The River Wensum Catchment: Review of Environment Agency Macroinvertebrate Monitoring 1985-2020.

Daniel Mills

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Anglian Area, Analysis and Reporting

Contents

Glossary

WHPT ASPT - A metric which uses UK macroinvertebrate assemblage data to indicate river ecological quality, sensitive to organic pollution and general water quality pressures. Higher WHPT ASPT scores correspond to macroinvertebrate assemblages more sensitive to pollution and it is inferred that sites with higher scoring assemblages are subject to reduced pressures.

‘ASPT’ refers to Average Score Per Taxon’. For example, ‘scores’ denote a sensitivity rating between -1 and 12.2, as produced for most common macroinvertebrate taxa by scientists. Higher scoring taxa have increased sensitivity to pollution pressure and are less likely to be found in impacted streams. The mean score of all macroinvertebrate taxa found at a study site provides ASPT (See: UKTAG 2014).

WHPT NTAXA - A simple metric of stream biodiversity as the total number of ‘scoring’ macroinvertebrate taxa included in WHPT ASPT calculations described above. In environmental management, WHPT NTAXA is typically used as a descriptor of habitat richness, -a factor widely associated with higher biodiversity (See: UKTAG 2014).

LIFE (FAMILY) - A metric which uses UK macroinvertebrate assemblage data to indicate river ecological quality, sensitive to low and inconsistent flow velocities. Higher LIFE scores correspond to macroinvertebrate assemblages more sensitive to reduced and/or inconsistent flow regimes. It is inferred that sites with higher scoring assemblages are subject to reduced pressures (See: Extence and Chadd 1999).

PSI (FAMILY) - A metric which uses UK macroinvertebrate assemblage data to indicate river ecological quality, sensitive to siltation and unfavourable stream sediment dynamics. Higher PSI scores are proportionate to the number of macroinvertebrate taxa present considered unlikely to live on stream beds with overlying silt. It is inferred that sites with higher scoring assemblages are subject to reduced siltation pressures (See: Turley et al. 2014).

RICT – River Invertebrate Classification Tool is a publicly available statistical modelling tool to estimate the ecological quality of UK Rivers. Using reference datasets on macroinvertebrate assemblages which exist in 'pristine' conditions, it models predictions of what macroinvertebrates should be at a given site, accounting for a series of physicochemical variables present. This includes expected WHPT ASPT, NTAXA, LIFE and PSI scores. The difference between the expected and observed scores is used to contextualise the ecological quality compared to a situation with little anthropogenic influence.

Observed to Expected (O:E) Ratio – This is the ratio comparison of a river's observed metric score to that expected under semi-pristine conditions, as modelled by RICT (see above). An O:E score above a given target or threshold (see below) indicates conditions greater than would be expected in a semi-pristine environment under that metric.

Target O:E Ratio – For the WHPT ASPT and WHPT NTAXA metrics, targets have been nationally set by the EA for Observed to Expected Ratios (see above) for rivers across England. These targets are currently an O:E ratio score of 0.86 for WHPT ASPT and 0.68 for WHPT NTAXA. O:E ratio scores above these targets indicate conditions greater than would be expected in a semi-pristine environment under these metrics. The 'targets' are routinely used by the EA as a boundary for good (or higher) stream conditions under the Water Framework Directive.

O:E Ratio Threshold – For the LIFE and PSI metrics, thresholds have been nationally set by the EA for Observed to Expected Ratios (see above) for rivers across England. These targets are an O:E ratio score of 1.0 for LIFE (on chalk stream rivers) and 0.7 for PSI. O:E ratio scores above these thresholds indicate conditions greater than would be expected in a semi-pristine environment under these metrics. However, these 'thresholds' are currently considered informative and are not routinely used as a boundary for good (or higher) stream conditions under the Water Framework Directive.

1. Introduction

This review aimed to assess temporal and spatial trends in macroinvertebrate assemblage data in the Wensum catchment collected by the Environment Agency and predecessor organisations between 1985-2020. The report is designed as a standalone summary of long-term monitoring datasets for the main river and its tributaries. It includes analysis of macroinvertebrate indicator metrics used for ecological appraisal in UK rivers. In addition, brief summaries of supporting fish and water quality monitoring, alongside reflection on restoration and land management change that may have impacted ecological quality in the catchment through time.

The River Wensum is notably one of only 31 English rivers to be designated as a whole Site of Special Scientific Interest (SSSI; Collins et al. 2013) and is considered one of the UK's most important lowland chalk stream habitats (Mainstone 1999). While centuries of anthropogenic modification have degraded ecological quality across the predominantly agricultural catchment (Armitage et al. 2001), the natural river course has changed little since the 1400's, with only limited channel straightening for navigation (Sear et al. 2006). As such, it is of high conservation potential and recreational importance for local people (Beardsley and Britton 2012).

In particular, the Wensum has enjoyed a recent history of proactive stakeholder engagement. For example, social and economic groups in angling, navigation and farming have developed strong communities working towards habitat restoration and improved biodiversity (Collins et al. 2012; Mainstone and Wheeldon 2016). Notable progress has been made to improve sewage treatment (Beardsley and Britton 2011), stream connectivity (Mainstone and Wheeldon 2016), habitat richness (Lewis 2001; RESTORE 2020) and sustainable land use (Lovett et al. 2015) over the past 30 years.

This report aims to provide a review of macroinvertebrate community change in this period and set a benchmark to evaluate future environmental stressors across the catchment. For example, acknowledged impacts from diffuse nutrient enrichment (Demars and Harper 2002), habitat modification (Beardsley and Britton 2012) abstraction (Weatherhead et al. 2014) and prolonged drought (Outram et al. 2014). Through clear understanding of past trends, including periods of success and failure; stakeholder efforts to improve ecological quality can be built on. It is hoped this review is of interest for all who enjoy or have contributed to life on the Wensum.

2. Review: Macroinvertebrate Monitoring

Data from all long-term monitoring sites on the Wensum and its tributaries were included in the review. To ensure comparability of sites, records were exempt where sampling was not undertaken using the standard Environment Agency 3-minute kick/sweep methodology. In addition, exemptions were made where site data contained less than 10 years of seasonally collected samples. The data sets therefore contained sufficient records to acknowledge variance in macroinvertebrate assemblages between sites, across different time periods. All raw data is available at: https://environment.data.gov.uk/ecology-fish/

2.1. Monitoring Site Locations

According to these criteria, macroinvertebrate sample data was extracted from the EA ecology database (Biosys) for 24 monitoring sites (see**: Table 1.**; mapped points: **Figure 1.**, p. 7;). At each site, raw macroinvertebrate assemblage lists per sample were used to calculate metrics which indicate the degree of various environmental stressors. Metrics were WHPT ASPT, WHPT NTAXA, LIFE and PSI scoring systems (S**ee glossary, pg. 3**).

Table 1. Monitoring Site name, location, sample frequency and years in record. Map No. refers to overleaf.

Site Name	Watercourse	Grid Ref	# Samples	Years
A1065 Bridge S. Raynham	***River Wensum***	TF8850024200	12	1990-2001
Tatterford Common	*River Tat*	TF8670028000	44	1986-2015
Coxford-Broomthorpe Rd.	*Rudham Stream*	TF8450028600	17	1986-1994
Sculthorpe Mill	***River Wensum***	TF8930030400	60	1986-2015
Langor Bridge	*Kettlestone Stream*	TF9610029300	13	1991-2014
Great Ryburgh Bridge	***River Wensum***	TF9640027400	24	1995-2015
Bintree Mill	***River Wensum***	TF9985024210	31	1990-2016
Twyford Bridge	*Foulsham Stream*	TG0170024500	21	1986-2015
Billingford Bridge	***River Wensum***	TG0040020200	18	1986-1994
DS Spong Bridge	*Blackwater Stream*	TF9890919168	36	1989-2013
Hoe Bridge	*Wendling Beck*	TF9832317306	52	1986-2015
Wendling Bridge	*Wendling Beck*	TF9340012800	13	1991-2003
Swanton Morley Bridge	***River Wensum***	TG0210018500	47	1987-2015
Eades Mill	*Blackwater Beck*	TG0950021300	45	1989-2017
Great Witchingham Bridge	***River Wensum***	TG1073518725	61	1990-2019
Stone Road Bridge	*River Tud*	TG0270012200	21	1995-2015
Whitford Bridge	*River Tud*	TG0660012800	26	1989-2006
Berry's Bridge Honningham	*River Tud*	TG0980011800	31	1989-2009
Ringland Bridge	***River Wensum***	TG1420013700	15	1987-1994
Taverham Bridge	***River Wensum***	TG1597013710	31	1995-2019
Costessey Park Bridge	*River Tud*	TG1698711267	59	1986-2019
Hellesdon Mill	***River Wensum***	TG1980010400	39	1989-2019
New Mills	***River Wensum***	TG2261009090	20	1995-2014
Fye Bridge	***River Wensum***	TG2320009000	23	1990-2000

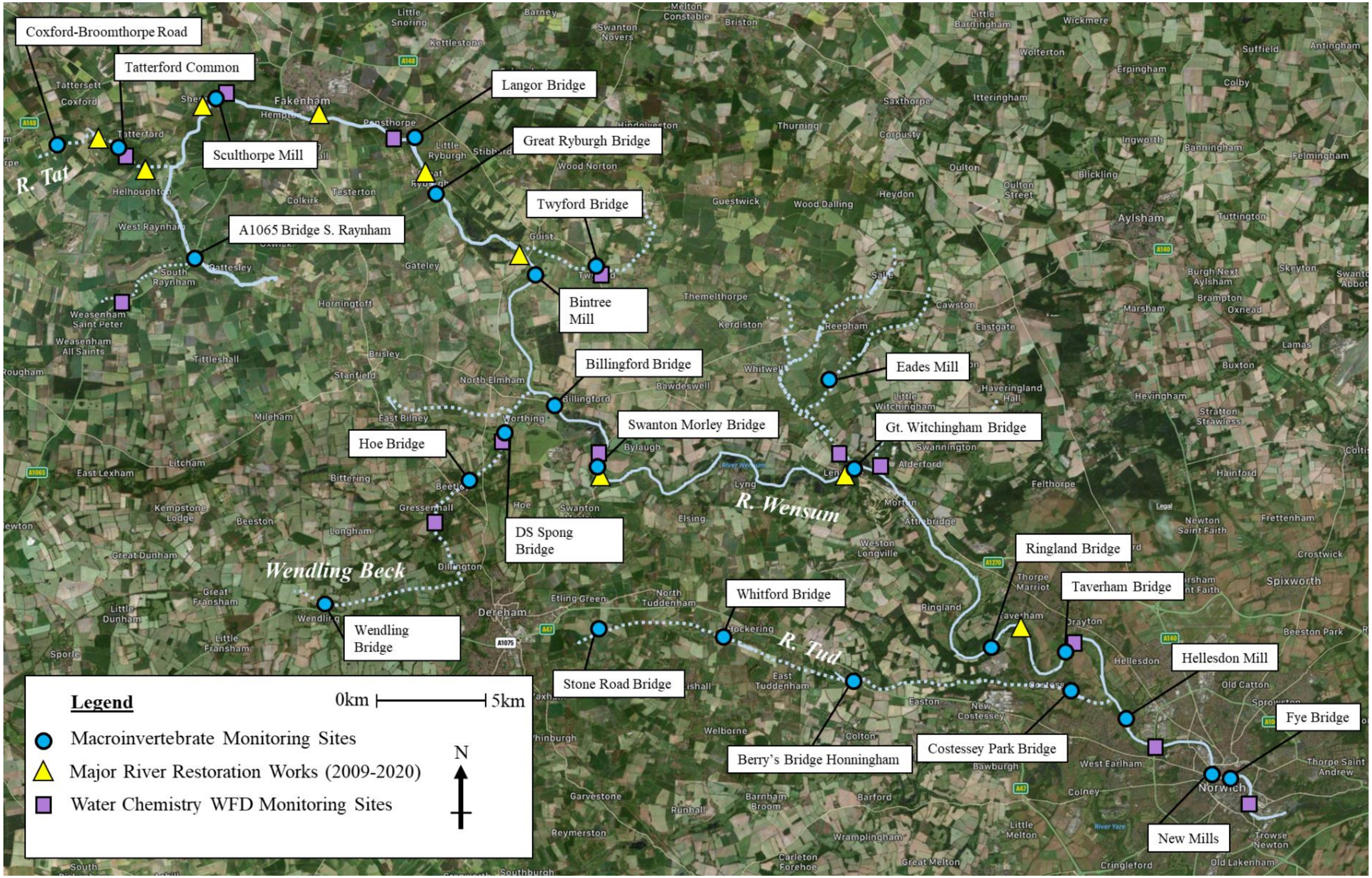

Figure 1. Location and name of macroinvertebrate monitoring sites in the Wensum catchment discussed in this review. Also included is the location of major river restoration works (**see Section 5, p. 31**) and WFD water quality monitoring sites (**see Section 4, p. 29**).

2.2. Macroinvertebrate Data Analysis

To contextualise raw metric scores across sites, ‘expected’ scores under semi-pristine conditions (i.e. without anthropogenic stress) were modelled for each of the 24 monitoring sites. This was done using the River Invertebrate Classification Tool (RICT; see: FBA 2020), which uses physicochemical variables from monitoring sites to calculate expected metric scores, including WHPT ASPT, WHPT NTAXA, LIFE and PSI. The physicochemical variables required from each site to calculate expected scores include stream alkalinity (as CaCO3 mg L^{-1}), substrate typology (% by category), distance from source (km^{-1}), width (m^{-1}), depth (cm^{-1}), slope (degree) and surficial geologic region (category via. NGR). These were also extracted from the EA ecology database and input to the RICT model using Microsoft Studio (Azure Machine Learning Studio); accessed via the Freshwater Biological Association website (FBA 2020).

