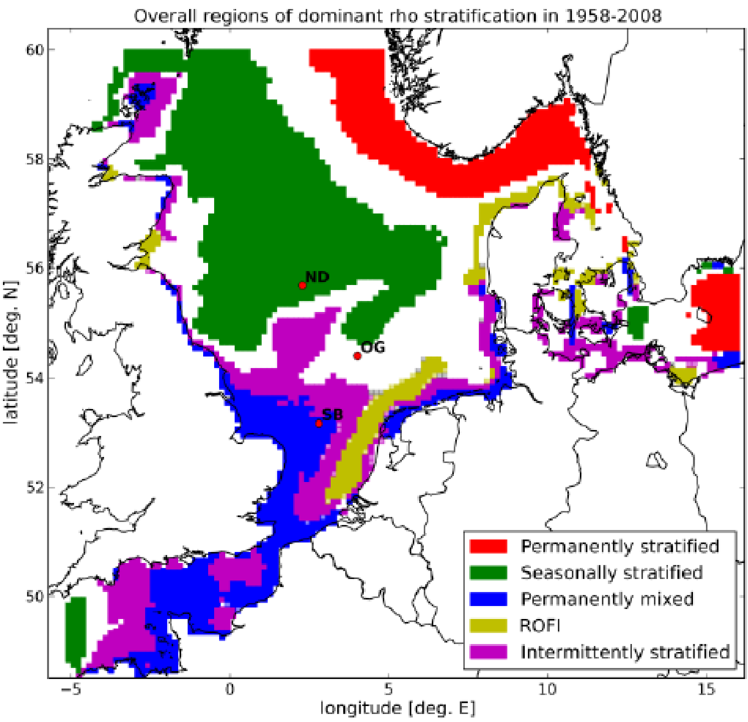


Figure A3.1: Regions in the North Sea defined by density (rho) stratification, based on a 51-year hindcast simulation of a coupled hydro-biogeochemical model (van Leeuwen et al. 2015). White areas = zones subject to significant inter-annual variability (e.g. the location of the tidal mixing front or fresh water discharge) or not captured by the imposed definitions. ROFI = region of freshwater influence, ND = North Dogger SmartBuoy, OG = Oyster Ground SmartBuoy, SB = Southern Bight (Sean Gas-field) SmartBuoy.

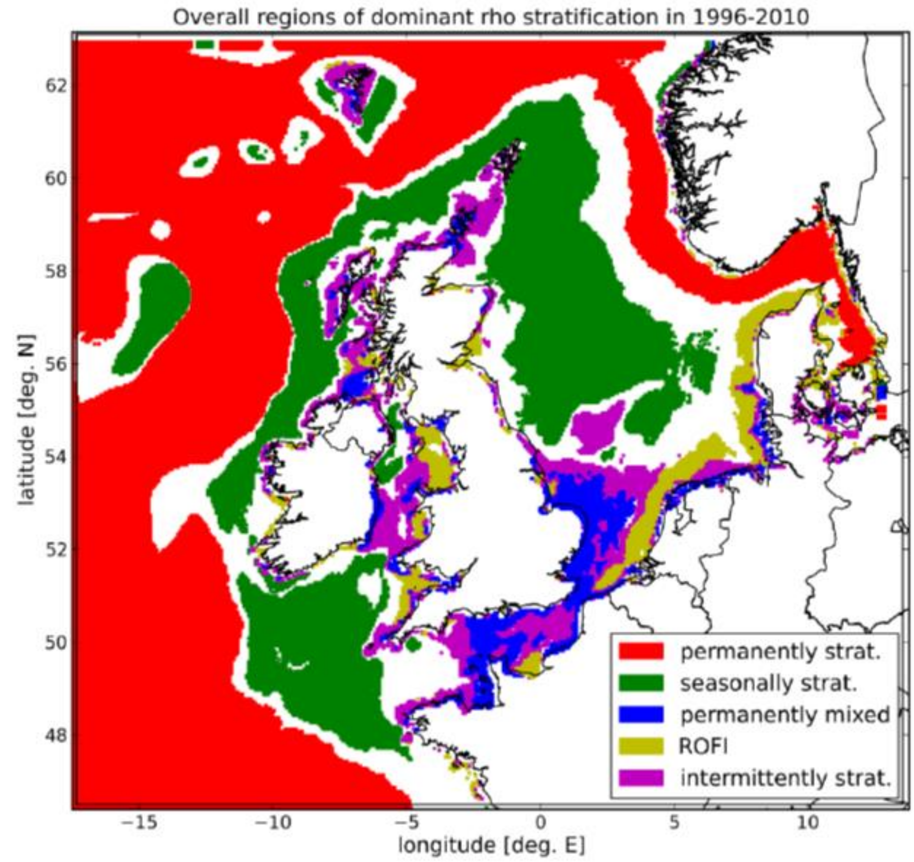


Figure A3.2: A shelf-wide map of regions defined by density (rho) stratification, based on a three year run (1996-1998) with a coupled hydro-biogeochemical model (Cefas, unpubl. data). White areas = zones subject to significant inter-annual variability or not captured by the imposed definitions

A number of studies have been carried out to assess the transport and fate of nutrients. These include modelling studies carried out as part of three international ICG-EMO (Inter-sessional Correspondence Group for Eutrophication Modelling) workshops under the auspices of OSPAR. Six coupled hydrodynamics-biogeochemistry models were used to quantify nutrient transport in the North Sea, using various methods to track nutrients through the full suite of biogeochemical calculations in the models (see www.cefas.defra.gov.uk/publications-and-data/miscellaneous-publications.aspx, Painting et al, 2013a. This cannot at present be obtained from observations. The models demonstrated the large spatial footprint of specific nutrient sources (in this case groups of rivers) and the extent to which these sources contribute to marine nutrient levels in the simulated ecosystem. Figure A3.3 illustrates the results for nitrogen from the GETM-ERSEM-BFM model run by Cefas. The contributions get progressively smaller with distance away from the sources as waters are transported with the ambient residual circulation, and as the influence of other sources, such as oceanic waters, increases. Nevertheless, nutrients can, over the years, travel over a thousand km away from their source and make a recognisable contribution to local nutrient pools. Reduction measures for a specific source can be expected to have the largest effect on the total nutrient burden within several hundreds of km of the source, and only within the plume to which the source contributes.

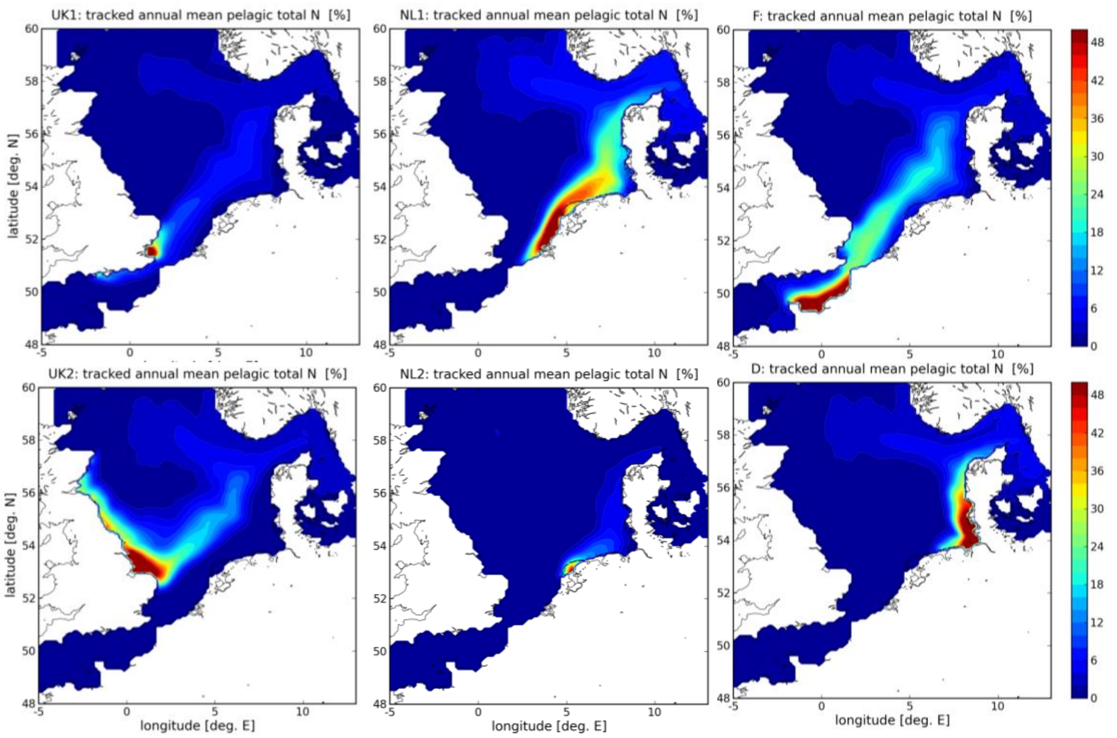


Figure A3.3 Tracked annual mean pelagic total (i.e. aggregated over all the compartments in the pelagic part of the ecosystem model) nitrogen content in the year 2002, after 5 years of tracking, from GETM-ERSEM-BFM (see www.nioz.nl/northsea_model), as percentage of all pelagic total nitrogen, originating from the river groups UK1, UK2, NL1, NL2, F1 and D (NL=Netherlands, F=France, D=Germany). Rivers in group UK1 include all rivers from East Anglia up to north Scotland. Rivers in UK2 include all rivers from the middle of the Channel to East Anglia. Rivers in NL1 include rivers along the Netherlands west coast; rivers in NL2 consist of the Lake IJssel outflows. Rivers in F1 include rivers between Cap de la Hague and Calais. Rivers in group D include all rivers entering the North Sea along the German northwest coast.

14 Annex 4 - Assessment Results - Nutrient Inputs

RID data on riverine and point source loads were used to calculate total annual loads of dissolved inorganic nitrogen (N) and phosphorus (P) into the regional seas (1990-2014, Figure A4.1). For the assessment period (2006-2014), total N loads were highest in the southern North Sea, the northern North Sea, the Celtic Sea and the Irish Sea.

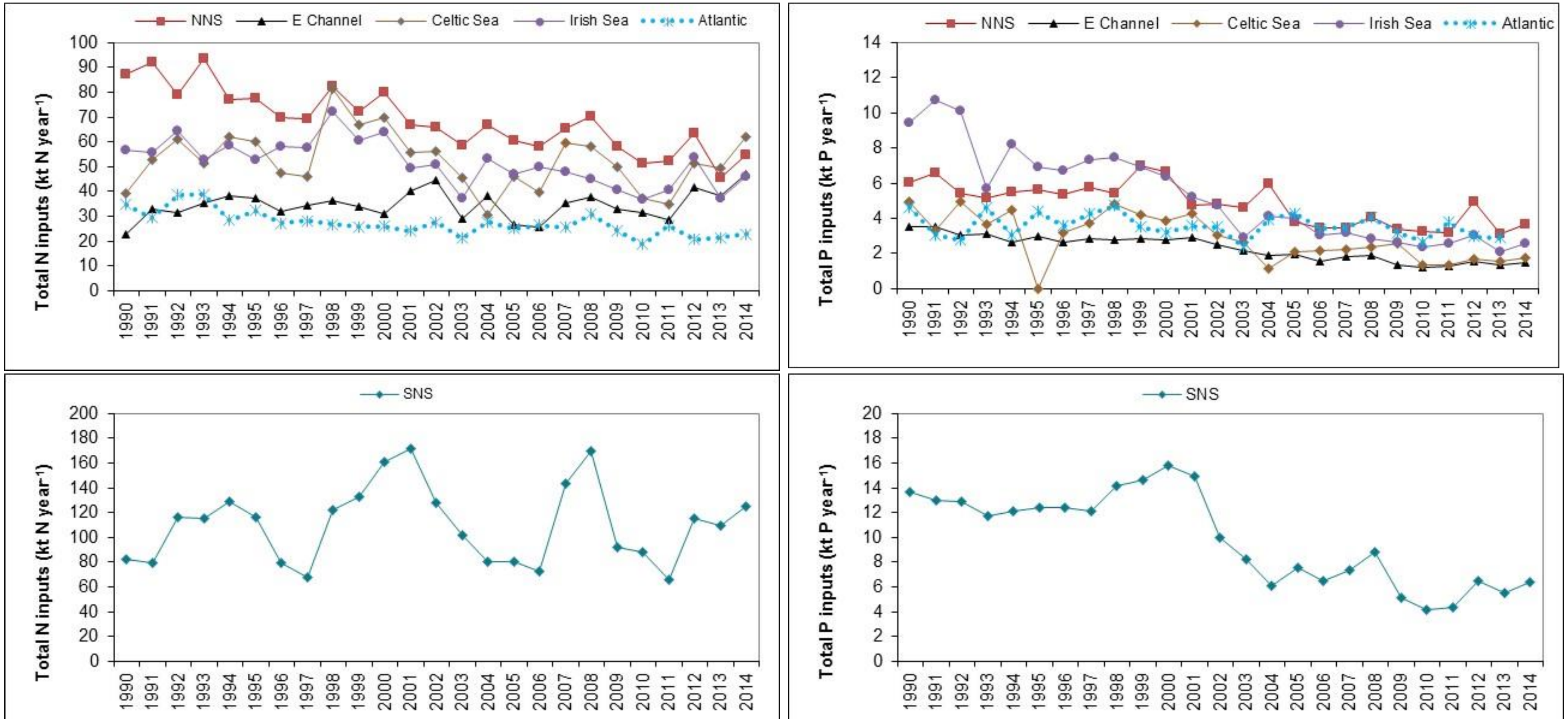


Figure A4.1: Total annual loads (1990 to 2014) of dissolved inorganic nitrogen (N, kt y^{-1}) and phosphorus (P, kt y^{-1}) to UK marine areas, which are broadly similar to regional seas shown in Figure 1. Riverine, sewage and industrial inputs were not flow corrected. Data were obtained from the Riverine Inputs and Direct Discharges (RID) monitoring programme. Note changes in scale in upper and lower plots.

