Hoveton Great Broad Dossier

Part of the review of lake restoration practices and their performance in the Broads National Park, 1980-2013

Produced by the Broads Authority

April 2016

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Site by site case histories:

1 Basic site characteristics

Hoveton is one of a series of medium sized broads that occur in the lower Bure valley downstream of Wroxham and which have an active connection to the main river (Figure 1). Including its northerly extension, Hudsons Bay, Hoveton Great Broad is connected to the river at five points. The largest and most downstream of these is dammed thereby preventing access by boats. This makes Hoveton Great Broad one of the largest unnavigable broads. Hoveton is essentially a repository of river-borne silt and is therefore very shallow. The broad is largely surrounded by alder and willow carr that is managed on an on-going basis to prevent shading of littoral habitat. Various attempts at management, including the use of artificial plants, fish and bird exclosures have been undertaken since the late 1980s with comparatively little success.

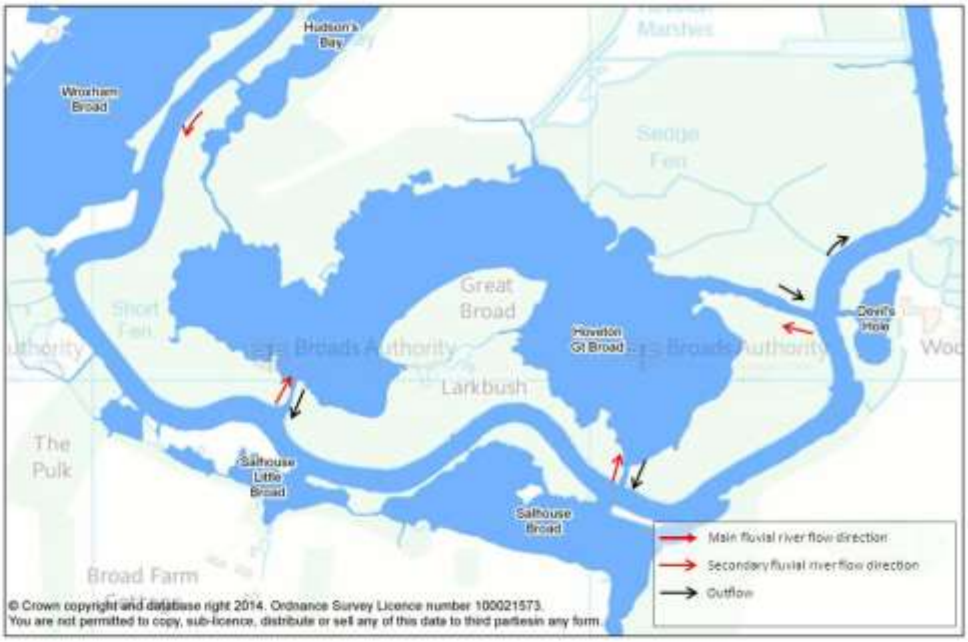


Figure 1 Geographical context of Hoveton Great Broad

Table 1 Basic site characteristics for Hoveton Great Broad

Hoveton Great Broad (UK Lake WBID GB30535977)

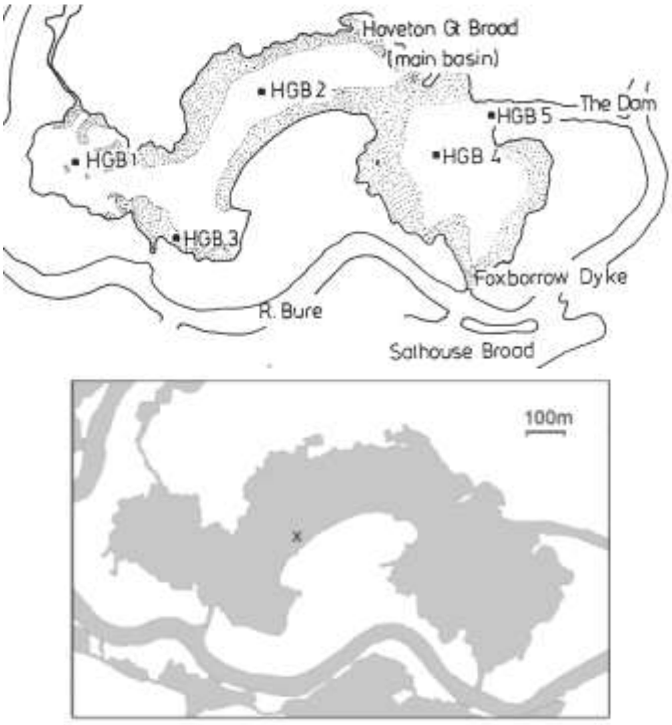
Location		
	(Easting 632115, Northing 316159)	
Water body area (Ha)	36.9	
Mean depth (m)	1.0	
Mean alkalinity (mEq/l)	3.9	
River system	River Bure	
Connectivity	Riverine	
Navigation	No	
Designations	Bure Broads and Marshes SSSI The Broads SAC Broadland SPA and Ramsar Bure Marshes NNR	
Water Framework Directive water body	Phosphorus boundary values	
	High/Good:	44 μg^{-1}
	Good/Moderate	59 μgl^{-1}
	Moderate/Poor	118 μgl-1
	Poor/Bad	236 μgl-1
	Chlorophyll boundary values	
	High/Good	9 μgl-1
	Good/Moderate	20 μgl-1
	Moderate/Poor	39 μgl-1
	Poor/Bad	118 μgl-1
Water Framework Directive Status (2013)	Moderate Ecological Status	
	Phytoplankton: No classification Macrophytes: Moderate Invertebrates:No classification Fish:No classification Phosphorus:No classification	
Favourable Condition Status	Unfavourable: no change	

2 Palaeolimnology

Hoveton Great Broad has been the subject of a number of palaeolimnological studies, namely; Moss (1988), Stansfield *et al*. (1989) and Hoare (2007). Plant and animal (cladocera, macroinvertebrates, bryozoans, molluscs & fish) macrofossils and diatom frustules have been examined from dated sediment cores. Historic aquatic plant records are fairly extensive for the site.

2.1 Sediment stratigraphy and dating

Figure 2 show the locations of the five sediment cores (HGB1-HGB5) collected in the 1980s by Moss (1988) and the two cores (HGBO1-2) collected on 14/01/2005 by Hoare (2007). The three cores (HGBP1 and HGBP2) taken by Stansfield *et al*. (1989) between November 1985 and April 1987 are not mapped, but were taken from an area intermediate between those from which cores HGB1 and HGB2 were taken.



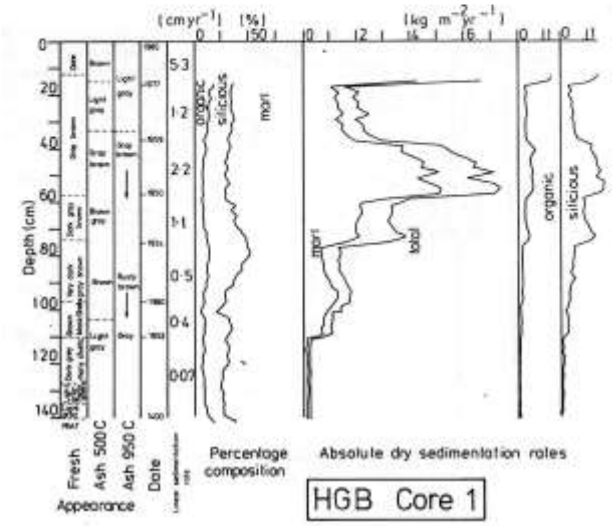
HGBO1 & HGBO2

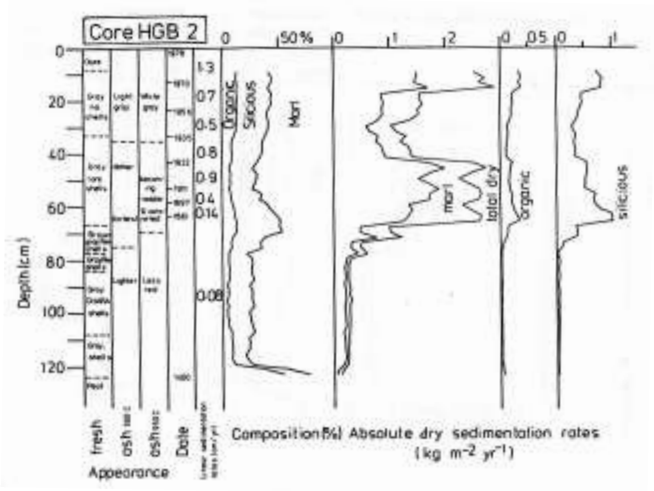
Figure 2a&b Locations of sediment cores taken from Hoveton Great Broad. Moss (1988) & Hoare (2007).

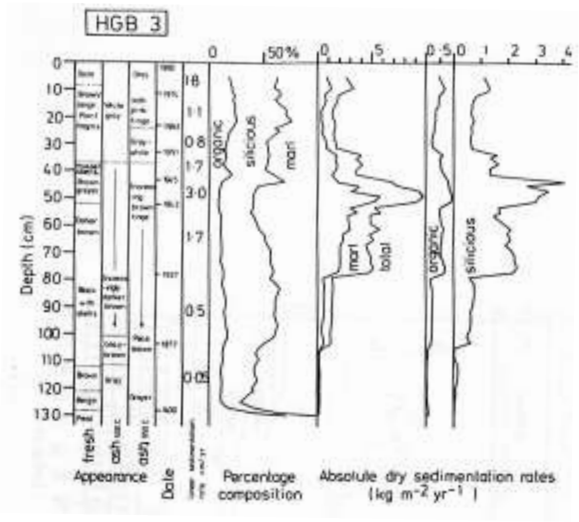
Core HGBO1 (85 cm in length) was collected using a large 14 cm diameter ‘Big Ben’ piston corer (Patmore *et al*, 2013), approximately 20 m out from the current south margin of the central basin in a water depth of 120 cm (Hoare, 2007). Photographic evidence (Figure 6) showed that this was an area where distinct regression of the littoral vegetation had occurred between the 1946 and 1969 pictures. A second core, HGB02 (164 cm in length) was collected using a standard 7.4 cm Livingstone corer, approximately 5 m away from HGBO1 (location: 52°41.376’ N, 1°25.338 E) and extended down to the pre-lake peaty sediments, allowing the stratigraphy of HGBO1 to be positioned chronologically in the context of the entire sediment sequence (Figure 3f). HGBO1 was radiometrically dated using ^{210}Pb and ^{137}Cs: ^{137}Cs concentrations were low, however it was possible to locate the 1963 peak in atomic weapons testing at ~16.5 cm. ^{210}Pb activity was very low and a long term chronology for HGBO1 could only be established for the top 20.5 cm of the core (post-1950s) therefore earlier stratigraphic changes are un-dated. Cores HGB1-HGB5 were between 120 and 140 cm in length and extended down to the basal peat deposits. These cores were all radiometrically dated using ^{210}Pb (Figure 3a-e from Moss, 1988). Concentrations of ^{137}Cs were measured in one core taken close to HGB2 at an earlier date and these results helped to establish the core chronologies. The three cores taken by Stansfield *et al*. (1989) were readily cross-correlated with HGB1-HGB5 by means of their prominent stratigraphy.