2.3. Observed Macroinvertebrate Communities

WHPT ASPT

Between 1985 and 2020, WHPT ASPT scores presented general improvement across most monitoring sites in the catchment. The highest scores on the River Wensum were consistently found at Great Witchingham Bridge in the lower-mid catchment, alongside Sculthorpe Mill and A1095 Road Bridge in the headwaters (**Figure 2 *c, a***). The highest scores on tributary monitoring sites were found at Costessey Park Bridge on the Tud and Spong Bridge on the Blackwater stream (**Figure 2 *f, e***). Sites with higher WHPT ASPT scores indicated more favourable stream water quality conditions, capable of supporting richer ecology.

In contrast, the worst performing sites on the Wensum River were at Fye Bridge and New Mills in central Norwich (**Figure 2 *d, c***) alongside Ringland Bridge in the lower mid-catchment. In the headwaters, the worst performing scores were found at Coxford-Broomthorpe Road on the Rudham Stream **(Figure 2 *e, f***). It should be noted that for Fye Bridge, Coxford-Broomthorpe Road and Ringland Bridge sites, only limited recent data were available to discount improvements over time. Where data was available for the years 2010-2020, mean ASPT scores were generally higher across the catchment compared to any other decadal interval (**See: Figure 6. p.15**). Please see **Section 2.4** (**p. 17**), for a comparison of observed WHPT ASPT scores with those expected (O:E ratios) under semi-pristine conditions.

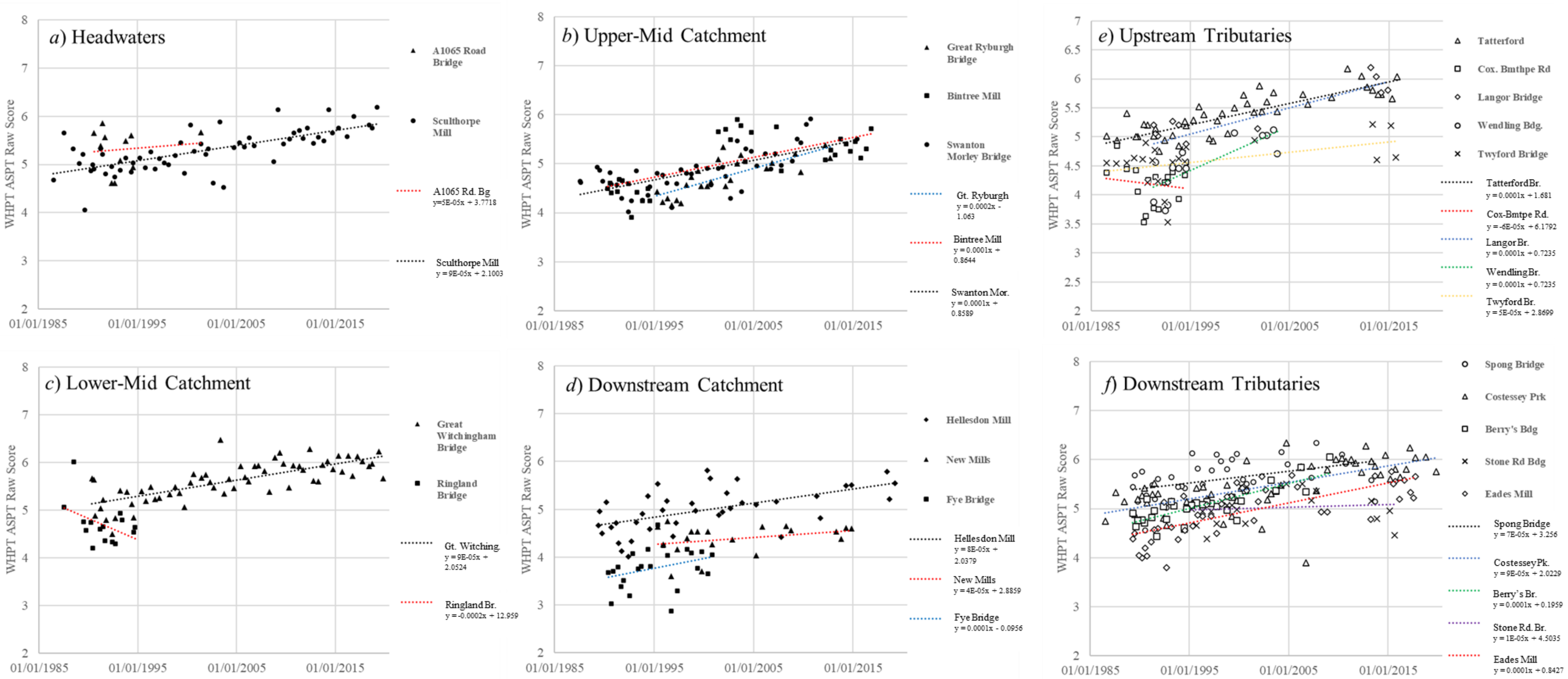

Figure 2. Raw WHPT ASPT Scores from 1985 to 2020 in the Wensum Catchment sorted by headwater, middle and downstream site groups.

WHPT NTAXA

From 1985 to 2020, WHPT NTAXA scores presented a slight but consistent trend of improvement across most upper Wensum sites and headwater tributaries. However, there were level or deteriorating conditions for most mid-catchment and downstream sites. The highest NTAXA scores on the River Wensum were found at the Sculthorpe Mill in the headwaters, alongside Bintree Mill in the upper mid-catchment and Hellesdon Mill, approximately 3 km upstream of Norwich (**Figure 3 *a, b, d***). The highest scoring tributary sites were at Tatterford Common on the Tatt alongside Costessey Park and Berry's Bridge on the Tudd (**Figure 3 *a*)**. Sites with higher WHPT NTAXA scores indicated more favourable stream habitat quality, capable of supporting richer ecology.

Generally, the lowest scoring sites on the Wensum were at Fye Bridge in central Norwich, alongside Ringland Bridge in the lower mid-catchment and A1095 Road Bridge in the headwaters (**Figure 3 *d, c, a***). At each of these sites however, only limited recent data were available to discount improvement over time. It was notable that sites at Great Ryburgh Bridge, Great Witchingham Bridge, and Swanton Morley Bridge showed declines up to the most recent data collection in 2019 (**Figure 3 *b, c***).

Mean NTAXA values per decade varied consistently between 15 and 34 across all River Wensum monitoring sites (**Figure 7, p. 15**) with the exception of Fye Bridge in central Norwich which showed lower values of 10 to 15 NTAXA. The highest mean NTAXA values recorded for any decade were found at Great Witchingham Bridge on the River Wensum (33 NTAXA; 2011-2020), Costessey Park Bridge on the Tud (34 NTAXA; 1991-2000) and Bintree Mill on the Wensum (32 NTAXA; 2011-2020). Contrary to ASPT values (**see: Section 2.3, p. 8**), higher mean NTAXA values were not consistently found in the most recent decade 2011-2020, except at headwater Wensum and upstream tributary sites (**Figure 7, p. 15**). Please see **Section 2.4** (**p. 19**), for a comparison of observed WHPT NTAXA scores with those expected (O:E ratios) under semi-pristine conditions.

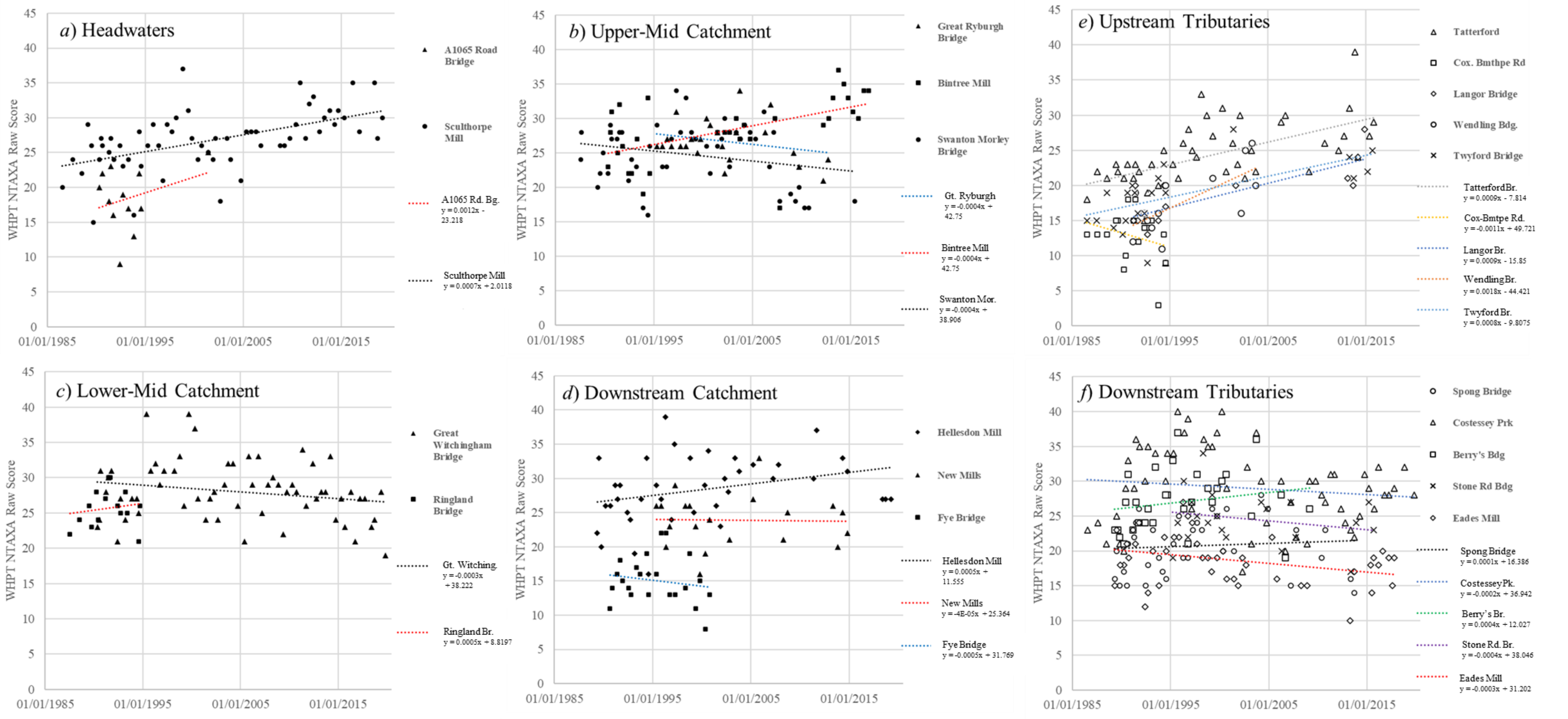

Figure 3. Raw WHPT NTAXA Scores from 1985 to 2020 in the Wensum Catchment sorted by headwater, middle and downstream site groups.

LIFE (Family)

Between 1985 to 2020, LIFE scores slightly improved across most sites in the catchment with long-term monitoring. The highest scores on the River Wensum were consistently found at Sculthorpe Mill and the A1065 Road Bridge in the headwaters, alongside Great Witchingham Bridge in the lower-mid-catchment, which showed steady improvement in LIFE scores over time (**Figure 4 *a, b***). The highest scoring tributary sites were at Tatterford Common on the Tat and Eades Mill on Blackwater Beck in the mid-catchment (**Figure 4 *e, f***). Sites with higher LIFE scores indicated more favourable stream flow conditions, capable of supporting richer ecology.

In contrast, the worst performing sites on the Wensum were at Fye Bridge and New Mills in central Norwich alongside Ringland Bridge in the lower mid-catchment (**Figure 4 *d, b, c***). In the case of New Mills, recent data suggested gradual improvement at this site, however decline was shown at Ringland Bridge without recent data to account for potential improvements (**Figure 4 *c***). Please see **section 2.4** (**p. 21**), for a comparison of observed LIFE scores with those expected (O:E ratios) under semi-pristine conditions.

PSI (Family)

Between 1985 to 2020, PSI scores slightly improved across most sites in the catchment with long-term monitoring. Similar to LIFE scores (see above), the highest scores on the Wensum were consistently found at the A1065 Road Bridge and Sculthrope Mill in the river headwaters, alongside Bintree Mill and Great Witchingham Bridge in the mid-catchment (**Figure 5 *a, b, c***). The highest scoring tributary sites were found at Tatterford Common on the Tat alongside Eades Mill on Blackwater Beck in the mid-catchment (**Figure 5 *e, f***). Sites with higher PSI scores indicated more favourable stream sediment flux with bed-substrate conditions capable of supporting richer ecology.*

In contrast, the lowest scoring River Wensum sites were at Fye Bridge and New Mills in central Norwich (**Figure 5 *d***) alongside Ringland Bridge in the mid-catchment. The lowest scoring tributary sites were at Coxford-Broomthorpe Road, DS Spong Bridge and Stone Road Bridge in the mid and lower catchment (**Figure 5 *d, b, c***). However, at several poor scoring sites (e.g. Fye Bridge, Ringland Bridge, Coxford-Broomthorpe Road), limited recent data was available to discount potential improvement. Notably, tributary sites at Langor Bridge and Stone Road Bridge showed the clearest long-term decline of any in the catchment (**Figure 5 *b, c, e***).

*Please see **section 2.4** (**p. 23**), for a comparison of observed PSI scores (O:E ratios) with those expected under semi-pristine conditions.