Trends in RID data by discharge type per PARCOM region are shown in Figures A4.2 to A4.7. The data were plotted by area with each row corresponding to a regional sea. The blue lines are the Sen trend lines, red lines are the Zhang trend lines.

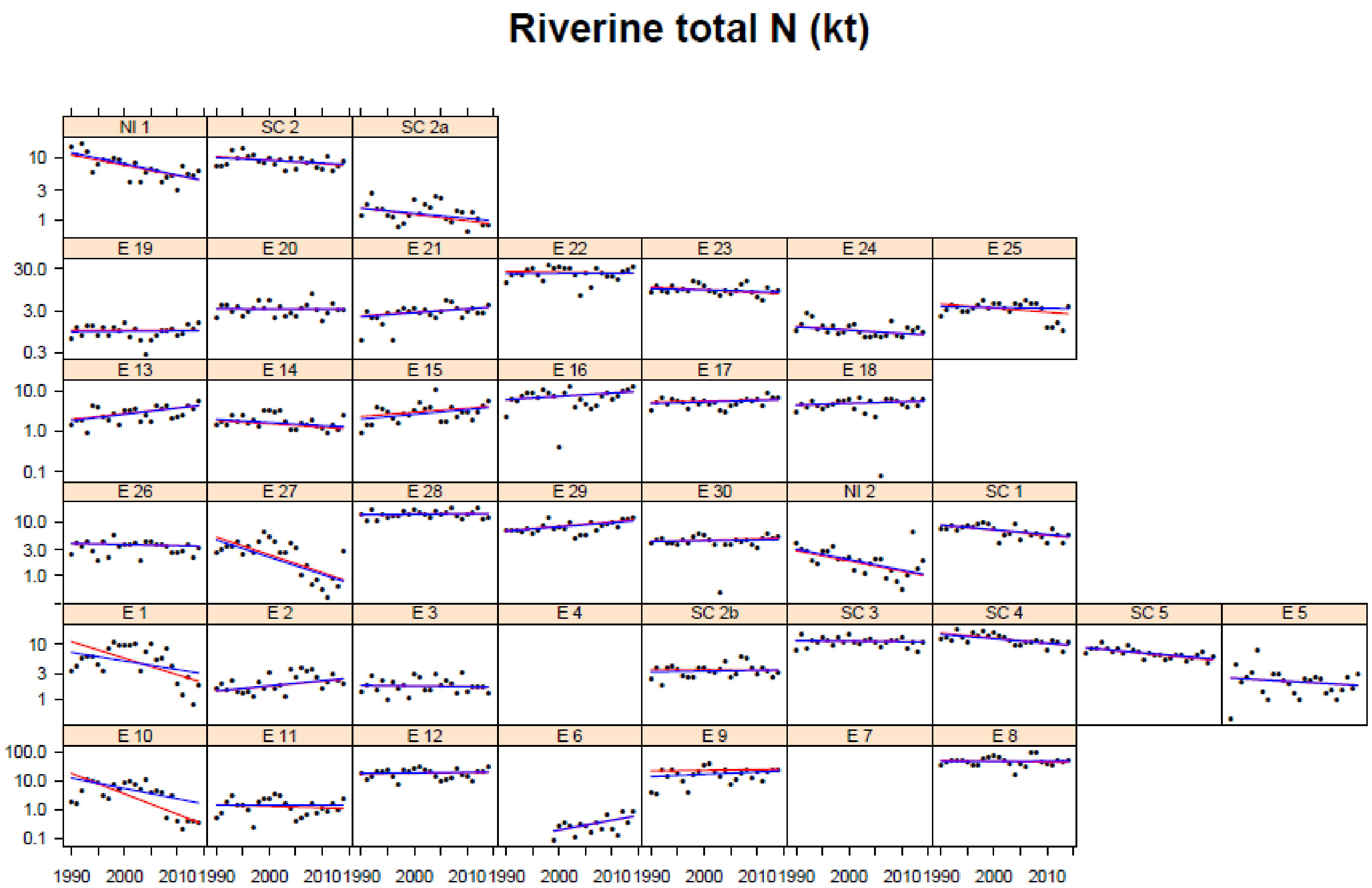


Figure A4.2: Riverine total N loads (Kt) plotted by PARCOM region, with each row corresponding to a regional sea. From top to bottom, the rows represent the following regional seas: Atlantic, Celtic Sea, English Channel, Irish Sea, northern North Sea, southern North Sea. The blue lines are the Sen trend lines, red lines are the Zhang trend lines.

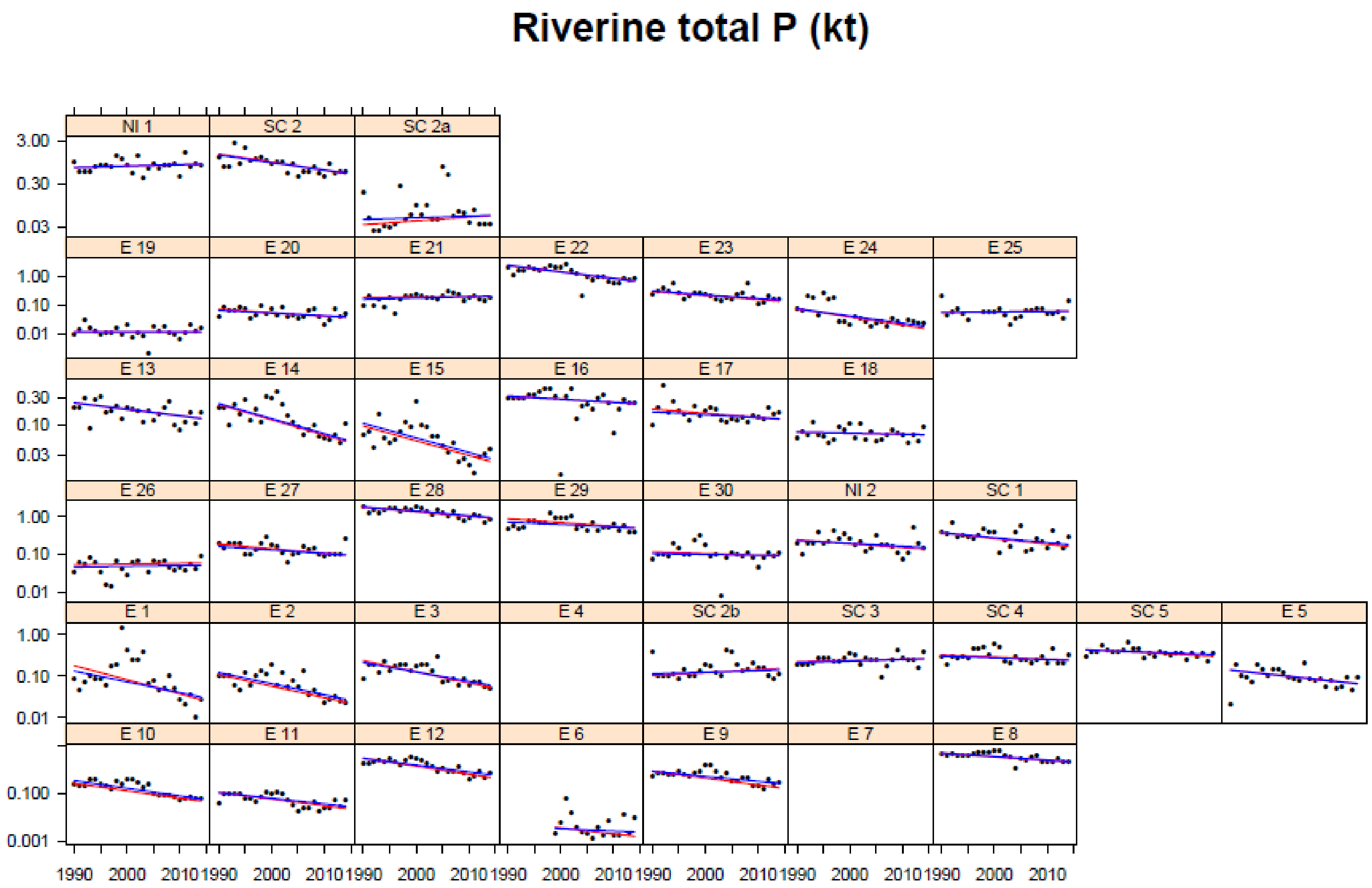


Figure A4.3: Riverine total P loads (Kt) plotted by PARCOM region, with each row corresponding to a regional sea. From top to bottom, the rows represent the following regional seas: Atlantic, Celtic Sea, English Channel, Irish Sea, northern North Sea, southern North Sea. The blue lines are the Sen trend lines, red lines are the Zhang trend lines.

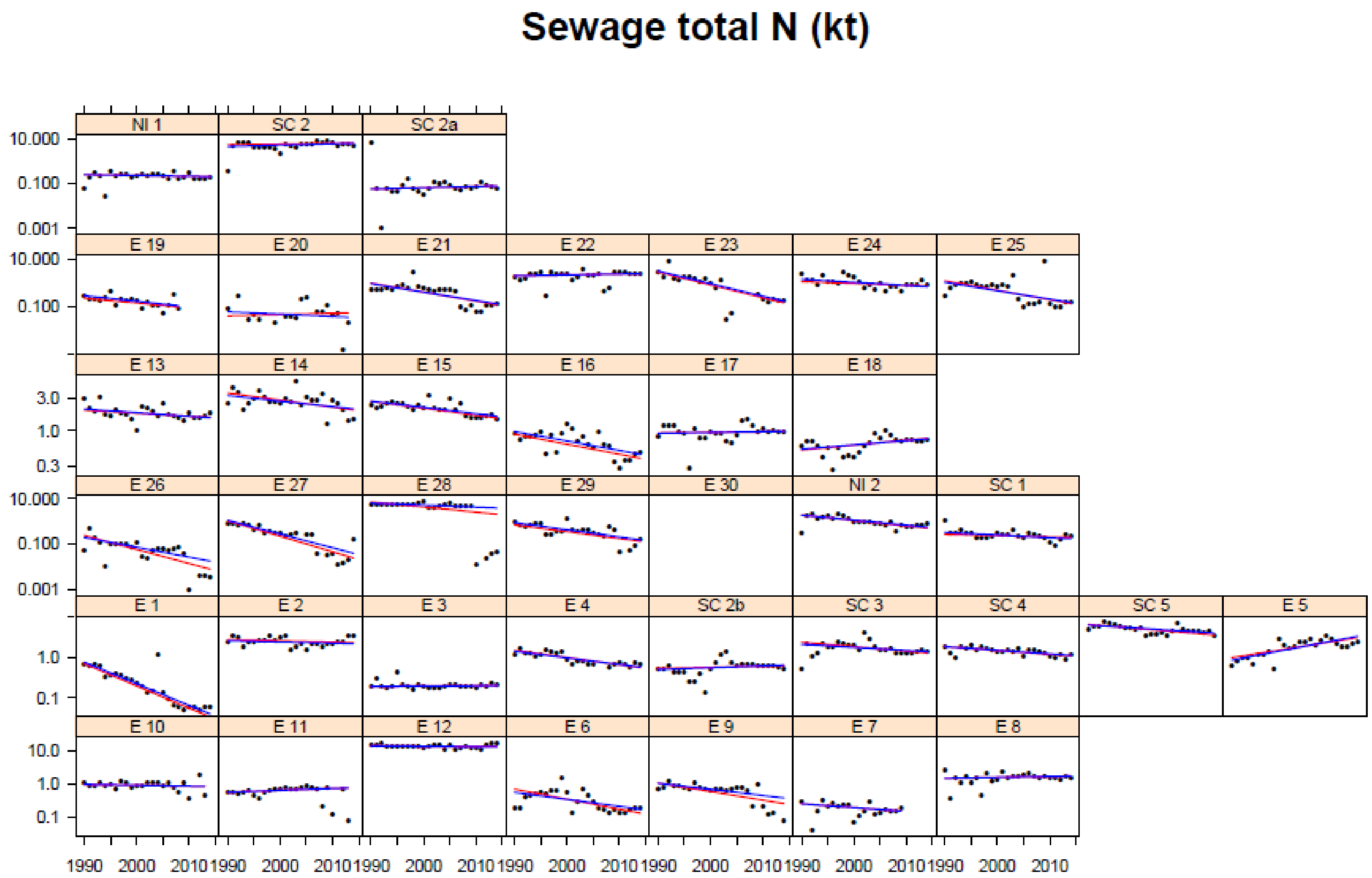


Figure A4.4: Sewage total N loads (Kt) plotted by PARCOM region, with each row corresponding to a regional sea. From top to bottom, the rows represent the following regional seas: Atlantic, Celtic Sea, English Channel, Irish Sea, northern North Sea, southern North Sea. The blue lines are the Sen trend lines, red lines are the Zhang trend lines.