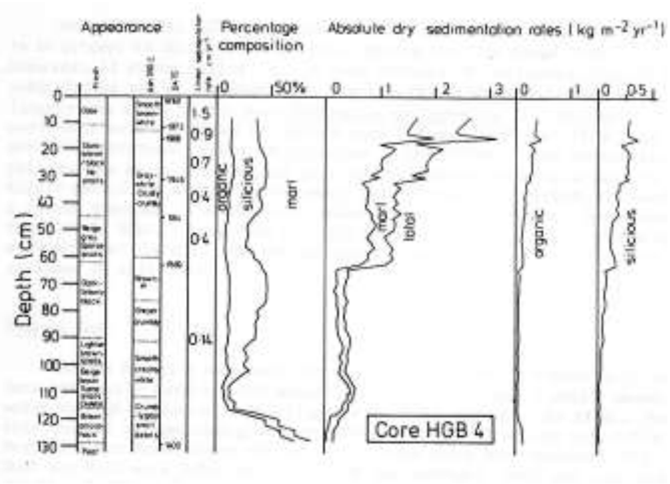
All cores examined showed three pronounced layers: Above the basin peat, the sediments were light in colour with frequent snail and *Chara* remains (Phase 1: pre-1850s). The middles of the cores were of darker sediment with fewer snail remains (Phase 2: 1850s-mid-1950s) and the upper sediments were of uniform beige or brown sediment, lacking snail remains though with occasional fibrous material (Phase 3: mid-1950s to 1980s).

For core HGB1, Moss (1988) reported very low linear sedimentation rates (~0.07 cm yr^{-1}) until the late 19th century when they increased to 0.4-1.1 cm yr^{-1}. There was a further marked rise in the 1950s, before a fall in the 1960s to ~1.2 cm yr^{-1}. In the late 1970s a very marked increase is apparent but may be overemphasised due to the soft ooze sediment.






HGB 3
Depth (cm)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
fresh
ash 550°C
ash 950°C
Appearance
Date
Linear sedimentation rate
1.8
1.1
0.8
1.7
3.0
1.7
0.5
0.05
0
50%
organic
siliceous
marl
Percentage composition
0
5
0.5
0
1
2
3
4
marl
total
organic
siliceous
Absolute dry sedimentation rates (kg m⁻² yr⁻¹)


Appearance
Linear sedimentation rate
Percentage composition
Absolute dry sedimentation rates (kg m⁻² yr⁻¹)
Depth (cm)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
1.5
0.9
0.7
0.4
0.4
0.14
0
50%
organic
siliceous
marl
0
1
2
3
0
1
0
0.5
marl
total
organic
siliceous
Core HGB 4

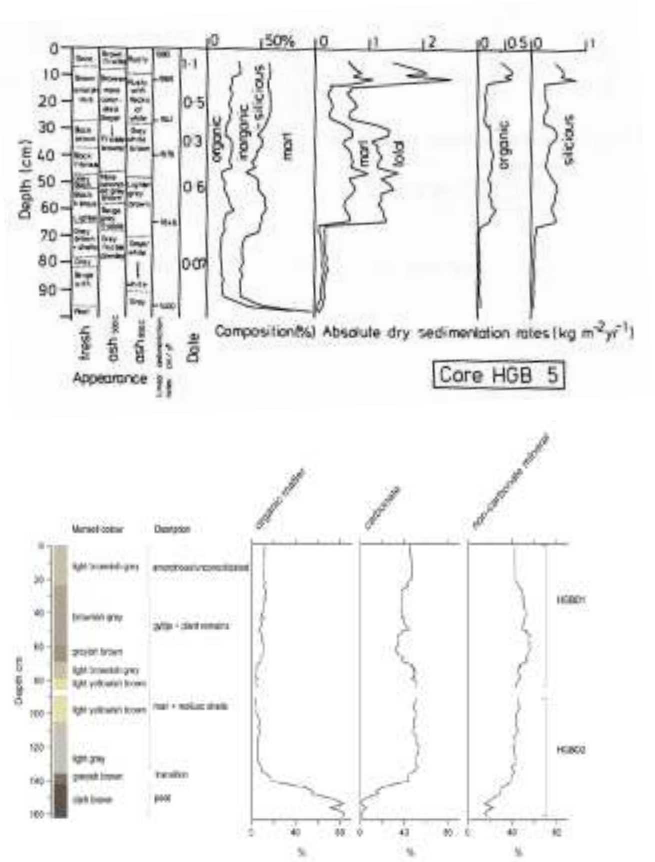


Figure 3a-f Characteristics of cores HGB1–HGB5 (Moss, 1988) and HGBO1-HGBO2 (Hoare, 2007).

2.2 Diatoms, historic macrophyte records and plant and animal macrofossils

2.2.1 Diatoms

Moss (1988) analysed ~70 levels each of cores HGB1, HGB2, HGB3 and HGB4 for absolute sedimentation rates of frustules of diatoms from different functional groups (Figure 4a-d) and Stansfield *et al*. (1989) presented the diatom data for core HGB1 (Moss, 1988), but with the addition of some diatom genera and individual species (Figure 5).

In core HGB1 (Figure 4a and Figure 5), Phase 1 (below 90 cm; pre-1890s) is characterised by an abundance of epiphytes (particularly Biraphidinean genera, with *Cocconeis placentula* and *Gomphonema* spp. dominant) and the absence of planktonic diatoms. The middle, dark layers of Phase 2 (90 to 50 cm; 1890s to mid-1950s) record a period of high sedimentation rates, with major increases in epi-benthic *Fragilaria* spp. and planktonic diatom populations beginning to increase. In Phase 3 (50 cm to surface; mid-1950s to 1980s) planktonic diatoms dominate (largely *Melosira granulata* & *M. islandica*). The sedimentary diatom profiles of cores HGB2-HGB4 are somewhat similar to that of core HGB1 and are not discussed individually here.

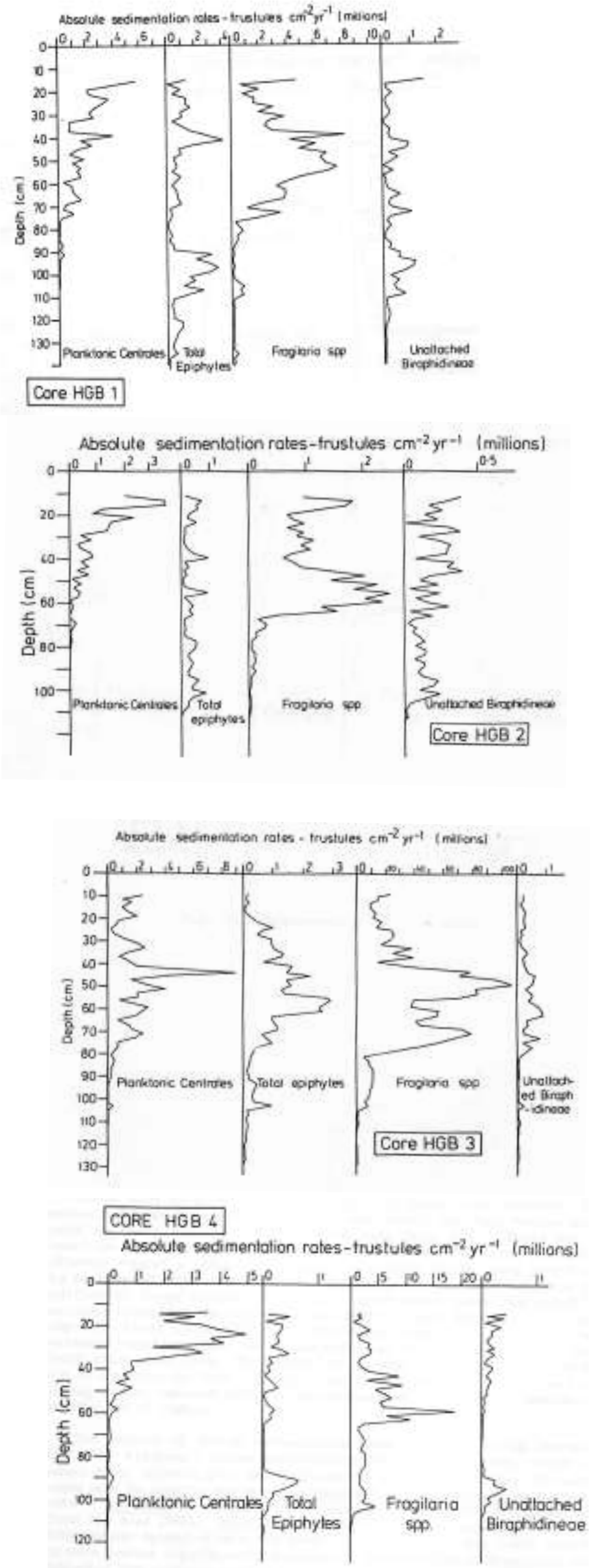


Figure 4a-d Absolute sedimentation rates of diatom frustules in cores HGB1-HGB4 (from Moss, 1988).