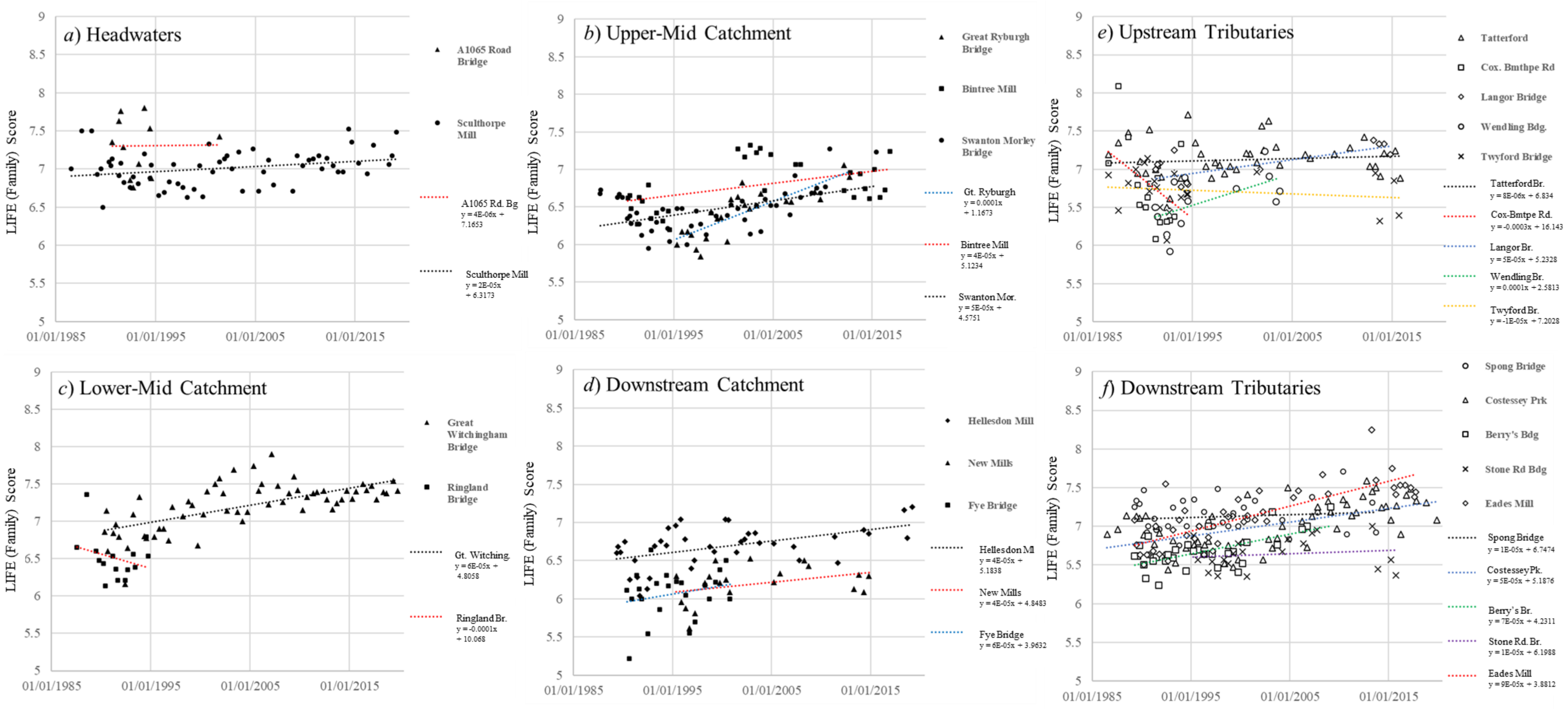

Figure 4. Raw LIFE (FAMILY) Scores from 1985 to 2020 in the Wensum Catchment sorted by headwater, middle and downstream site groups.

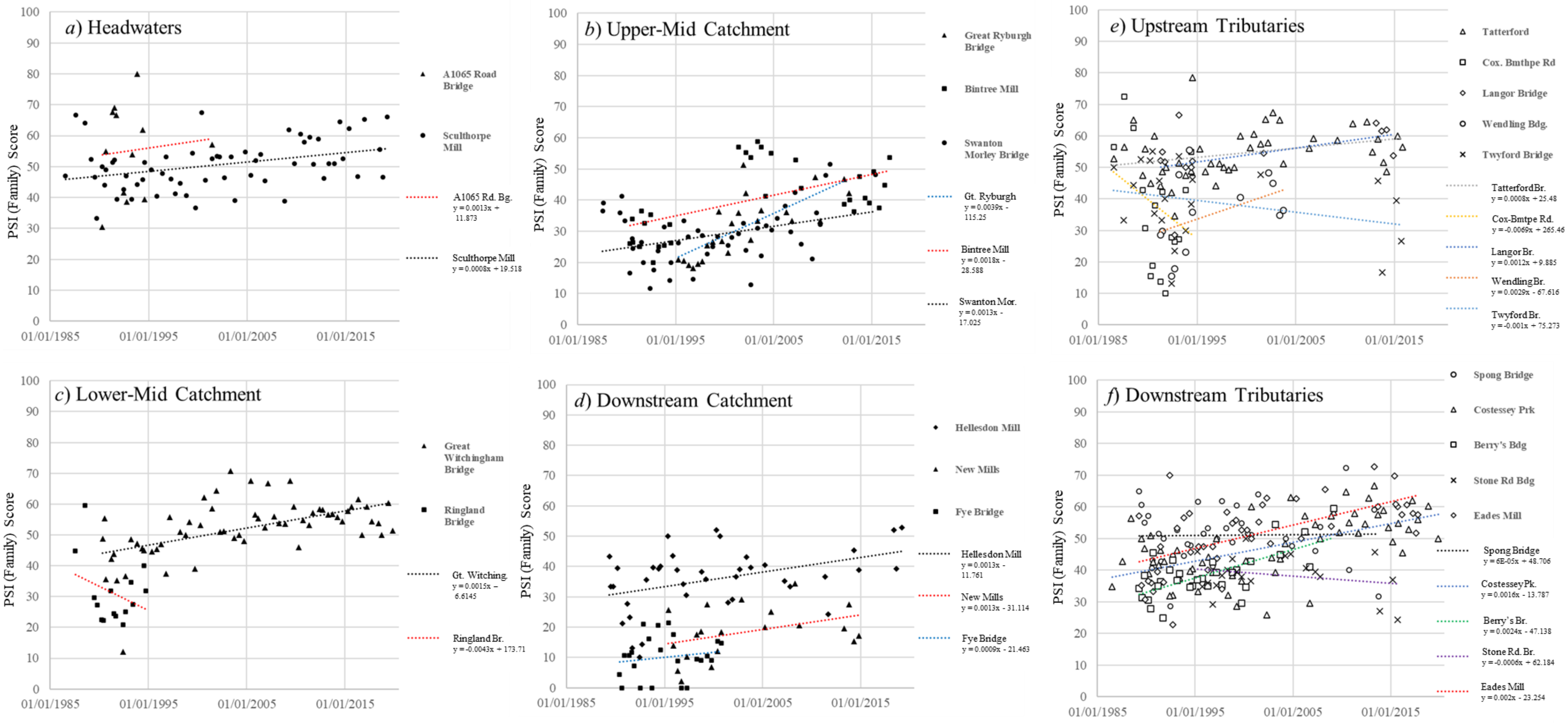

Figure 5. Raw PSI (FAMILY) Scores from 1985 to 2020 in the Wensum Catchment sorted by headwater, middle and downstream site groups.

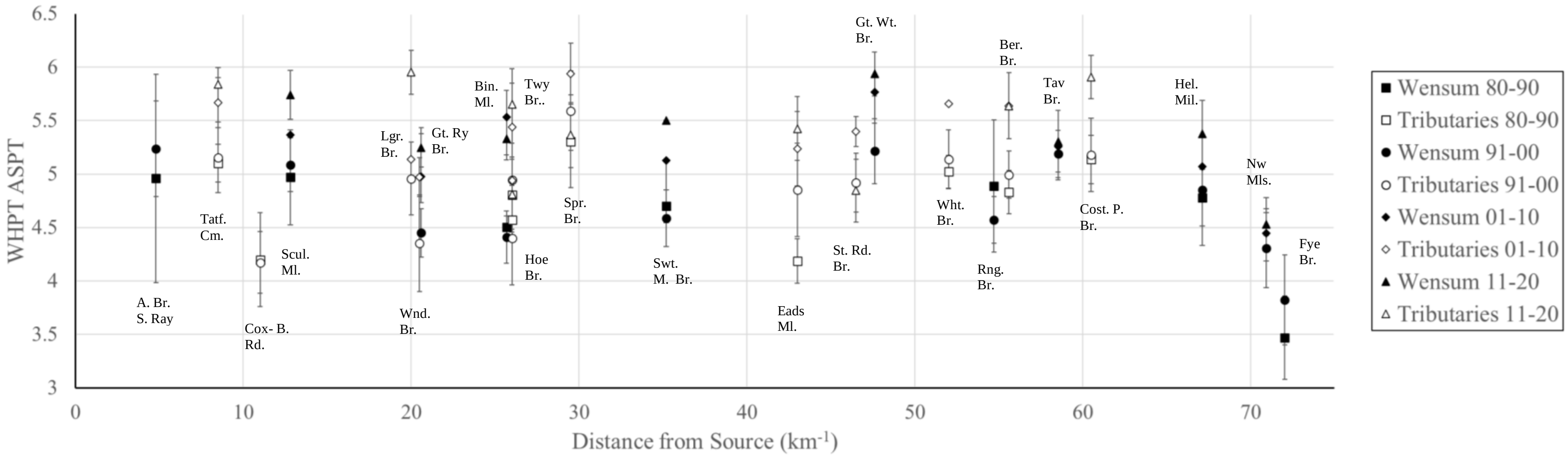

Figure 6. Mean WHPT ASPT Scores per monitoring site in the Wensum catchment by decade period and approximate distance from the Wensum source. Filled symbols denote River Wensum monitoring sites and unfilled symbols Wensum tributary sites. Plot markers: *square* 1980-1990, *circle* 1991-2000, *diamond* 2001-2010, *triangle* 2011-2020. Error bars denote standard deviation.

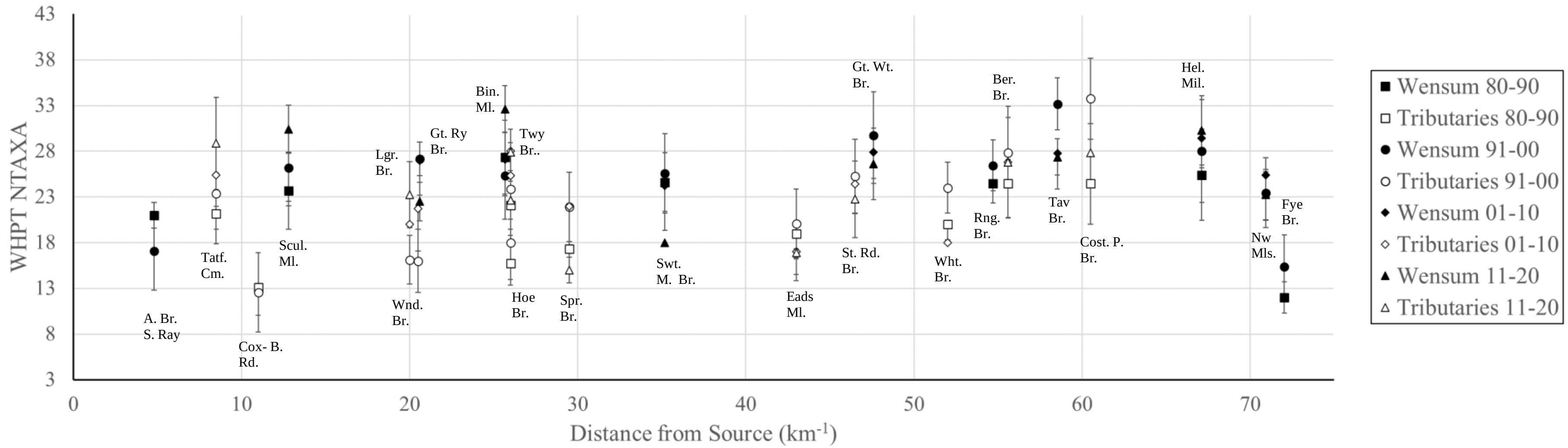

Figure 7. Mean WHPT NTAXA Scores per monitoring site in the Wensum catchment by decade period and approximate distance from the Wensum source. Filled symbols denote River Wensum monitoring sites and unfilled symbols Wensum tributary sites. Plot markers: *square* 1980-1990, *circle* 1991-2000, *diamond* 2001-2010, *triangle* 2011-2020. Error bars denote standard deviation.

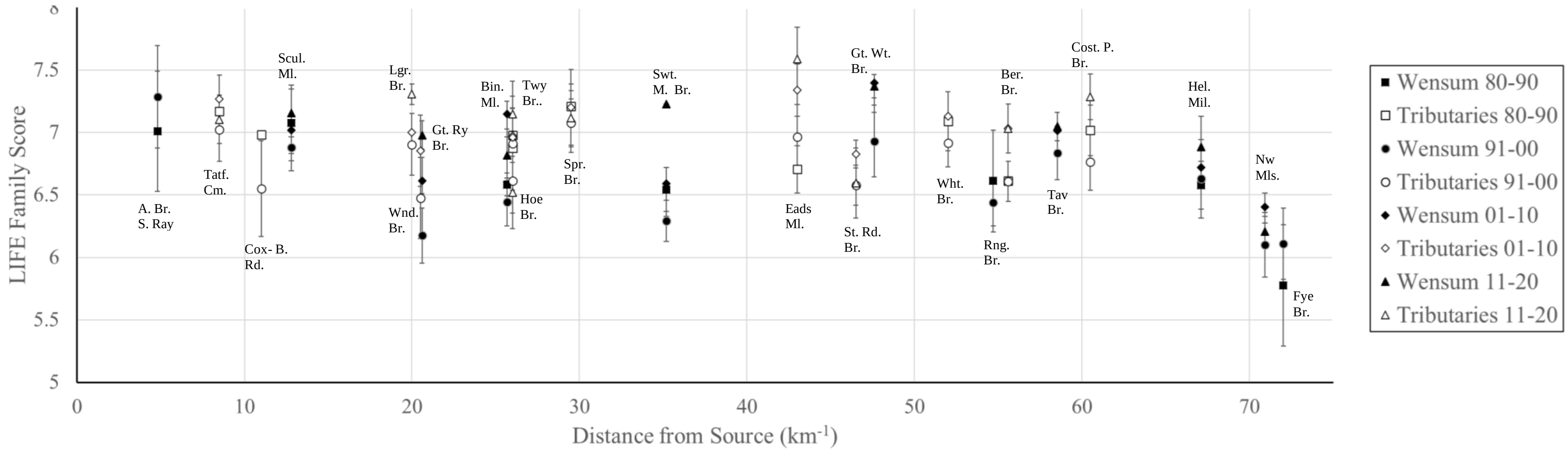

Figure 8. Mean LIFE (FAMILY) Scores per monitoring site in the Wensum catchment by decade period and approximate distance from the Wensum source. Filled symbols denote River Wensum monitoring sites and unfilled symbols Wensum tributary sites. Plot markers: *square* 1980-1990, *circle* 1991-2000, *diamond* 2001-2010, *triangle* 2011-2020. Error bars denote standard deviation.