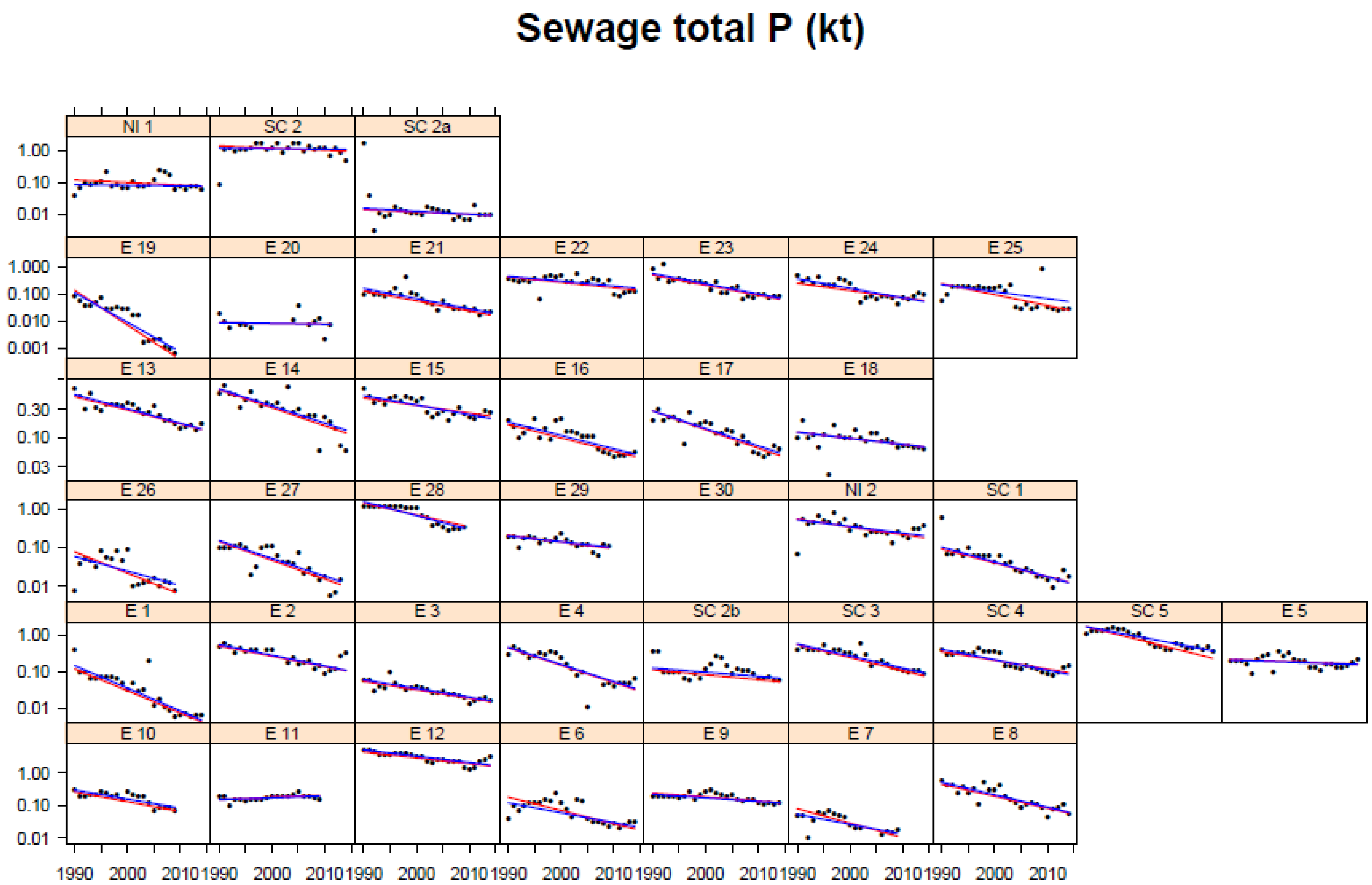


Figure A4.5: Sewage total P loads (Kt) plotted by PARCOM region, with each row corresponding to a regional sea. From top to bottom, the rows represent the following regional seas: Atlantic, Celtic Sea, English Channel, Irish Sea, northern North Sea, southern North Sea. The blue lines are the Sen trend lines, red lines are the Zhang trend lines.

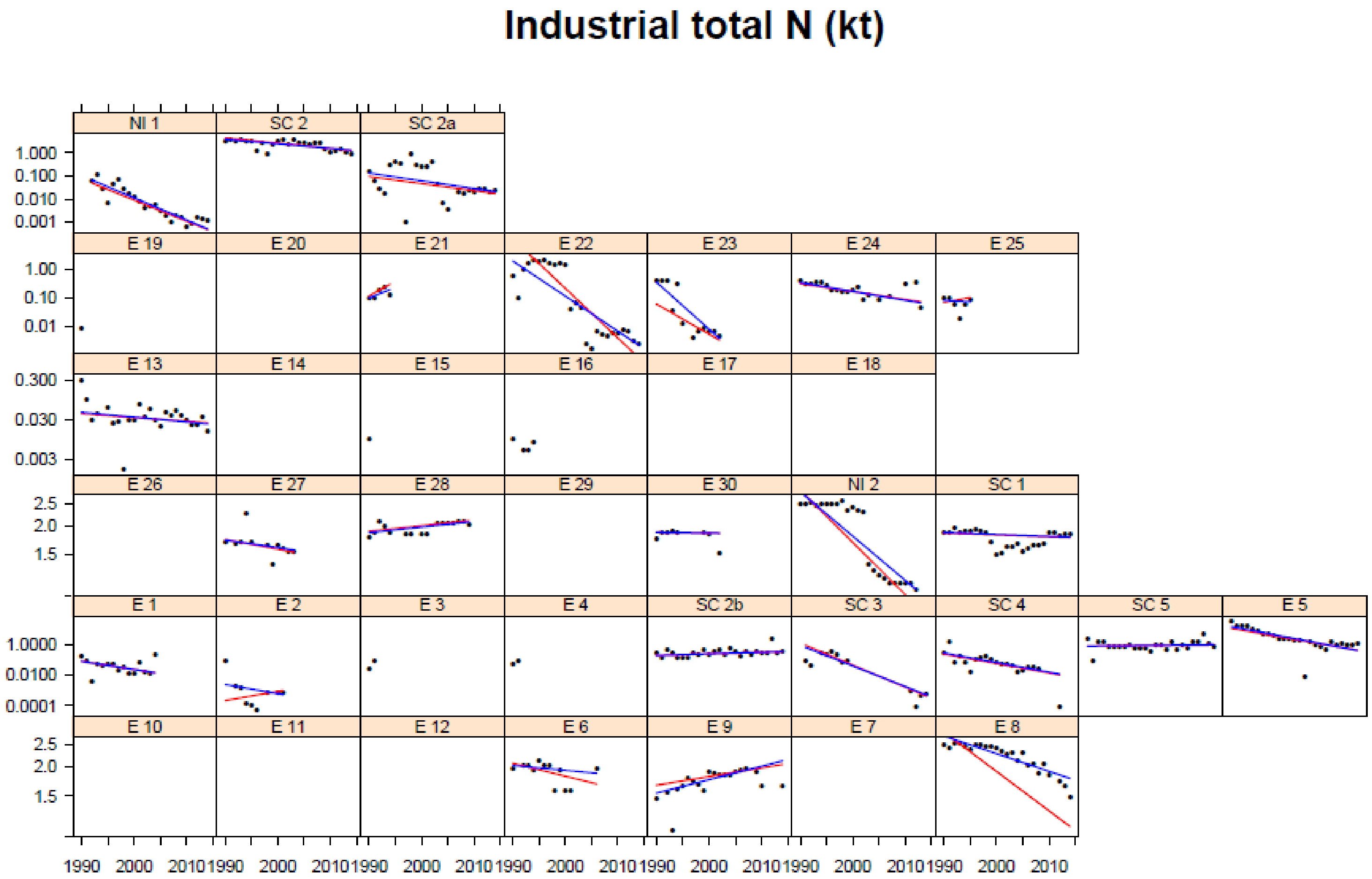


Figure A4.6: Industrial total N loads (Kt) plotted by PARCOM region, with each row corresponding to a regional sea. From top to bottom, the rows represent the following regional seas: Atlantic, Celtic Sea, English Channel, Irish Sea, northern North Sea, southern North Sea. The blue lines are the Sen trend lines, red lines are the Zhang trend lines.

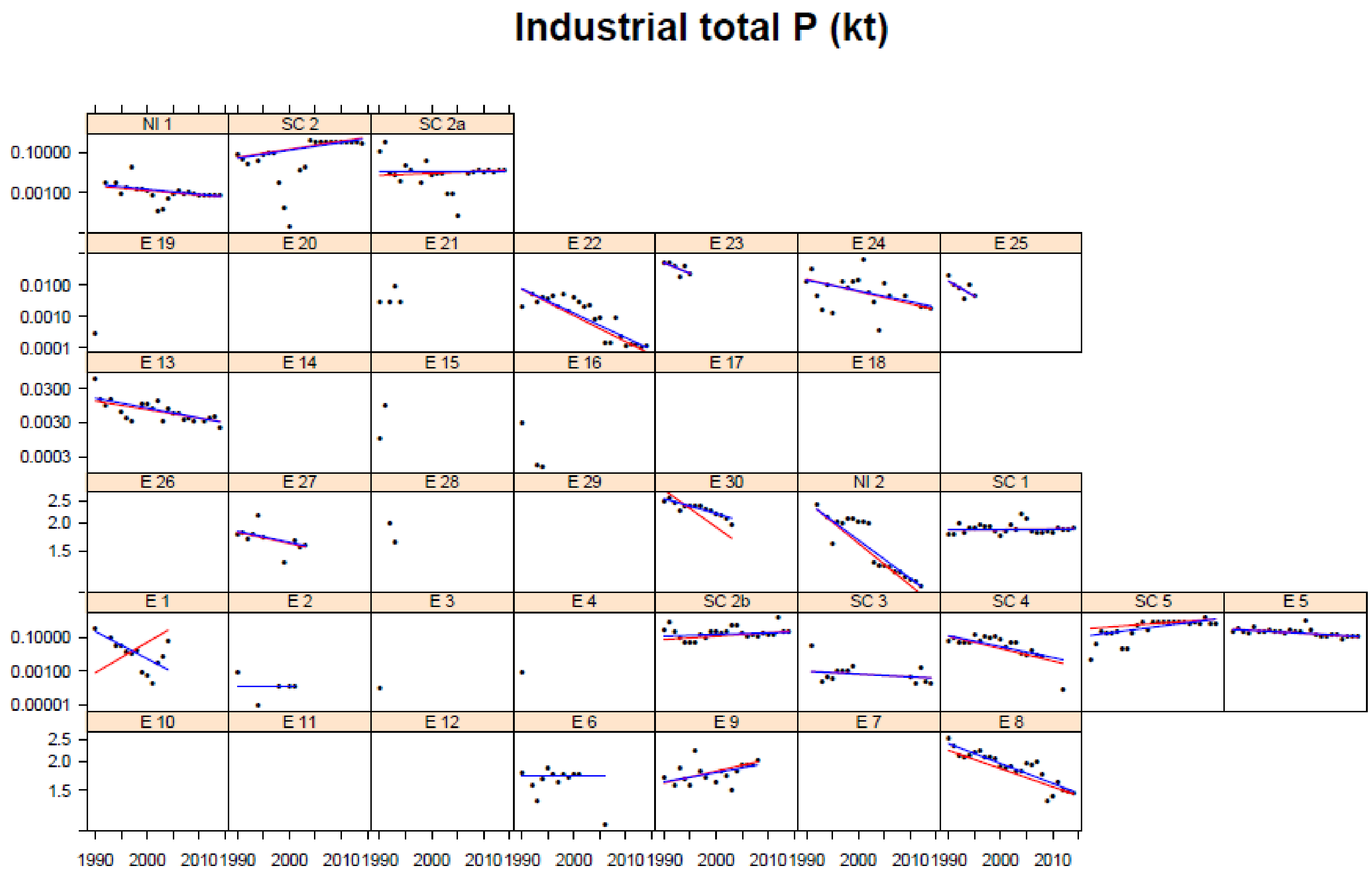
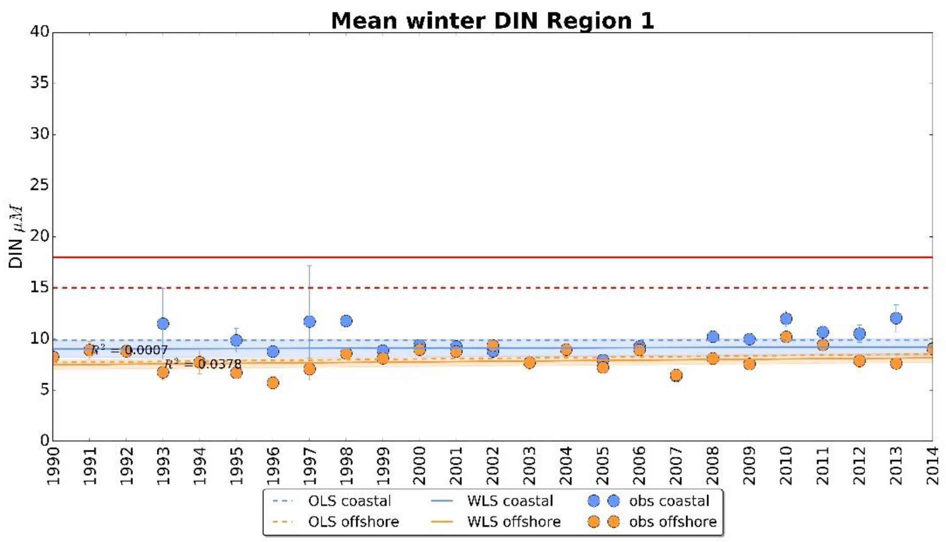