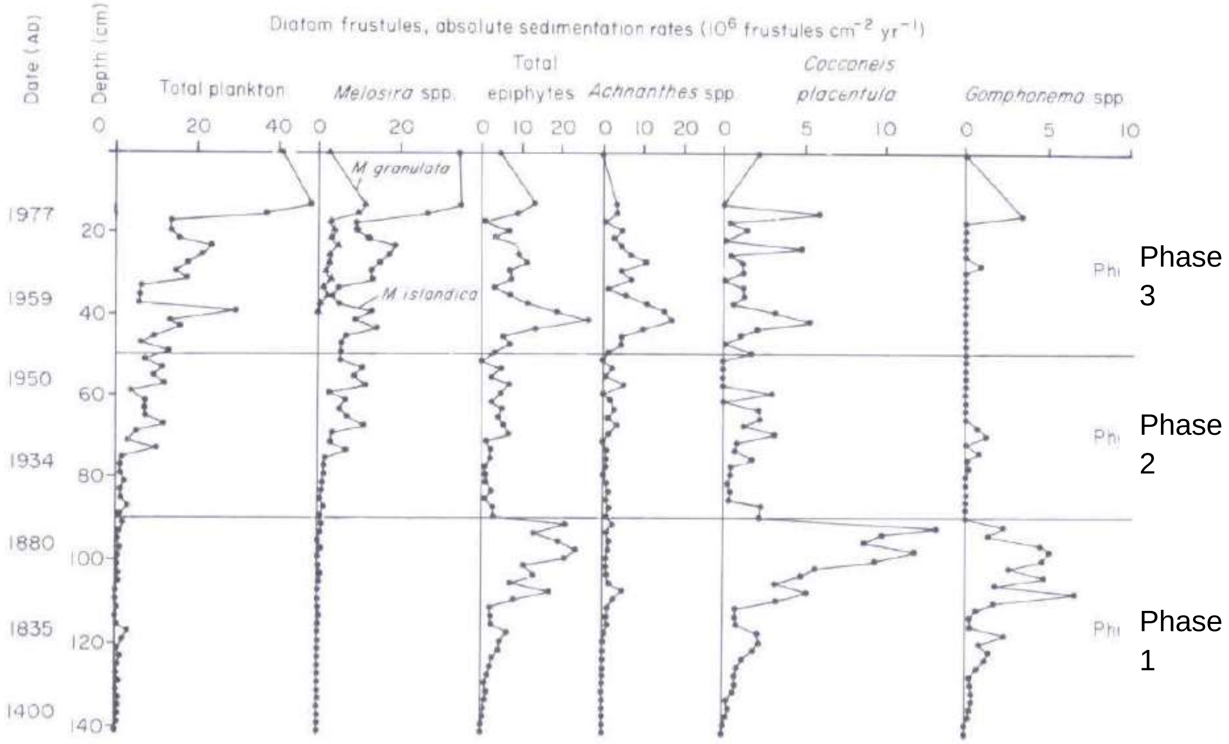


Figure 5 Changes in absolute sedimentation rates of diatoms from the dated sediment core HGB1 (Moss, 1988). *Melosira* is the major plankton genus present in the core; other genera and species illustrated are those that are particularly abundant (Stansfield *et al*. 1989).

2.2.2 Historic macrophyte records

There are numerous historic aquatic macrophyte records for submerged and floating-leaved plants in Hoveton Broad. Hoveton's earliest records (1805-1883), and occasional later records, do not specify whether they are from Hoveton Great Broad or Hoveton Little Broad. The following records have mostly been extracted from the database of Madgwick (2009):

The first macrophyte records for Hoveton, dating back to 1805 and noted in the Flora of Norfolk (1886), are for *Stratiotes aloides* and *Circuta virosa*. There is then a gap of almost 50 years before the next record in 1854, when *Ranunculus peltatus* and *R. circinatus* were recorded by E.F. Linton. Between 1847 and 1883 many records are for marginal species, including *Carex appropinquata, C. paniculata, C. acutiformis* and *Potentilla palustris*. In 1883, Davies (1883) recorded a dense growth of *Elodea canadensis* in Hoveton Great Broad and he commented that "the American weed, *Anacharis alsinastrum* [*E. canadensis*] has increased to such an extent that the grebes, being diving birds and greatly harassed by it, forsook the Broad for a time, but the weed has died off in a remarkable manner, and the grebes have returned". There were, however, further records for *E. canadensis* in 1884 and again in 1885, when it was recorded growing alongside *Potamogeton alpinus, P. lucens, Ceratophyllum demersum* and *Chara globularis* (also recorded from the narrow inlet in the same year). There is another record for *C. demersum* in 1902 by F. Long. There is then a gap in the records for aquatic species until 1947, when J.A. Lambert recorded a dominance of *S. aloides*, growing alongside *C. demersum* and *Myriophyllum verticillatum*. *S. aloides* was recorded again in 1950 by Lambert & Jennings (1951), when *C. demersum*, *Azolla filiculoides*, *Nymphaea alba*, *Nuphar lutea*, *Lemna minor*, *L. trisulca*, *M. verticillatum* and *P. lucens* were also recorded. *S. aloides* had disappeared by 1953 (Lambert, 1965). The first record for *Najas marina* was in 1959 (Jermy (1977) and Rocke (1977)) and it was recorded again in 1963 (Jermy *et al.,* 1963), but not thereafter until 1999 and 2000 (Broads Authority). In 1964, Sambrook (1964) recorded *Persicaria amphibia* and *N. lutea*. In 1969, *C. demersum* gave 45% cover (Morgan & Britton, 1969). Surveys conducted in the late 1960s and 70s found much of the former aquatic macrophyte diversity and abundance had disappeared. In June 1973, Mason & Bryant (1975) recorded only *N. alba* and *N. lutea* at moderate abundances and in 1977, Jackson (1978) noted only *Potamogeton pectinatus*, *P. crispus* and *N. alba*. The Broads Authority have carried out regular aquatic macrophyte surveys since 1983; the species occurring with greatest regularity have been *N. lutea*, *P. pectinatus* and *P. crispus*, with occasional records for *C. demersum*, *E. canadensis*, *N. alba* and *N. marina*. There have been no recent records for broad-leaved *Potamogeton spp.*, *C. globularis* or *S. aloides* all of which were regular components of Hoveton's late 19th and early-to-mid 20th century aquatic macrophyte flora.

Madgwick (2009) calculated the average change index for Hoveton Great Broad's aquatic macrophyte assemblage to be ~0.8; similar to values calculated for Cockshoot and Filby Broads and indicative of significant change in macrophyte composition from past to present.

Aerial photographs displayed in Figure 6 illustrate the extent of littoral and open-water aquatic macrophytes in Hoveton Great Broad between 1946 and 1980, with an almost total loss of open-water aquatic vegetation evident between 1961 and 1980 (Sayer *et al*. 2006).

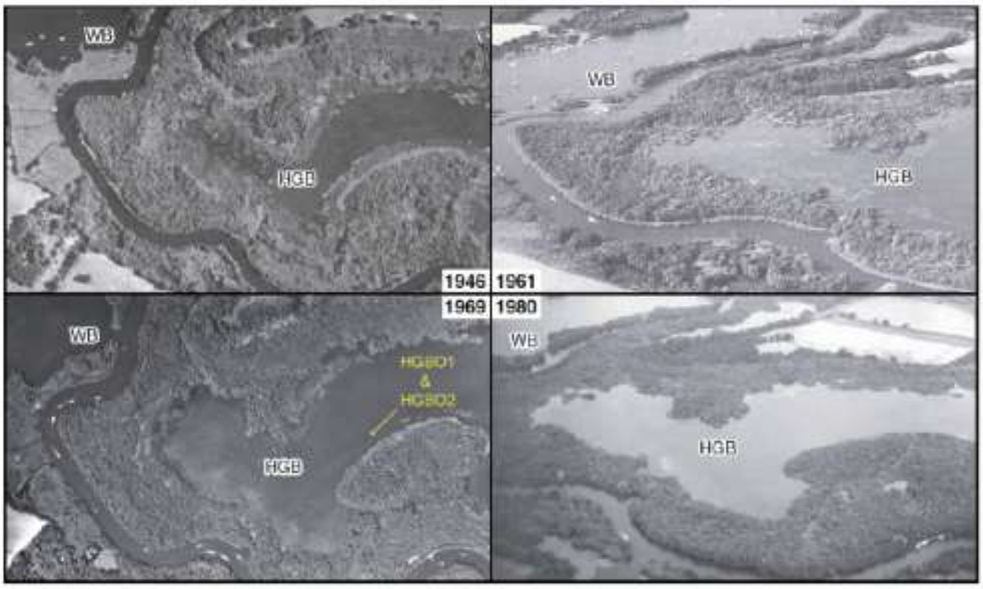


Figure 6 Aerial photography showing the loss of littoral and aquatic macrophytes from Hoveton Great Broad (HGB) (Sayer *et al*. 2006). The navigable River Bure and Wroxham Broad (WB) are also visible in each picture.

2.2.3 Plant macrofossils

Hoare (2007) analysed 17 levels of core HGBO1 for plant macrofossil remains. Soluble tri-butyl-tin (TBT) concentrations were also measured in HGBO1 and investigated as a potential causal mechanism for the decline of aquatic macrophytes. Figure 6 illustrates the TBT and plant macrofossil data, which includes 10 different taxa, eight of which are submerged species:

Within the marl sediment below 65 cm depth (Zone 1), the greatest abundance and diversity of submerged macrophyte remains was found. *Chara* sp. oospores were numerically dominant in this zone, with significant representation of *Zannichellia palustris*, *Najas marina*, *Ceratophyllum* sp. and *Potamogeton pusillus* agg. Above 65 cm *Chara* sp. oospores declined rapidly, with the community shifting to a mixture of *Myriophyllum spicatum*, *P. pusillus*, *C. demersum* and Nymphaeaceae up to the top of Zone 2. Nymphaeaceae trichosclereids were numerically dominant within zone 2b, effectively replacing all other submerged species above 40 cm. Furthermore, both the white, *Nymphaea alba* and yellow *Nuphar lutea* waterlily seeds were present in Zone 3 (above 20 cm). This suggests the occurrence of both species in mixed beds. However, the relative abundance of trichosclereids declined rapidly in Zone 3 compared to Zone 2b, indicating reduced presence of such lily beds.

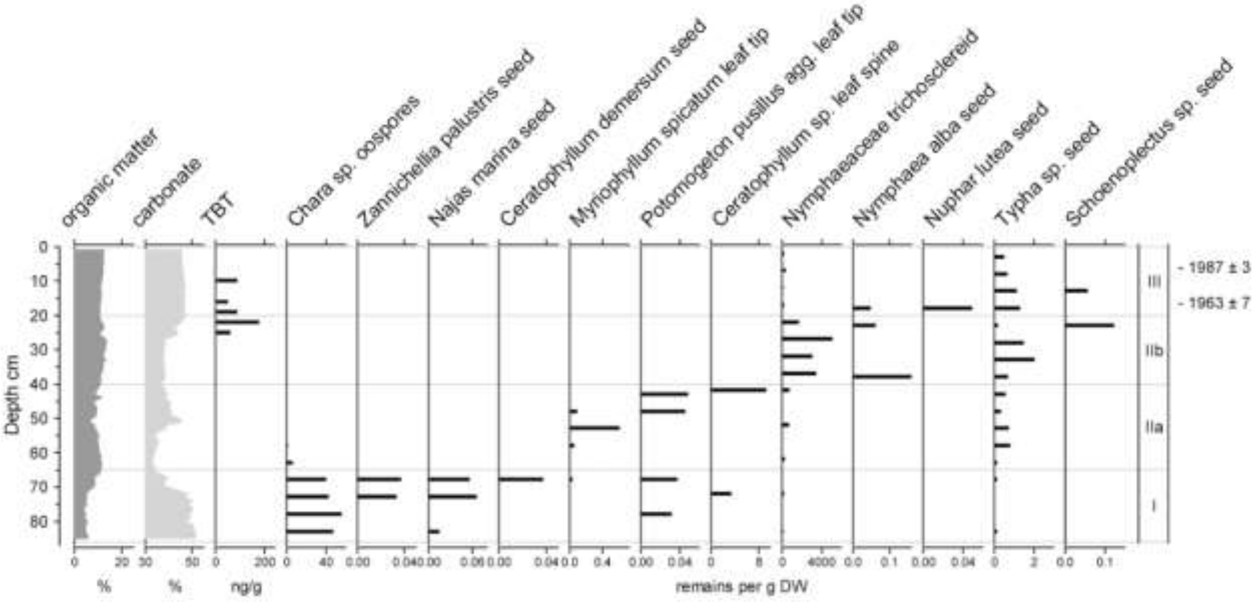


Figure 7 HGBO1 plant macrofossil stratigraphy (from Hoare, 2007).