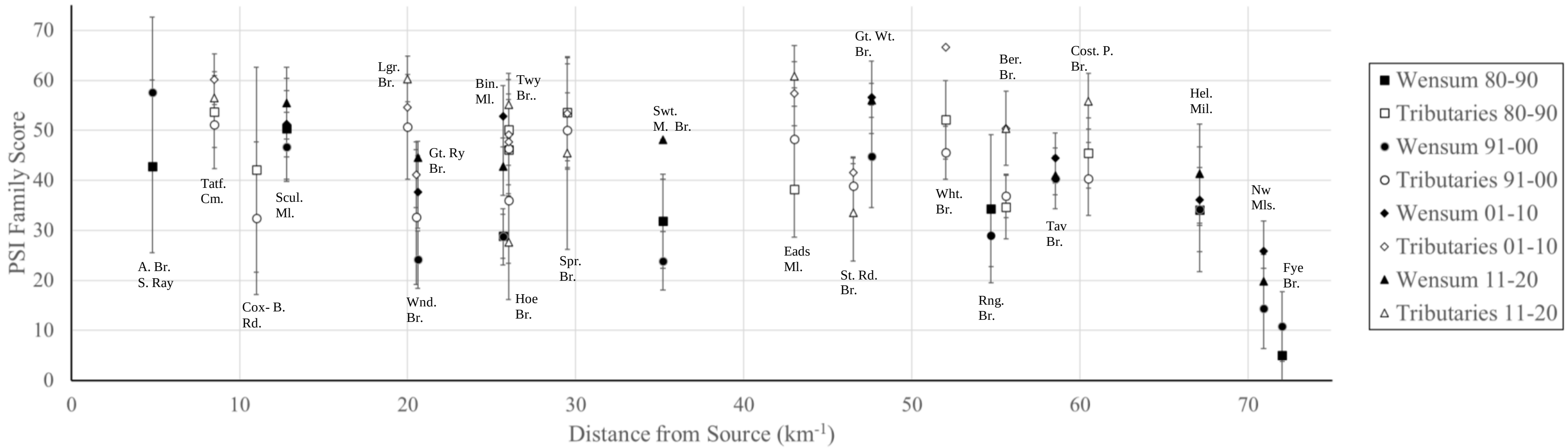

Figure 9. Mean PSI (FAMILY) Scores per monitoring site in the Wensum catchment by decade period and approximate distance from the Wensum source. Filled symbols denote River Wensum monitoring sites and unfilled symbols Wensum tributary sites. Plot markers: *square* 1980-1990, *circle* 1991-2000, *diamond* 2001-2010, *triangle* 2011-2020. Error bars denote standard deviation.

2.4. Observed Compared to Expected Communities

WHPT ASPT O:E Ratios

Between 1985 and 2020, WHPT ASPT O:E ratios presented consistently favourable conditions, with scores largely above the 0.86 target throughout the catchment. In addition, trends of improvement were common across sites. The highest O:E ratios on the Wensum were found at Great Witchingham Bridge in the lower-mid catchment, alongside Sculthorpe Mill in the upper Wensum (**Figure 10 *c, a***). Throughout the time series, O:E values here increased well above the target of 0.86, meaning macroinvertebrate communities indicated stream water chemistry conditions greater or the same as expected under semi-pristine conditions. The highest scoring tributary sites were at Tatterford Common on the Tat and DS Spong Bridge on the Blackwater stream (**Figure 10 *e*)**, which showed similarly consistent improvements and highly favourable scores.

While most sites surpassed the O:E target of 0.86 from at least the year 2000, some performed more poorly. The worst performing on the River Wensum were sites at Fye Bridge in the downstream catchment and Ringland Bridge in the lower mid-catchment (**Figure 10 *d, c***). Here, O:E values were consistently lower than the target value of 0.86 between 1985-2000, meaning macroinvertebrate communities indicated water quality conditions worse than would be expected under a semi-pristine environment. While other Wensum sites clearly improved over time from a similar position (e.g. Bintree Mill, Great Ryburgh Bridge), no recent data was available to confirm similar trends at Ringland and Fye Bridge. The worst scoring tributary sites were at Coxford-Broomthorpe Road on the Rudham Stream and Wendling Bridge on the Wendling River **(Figure 10 *e***). These sites again showed O:E values consistently lower than the 0.86 target during the earliest part of the time series. While Wendling Bridge showed some improvement up to 2004, again no recent data was available to assess subsequent trends at Coxford-Broomthorpe Road.

Where data was available for the years 2011-2020, mean O:E ASPT scores at most sites were higher than for any other decadal interval **(Figure 14, p. 25)**. To underline improvements seen, O:E values for all sites in the catchment upstream of Norwich, had rose consistently above the critical threshold of 0.86 by the year 2000, with the exception of Ringland Bridge on the Wensum and Twyford Bridge on the Foulsham Stream. This means that most macroinvertebrate communities in the catchment indicated stream water quality conditions the same or greater than would be expected in a semi-pristine environment.

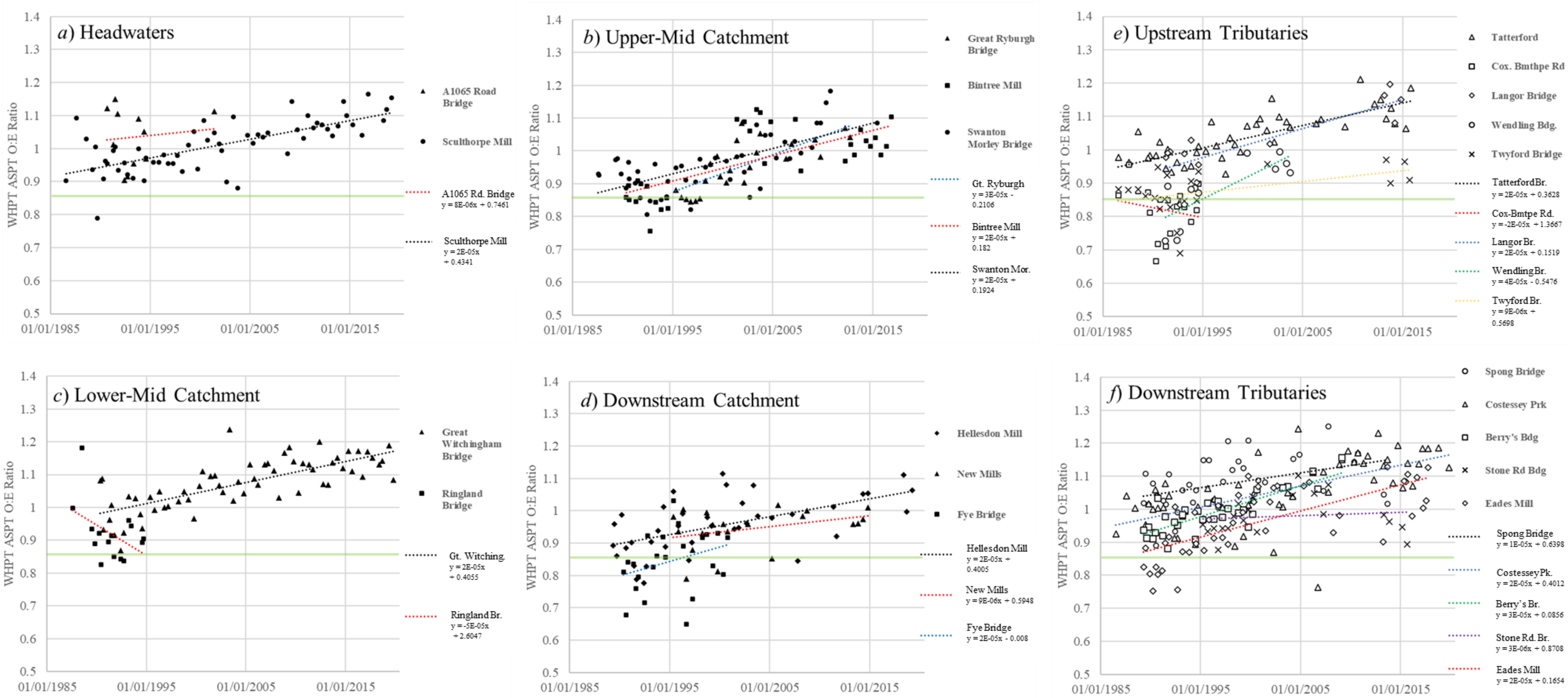

Figure 10. Observed: Expected WHPT ASPT ratios from 1985 to 2020 in the Wensum Catchment sorted by headwater, middle and downstream site groups. Green line denotes the WHPT ASPT target O:E ratio, set nationally by the EA.

WHPT NTAXA O:E Ratios

From 1985 to 2020, NTAXA O:E ratios presented favourable conditions at most sites, with scores generally above the 0.68 target. There was a slight but still consistent trend of improvement across sites in the upper catchment, but more concerningly, level or deteriorating conditions for the majority of mid-catchment and downstream sites. The highest O:E ratios on the River Wensum were found at Sculthorpe Mill in the headwaters, Bintree Mill in the upper mid-catchment and Hellesdon Mill, located <5km upstream of Norwich (**Figure 11 *a, b, d***). Throughout the time series, O:E values at these sites increased well above the target of 0.68, meaning macroinvertebrate communities indicated stream habitat conditions greater or the same as would be expected under semi-pristine conditions. The highest ratio scores on tributary sites were at Costessey Park and Berry's Bridge on the Tudd (**Figure 11 *a*)**, which showed similarly favourable O:E ratios across time series.

Again, despite scores that generally remained higher than the O:E target of 0.68, conditions were level or deteriorating at most sites in the mid and downstream catchment. The lowest NTAXA O:E scoring sites on the Wensum were at Fye Bridge in central Norwich alongside Ringland Bridge in the mid-catchment and A1095 Road Bridge in the headwaters (**Figure 11 *d, c, a***). Here, O:E values were consistently near to or lower than the critical threshold of 0.68, meaning macroinvertebrate communities indicated stream habitat conditions marginally favourable and unfavourable. It was also notable that at Great Ryburgh Bridge in the upper-mid catchment, there was a clear long-term decline, with most recent data showing scores very close to the O:E target value (**Figure 11 *b***). Other Wensum sites were also poorly performing, (e.g. Fye Bridge, A1065 Road Bridge), but limited recent data was available to rule out subsequent improvements.

The majority of level or declining records at tributary sites were also found in the lower catchment (**Figure 11 *f***). However, the worst O:E scores were at Coxford-Broomthorpe Road on the Rudham Stream and Wendling Bridge on the Wendling River, both upper catchment tributaries **(Figure 10 *e***). These sites showed O:E values consistently lower than 0.68 in the earliest part of the time series. As for WHPT ASPT, Wendling Bridge showed clear improvement up to 2004, but no recent data was available to assess subsequent trends. It was notable that Eades Mill on the Blackwater Beck in the lower catchment showed a particularly clear long-term decline, with most recent data showing scores lower than the O:E target value (**Figure 11 *f***).

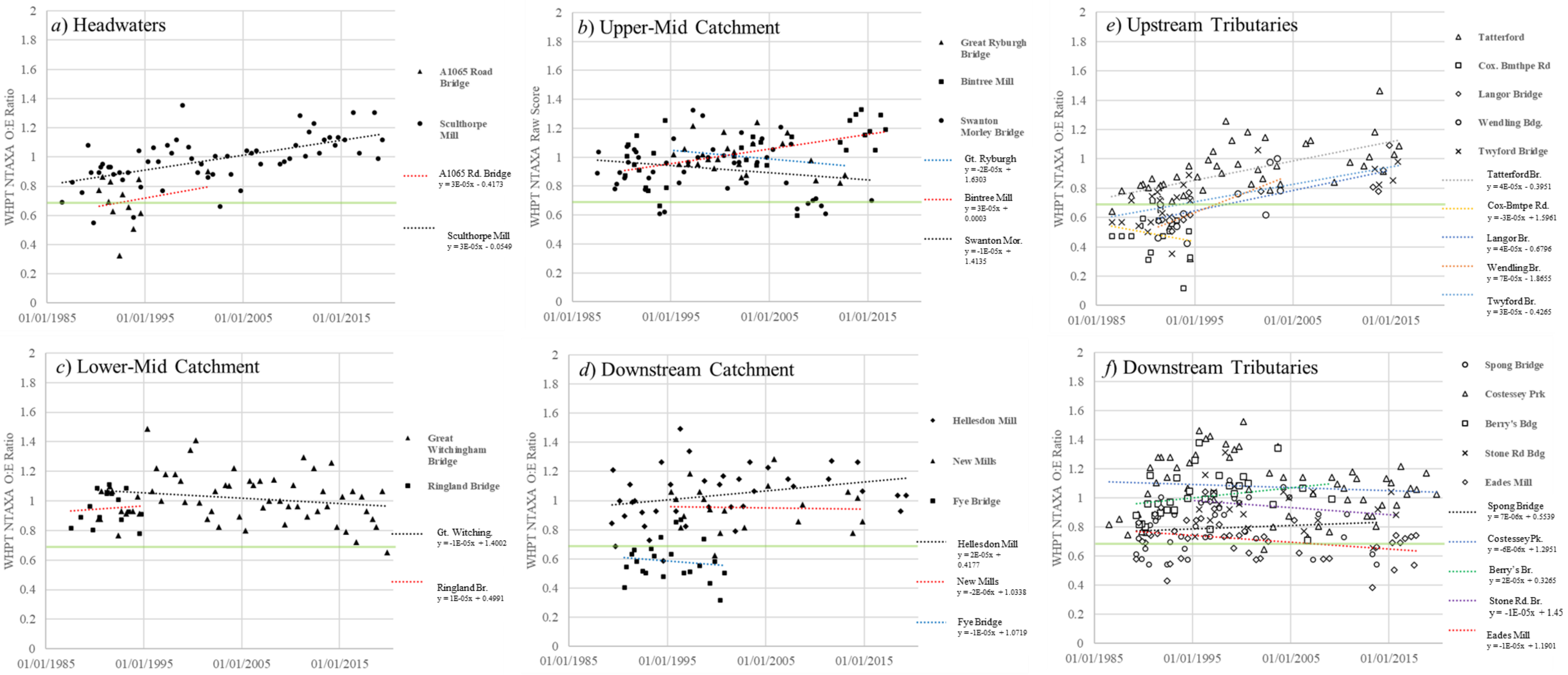

Figure 11. Observed: Expected WHPT NTAXA ratios from 1985 to 2020 in the Wensum catchment sorted by headwater, middle and downstream site groups. Green line denotes the WHPT NTAXA target O:E ratio, set nationally by the EA.