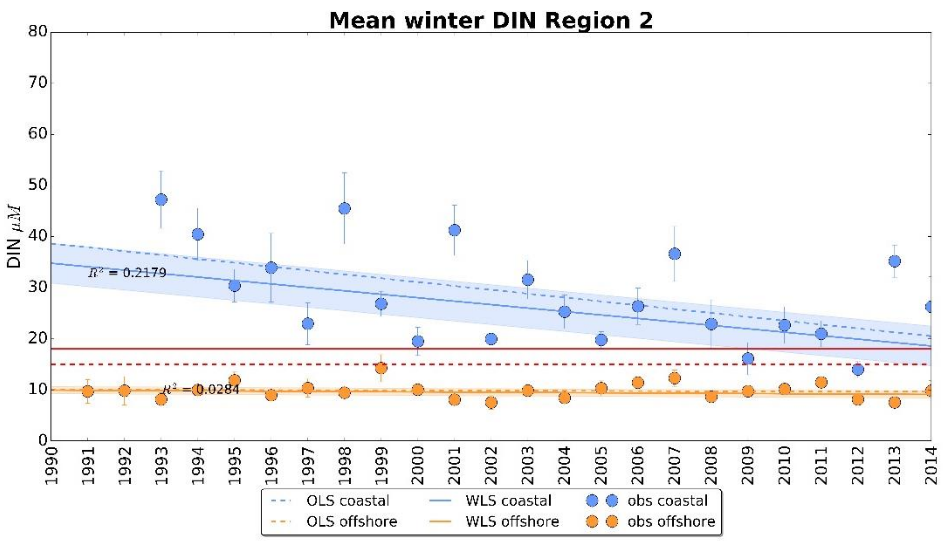
Figure A4.7: Industrial total P loads (Kt) plotted by PARCOM region, with each row corresponding to a regional sea. From top to bottom, the rows represent the following regional seas: Atlantic, Celtic Sea, English Channel, Irish Sea, northern North Sea, southern North Sea. The blue lines are the Sen trend lines, red lines are the Zhang trend lines.

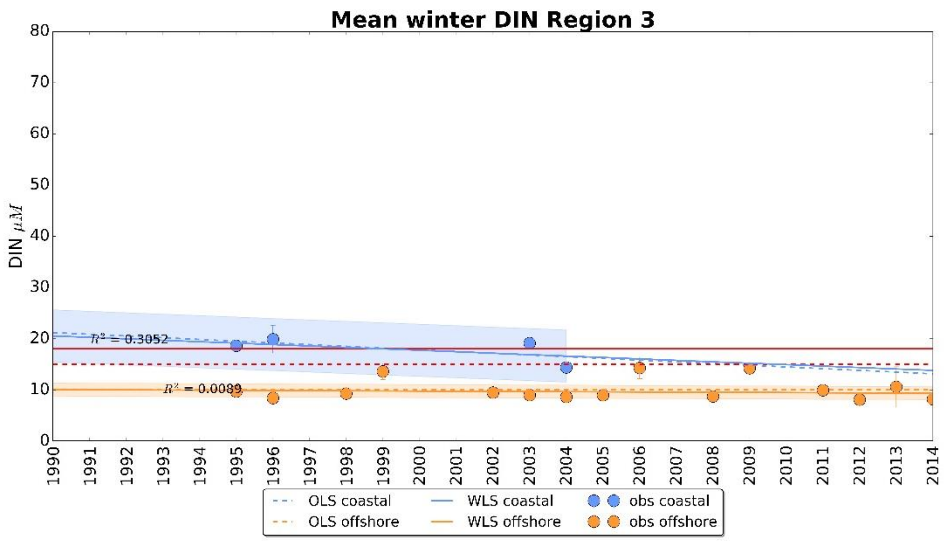
Recent estimates from the caged fish farm industry to the north and west of Scotland suggest that they may be a significant source of nutrients into the North and west of Scotland where freshwater inputs are low, and comparable to riverine inputs (Baxter et al. 2011), which are relatively low. These nutrient inputs are mainly in the form of faecal and particulate organic matter deposited on the seabed. While they may not be available for immediate use by algae or higher forms of plant life they are likely to make an important contribution to biogeochemical cycling in the region.

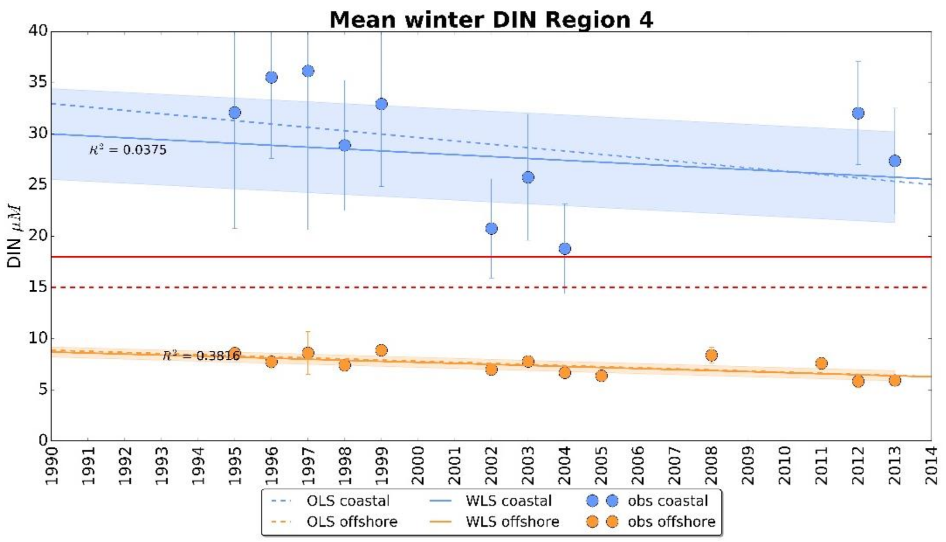
Atmospheric discharges are also an important source of nitrogen into our seas (Defra 2010). Nitrogen is emitted into the atmosphere by industry, transport (including shipping) and from agricultural practices. Agriculture accounted for 37–44% of atmospheric nitrogen deposited into the UK's seas (OSPAR 2010b).