2.2.4 Animal macrofossils

Stansfield *et al*. (1989) analysed 15-18 levels of cores HGBP2 and HGBP3 for cladocerans (chydorids and *Bosmina*) and mollusc remains (Figure 10 - Figure 12) and also measured organochloride concentrations to investigate their potential as a causal mechanism for the loss of submerged plants by way of toxicity to cladoceran grazers (Figure 11-Figure 12).

Hoare (2007) analysed 17 levels of core HGBO1 for mollusc remains (Figure 8) and 13 for cladocera (Figure 13). In addition, soluble tri-butyl-tin (TBT) concentrations were measured in HGBO1 and investigated as a potential causal mechanism for the decline of aquatic macrophytes (Figure 7) and associated ecological changes (Figure 8 and Figure 13).

2.2.5 Molluscs

The total mollusc remain curve (Figure 8) of Hoare (2007) is highly comparable to those displayed by Stansfield *et al*. (1989) in Figure 11 and Figure 12. Stansfield *et al*. (1989) did not display graphs for individual mollusc species, therefore only the gastropod and bivalve mollusc macrofossil remains enumerated through core HGBO1 (Hoare, 2007) are discussed here: A total of 17 taxa were identified with 13 species (Figure 8). All of the identified prosobranch gastropod taxa were recorded in the bottom, marl section of the core, below 65 cm (Zone 1). The most abundant species were *Valvata cristata*, *V. piscinalis*, *Bithynia tentaculata* and *Lymnaea peregra*. The pulmonate gastropods were also well represented in this zone, as was *Pisidium* sp. (pea mussels). Above 65 cm mollusc diversity and abundance declined extremely rapidly, with most taxa absent throughout Zone 2, until ~45 cm where there was a limited recovery. Within Zone 3 *Acroloxus lacustris* and *Gyraulus crista* appeared for the first time and juveniles of the genus *Valvata* were also found at densities similar to Zone 1. Zone 3 is characterised by large densities of bivalve glochidia (probably *Anodonta* sp. larval spats), suggesting either a large recruitment, or possibly poor survival, during this period. *Dreisenna polymorpha* appeared for the first time at the top of Zone 3. The most numerically abundant mollusc in the uppermost Zone 4 (above 25 cm), was *G. crista*, although it occurred at low numbers compared to the dominant taxa in Zone 1. *A. lacustris* declined and disappeared in Zone 4. *V. piscinalis* and *B. tentaculata*, which were both recorded in Zone 3, declined again in Zone 4. *Valvata* sp. juveniles which were relatively abundant in Zone 2 also declined above 25 cm.

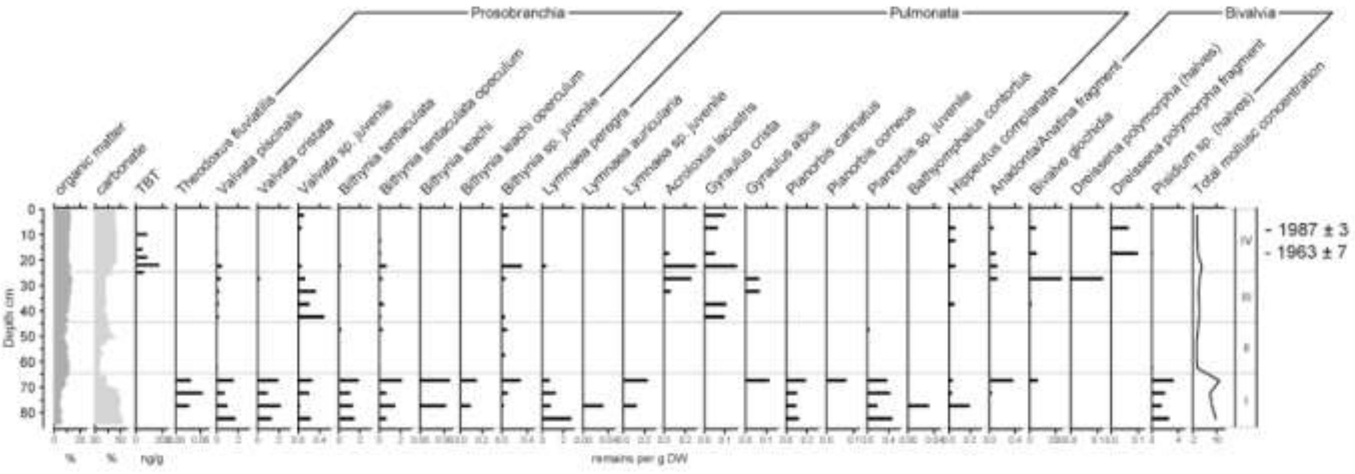
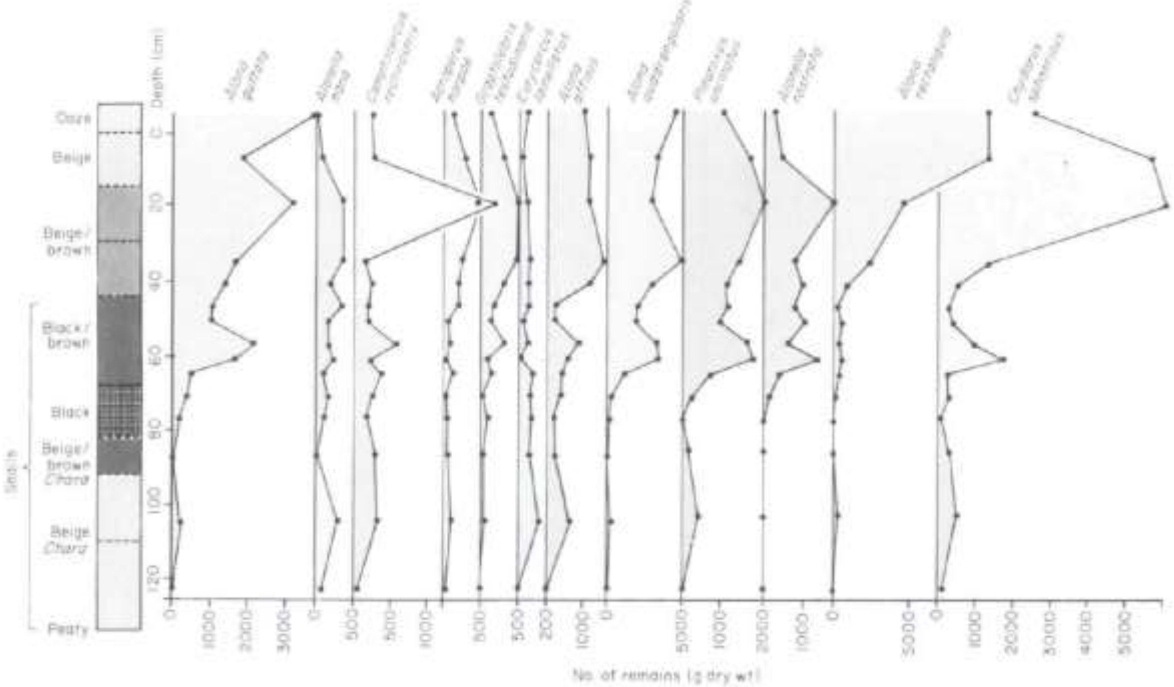


Figure 8 HGBO1 mollusc stratigraphy (from Hoare, 2007).

2.2.6 Cladocerans

Stansfield *et al*. (1989) found the remains of 23 species of Cladocera in the sediments of Hoveton Great Broad, all but two from the family Chydoridae. For core HGBP2, Figure 9 displays results for the most abundant taxa and Figure 11 displays the density of remains of *Bosmina* (hatched) and chydorids; numbers of *Bosmina* as a percentage of the total remains; percentages of chydorid remains in different water quality groups; density of snail remains and concentrations of organochloride compounds. Figure 10 and Figure 12 display the same for core HGBP3. The trends in cores HGBP2 and 3 are similar, with the total number of cladoceran remains showing a general trend of increase up the cores. Densities are low throughout Phase 1 and 2 and then rise quite dramatically as Phase 2 is replaced by Phase 3. This was followed by a period of decline, particularly for *Bosmina*, and then a steady increase towards the top of the cores. The numbers of chydorids became steady near the surface. A switch from clear-water associated chydorids to turbid-water forms coincides with the loss of aquatic plants in the 1950s. Residues of dieldrin (HEOD), DDD and TDE were found in the Hoveton Great Broad cores, with the DDT derivatives particularly associated with the end of the phase of submerged plant dominance. *Bosmina* remains become more abundant after this point.



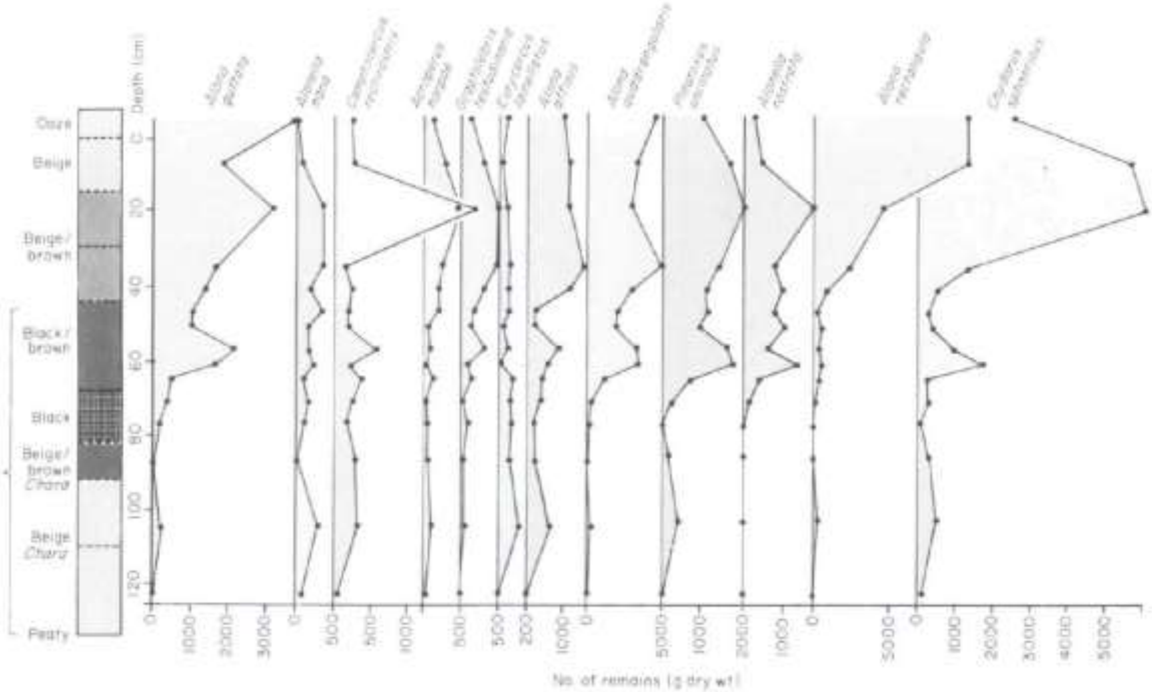


Figure 9 Core description and changes in the densities of the most abundant remains in each case of chydorid species found in Hoveton Great Broad Core 2 (from Stansfield *et al*., 1989).