LIFE (Family) O:E Ratios

From 1985 to 2020, LIFE O:E ratios presented marginally favourable conditions at most sites, with scores throughout the catchment frequently failing to reach the 1.0 threshold for chalk streams. A slight trend of improvement was found across some sites, with the highest scores on the River Wensum consistently found at Sculthorpe Mill and the A1065 Road Bridge in the headwaters, alongside Great Witchinham Bridge in the lower-mid-catchment (**Figure 12 *a, b***). Here, O:E values were consistently above the threshold value of 1 from 1985 to present (where data was available), meaning macroinvertebrate communities indicated stream flow conditions greater or the same as would be expected in a semi-pristine environment. The highest scoring tributary sites were at Tatterford Common on the Tat and Eades Mill on Blackwater Beck in the mid-catchment (**Figure 12 *e, f***), which showed similarly favourable O:E scores throughout the time series.

Generally, the worst O:E ratio scores on the Wensum were found at Fye Bridge and New Mills in central Norwich and Ringland Bridge in the mid-catchment (**Figure 12 *d, b, c***). Here, O:E values were consistently near or lower than the threshold value of 1, meaning macroinvertebrate communities indicated stream flow conditions the same or worse than would be expected in a semi-pristine environment. In the case of New Mills, recent data suggested some gradual improvement at this site but at Ringland Bridge, decline in O:E scoring was suggested until the last available data in 1994 (**Figure 12 *c***).

In general, tributary monitoring sites in both the upper and lower catchment showed a similar range of LIFE O:E scores to the Wensum sites. There were limited trends of improvement over time and frequent failures to reach the threshold of 1 O:E at most sites. Despite this, slightly improving LIFE O:E scores were found in recent years (2011-2020) for three mid-catchment Wensum sites at Hellesdon Mill and Great Ryburgh Bridge (**Figure 16, p 26**). In these cases, O:E values rose more consistently above the critical threshold of 1 from approximately the year 2005 onwards, meaning macroinvertebrate communities indicated stream flow conditions the same as would be expected in a semi-pristine environment.

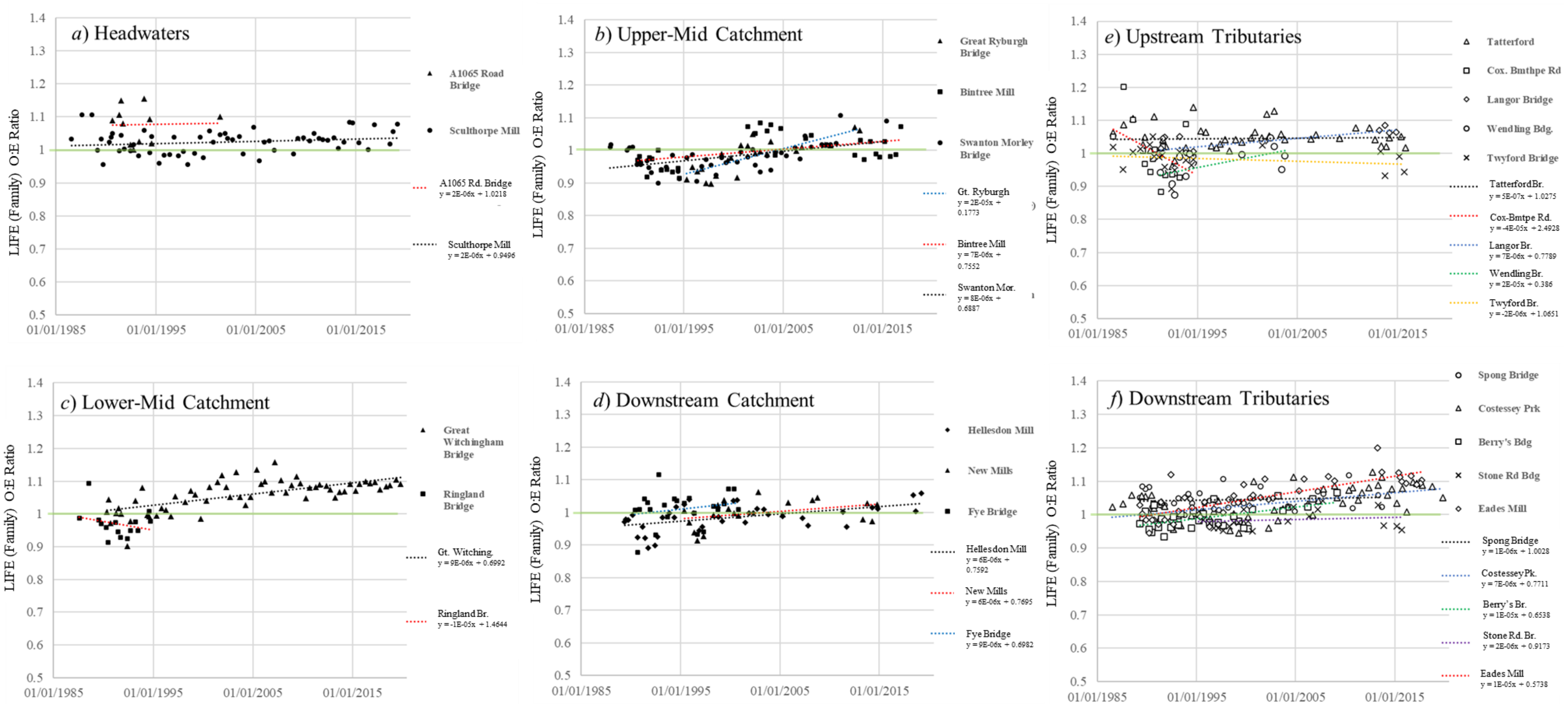

Figure 12. Observed: Expected LIFE (Family) ratios from 1985 to 2020 in the Wensum catchment sorted by headwater, middle and downstream site groups. Green line denotes the LIFE O:E ratio threshold for favourable conditions in a chalk stream, set nationally by the EA.

PSI (Family) O:E Ratios

From 1985 to 2020, PSI O:E ratios presented favourable conditions at most sites, with scores generally above the 0.7 target. Similar to LIFE scores (see above), the highest O:E ratios on the Wensum were consistently found at the A1065 Road Bridge and Sculthrope Mill in the river headwaters, alongside Great Witchingham Bridge in the mid-catchment (**Figure 13 *a, b, c***). Also, the highest scoring tributary sites were found at Tatterford Common on the Tat alongside Eades Mill on the Blackwater Beck in the mid catchment (**Figure 13 *e, f***). Throughout the time series, O:E values at each of these sites increased well above the threshold of 0.7, meaning macroinvertebrate communities indicated stream sedimentation pressures were comparably reduced or the same as would be expected in a semi-pristine environment.

The lowest scoring River Wensum sites were at Fye Bridge and New Mills in central Norwich (**Figure 13 *d***) alongside Ringland Bridge in the mid-catchment. Here, O:E values remained below the threshold of 0.7 throughout much of the time series, meaning macroinvertebrate communities indicated worse stream sediment conditions than would be expected in a semi-pristine environment. Ringland Bridge showed deterioration in O:E ratios over time, up to 1994, when records ended. Limited recent data was available to discount improvement over time.

The lowest scoring tributary sites were at Twyford Bridge, Coxford-Broomthorpe Road and Wendling Bridge on various rivers in the upper catchment, alongside Stone Road Bridge on the Tudd in the lower catchment. They each showed only marginally favourable O:E scores, with decline over time in most cases (**Figure 13 e, *f***). It should be noted again however, that Coxford-Broomthorpe Road and Wendling Bridge held limited recent data to discount improvement over time.

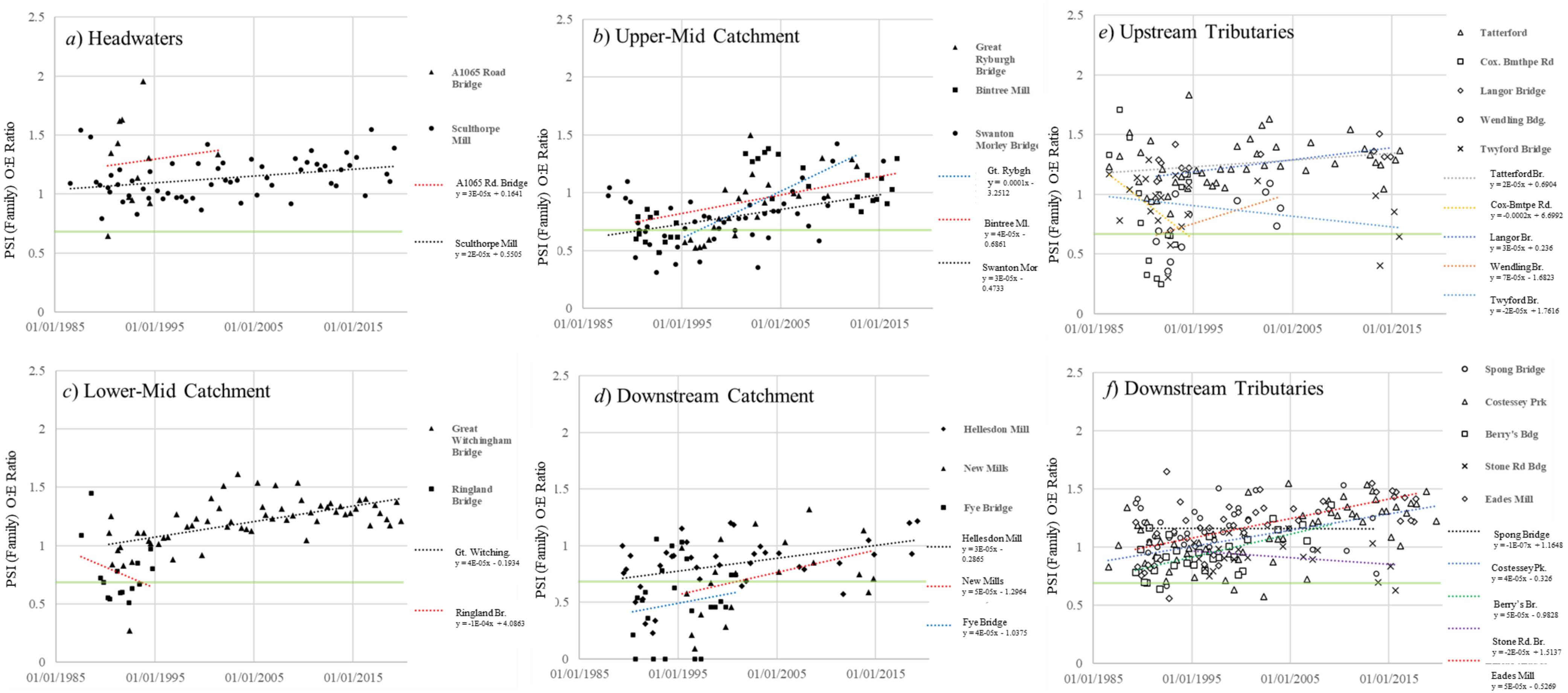

Figure 13. Observed: Expected PSI (Family) ratios from 1985 to 2020 in the Wensum Catchment sorted by headwater, middle and downstream site groups. Green line denotes the PSI O:E ratio threshold for favourable conditions, set nationally by the EA.

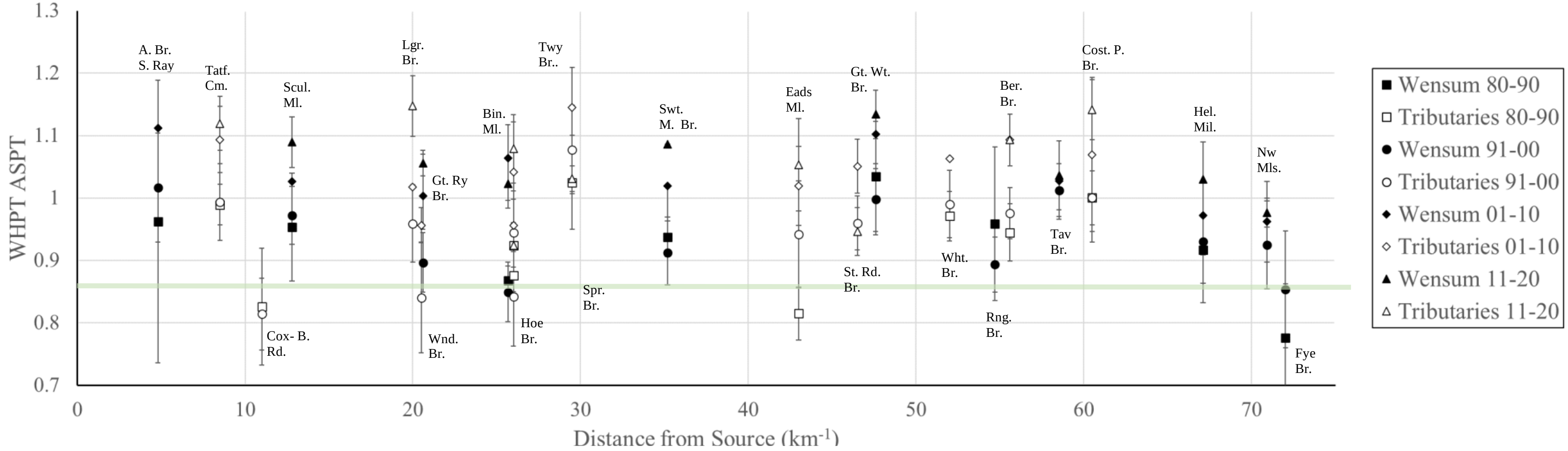

Figure 14. Mean Observed:Expected WHPT ASPT ratios per monitoring site in the Wensum catchment by decade period and approximate distance from the Wensum source. Filled symbols denote River Wensum monitoring sites and unfilled symbols Wensum tributary sites. Plot markers: *square* 1980-1990, *circle* 1991-2000, *diamond* 2001-2010, *triangle* 2011-2020. Error bars denote standard deviation.