15 Annex 5 – Trends in Assessment Parameters DIN, TOxN, Chl, DO









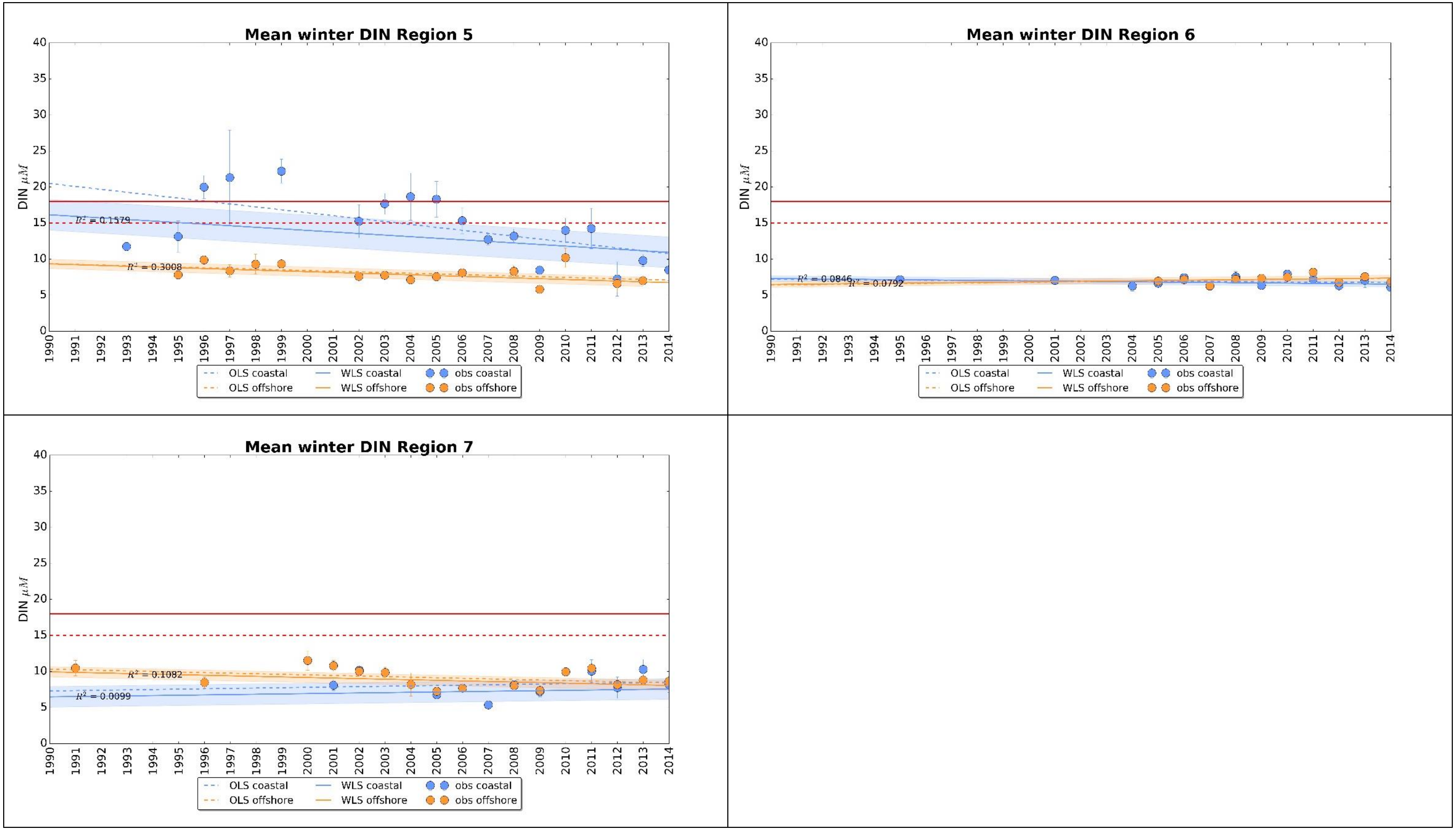


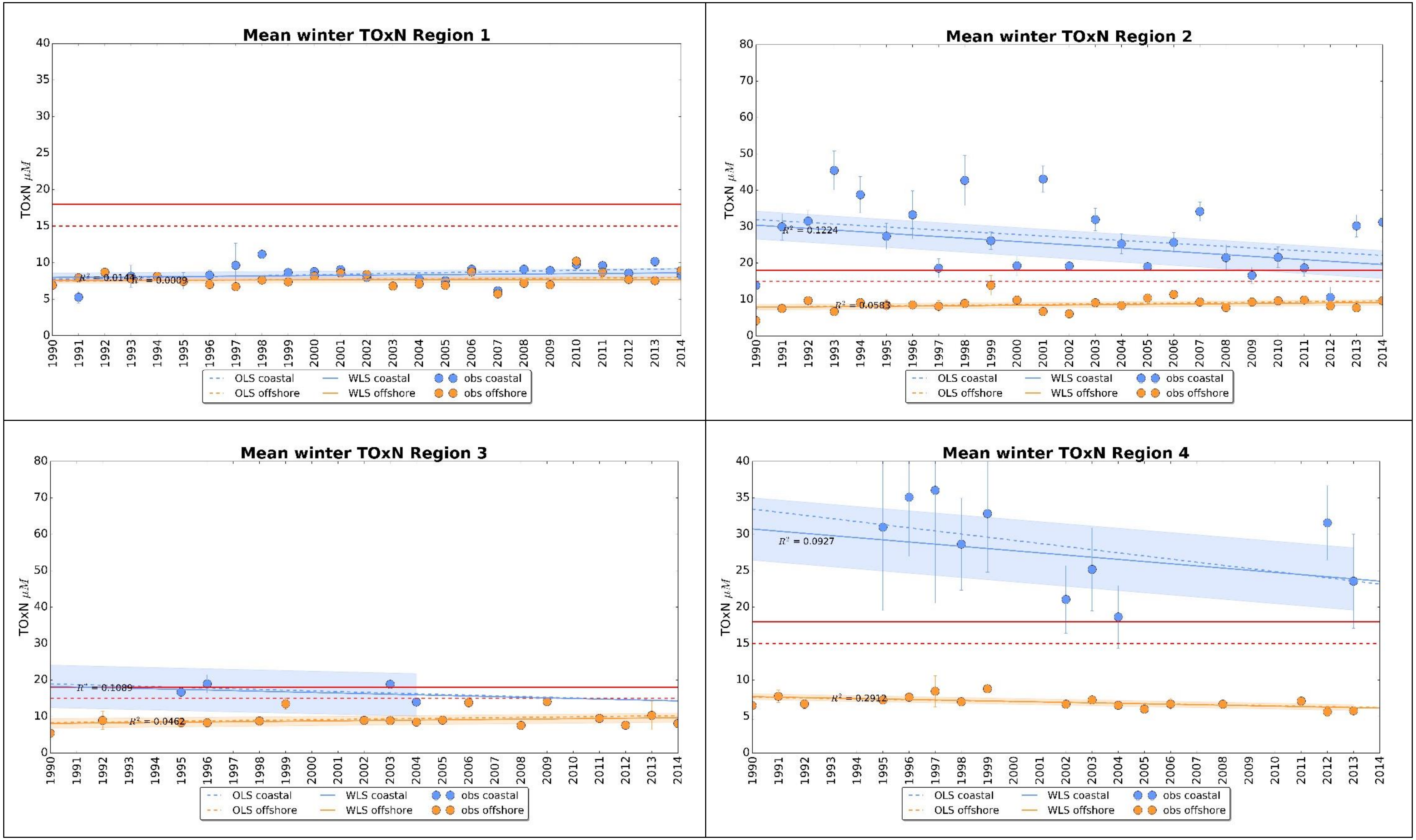
Figure A5.1: Trends in mean winter DIN (µM) in Regional Seas 1 to 7, from 1990 to 2014. Data from all depths were used and are plotted separately for coastal (blue symbols) and offshore (orange symbols) water. A 95% confidence interval is provided for every mean value. Results are shown for years with five or more data points. Obs = observations, OLS = ordinary least squares regression, WLS= weighted least squares regression (the width of the confidence interval was used as weight). Shading indicates 95% confidence levels around the WLS. Assessment thresholds are shown for coastal water (solid line, 18 µM) and offshore water (dashed line, 15 µM). Data shown here were not normalised.

Table A5.1. Mann-Kendall results for DIN for the ***coastal areas*** *using the annually averaged data (once all filters had been applied, see Annex 2). Where p-values are less than 0.05 (in bold), it is assumed that there is a trend. The sign of the MK Statistic indicates an upward or downward slope. For p-values greater than 0.05, a trend could not be detected statistically. n = number of data points. Mean winter values were not normalised.*

Region	n	MK Statistic	p-value
1	19	0.4898	0.6243
2	**22**	**-2.3693**	**0.0178**
3	4	-0.3536	0.7237
4	10	-1.61	0.1074
5	**18**	**-2.3484**	**0.0189**
6	13	-0.4276	0.6689
7	10	0.8944	0.3711
8			

Table A5.2. Mann-Kendall results for DIN for the ***offshore area*** *using the annually averaged data (once all filters had been applied, see Annex 2). Where p-values are less than 0.05 (in bold), it is assumed that there is a trend. The sign of the MK Statistic indicates an upward or downward slope. For p-values greater than 0.05, a trend could not be detected statistically. n = number of data points. Mean winter values were not normalised.*

Region	n	MK Statistic	p-value
1	25	1.0044	0.3152
2	24	-0.0248	0.9802
3	15	-0.3961	0.6921
4	**13**	**-2.2601**	**0.0238**
5	15	-1.6833	0.0923
6	10	0.8944	0.3711
7	16	-1.3962	0.1627
8			


Mean winter TOxN Region 1
TOxN μM
R^2 = 0.0009
Mean winter TOxN Region 2
TOxN μM
R^2 = 0.1224
R^2 = 0.0583
Mean winter TOxN Region 3
TOxN μM
R^2 = 0.1089
R^2 = 0.0462
Mean winter TOxN Region 4
TOxN μM
R^2 = 0.0927
R^2 = 0.2912
OLS coastal
WLS coastal
obs coastal
OLS offshore
WLS offshore
obs offshore

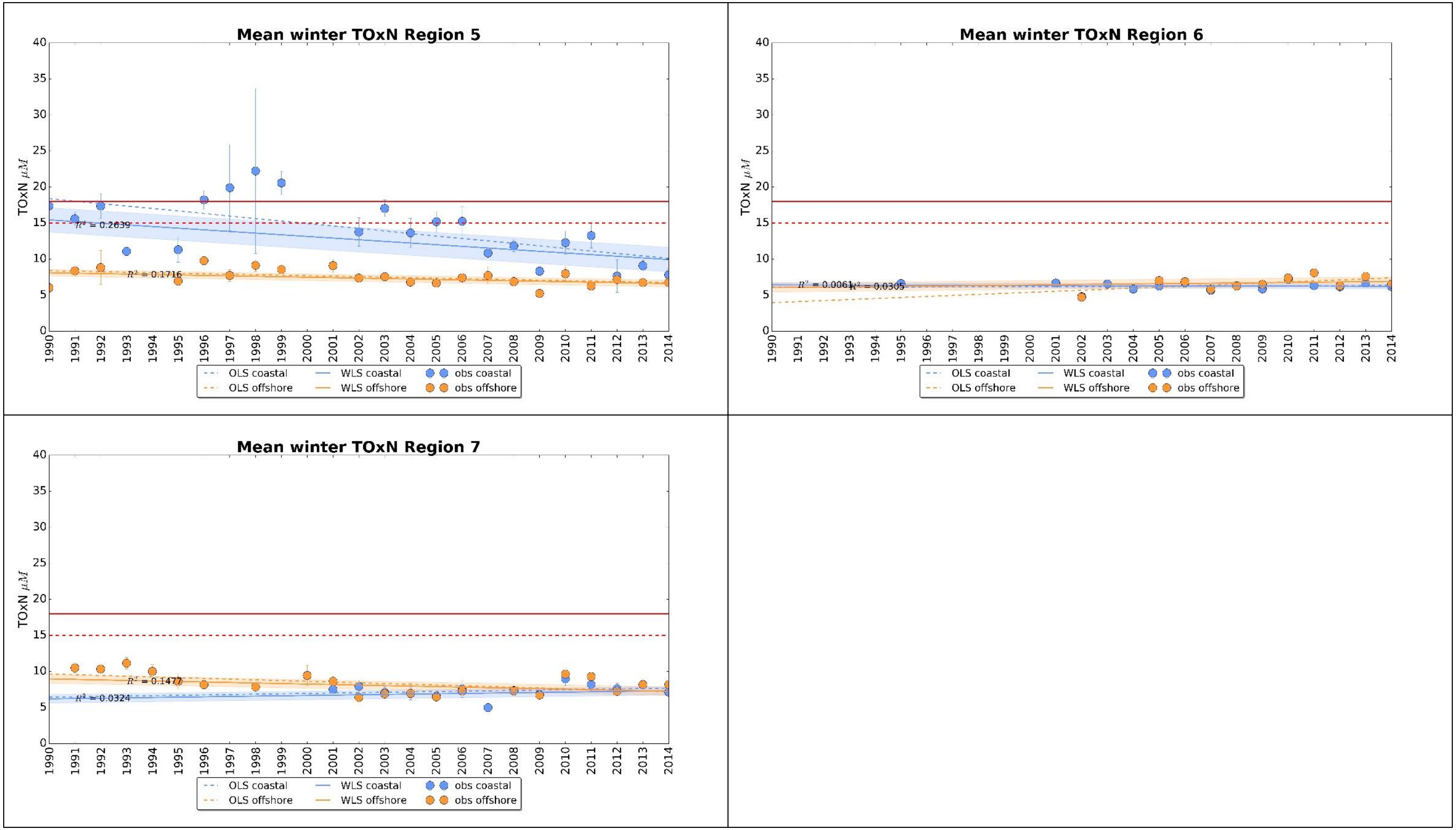


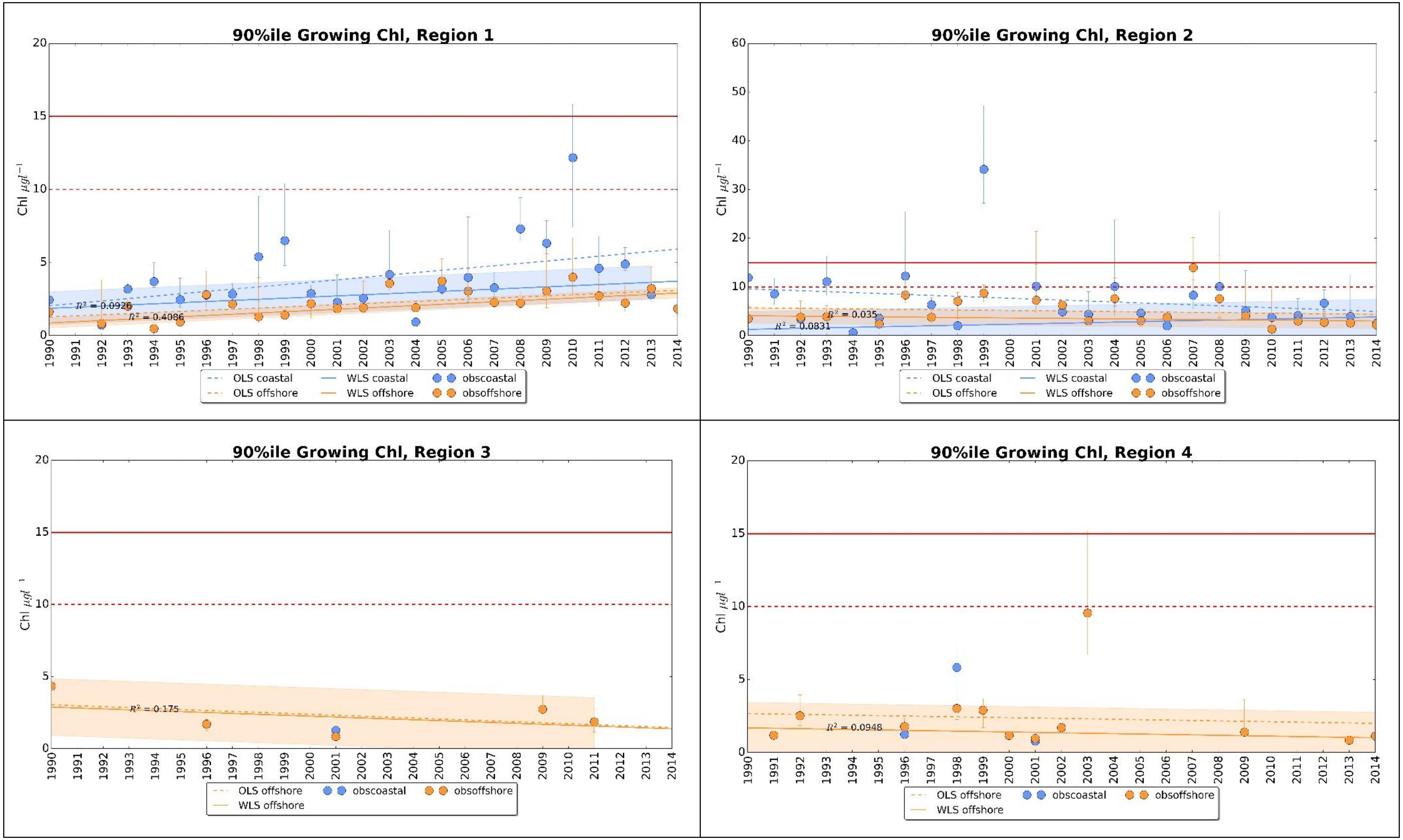
Figure A5.2: Trends in mean winter TOxN (µM) in Regional Seas 1 to 7, from 1990 to 2014. Data from all depths were used and are plotted separately for coastal (blue symbols) and offshore (orange symbols) water. A 95% confidence interval is provided for every mean value. Results are shown for years with five or more data points. Obs = observations, OLS = ordinary least squares regression, WLS= weighted least squares regression (the width of the confidence interval was used as weight). Shading indicates 95% confidence levels around the WLS. Assessment thresholds are shown for coastal water (solid line, 18 µM) and offshore water (dashed line, 15 µM). Data shown here were not normalised.