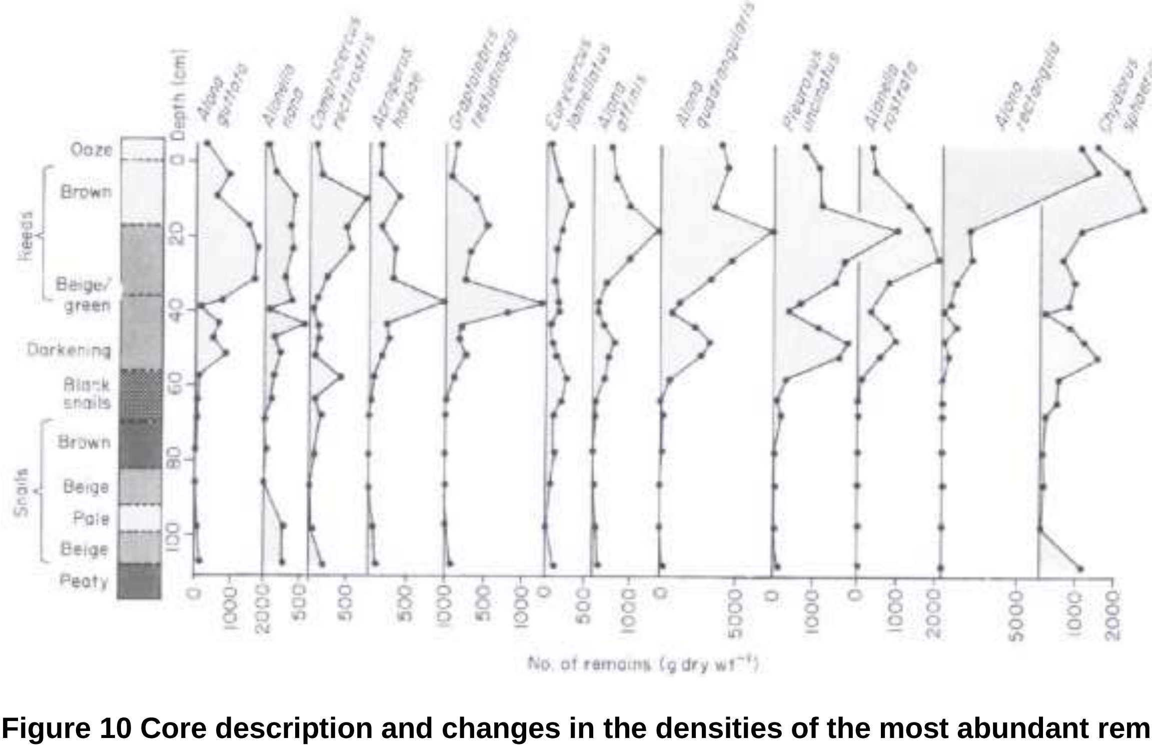


Figure 10 Core description and changes in the densities of the most abundant remain in each case of chydorid species found in Hoveton Great Broad Core 3 (from Stansfield *et al*., 1989).

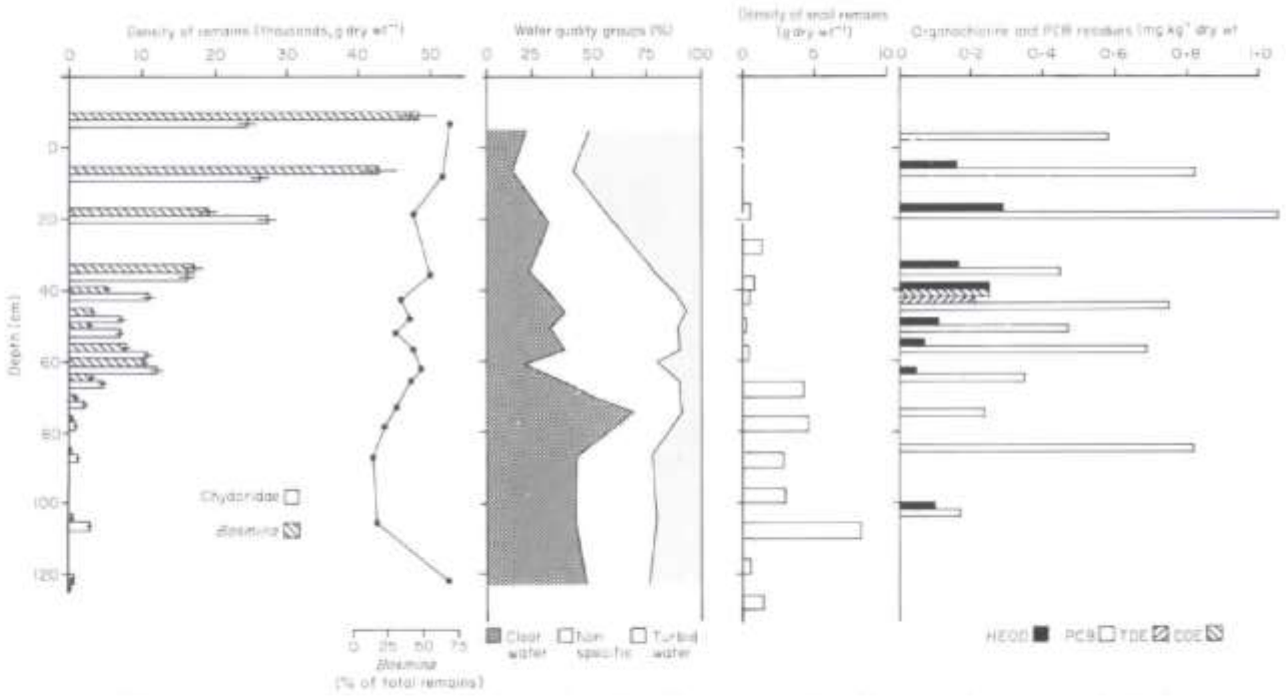


Figure 11 Density of remains of Bosmina (hatched) and chydorids; numbers of Bosmina as a percentage of the total remains; percentages of chydorid remains in Whiteside's (1970) water quality groups; density of snail remains and concentrations of organochloride compounds, in HGBP2 (Stansfield et al. 1989).

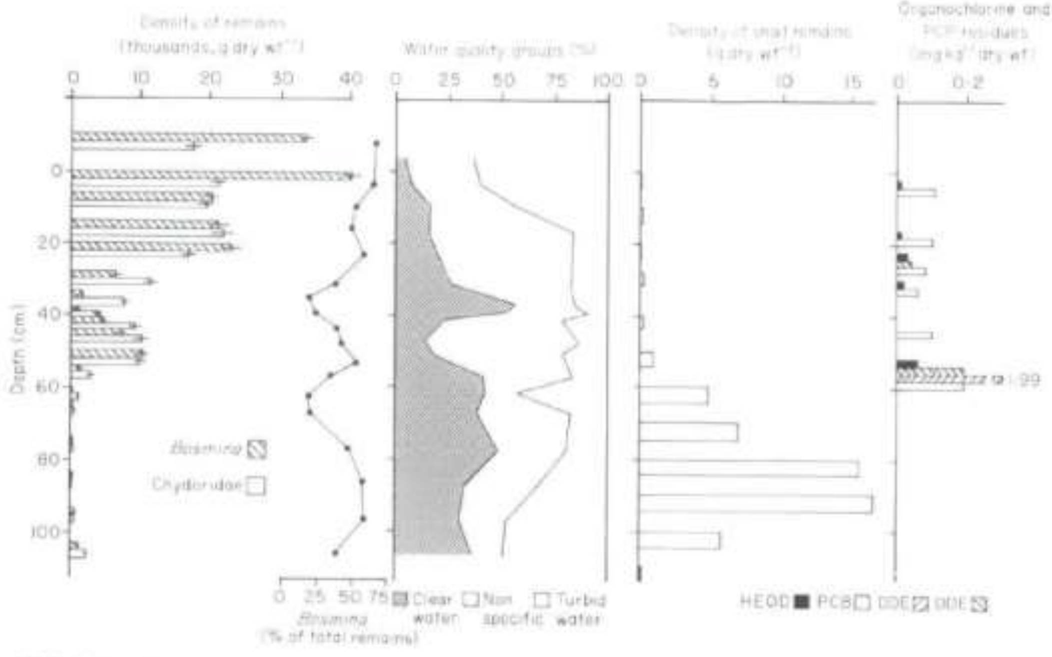


Figure 12 Density of remains of *Bosmina* (hatched) and chydorids; numbers of *Bosmina* as a percentage of the total remains; percentages of chydorid remains in Whiteside's (1970) water quality groups; density of snail remains and concentrations of organochloride compounds, in HGBP3 (Stansfield *et al*. 1989).

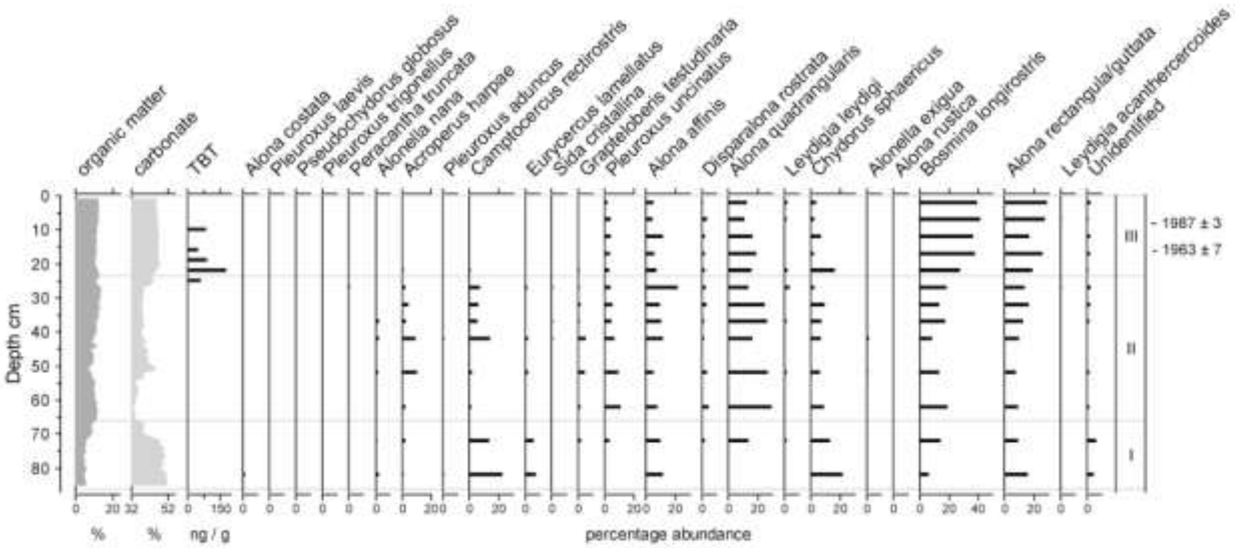


Figure 13 Percentage abundance of cladoceran remain types in core HGBO1 (from Hoare, 2007).