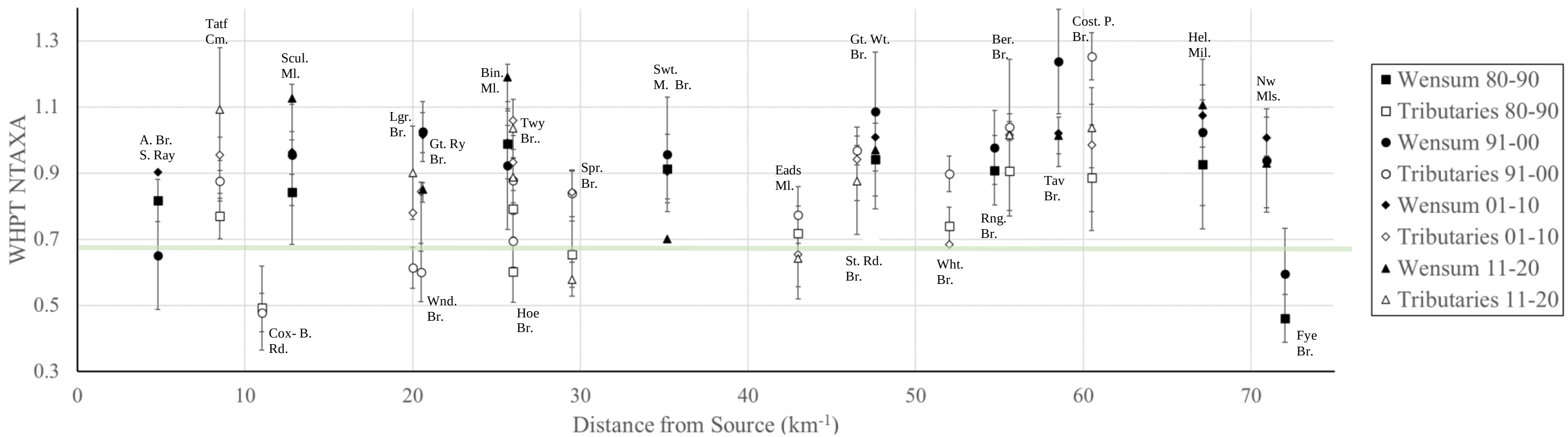

Figure 15. Mean Observed:Expected WHPT NTAXA ratios per monitoring site in the Wensum catchment by decade period and approximate distance from the Wensum source. Filled symbols denote River Wensum monitoring sites and unfilled symbols Wensum tributary sites. Plot markers: *square* 1980-1990, *circle* 1991-2000, *diamond* 2001-2010, *triangle* 2011-2020. Error bars denote standard deviation.

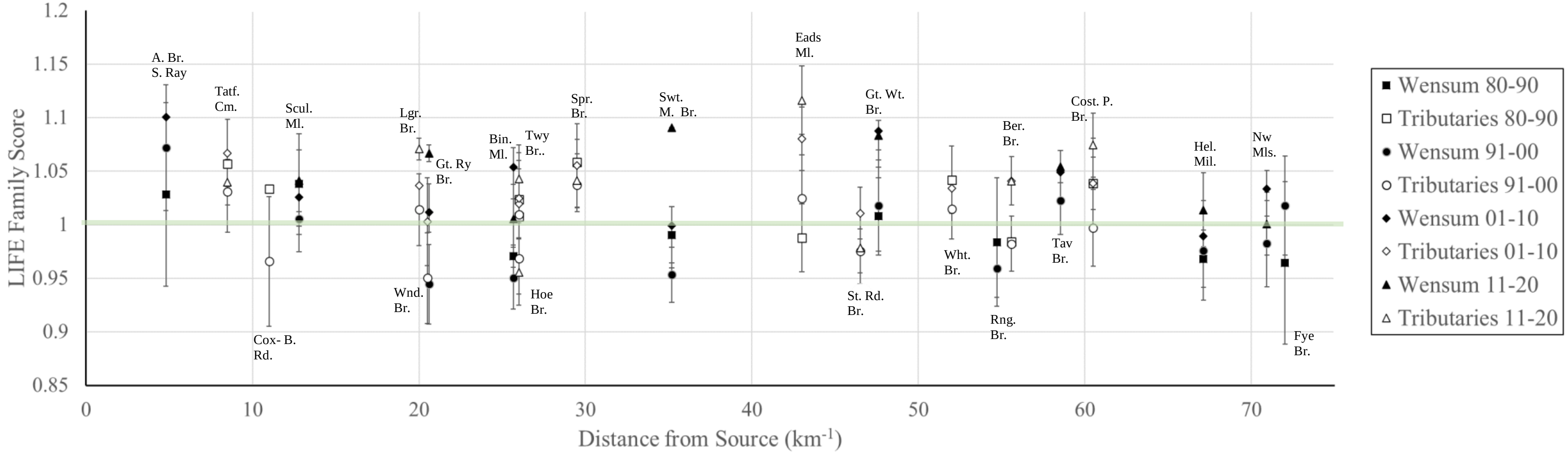

Figure 16. Mean Observed:Expected LIFE (FAMILY) ratios per monitoring site in the Wensum catchment by decade period and approximate distance from the Wensum source. Filled symbols denote River Wensum monitoring sites and unfilled symbols Wensum tributary sites. Plot markers: *square* 1980-1990, *circle* 1991-2000, *diamond* 2001-2010, *triangle* 2011-2020. Error bars denote standard deviation.

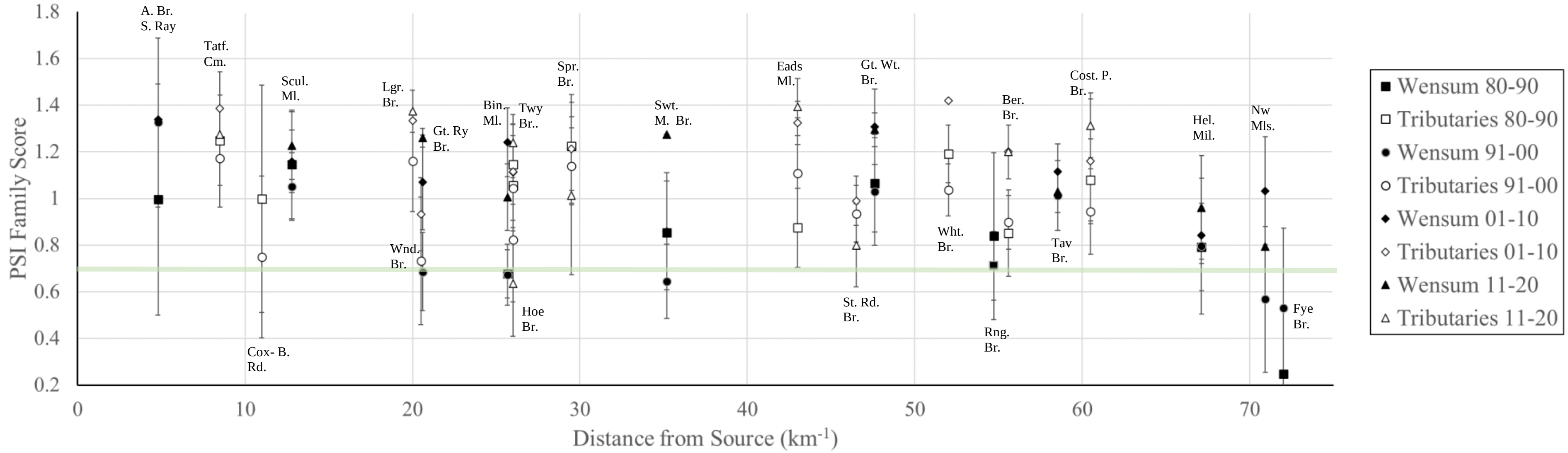

Figure 17. Mean Observed:Expected PSI (FAMILY) ratios per monitoring site in the Wensum catchment by decade period and approximate distance from the Wensum source. Filled symbols denote River Wensum monitoring sites and unfilled symbols Wensum tributary sites. Plot markers: *square* 1980-1990, *circle* 1991-2000, *diamond* 2001-2010, *triangle* 2011-2020. Error bars denote standard deviation.

3. Summary: Fisheries Monitoring

3.1. Monitoring Site Locations

There are 28 routinely visited EA fish survey sites in the Wensum catchment, including on the Tud and Tat tributaries (**Table 2**). At these locations, surveys are scheduled to take place at least once every 5 years. The longest and best resolution records are found on the River Wensum at Great Ryburgh Bridge (nr. Fakenham), Elsing Mill (nr. Swanton Morley) and Hellesdon Road (c. 1km US Norwich). These sites have been sampled at least once every 2 years between 1986-2020 and are located equidistantly in upper, middle and lower reaches the river (**See Map; Figure 1, p. 7**).

Table 2. Name, location and sampling frequency for routine Wensum catchment fish monitoring sites.

Site Name	Waterbody	EA Site ID	NGR	No Surveys	First Survey	Mst. Rec. Sur.
D/S Gt Ryburgh Bridge	*Wensum*	1476	TF9659326837	22	09/06/1986	31/07/2019
D/S Elsing Mill	*Wensum*	1485	TG0510217838	22	23/06/1986	15/08/2019
Alders Spinney	*Wensum*	1494	TG1667612847	20	22/07/1986	06/08/2019
Hellesdon Road (Albert's)	*Wensum*	1503	TG1991409798	19	04/08/1986	03/07/2019
Hellhoughton Common	*Wensum*	1462	TF8731126605	14	06/03/1986	05/04/2019
U/S Fakenham Mill	*Wensum*	1469	TF9139629620	13	19/03/1986	11/04/2019
Costessey Gravel Works	*Tud*	1712	TG1537111578	13	26/07/1988	18/06/2019
U/S Sculthorpe Mill	*Wensum*	1467	TF8892830003	12	11/03/1986	08/06/2018
U/S Bintree Mill	*Wensum*	1479	TF9977324495	11	12/06/1986	17/08/2018
Tatterford Common	*Tat*	1464	TF8704728022	11	03/03/1986	15/05/2018
South Mill Farm	*Wensum*	1465	TF8804528035	11	26/02/1986	21/05/2018
Pensthorpe Hall	*Wensum*	1474	TF9445928802	11	10/06/1986	07/08/2018
County School	*Wensum*	1480	TF9922622732	11	18/06/1986	04/09/2018
U/S Lenwade Mill	*Wensum*	1488	TG1007917891	10	01/07/1986	11/09/2018
Lyng Side Channel	*Wensum*	32198	TG0721217914	10	06/10/2005	16/10/2016
Lenwade Bridge	*Wensum*	32196	TG1017218225	10	06/10/2005	16/10/2016
Fakenham Common	*Wensum*	1470	TF9257429273	10	20/03/1986	14/06/2018
U/S Whitford Bridge	*Tud*	1706	TG0642812799	9	04/08/1988	29/06/2018
U/S Hill Farm Bridge	*Tud*	1711	TG1263511570	9	28/07/1988	17/07/2018
Taverham	*Wensum*	32195	TG1600013600	9	13/10/2005	23/10/2016
Rotten Row	*Tud*	1707	TG0858012201	9	03/08/1988	04/06/2018
Rogers Farm	*Tud*	1714	TG1863811110	9	19/07/1988	18/06/2018
Hellesdon	*Wensum*	32200	TG1985610295	9	17/10/2005	29/09/2015
D/S Costessey Weir	*Wensum*	32194	TG1760013100	9	20/10/2005	23/10/2016
Ringland Bridge	*Wensum*	32199	TG1412613697	8	07/10/2005	30/09/2015
Attlebridge Hall Farm	*Wensum*	32197	TG1382015614	8	12/10/2005	30/09/2015

Please note, data is available from these sites at: https://environment.data.gov.uk/ecology-fish/

3.2. Recent Observations of Fish Populations (2015-2020)

In recent monitoring to support the Water Framework Directive (Cycle 2 & 3; 2013-2019), a total of sixteen fish species have been identified across fish survey sites in the catchment. In general, communities in upper and headwater reaches of the catchment have been dominated by brown trout, bullhead and stone loach populations, alongside smaller numbers of eel, lamprey and pike. A comparably more diverse fish assembly progressively occurs with distance downstream. For example, in the mid to lower-catchment, site populations become characterised by brown trout, bullhead, bream, chub, dace, eel, gudgeon, lamprey, minnow, perch, pike, roach, rudd, stone loach and stickleback. These taxa commonly feature in sampling captures downstream of Swanton Morley (mid-catchment), alongside smaller numbers of eel, lamprey, pike and occasionally, tench. More recently, sea trout have been anecdotally caught between Swanton Morley and Lenwade, suggesting significant improvement in stream connectivity to the mid-catchment. Fisheries officers at the EA (Pers. Coms.) attribute general increases in numbers of trout and other game fish in the mid-catchment to river restoration measures (specifically the creation of gravel-riffle features; **See Section 5, p. 31**.