Table A5.3. Mann-Kendall results for TOxN for the ***coastal areas*** *using the annually averaged data (once all filters had been applied, see Annex 2). Where p-values are less than 0.05 (in bold), it is assumed that there is a trend. The sign of the MK Statistic indicates an upward or downward slope. For p-values greater than 0.05, a trend could not be detected statistically. n = number of data points. Mean winter values were not normalised.*

Region	n	MK Statistic	p-value
1	21	1.4801	0.1388
2	25	-1.4715	0.1412
3	4	-0.3536	0.7237
4	10	-1.61	0.1074
5	**22**	**-3.0462**	**0.0023**
6	15	0.198	0.8430
7	14	0.6576	0.5108
8			

Table A5.4. Mann-Kendall results for TOxN in ***offshore areas*** *using the annually averaged data (once all filters had been applied, see Annex 2). Where p-values are less than 0.05 (in bold), it is assumed that there is a trend. The sign of the MK Statistic indicates an upward or downward slope. For p-values greater than 0.05, a trend could not be detected statistically. n = number of data points. Mean winter values were not normalised.*

Region	n	MK Statistic	p-value
1	25	0.6774	0.4982
2	25	1.4248	0.1542
3	17	1.0301	0.3030
4	17	-1.8542	0.0637
5	**22**	**-2.2**	**0.0278**
6	11	1.4013	0.1611
7	**21**	**-2.0238**	**0.0430**
8			


90%ile Growing Chl, Region 1
Chl $\mu g l^{-1}$
R^2 = 0.0926
R^2 = 0.4086
OLS coastal
WLS coastal
obscoastal
OLS offshore
WLS offshore
obsoffshore
90%ile Growing Chl, Region 2
R^2 = 0.035
R^2 = 0.0831
90%ile Growing Chl, Region 3
R^2 = 0.175
90%ile Growing Chl, Region 4
R^2 = 0.0948
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014

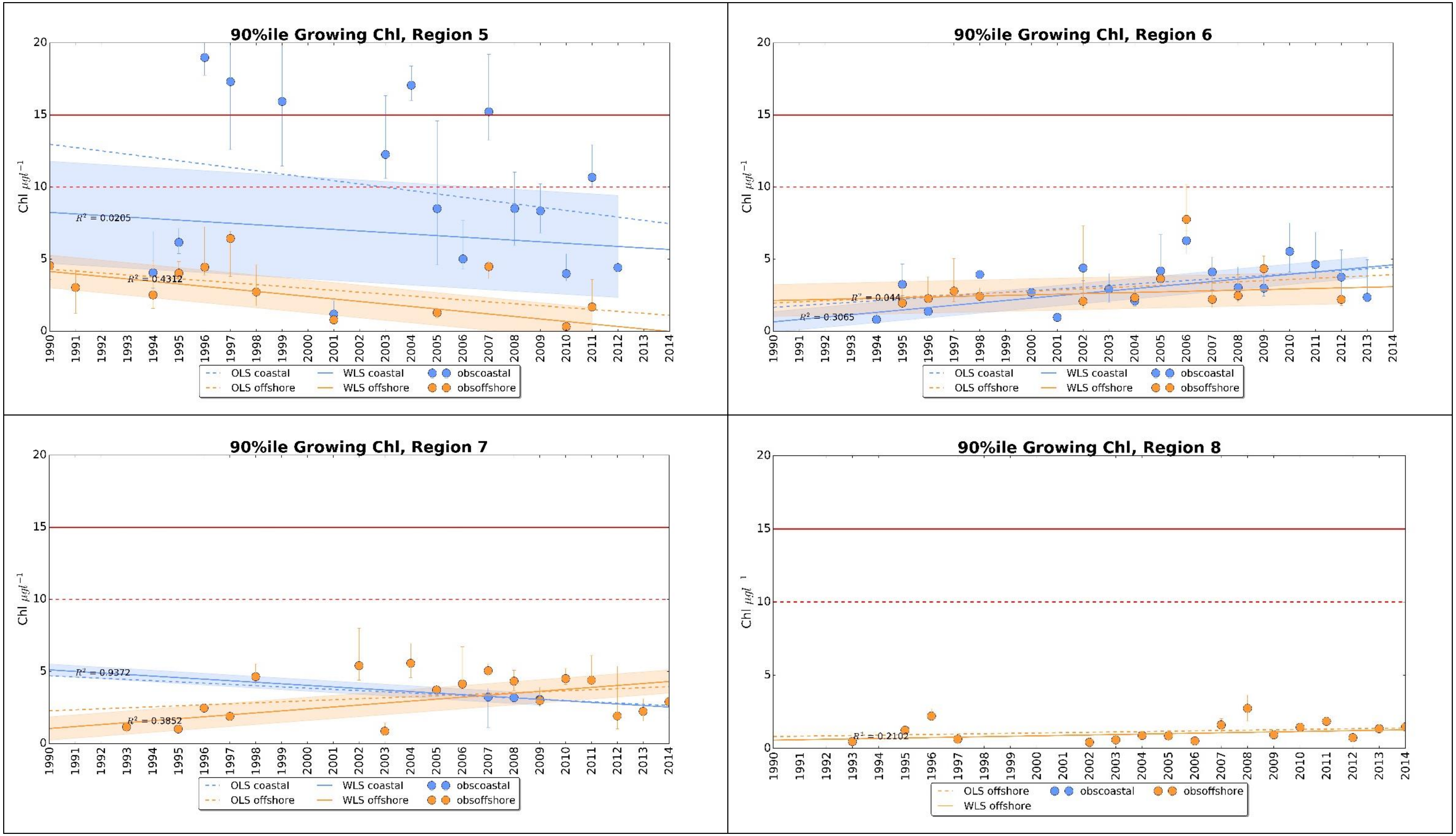


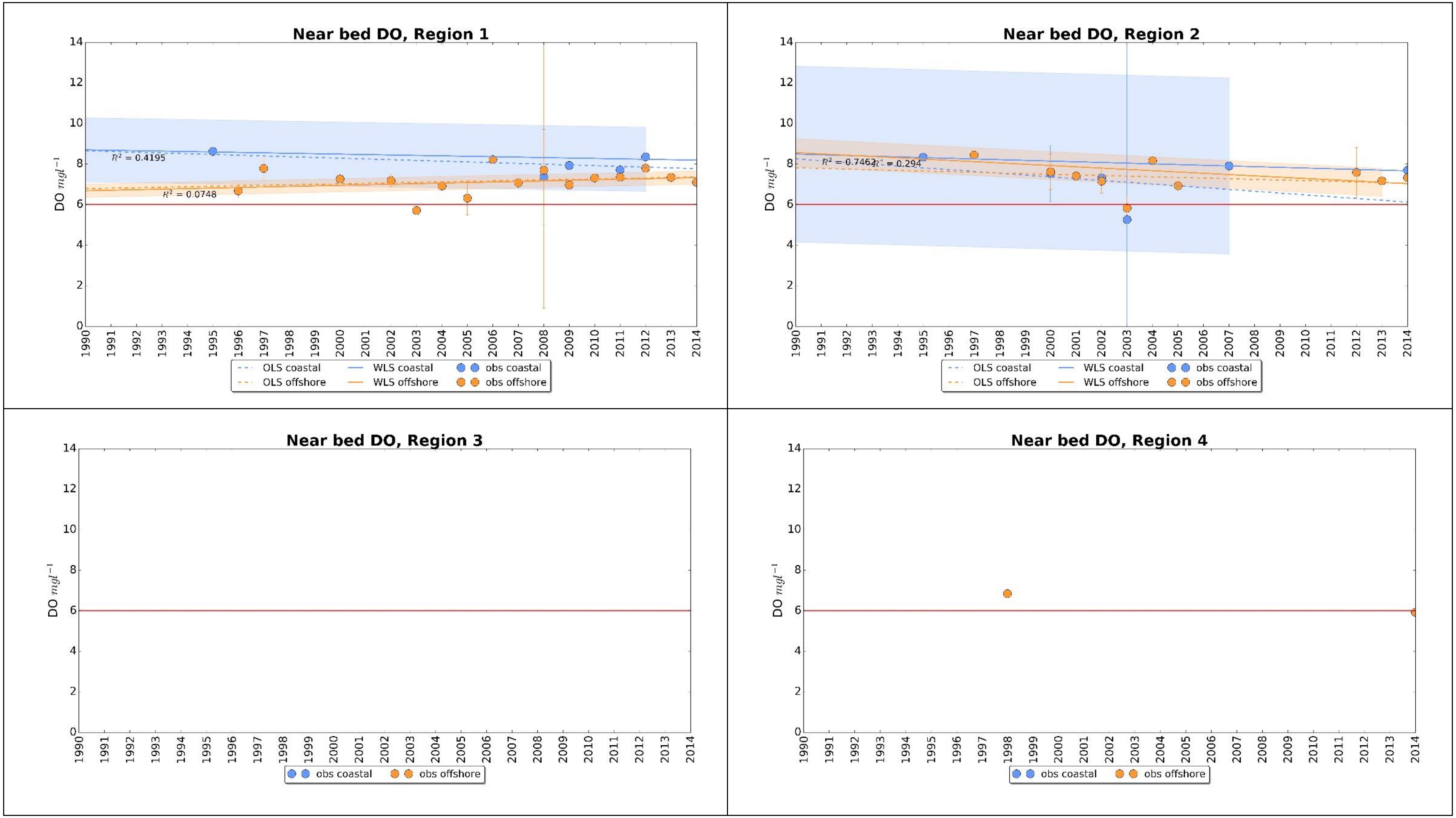
Figure A5.3: Trends in growing season chlorophyll 90th %ile in Regional Seas 1 to 8, from 1990 to 2014. Data from all depths were used and are plotted separately for coastal (blue symbols) and offshore (orange symbols) water. A 95% confidence interval is provided for every 90th %ile value. Results are shown for years with five or more data points. Obs = observations, OLS = ordinary least squares regression, WLS= weighted least squares regression (the width of the confidence interval was used as weight). Shading indicates 95% confidence levels around the WLS; results are shown only where means were available for 5 or more years. Assessment thresholds are shown for coastal water (solid line, 15 µg l^{-1}) and offshore water (dashed line, 10 µg l^{-1}).

*Table A5.5: Mann-Kendall results for chlorophyll 90th percentiles for the **coastal areas**. Where p-values are less than 0.05 (in bold), it is assumed that there is a trend. The sign of the MK Statistic indicates an upward or downward slope. For p-values greater than 0.05, a trend could not be detected statistically. n = number of data points. nan = no data.*

Region	n	MK Statistic	p-value
1	**23**	**2.4303**	**0.0151**
2	24	-1.3148	0.1886
3	1	nan	nan
4	4	0	1
5	16	-1.1259	0.2602
6	18	1.5909	0.1116
7	3	-1.1547	0.2482
8	0	nan	nan

*Table A5.6: Mann-Kendall results for chlorophyll 90th percentiles for the **offshore areas**. Where p-values are less than 0.05 (in bold), it is assumed that there is a trend. The sign of the MK Statistic indicates an upward or downward slope. For p-values greater than 0.05, a trend could not be detected statistically. n = number of data points. nan = no data.*

Region	n	MK Statistic	p-value
1	**24**	**2.952**	**0.0032**
2	22	-1.5231	0.1277
3	5	-0.25	0.8026
4	12	-1.1676	0.2430
5	12	-1.4423	0.1492
6	12	1.0302	0.3029
7	18	0.606	0.5445
8	17	1.607	0.1081



Near bed DO, Region 1
DO mgl^{-1}
R^2 = 0.4195
R^2 = 0.0748
OLS coastal
WLS coastal
obs coastal
OLS offshore
WLS offshore
obs offshore
Near bed DO, Region 2
DO mgl^{-1}
R^2 = 0.7462
R^2 = 0.294
OLS coastal
WLS coastal
obs coastal
OLS offshore
WLS offshore
obs offshore
Near bed DO, Region 3
DO mgl^{-1}
obs coastal
obs offshore
Near bed DO, Region 4
DO mgl^{-1}
obs coastal
obs offshore