2.2.7 Other invertebrate and macroinvertebrate macrofossil remains

In core HGBO1 (Hoare, 2007), percid scales and fragments were represented in the lowermost zone 1 of HGBO1, but cyprinid scales were infrequent and low in number. Percid and cyprinid scales both increased to maximal concentrations in zone 3 and then became less abundant in zone 4 after the introduction of TBT. The most frequent macroinvertebrate remains found throughout the core were of Trichoptera, *Piscicola geometra* and Chironomidae. The latter had the greatest abundance in zone 1. All invertebrate remains appeared to have a reduced abundance in zone 2. Both *P. geometra* and the various caddis fly remains, including *Orthotrichia* sp. had the greatest abundance in zone 3 and declined rapidly in zone 4.

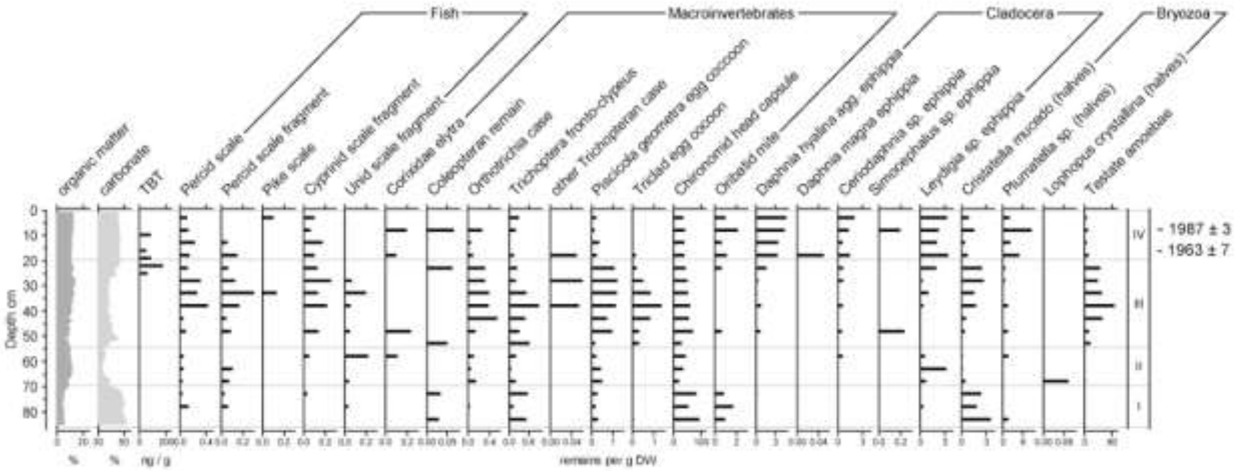


Figure 14 HGBO1 vertebrate and invertebrate organism macrofossil stratigraphy (from Hoare, 2007).

2.3 Summary

Figure 15 provides a summary of the main palaeoecological changes which have occurred throughout Hoveton Great Broad's history. Historical plant records, in combination with diatom, plant and animal macrofossil data have revealed that the Broad was characterised by pre-1900s low disturbance conditions (Phase 1) where sediments were light in colour, rich in carbonates, with low-growing charophytes the most significant component of the macrophyte community. Associated with this charophyte period were highly abundant and diverse mollusc communities, the presence of several plant-associated cladoceran species and abundant epiphytic diatom genera with no planktonic diatoms. Even at this stage however, Hoveton Great Broad was potentially more fertile than some isolated broads due to its connectivity to the Bure. There was then a decline in molluscs, charophytes, and epiphytic diatoms around the 1900s, probably as a result of nutrient enrichment. This led to Phase 2; the development of a diatom community dominated by epi-benthic *Fragilaria* spp., with increasing numbers of planktonic diatom taxa and a relatively diverse macrophyte community dominated by ranker plants and waterlilies. Phase 2 coincides with increasing nutrient loadings, the introduction of TBT and the liberal use of organochloride pesticides between the 1950s and 60s. In Phase 3, sparse plant macrofossils were found in the sediments, suggesting very little macrophyte growth. The diatom flora progressed further towards a plankton-dominated community and the cladoceran community also shifted from benthic to planktonic production post-1950s. Aerial photography shows minimal plant growth in 1969 and 1980 and surveys confirm the depauperate macrophyte community present in Hoveton Great Broad around this time. Madgwick (2009) calculated the average change index between past and present aquatic macrophyte communities to be 0.8, providing further evidence for a significant shift in community composition over Hoveton Great Broad's history.

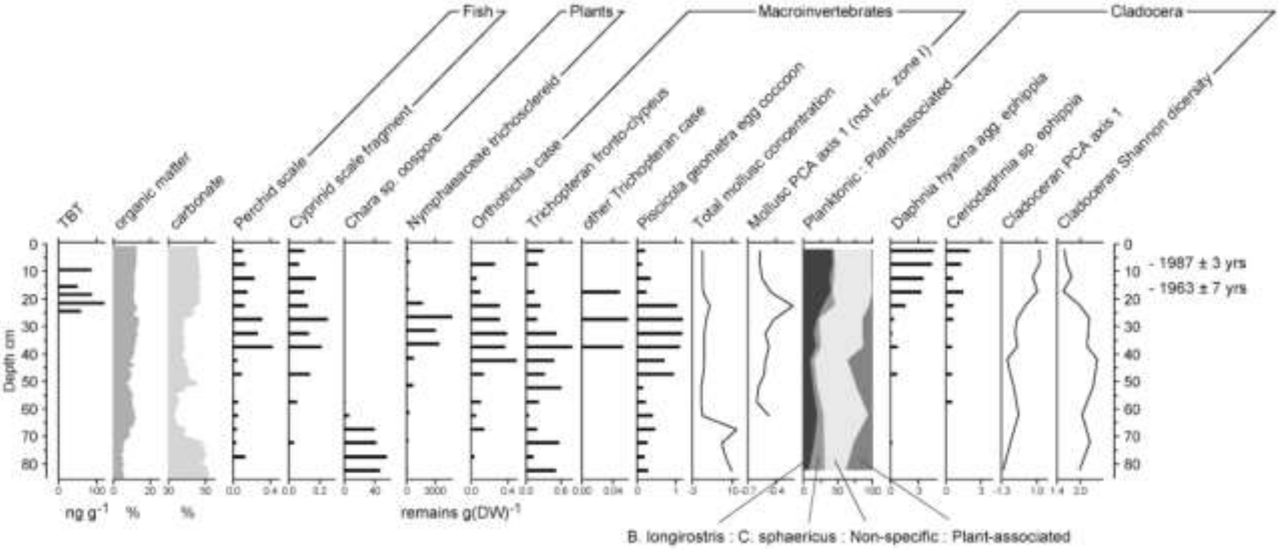


Figure 15 Summary of HGBO1 palaeolimnological proxy results (from Hoare, 2007).

3 Chronology of management activities and key events

Table 2 Chronology of management activities and key events for Hoveton Great Broad (those marked with * shown on figures below)

Date	Description
1986*	Experimental P removal at Briston, Aylsham and Belaugh STW
1990*	Fish exclosure installed (removed 2003)
1985-1987	Artificial macrophyte trials
1997*	1mg/l effluent standard on discharges from Aylsham & Briston STWs
1998*	1mg/l effluent standard on discharges from Coltishall STW
1999*	1mg/l effluent standard on discharges from Belaugh STW
2001-2013	Creation of embayments with intermittent fish removal
2003*	2mg/l effluent standard on discharges from Rackheath, Roughton & Aldborough STWs
1999/2000 and on-going	Removal of alder and willow shade from 4.2km of shoreline
1993-2003	Bird exclosures

4 Water quality

When making assessments of changes, data from Hoveton Great Broad has been compared to conditions in the River Bure. A site positioned down stream of Wroxham Broad, which is upstream of the entrance to Hoveton Great Broad has been treated as the site most likely to represent inflow conditions, although the river at this point is still slightly affected by tidal water movement. (Additional data from UEA studies are available for this site and it would be useful to use these to update this template when time becomes available)

4.1 Total Phosphorus

Total phosphorus in Hoveton Great Broad has reduced significantly (Mann Kendall tau = -0.648 $p<0.001$) since the mid-1980s (Figure 16). Monitoring of this site has been infrequent since 2009 but the broad now has a median TP concentration of 82 $\mu g l^{-1}$ (2003-2012) placing it in Moderate status under the WFD. The broad is linked to the river and throughout the earlier period of monitoring (prior to 1995) had a very similar TP concentration which provides an estimate of likely changes in the broad. These data suggest that the decline in P has stopped (Mann Kendall tau = 0.022 p=0.5) and that both the river and the broad are at a new stable P concentration. Comparing TP levels at all monitored stations in the tidal River Bure shows a clear relationship between TP and river discharge, with peaks of TP and discharge occurring in 2001 and 2007, with the dip between 2005-2007 being associated with lower flows. Recent monitoring data is inadequate in frequency to be certain if the broad now has higher TP concentrations than the river, but from the limited data this appears to be the case. TP inside the fish exclosure in the Broad was slightly lower than that in the Broad (median enclosure 72 µgl^{-1} in comparison with 89 µgl^{-1} during the period 1991-1994).