In terms of ecological quality under WFD (Cycle 2; 2016) standards, there is still significant room for improvement of fish populations in the catchment. For example, data between 2013-2019 indicated that of all sites surveyed, 41% were at less than good status for fish classification (derived using the FCS2 tool; WFD UKTAG 2014). Further, that 14% of all sites were at ‘moderate’ status, 24% at ‘poor’ and one site at bad. The most unfavourable sites in the catchment were found on Wendling Brook, Swannington Beck, and Blackwater. Each are on Wensum tributaries and in 2016, were primary reasons for waterbody failures in the catchment under Cycle 2 of the WFD.

EA fisheries officers (Pers. Comms.) concur that the poorest fish assemblages sites are typically found on the upper Wensum tributaries, showing either species absence where they would be expected, or when present, low abundances. In particular, it is thought that reduced stream habitat quality, limited floodplain connectivity, local abstraction pressure and the presence of impoundments to migration (e.g. weirs) have contributed to these upstream and headwater failures. Notably, there have been widely acknowledged historical declines in fish abundance and weight in the upper Wensum between 1983-2010. Here, improved water quality through Phosphate stripping was associated with reduced productivity and growth in overall fish populations (Beardsley 2012; Beardsley and Britton 2012).

Underlining a difference in upper and lower catchment populations, all monitoring sites classified as ‘good’ or ‘high’ status under the WFD (Cycle 2; 2016) were located on the main River Wensum, downstream of Fakenham or on the Tudd, a major, lowland tributary. This trend was surprising in in relation to the discussed macroinvertebrate records. For example, the lowest performing reaches for fish in the upstream, typically contained some of the highest performing macroinvertebrate sites. This contrast may underline the importance of physical impoundments for fish passage towards the catchment headwaters.

4. Summary: Water Quality Monitoring

4.1 Monitoring Site Locations

There are 23 routinely visited EA water quality survey sites in the Wensum catchment, including on the Tud, Tat, Wendling Brook, Blackwater and Swannington Beck tributaries (**Table 3**). At these locations, surveys have taken place at least once every month from different start dates over the past 20 years. The longest and highest resolution records are found on the River Wensum at Sculthorpe Mill, Helhoughton Bridge, Swanton Morley Bridge, Tatterford Common and Sweet Briar Road Bridge, which each include over 750 individual samples since 2000. These sites are located throughout the upper, middle and lower reaches the river and have been used to inform the Wensum's water quality status designation under the Water Framework Directive (Cycle 2; 2016). The parameters/determinands measured include pH, Phosphate, Dissolved Oxygen, Nitrate, Nitrite, Conductivity, Ammonia, Alkalinity and Temperature. At one site in central Norwich (Carrow Bridge), polyaromatic hydrocarbons and other more complex priority pollutants have also been measured.

Table 3. Name, determinands, location and sampling frequency of routine EA water chemistry monitoring sites in the Wensum catchment between 2000-2020.

Sampling Point Name	Determinands	Sampling Frequency	Esting Nthings
R.Wensum Sweet Briar Rd.Br	Extended Suite	1478 samples taken between 2000 and 2020	620600 309500
R.Wensum Swanton Morley Bridge	Standard Suite	840 samples taken between 2000 and 2020	602100 318500
R.Wensum Sculthorpe Mill	Standard Suite	817 samples taken between 2000 and 2020	589300 330400
R.Wensum Great Witchingham Bridge	Standard Suite	786 samples taken between 2000 and 2020	610735 318725
R.Tat Tatterford Common (R.Wensum)	Standard Suite	753 samples taken between 2000 and 2020	586700 328000
R.Tud Costessey Park Bridge	Standard Suite	711 samples taken between 2000 and 2020	617000 311200
R. Wensum Helhoughton Bridge	Standard Suite	653 samples taken between 2020 and 2006	587300 326800
R. Wensum, Old Rail Bridge, Alderford	Standard Suite	65 samples taken between 2020 and 2007	612200 317800
Foulsham Str.Twyford Bridge (R.Wensum)	Standard Suite	52 samples taken between 2017 and 2012	601700 324500
Kettlestone Str. Langer Br.	Standard Suite	49 samples taken between 2017 and 2013	596100 329300
Wendling Beck Gressenhall Br.(R.Wensum)	Standard Suite	273 samples taken between 2020 and 2000	596600 315300
Blackwater Drn.Gt.Witchngham(R.Wensum)	Standard Suite	269 samples taken between 2020 and 2000	610700 318800
R.Wensum Great Ryburgh Bridge	Standard Suite	268 samples taken between 2020 and 2000	596400 327400
R.Wensum New Mills	Standard Suite	265 samples taken between 2020 and 2000	622634 309078
R. Wensum Goggs Mill Rd. Br. Hempton	Standard Suite	25 samples taken between 2020 and 2018	591396 329620
R. Wensum Lyng Road Bridge	Standard Suite	25 samples taken between 2020 and 2018	607184 317810
R.Wensum Carrow Bridge Norwich	Polyamoratics	248 samples taken between 2020 and 2000	623900 307700
R.Wensum Taverham Bridge	Standard Suite	241 samples taken between 2020 and 2000	616000 313650
R.Tud Watering Fm.Br.	Standard Suite	178 samples taken between 2020 and 2000	600100 311100
Blackwater, D/S Spong Bridge	Standard Suite	175 samples taken between 2017 and 2013	598978 319188
R.Tud Honingham Church Fm.Br.	Standard Suite	118 samples taken between 2020 and 2000	609800 311800
R.Wensum County School Bridge	Standard Suite	11 samples taken between 2020 and 2019	599230 322710
R.Wensum Whitefriars Bridge	Standard Suite	10 samples taken between 2020 and 2019	623425 309175

Please note that water quality data from these sites is available at:
https://environment.data.gov.uk/water-quality/view/landing

4.2. Water quality in the Wensum catchment under Water Framework Directive (Cycle 2) standards (2013-2016)

13 of the 23 monitoring sites above have been used to assess water quality under standards set by the WFD (Cycle 2; 2016). Across most sites, this assessment indicated at least 'good' or 'high' status in water quality across the catchment. This suggested favourable conditions for key determinands, which included Ammonia, Dissolved Oxygen and Phosphate concentrations, alongside Temperature (**See: Table 4**). In the case of Ammonia concentrations, which when elevated are highly damaging to fish populations (see: Randall and Wright 1987), concentrations were low enough to retain 'high' status across all monitoring sites. For Phosphate, a parameter typically associated with algal blooms and subsequent Dissolved Oxygen crashes (Hynes 1975), concentrations were also low enough to retain at least 'good' status across all sites. EA Water Quality Monitoring Officers (Pers. Comms.) suggest that such favourable results on a river historically impacted by these stressors (see: Roberts and Cooper 2018) are may be due to progress by water company Asset Management Plans towards phosphate stripping at Wastewater Treatment Works/Water Recycling Centres in the upper catchment (**For most recent targets see: Table 5, p.31**). While it is difficult to exclude confounding factors, such changes may have been a factor driving improved macroinvertebrate assemblages at several sites since 2005 (e.g. under the WHPT ASPT metric, **see section 2.3 p. 9**), particularly in the headwaters and upper-catchment.

Table 4. Water Quality Status for Monitoring Sites Assessed under Water Framework Directive Standards in Cycle 2, 2013-2016.

WB id	Water body Name	Site ID	Site Name	Ammonia	Dissolved oxygen	Phosphate	Temperature
GB105034051020	Wendling Beck	WEN140	WENDLING BECK GRESSENHALL BR.(R.WENSUM)	High	Moderate	Good	Good
GB105034051050	Blackwater (Wendling Beck)	WEN111	BLACK WATER D/S SPONG BRIDGE	High	High	Good	High
GB105034051070	Swannington Beck	WEN223	OLD RAIL BR.ALDERFORD	High	Good	High	High
GB105034051111	Wensum (to Tatterford)	WEN020	R.WENSUM HELHOUGHTON BRIDGE	High	High	High	High
GB105034051120	Blackwater Drain (Wensum)	WEN210	BLACKWATER DRN.GT.WITCHNGHAM(R.WENSUM)	High	Moderate	High	High
GB105034055850	Foulsham Tributary	WEN090	FOULSHAM STR.TWYFORD BRIDGE (R.WENSUM)	High	High	Good	High
GB105034055860	Little Ryburgh Tributary	WEN060	KETTLESTONE STR. LANGER BR. (R.WENSUM)	High	High	Good	High
GB105034055870	Tat	WEN010	R.TAT TATTERFORD COMMON (R.WENSUM)	High	High	Good	High
GB105034055881	Wensum US Norwich	WEN040	R.WENSUM SCULTHORPE MILL	High	Poor	High	High
GB105034055881	Wensum US Norwich	WEN180	R.WENSUM SWANTON MORLEY BRIDGE	High	Good	Good	Good
GB105034055881	Wensum US Norwich	WEN235	R.WENSUM TAVERHAM BRIDGE	High	High	High	Good
GB105034055882	Wensum DS Norwich	WEN250	R.WENSUM SWEET BRIAR RD.BR	High	High	Good	High
GB105034055882	Wensum DS Norwich	WEN280	R.WENSUM CARROW BRIDGE NORWICH	High	High	Good	High

It was notable that three sites in the upper and mid catchment failed to achieve 'good' status for Dissolved Oxygen, including 'moderate' conditions at Gressenhall Bridge (Wendling Beck) and Great Witchingham Bridge (Blackwater Drain) and 'poor' conditions at Sculthorpe Mill (R. Wensum). This parameter is important for fish and macroinvertebrate respiration

(Hynes 1975) and may have deteriorated at these sites due to stressors such as organic pollution, algal bloom and reduced flow conditions. In relation to the discussed macroinvertebrate records, it was particularly surprising that the Sculthorpe Mill site performed so poorly for Dissolved Oxygen. For example, macroinvertebrate monitoring at Sculthorpe Mill presented one of the highest performing assemblages of any site under the WHPT ASPT metric, which is usually sensitive to unfavourable Dissolved Oxygen levels. Further investigation may be required to ascertain why such low water quality readings are being recorded here, despite highly sensitive ecological communities being apparent.

Table 5. List of Water Company Asset Management Plan P-stripping works to improve water quality on the Wensum, including most recent target concentration & National Grid Reference.

Scheme Type	AMP Round	Treatment Works	Target (mg L)	Removal Start Date	NGR
P-Removal	AMP5	*Bylaugh STW*	2.5	31/12/2012	TG0372018170
P-Removal	AMP3	*Dereham STW*	1	01/01/2005	TF9754013790
P-Removal	AMP5	*East Rudham STW*	2	31/12/2012	Not available
P-Removal	AMP3	*Fakenham STW*	2	01/01/2003	TF9226029180
P-Removal	AMP5	*Foulsham STW*	1	31/12/2012	TG0246024350
P-Removal	AMP5	*North Elmham STW*	1	31/12/2012	TF9975221199
P-Removal	AMP5	*Reepham (Norfolk) STW*	1	31/12/2012	TG1045022570
P-Removal	AMP5	*Sculthorpe STW*	1	31/12/2012	TF8356031250

5. Summary: River Restoration Projects

The majority of strategic, large-scale river restoration works in the catchment have occurred following implementation of the River Wensum Restoration Strategy in 2009 (NE 2009). Prior to 2009, restoration schemes were generally sporadic, relatively small-scale and carried out either by the EA or stakeholder groups such as the Bintry Mill Trout Fishery or Norfolk Anglers Conservation Association. Initial efforts were concentrated in the upper catchment, including riparian weed planting and tree removal (Fakenham Mill; 1997; 2001), insertions of willow hurdles (Hempton; in 1998) and excavation works to create gravel glides and pools (Hempton; in 2004).

Since these earlier schemes, at least nine major restoration works have been completed throughout the Wensum (**Table 6, p 32**). These have focussed on improving multiple aspects of stream ecology through the creation of diverse riparian habitats, more naturalistic flow conditions, greater stream connectivity, improved wetland dynamics, channel form, substrate typology and channel sinuosity. These changes would be expected to improve stream fish and macroinvertebrate diversity, in particular (See: Beechie et al. 2008). For example, by providing greater habitat heterogeneity, flow refugia and spawning opportunities for animals alongside riparian buffers from nutrient-enriched agricultural runoff.

Table 6. List of major restoration works in the Wensum Catchment since implementation of the River Wensum Restoration Strategy (NE 2009); continued on next page.

Grid Reference	Location	Project Name	Project description	Date / Partners
TF 99067 23263 to TF 99202 22743	Bintree: Btw. Yarrow Bridge & County School Bridge	**Bintree Restoration Scheme**	Achieved flow diversification and greater connectivity of river to floodplain habitats through large scale bed-raising using locally sourced gravel. Also, gross planform change as implemented through channel narrowing and insertion of large woody debris flow deflectors and brushwood mattresses.	**September 2009** With: Bintry Mill Trout Fishery, Nat. Eng. & Water Man. Alliance
TF 93666 29206 to TF 94015 29064	Gt. Ryburgh: Land Adjacent to Gt. Ryburgh Common	**Great Ryburgh Common Scheme**	Reversal of channel straightening by diverting stream into historic meander loop. Creation of wetland backwater downstream of the channel plug adjacent to the restored meander. Resectioning of historical meander channel and immediate US/DS sections to ensure appropriate flow and water level.	**October to December 2010** With: Nat. Eng. & Water Man. Alliance, ATKINS
TF 96420 26962 to TF 97398 26110	1.32km reach of the R. Wensum between Gt. Ryburgh Mill & Sennowe Bridge	**Ryburgh End Restoration Scheme**	Reconnection of a sinuous, paleochannel to the floodplain by excavation, reversing channel straightening and building on the Gt. Ryburgh Common Scheme desc. above. Various plugging and resectioning of river channel to ensure appropriate flow & water level.	**September to December 2011** With: Nat. Eng. & Water Man. Alliance
TG 02031 18359 to TG 02760 17770	0.88km reach of R. Wensum downstream of Swanton Morley weirs	**Swanton Morley Restoration Scheme**	Installation of gravel glides, pools, berms, woody debris and selective tree planting to re-establish natural channel form and improve connectivity of river to floodplain. In addition, the creation of fish refuge areas in the floodplain by excavation of spoil embankments.	**June to September 2012** With: Nat. Eng. & Water Man. Alliance, ATKINS
TF 89690 29869 to TF 91287 29661	2.1km DS Sculthorpe Mill to Night Common	**Sculthorpe Moor Restoration Scheme**	Followed from the Swanton Morley Restoration Scheme. Installation of gravel glides, pools, berms, woody debris and selective tree planting to re-establish natural channel form and improve connectivity of river to floodplain. In addition, the creation of fish refuge areas in the floodplain by excavation of spoil embankments.	**Sept 2012 to Nov 2013** With: Nat Eng., Water Man. Alliance., Fakenham Angling Club, Hawk & Owl Trust, Norf. Ornith. Assoc.