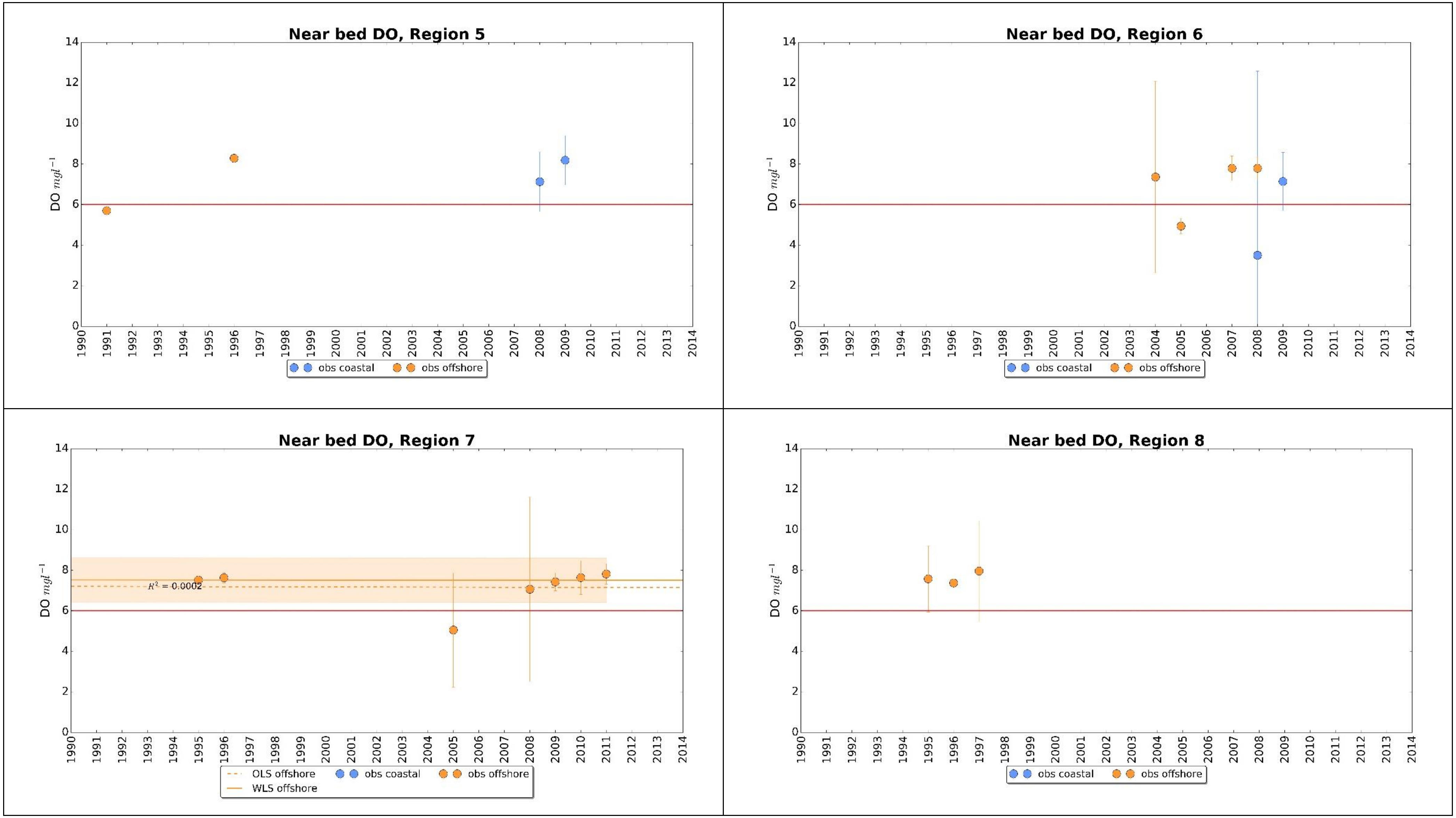


Figure A5.4: Trends in near bed dissolved oxygen (DO, mg l^{-1}, mean value in lowest quartile) in Regional Seas 1 to 8, from 1990 to 2014. Data are plotted separately for coastal (blue symbols) and offshore (orange symbols) water. A 95% confidence interval is provided for every mean value. Results are shown for years with five or more data points. Obs = observations, OLS = ordinary least squares regression, WLS= weighted least squares regression (the width of the confidence interval was used as weight). Shading indicates 95% confidence levels around the WLS; results are shown only where means were available for 5 or more years. Assessment threshold is 6 mg l^{-1} for both coastal and offshore waters.

*Table A5.7: Results of Mann-Kendall (MK) analyses for DO (mg l^{-1}) in **coastal areas** using the annually averaged data filtered by salinity, season and depth. The sign of the MK statistic gives the direction of the trend. Where p-values are less than 0.05 (in bold), it is assumed that there is a significant trend. For p-values greater than 0.05, a trend could not be detected statistically. n = number of data, nan = no data or insufficient data.*

Region	n	MK Statistic	p-value
1	5	0	1
2	6	-0.378	0.706
3	0	nan	nan
4	0	nan	nan
5	2	0	1
6	2	0	1
7	0	nan	nan
8	0	nan	nan

*Table A5.8: Results of Mann-Kendall (MK) analyses for DO (mg l^{-1}) in **coastal areas** using the annually averaged data filtered by salinity, season and depth. The sign of the MK statistic gives the direction of the trend. Where p-values are less than 0.05 (in bold), it is assumed that there is a significant trend. For p-values greater than 0.05, a trend could not be detected statistically. n = number of data, nan = no data or insufficient data.*

Region	n	MK Statistic	p-value
1	16	1.04	0.3
2	10	-1.07	0.28
3	0	nan	nan
4	2	0	1
5	2	0	1
6	4	0.11	0.29
7	7	1.21	0.23
8	3	0	1

16 Annex 6 – Temporal trends in SmartBuoy parameters

Moorings such as SmartBuoys and landers return high-frequcny data for a number of paramters, such as temperature, salinity, nutrients and chlorophyll. For example, SmartBuoys deployed at the Thames and Dowsing sites in the southern North Sea (Figure A6.1).

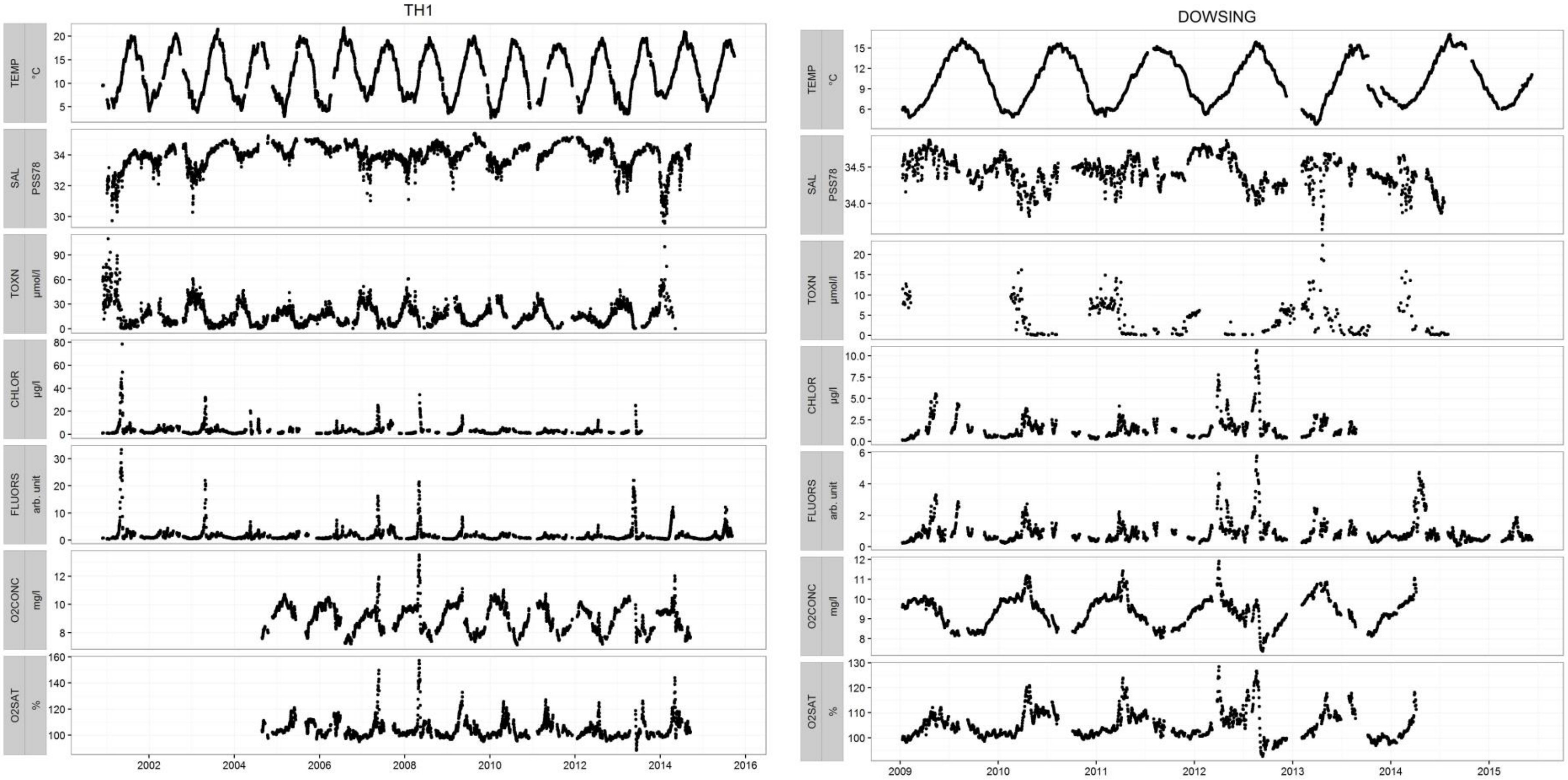


Figure A6.1: Temporal trends in high frequency data from the SmartBuoy deployed at the Thames and Dowsing sites in the southern North Sea (see Figure 2). Data are plotted as daily averages.

17 Annex 7 - Classifications under related EU Directives

Since the early 1990s, eutrophication of estuaries and coastal waters has been assessed on a regular (4 yearly) basis in the UK for the purposes of the Urban Waste Water Treatment Directive (UWWTD) and the Nitrates Directive. The UK developed weight-of-evidence based approaches for these assessments, reflecting the definitions of eutrophication in the directives and the requirement to identify affected waters. Since the advent of the Water Framework Directive (WFD), approaches to monitoring and assessment of eutrophication for UWWTD and the Nitrates Directive have been increasingly integrated with those for the WFD. The WFD requires water bodies to be classified using a “one-out-all-out” approach across the physico-chemical and biological quality elements used in the assessment of ecological status, so the status class of a water reflects the poorest status of any individual element. The range of pressures and impacts covered by the scope of ecological status is broad and the assessment and reporting of ecological status under WFD does not explicitly or formally require reporting of eutrophication. However, the reference-based tools for nutrients and their impacts are well suited to use in assessing eutrophication (see Annex 1 for further details), with Good Ecological Status for the relevant elements providing appropriate indicator thresholds; good status for nutrients, the algal/plant and other relevant elements involves an absence of eutrophication problems. In the UK the results for the eutrophication-related quality elements and other evidence of impacts are combined, using weight-of-evidence based methods, which allow the certainty of eutrophication in individual water bodies to be assessed. These assessments are used for decisions on designations under UWWT and Nitrates Directives and for targeting of regulatory control measures under the WFD.

Assessments of WFD ecological status and of eutrophication for estuarine (transitional) and coastal water bodies in the UK have been carried out by the Environment Agency (England), Natural Resources Wales (NRW), the Scottish Environment Protection Agency (SEPA) and the Department of Agriculture, Environment and Rural Affairs (DAERA) in Northern Ireland. These assessments are carried out to comply with the 4-yearly review timetables for UWWTD and Nitrates Directive and for WFD classification and reporting associated with the 6-yearly WFD River Basin Management planning cycle under which the latest plans were published in 2015. These assessments were used as the basis for reporting on OSPAR eutrophication status in this latest COMP.

The “read across” between the eutrophication assessments for WFD, UWWT and Nitrates Directives and OSPAR eutrophication classes requires interpretation for individual waters and thus involves a degree of expert judgement. Classification for OSPAR purposes is considered to be relevant to those estuaries or coastal water bodies found to be affected by eutrophication – these waters are considered to be small “hot spots” in terms of the OSPAR COMP. Estuarine and coastal water bodies which are initially designated as affected by eutrophication for UWWT and Nitrates Directive purposes are normally considered to meet the OSPAR definition of a Problem Area and are thus declared as such under OSPAR. In some cases, where UWWT/Nitrates Directives designation relates to the likelihood of eutrophication, a Potential Problem Area may be declared. As control measures begin to improve water quality, the certainty of eutrophication will reduce and the OSPAR status will be amended from Problem Area to Potential Problem Area. Over time these water bodies will move towards Non Problem Area status but will be generally retained as Potential Problem Areas if there is a risk that problems may return without continued application of nutrient control measures.

This Annex provides summaries of the OSPAR classifications for transitional and coastal water bodies under the WFD and related Directives (see also DAERA 2016). In total approximately 750 water bodies were assessed (Table A7.1).

In total, 21 Problem Areas and 11 Potential Problem Areas were identified during the third application of the COMP (Figure A7.1). This represents a decrease from the number of Problem Areas identified during the second application of the Common Procedure. The number of Potential Problem Areas has increased during consecutive application of the Common Procedure, partly due to improved monitoring and assessment and partly due to improved status of water bodies previously designated as Problem Areas.

Classification results for Problem Areas and Potential Problem Areas by water body and country are shown on Table A7.2 (see also Figure A7.2). The Problem Areas and Potential Problem Areas are found in Regional Seas 1, 3, 4, and 5 (see Figure 7 in the report) and are predominantly estuaries or harbours with restricted water circulation.