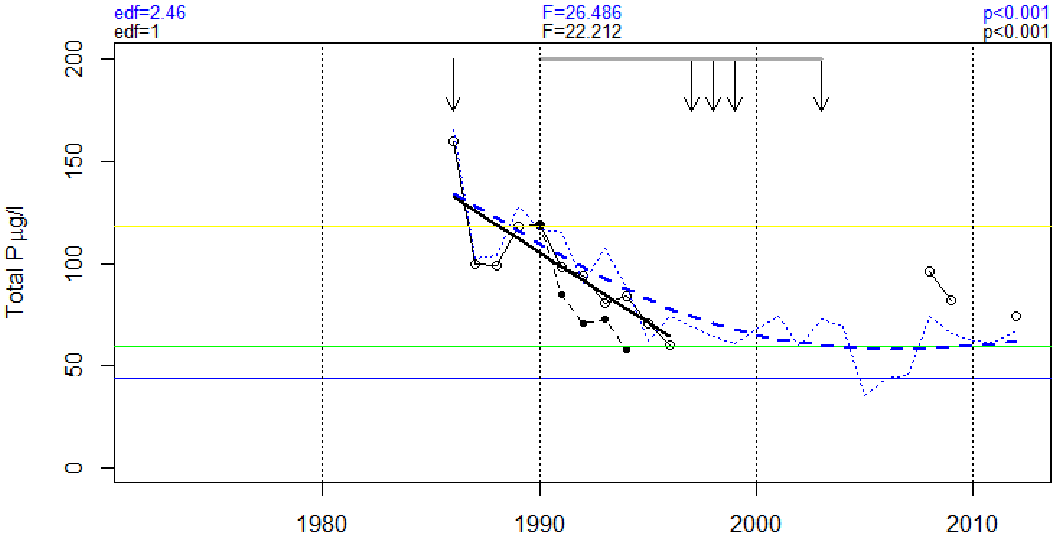


Figure 16 Trend in annual mean TP for Hoveton Great Broad (solid black line), compared with trend in the River Bure d/s Wroxham Broad (broken blue line) and in the Fish Exclosure (broken dotted line solid circles), showing GAM smoothers. Horizontal lines mark WFD boundary values, arrows mark key events, grey line marks period that fish exclosure was present.

The seasonal trend in TP in Hoveton Great Broad is similar to many shallow lakes with maximum values occurring in July – August (Figure 17), although there is some evidence to suggest that since 2008 this peak occurs slightly earlier in June (Figure 17c & d). A similar seasonal pattern, with a summer peak, is seen in the river (Figure 18), but the magnitude of this summer peak in the river is now much lower than it is in Hoveton Great Broad (Figure 19). Prior to 1996, when the river and broad were in a period of declining P following introduction of P removal from STWs, the magnitude of the seasonal pattern was as high in the river as it was in the broad. Higher TP in the summer relative to the winter (Figure 21) is indicative of the release of phosphorus from sediments and it seems likely that in the 1990s this was occurring in both the river and Hoveton Great Broad. However, since 2008, when monitoring of Hoveton Great Broad was re-started, it seems likely that the broad is still experiencing significant release of phosphorus from the sediment in May and June (in contrast to the river) and this is likely to account for the higher TP in Hoveton relative to the river seen in Figure 17.

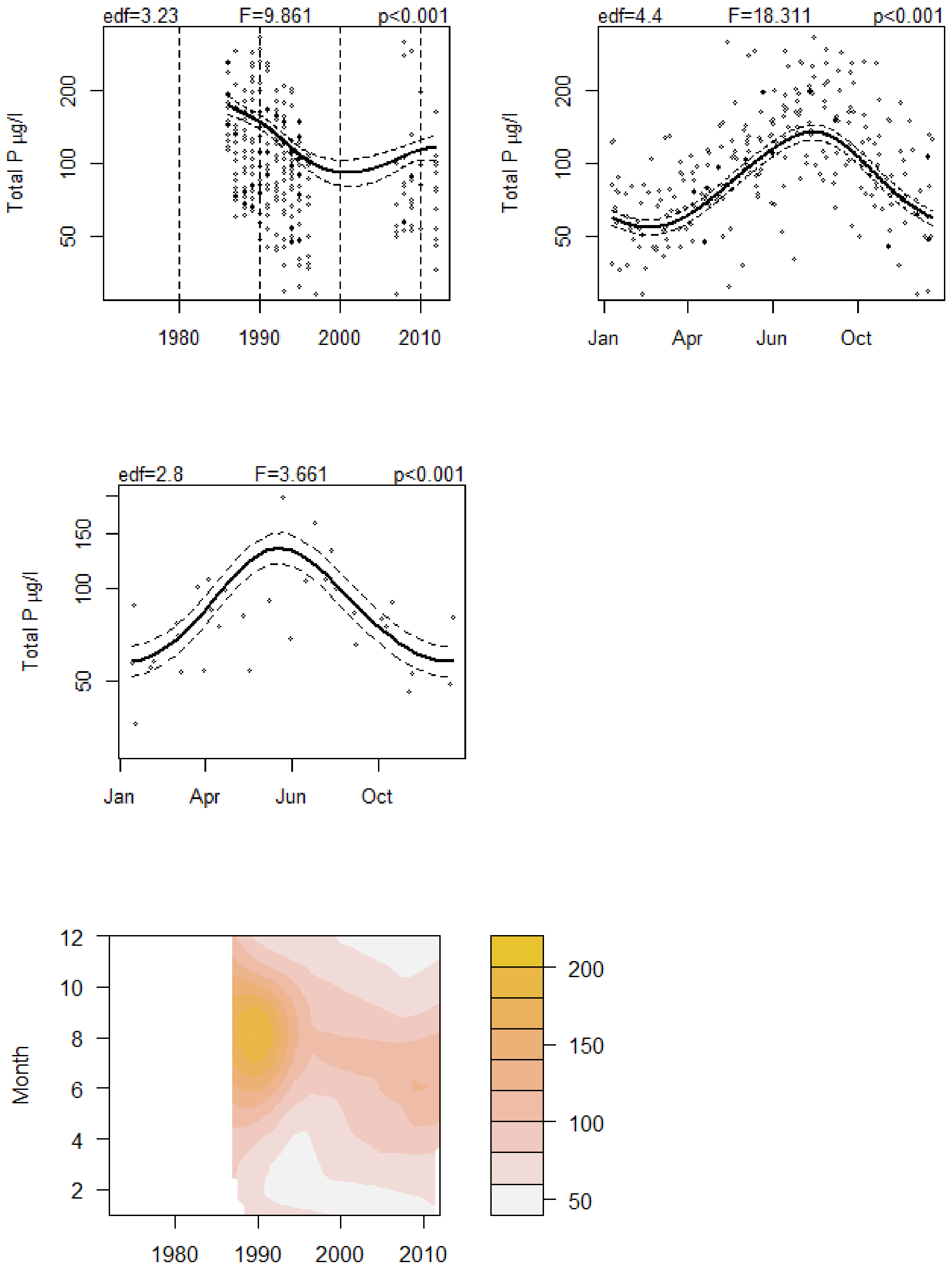


Figure 17 Changes in TP for Hoveton Great Broad: a) Long term trend (Annual); b) Seasonal trend (1986-1998), c) Seasonal trend (2008-2012), c) contour plot showing changes in seasonality with time. (Trends extracted using GAMM model, contour plot using a bi-variate GAM model)

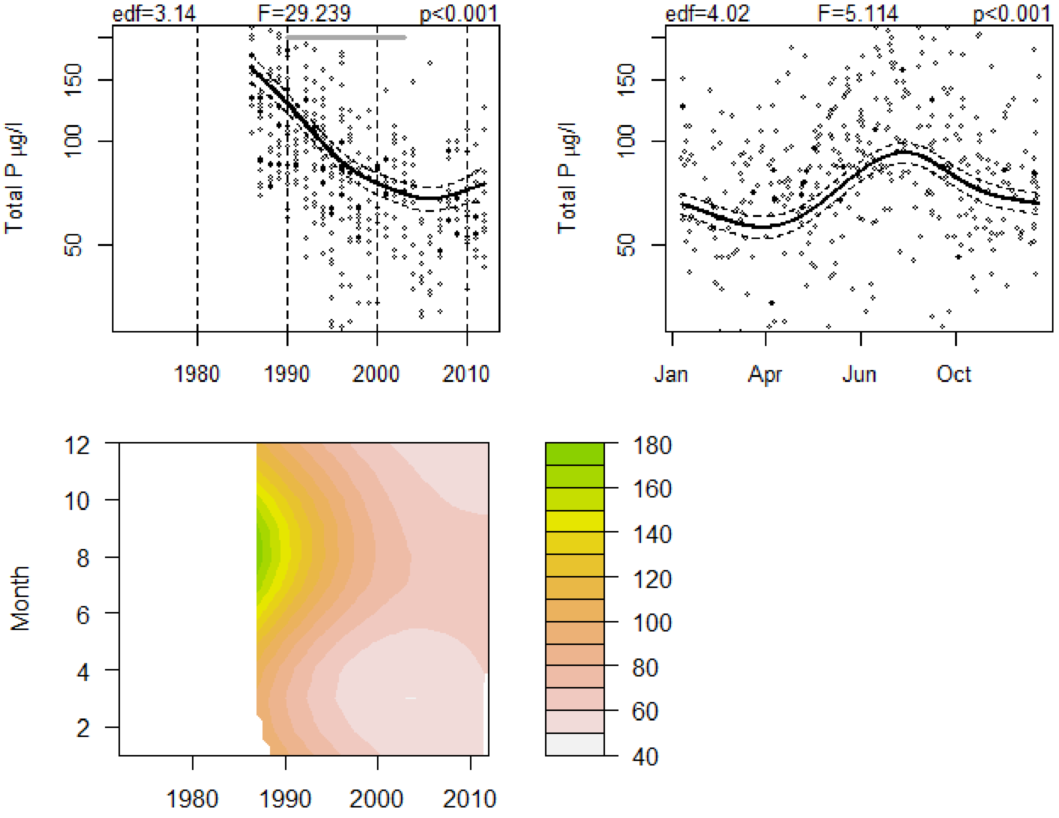


Figure 18 Changes in TP for River Bure d/s Wroxham Broad (inflow to Hoveton Great Broad: a) Long term trend (Annual); b) Seasonal trend c) contour plot showing changes in seasonality with time. (Trends extracted using GAMM model, contour plot using a bi-variate GAM model)

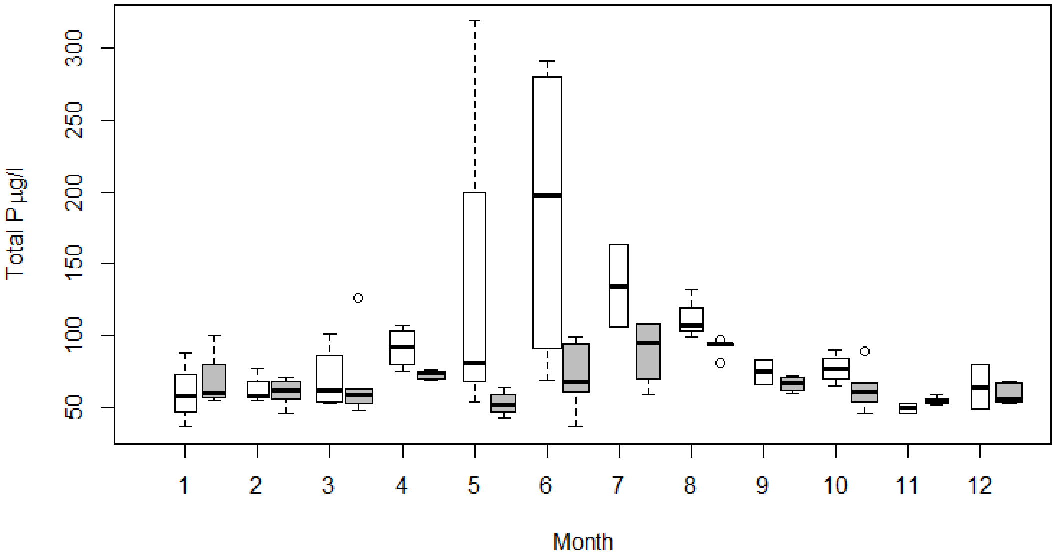


Figure 19 Comparison of monthly range of TP in Hoveton Great Broad (open bars) with TP in the River Bure d/s of Wroxham Broad (grey bars) for 2008-2012. Bar width proportional to number of samples.