TF 85044 28814 to TF 86701 27978	2.2km of the River Tat from Broomsthorpe Road Br. To Tatterford Road. Br.	**River Tat Restoration Scheme**	Renaturalisation of channel landforms and floodplain features through glide-pool creation, channel narrowing and installation of large-woody debris features. In addition, selective felling to promote riparian plant growth.	**May to August 2013** With: Nat. Eng. & Water Man. Alliance, ATKINS
TF 87323 27935 to TF88232 29056	1.9km of the R. Wensum US Dunton Roadbridge	**South Mill, Tatterford**	Re-naturalisation of channel form and improved flow function. Included importation of locally sourced gravels to create glides, alongside excavation of pool/riffle sequences and sections of channel narrowing. Set back bankside fencing to improve fishing access and allow riparian planting to shade/reduce levels of choking in-channel vegetation.	**June to September 2015** With: Nat. Eng., var. landowners & local fishing syndicate
TG 16437 13334 to TG 16641 12307	1.2 km of the R. Wensum DS Taverham Road Bridge	**Place Farm, Costessey**	Renaturalisation of channel form and flow function using gravel glides with material imported from local quarry. Improved riparian management, including chalk linings on sections of bed at banksides used for cattle poaching. In addition, excavation of bank profiles to encourage riparian plant growth and insertion of woody debris to increase habitat heterogeneity.	**June to September 2018** With: Nat. Eng., landowners, Wensum Fisheries & Anglian Water
TG 10169 18210 to TG 11091 18409	1.4km of the R. Wensum DS Lenwade Mill	**Lenwade Mill to Wooden Footbridge, Lenwade**	Excavation of banks to naturalise channel form and reconnect flood plain. Pinning of brushwood faggots near bank to stabilise vegetation planted using biodegradable geotextile. Insertion of woody debris snags in stream to increase habitat heterogeneity.	**August to October 2019** With: Nat. Eng. & Landowners

Between 2009 – 2018, the restoration schemes described were concentrated upstream of Swanton Morley, with initial efforts focussed on the upper Wensum near Sculthorpe Moor, Fakenham, Great Ryburgh and Bintree. It is notable in these cases that the restoration schemes took place either on or immediately upstream of the reaches where the EA's macroinvertebrate sampling sites are located. While it is difficult to exclude confounding factors at this level of study (such as improved P-stripping at treatment works), these restorations may have been a factor for improved macroinvertebrate assemblages at nearby sites between Coxford-Broomthorpe and Bintree (e.g. for WHPT ASPT metric). While macroinvertebrate assemblages did not see such clear improvements at downstream sites, more recent 2018-19 restoration schemes near Lenwade Mill and Place Farm (between Ringland and Taverham

Bridge) have taken place (**See Map; p. 7**). It is possible that given additional lag time, these works could have similar, positive impacts on ecology in the lower Wensum reaches, including sites at Ringland and Taverham Bridge.

6. Discussion

Downstream monitoring sites in central Norwich (New Mills and Fye Bridge) were generally the poorest performing across all macroinvertebrate ecological quality metrics. Here, engineered modification of bank habitat and channel morphology by vertical piled walls, navigation locks, weirs and sheet piling (see: Natural England 2009; Norwich City Council 2020) may have factored strongly. Such features are widely associated with unfavourable ecological quality, reducing natural habitat heterogeneity (Bevan et al. 2001; Francis 2008; Everard 2012) alongside stream flow and sediment dynamics (Im et al. 2011; Shuker et al. 2015; Stranko et al. 2012). Further, wastewater overflow and varied diffuse pollution sources from Norwich have been acknowledged to impact water quality up to the present day (Natural England 2009; Norwich City Council 2020).

By contrast, monitoring sites upstream of Norwich presented higher scores and more favourable conditions in relation to those expected by RICT. Many records also showed improvement over time, which was particularly strong in the case of WHPT ASPT scoring. This metric indicated steady reduction in stressors associated with organic pollution and general water chemistry across both main river and tributary sites. It is likely that this was due to implementation of better end-of-pipe treatments in Norfolk's larger sewage works (under EU Urban Wastewater Directive 91/271/EC; Roberts and Cooper 2018), phosphate stripping at smaller upstream works between c.1985-1997 (Beardsley 2012; Beardsley and Britton 2012) and ongoing water company AMP scheme improvements (**Section 4, p. 30)**. Notably, better conditions may also have resulted from various catchment-wide efforts of stakeholders towards sustainable land management (e.g. Catchment Sensitive farming; Collins et al. 2007, River Wensum Strategy; Natural England 2009) and large-scale habitat restoration (**Section 5, p 31**, **also:** Lewis 2001). Supporting evidence for successful land management and habitat restoration included at slight improvements in WHPT NTAXA scoring at several sites. Most notably, Hellesdon Mill, Bintree Mill, Gt. Witchingham Bridge and Sculthorpe Mill on the Wensum, alongside Costessey Park and Berry's Bridge on the Tud.

At these sites, trends suggested not only improved water chemistry and habitat quality (WHPT ASPT & NTAXA), but slightly increased flow consistency and rate (LIFE). In particular, this could have followed adoption of more sustainable abstraction licensing strategies (e.g. CAMS process & Water Company AMP Schemes; EA 2017) alongside specific low flow augmentation schemes (e.g. at Costessey Mill; Mott MacDonald 1990). Further, ongoing efforts to remove impoundments, improve stream connectivity and achieve more naturalistic flows (Natural England 2009). In the latter case, examples include installation of silt traps, flow deflectors and glide-pool features (e.g. at Blackwater and Great Ryburgh; Norfolk Rivers Trust 2020), alongside various riparian and wetland habitat restorations under the Wensum Restoration Strategy (NE 2009). More negatively however, it is possible improvements were driven by the comparably shorter, non-sequential drought periods in 2011-2020 when compared to the years 1989 to 1992 (Boar et al. 1995). Detailed future monitoring through future drought periods (expected to be increasingly severe; EA 2018) will be needed to clarify whether management efforts have been successful, while providing warning on which reaches in the catchment are least resilient to drought.

This is important because despite apparent improvements in water chemistry since 1985, most monitoring sites failed to consistently reach or exceed expected score thresholds for the LIFE metric, which is sensitive to low flow pressures. This finding may reflect acknowledged abstraction pressures still present in the catchment (Natural England 2015); which may reduce stream flows (i.e. LIFE scores), natural sediment flux (i.e. PSI scores), riparian habitat extent (i.e. NTAXA scores) and the dilution of chemical pollutants (i.e. ASPT scores). To underline this risk, the data highlighted Twyford Bridge on the Foulsham Stream near Bintree, where scores were in long term decline under the LIFE metric, despite generally wetter climatic conditions than seen in 1989-1992.

Elsewhere in the catchment, further indications of stress were found at other sites, but typically over more discrete time periods. For example between 1980-1990 at Bintree Mill near Guist village, where ASPT raw and O:E scores were lower than any other site upstream of Norwich. This indicated localised organic pollution and water chemistry issues before a later recovery. Indeed, more recent monitoring at Bintree Mill (2011-2020) showed observed scores for all metrics markedly higher than those ‘expected’ under RICT-derived targets and thresholds. There may be lessons to learn from the improvements seen at or near the Bintree Mill site. For example, the nearby implementation of channel narrowing, riffle construction, cattle fencing, flow deflectors and riparian tree planting by Bintree Angling Club (between 2001-2007;

RESTORE 2020) and major restoration works in 2009 under the Wensum Restoration Strategy (**See section 5, p. 31**). Further monitoring upstream and downstream restored reaches could better evaluate the efficacy of these efforts (alongside others on the river), with a view to repeating evidenced success elsewhere in the catchment.

In particular, similar restoration efforts could be used to improve stream habitat quality at several sites where habitat quality (measured by WHPT ASPT) was shown to decline over the time series. For example, mid and lower catchment sites at Gt. Ryburgh Bridge, Gt. Witchingham Bridge and Swanton Morley Bridge on the Wensum, alongside Eades Mill on the Blackwater Beck and Costessey Park on the Tudd. At these sites, more severe downstream pressures may include relatively intensified abstraction, channel modification and wastewater pollution from more urban populations. Also, accumulation of pollutants entering the Wensum from upstream tributaries and drainage channels (e.g. Roberts and Cooper 2017; Sear et al. 2006). In addition, more erodible, sandy topsoils predominant from Lenwade to Norwich, which may input greater diffuse pollution and sediment to these reaches (see: Sear et al. 2006). Finally, it could also be significant that the River Wensum Restoration Strategy (NE 2009) has only implemented its downstream schemes more recently (e.g. at Costessey Mill & Lenwade; 2018-19; **See section 5**, **p. 31**). Subsequent improvements to NTAXA scores near these reaches may only occur after some lag time. Again, without strategic monitoring to assess both land management and restoration efficacy, trends in ecological quality will be difficult to explain in future across the catchment.

Problematically, confounding factors for reliable and comparable monitoring between sites may have also developed. For example, the American Signal Crayfish has been found in the mid-Wensum near Lyng (1990), Swanton Morley (2015) and Lenwade (2012) according to the National Biodiverity Network Atlas (NBN 2020), alongside various anecdotal evidence for other mid catchment locations. The Signal Crayfish is a highly successful UK invasive shown to reduce macroinvertebrate biodiversity through direct predation (Mathers et al. 2016 *a*). In and turn, this may cause reduction to NTAXA scores and increases to WHPT ASPT and LIFE scores (Mathers et al. 2016 *b*). In the latter cases, due to preferential consumption of species non-sensitive to pollution and poorer flow conditions. To validate the general improvements seen for macroinvertebrate communities in recent years, it is therefore essential to clarify the distribution of invasive crayfish in the Wensum catchment, and qualify their potential impact on EA metrics.

This will be important because reliable monitoring as already discussed, can provide new insights into the catchment's ecology. In this study for example, it was suggested that the lowest performing reaches for fish were in the upstream catchment, which typically contained the highest performing macroinvertebrate sites. This contrast potentially underlined the importance of physical impoundments for fish passage towards the catchment headwaters, rather than water chemistry and stream habitat issues, per se. To keep providing similar insights with monitoring, it will be important to consider how data quality and coverage on the Wensum can be improved. For example, a bespoke programme of return macroinvertebrate sampling sites not recently visited, would be a useful start point. Even if limited in scope, this would provide an update on ecological quality at several locations, where recent improvements and declines found elsewhere in the catchment cannot be accounted. Potential examples include the sites at Coxford-Broomthorpe Road (last visited 1994), Ringland Bridge (last visited 1994), Spong Bridge (last visit 2015) Stone Road Bridge (last visited 2015), Twyford Bridge (last visited 2016), Great Ryburgh Bridge (last visited 2016), Eades Mill (last visited 2017), New Mills (Norwich; last visited 2014), and Fye Bridge (Norwich; last visited 2000). Updates to our understanding at these locations could help build a more complete, catchment-wide picture to better prioritise future restoration efforts and river management programmes.

6. Conclusions

i.) Sampling at several long-term monitoring sites in the Wensum catchment have been discontinued by the EA since 2015. At these locations, we cannot tell whether improvements or declines seen elsewhere in the catchment have occurred. A bespoke programme of sampling to update records at these sites, even if limited in scale, could help elucidate continuing environmental stressors in the Wensum catchment.

ii.) Downstream monitoring sites in central Norwich (New Mills and Fye Bridge) were generally poorest performing across all macroinvertebrate quality metrics. This could be due to comparably heavy modification of bank habitat and channel morphology, alongside higher levels of urban pollution.

iii.) In comparison, monitoring sites upstream of Norwich presented higher mean scores across all macroinvertebrate metrics. In the case of WHPT ASPT (sensitive to water chemistry stressors), improvements over time were particularly widespread and consistent. Possible factors include catchment-wide improvements in sewage treatment alongside stakeholder efforts to achieve catchment sensitive farming and habitat restoration.

iv.) Upstream of Norwich, Twyford Bridge on Foulsham Stream, in the mid-catchment, showed long term decline of LIFE scores, a metric sensitive to pressure from low flow (LIFE). Throughout the catchment in general, a degree of pressure from low flow was widely evidenced by more marginal LIFE O:E scores when compared to other metrics. This, measured in respect to RICT-derived thresholds for favourable conditions in chalk streams, set nationally by the EA.

v.) Stream habitat quality (indicated by NTAXA scores) generally retained favourable conditions across the catchment, but decreased consistently over time at several Wensum and tributary sites downstream Twyford Bridge (mid-catchment). Notably, these declines occurred despite several efforts to improve land management and habitat on the Wensum.

v.) Additional research is recommended to evidence the most successful forms of land management and river restoration practices. Useful lessons may be found in reaches where restoration has taken place which displayed improving metric scores over time. To support this approach, confounding factors such as the presence of non-native American Signal Crayfish, which can skew macroinvertebrate metric scores, will need to be accounted for through monitoring programmes by the EA and partners.

vi.) Fish population records were lowest performing in the upstream Wensum catchment, which typically contained some of the highest performing macroinvertebrate sites. This contrast may underline the importance of physical impoundments for fish passage towards the catchment headwaters, rather than persistent water chemistry and stream habitat issues.

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