The Problem Areas and Potential Problem Areas fall within OSPAR Region II (north east and southern coasts of the UK) and OSPAR Region III (south-west coasts of England and Wales, and Northern Ireland).

Table A7.1: Summary of overall outcomes in terms of PAs and PPAs from assessments in WFD water bodies in England, Wales, Scotland and Northern Ireland for all applications of the COMP. PA = Problem Area, PPA = Potential Problem Area.The number of water bodies assessed is indicated in brackets (up to 167 in England, 55 in Wales, 507 in Scotland and 27 in Northern Ireland).

		England (167)		**Wales (55)**		**Scotland (507)**		**N Ireland (27)**		**TOTAL**	
		PA	PPA	PA	PPA	PA	PPA	PA	PPA	PA	PPA
COMP 1	2002	9	2	1	1	1	0	3	0	14	3
COMP 2	2008	16	2	2	0	1	1	4	3	23	6
COMP 3	2016	12	5	2	1	1	1	6	4	21	11

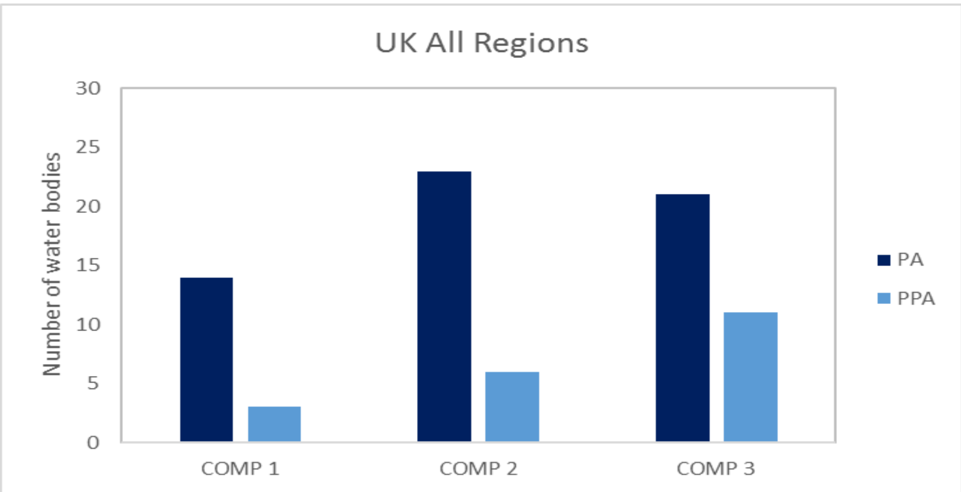


Figure A7.1: Summary of overall UK outcomes from assessments in WFD water bodies from all applications of the COMP.

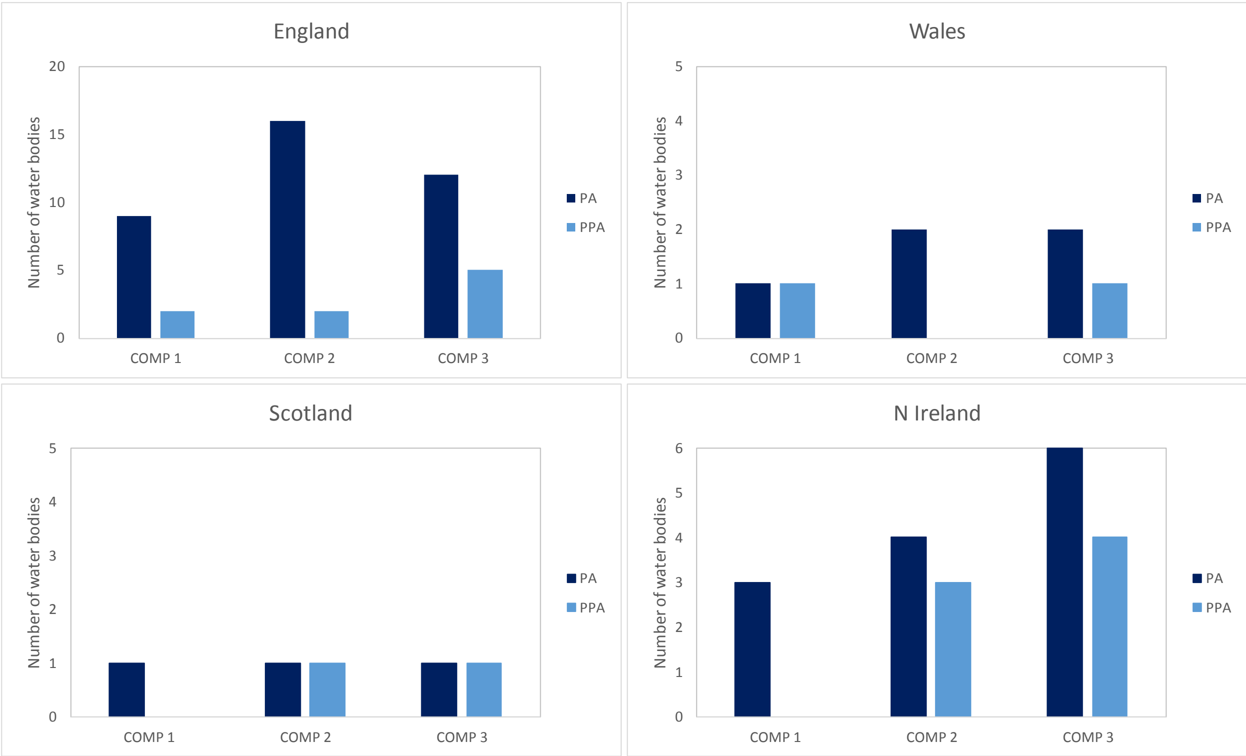


Figure A7.2: Summary of overall outcomes from assessments in WFD water bodies in England, Wales, Scotland and Northern Ireland for all applications of the COMP.

Table A7.2: Overall classification results for water bodies assessed as Problem Areas (PAs) or Potential Problem Areas (PPAs) associated with designations under the Nitrates Directive or Urban Waste Water Treatment Directive. NPA = Non Problem Area. HMWB = heavily modified water body.

Country	Assessment Area	OSPAR 2002	OSPAR 2008	OSPAR 2016
England	Chichester Harbour	PA	PA [1]	PA [1]
	Eastern Yar (Solent)		PA [1]	PA [1]
	Fal Lower estuary		PA [1]	PPA [2]
	Fleet Lagoon (The Fleet)	PPA	PPA [1]	PA [1]
	Hamble Estuary		PA [1]	PA [1]
	Holes Bay	PA	PA [1]	PA [1]
	Holy Island & Budle Bay (Lindisfarne NNR)	PA	PA [1]	PA [1]
	Kingsbridge			PA [3]
	Langstone Harbour	PA	PA [1]	PPA[1, 2]
	Medina estuary (Solent)		PA [1]	PA [1]
	Newtown River (Newtown Harbour)		PA [1]	PA [1]
	Pagham Harbour	PA	PA [1]	PPA[1, 2]
	Poole Harbour	PPA	PPA [1]	PA [1]
	Portsmouth Harbour	PA	PA [1]	PA [1]
	Taw Estuary	PA	PA [1]	PPA[1, 2]
	Tees (Seal Sands)	PA	PA [1]	PA [1]
	Truro, Tresillian, Fal Upper	PA	PA [1]	PPA [1, 2]
Wales	Burry Inlet Inner (Loughor estuary)	PPA	PA [1]	PA [1]
	Milford Haven Inner			PPA
	Tawe - Beaufort Weir to Barrage	PA	PA [1]	PA [1]
Scot-land	South Esk estuary (Montrose basin)		PPA	PPA
	Ythan estuary	PA	PA	PA [1]
Northern Ireland	Bann Estuary (HMWB) [4]			PPA
	Belfast Harbour	PA		PA
	Belfast Lough Inner	PA	PA	PA
	Connswater (HMWB) [4]			PPA
	Dundrum Bay Inner			PA
	Foyle estuary and Lough [4]		PPA	PPA
	Lagan Estuary (HMWB)	PA	PA	PA
	Newry Estuary (HMWB)			PA
	Quoile Pondage (HMWB)		PA	PA
	Roe Estuary [4]			PPA
	Strangford Lough North		PPA	NPA

[1] Sensitive Areas (Urban Waste Water Treatment Directive) or Polluted Areas (Nitrates Directive).
[2] Designated previously but improving in response to management measures.
[3] Not yet formally classified as a PA, but likely to be designated as a Polluted Water (Eutophic) under the Nitrates Directive.
[4] Final classification based on WFD results and expert judgement.

Measures to reduce nutrient inputs

The main existing measures to reduce nutrient inputs are taken through:

River basin management plans (RBMPs) developed under the Water Framework Directive (2000/60/EC)

These include measures to achieve the objectives for specific water bodies, particularly where nitrogen thresholds set under the WFD have resulted in the classification of 'moderate status' and an additional assessment of the biological quality indicates that measures to tackle eutrophication are necessary. The particular river basin districts concerned are indicated in the RBMPs and associated documents. The particular types of measure which have been included in the RBMPs are as follows:

- Reduced use of fertilisers, better fertiliser and manure management and farm management practices to reduce nutrient run-off, eg through the Nitrates Directive (91/676/EEC) and the WFD. There are also more general measures to tackle diffuse agricultural pollution including codes of good agricultural practice, agri-environment schemes and Catchment Sensitive Farming (CSF).
- In Scotland specific legislative measures have been introduced, by the Water Environment (Controlled Activities)(Scotland) Regulations, to implement WFD and which contain general binding rules to mitigate diffuse pollution.
- Measures are in place across the UK to work with farmers to secure good practice and improve environmental protection measures, including the Rural Development Programmes in England, Wales, Scotland and Northern Ireland. The above programmes which contribute to reducing nitrates from entering rivers and coastal areas are contributing to a significant reduction of diffuse pollution from agriculture.
- Some of the measures proposed in the RBMPs are voluntary. However, these have been developed following extensive consultation through the draft RBMPs, the liaison panels and location specific workshops, and are considered to be deliverable and achievable within the next cycle and will complement the suite of basic measures that are in place.
- Reduced nutrient inputs arising from sewage treatment works (STWs), eg through application of the EC Urban Waste Water Treatment (UWWT) Directive (91/271/EEC), the creation of 'UWWT Directive Sensitive Areas' and the implementation of STW nutrient reduction measures for the Habitats Directive (92/43/EEC).

The organisations responsible for these WFD-related measures are: in England, Defra; in Wales, the Welsh Government for western Wales, and for the river Severn and the river Dee joint responsibility between England and Wales; in Scotland, the Scottish Government; and in Northern Ireland, the Department of Agriculture, Environment and Rural Affairs (DAERA).

The RBMPs are reviewed at the end of each 6-year cycle as outlined in the WFD and a programme of measures is agreed to meet the objectives outlined in the plan. National environment agencies are currently updating the WFD RBMPs referred to above.

In England, the Countryside Stewardship (previously New Environmental Land Management Scheme, NELMS) from 2016, under the Rural Development Programme, will be an important future mechanism for reducing diffuse agricultural water pollution. In Northern Ireland, a new agri-environment scheme for the Northern Ireland Rural Development Programme 2014-2020 is being developed and will run from 2016 to 2020.

Reduced emissions to the atmosphere

- Emissions of nutrients to the atmosphere are reduced through the setting of appropriate emission limits through the Industrial Emissions Directive (2010/75/EU) which sets emission limits for nitrogen in line with the best available abatement technologies. This measure is also aimed at reducing any possible contribution to trans-boundary impacts of nutrients to the waters of other countries.
- Emissions of nitrogen oxides and ammonia are reduced though implementation of the National Emissions Ceiling Directive (2001/81/EC) which sets emission ceilings on forms of nitrogen. This measure is also aimed at reducing any possible contribution to transboundary impacts of nutrients to the waters of other countries.

The control of Nitrogen Oxides (NOx) emissions from ships through the Merchant Shipping (Prevention of Air Pollution from Ships) Regulations 2008 (as amended)

This measure, which requires engines installed on a ship to meet the specified NOx emission standard, is primarily designed to improve air quality. It will also contribute to the reduction of NOx inputs to both UK waters and the waters of other countries. The organisation responsible for implementation of these regulations is the Department for Transport.

Timescale for recovery

The timescales for recovery once measures are in place can be lengthy – a few decades - particularly when macroalgal growth is the issue. Many designated waters have measures under both Urban Waste Water Treatment Directive (UWWTD) and the Nitrates Directive which bear down on sewage effluent and agricultural nitrogen pressures. In no cases do we expect swift recovery. Some of the areas have contributions from groundwater feeding river flow where it will take decades for nitrate levels to reduce in response to measures. We have seen reductions in nutrient loadings at sites designated under UWWTD, as expected, and in some areas there is evidence that river nitrogen loadings may be falling. Evidence of biological improvements seems to be potentially apparent in certain estuaries, but it is too early to be clear on trends and whether they will be sustained.