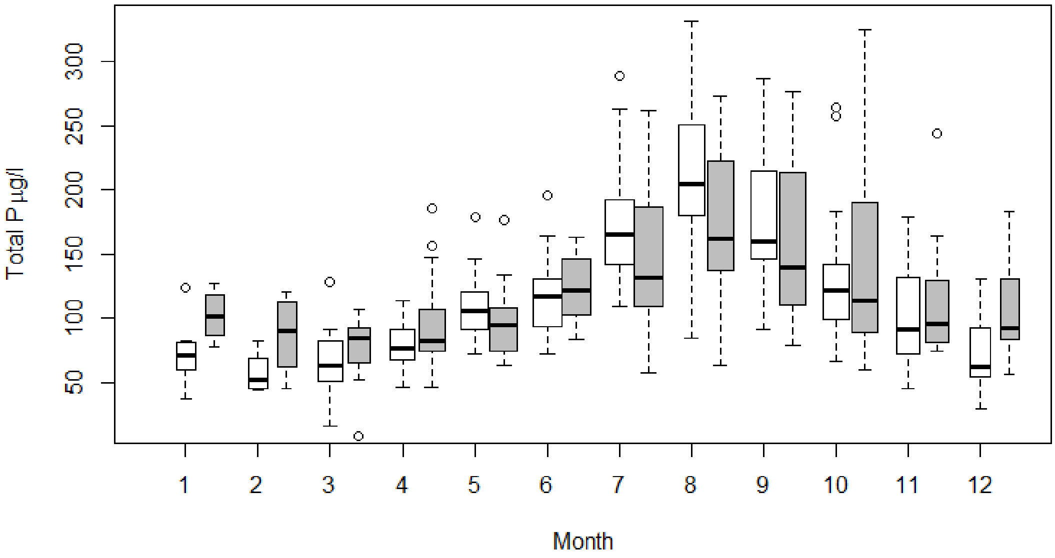


Figure 20 Comparison of monthly range of TP in Hoveton Great Broad (open bars) with TP in the River Bure d/s of Wroxham Broad (grey bars) prior to 1996. Bar width proportional to number of samples.

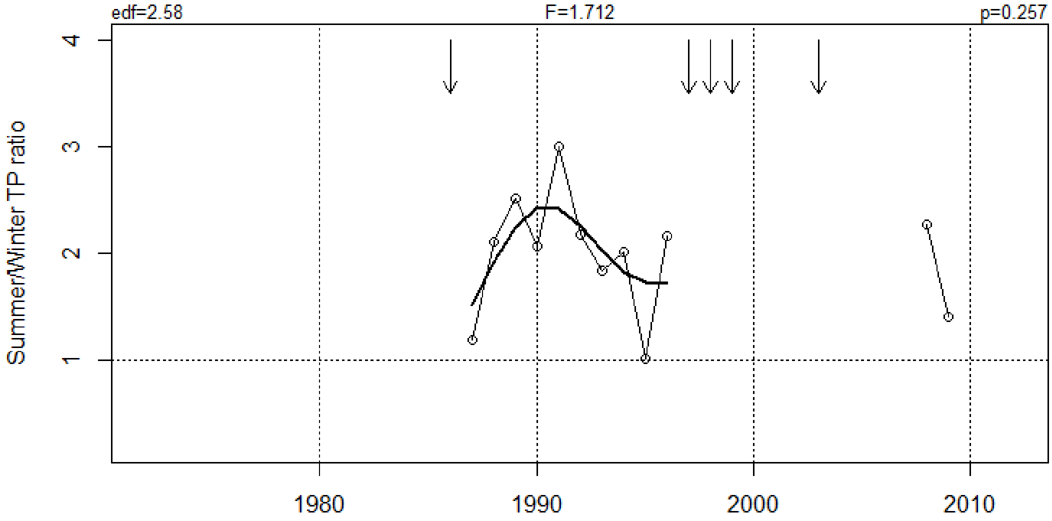


Figure 21 Trend in ratio of summer/winter mean TP for Hoveton Great Broad (solid black line) showing GAM smoothers. Arrows mark key events.

4.2 Soluble Reactive Phosphorus

Soluble phosphorus in Hoveton Great Broad has shown little change (Mann Kendall tau = 0.236 p=0.175) although recent monitoring has not included this parameter (Figure 22). Soluble phosphorus in the river is higher than in the broad and while it followed a similar pattern to that of Hoveton Great Broad in the 1990s it has subsequently increased, although taking the last decade (2003-2012) the increase is only marginally significant (Mann Kendall tau = 0.422p=0.054) and subject to clear peaks and troughs. The seasonal pattern of SRP in Hoveton Broad shows a clear peak in June which is entirely consistent with the release of phosphorus from the sediment (Figure 23b & c).

In conclusion there is little doubt from the monitoring data that the sediment in Hoveton Great Broad was a significant source of phosphorus in the early summer during the 1990s. It is less certain that this is still the case as soluble phosphorus data are not available for this period. However, the patterns of TP and comparison with the river upstream of the broad suggest that this is still likely to be occurring.

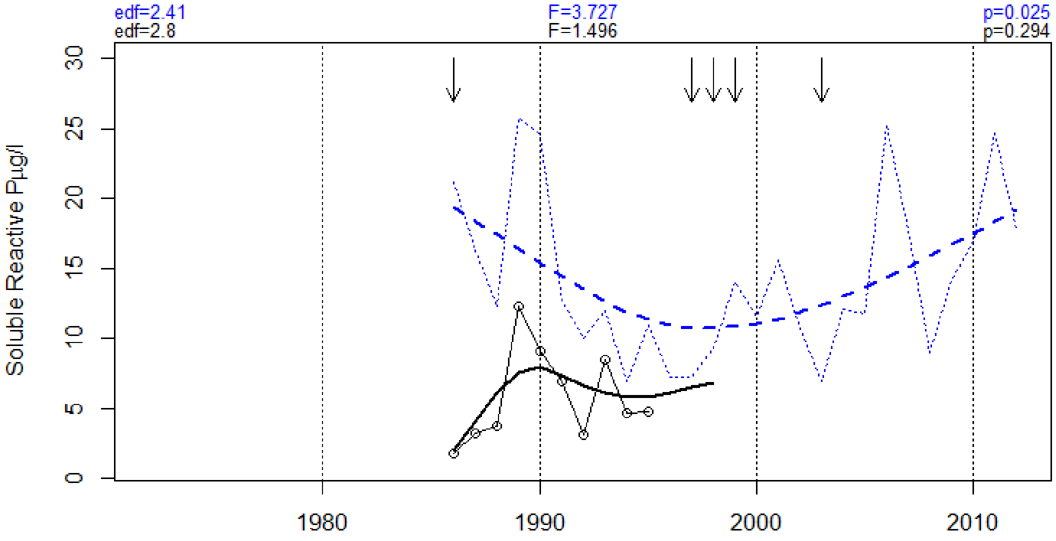


Figure 22 Trend in annual mean SRP for Hoveton Great Broad (solid black line) compared with trend in River Bure d/s Wroxham Broad, showing GAM smoothers. Vertical lines mark key events.

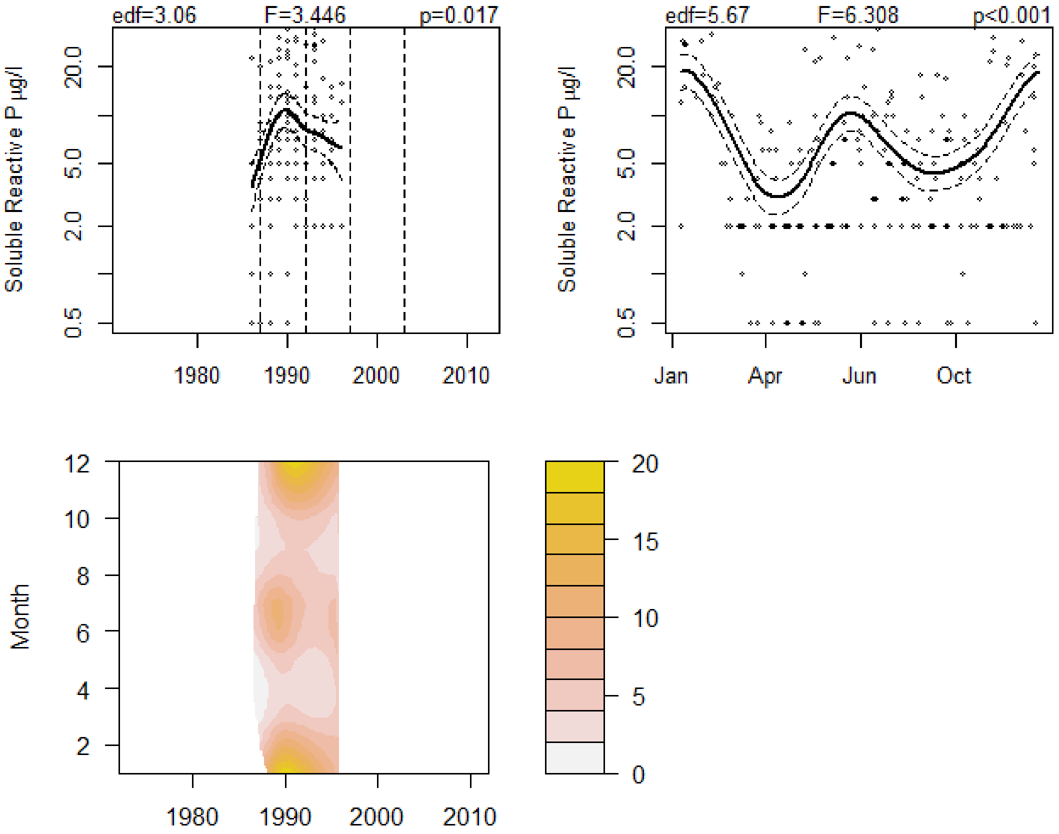


Figure 23 Changes in SRP for Hoveton Great Broad: a) Long term trend (Annual); b) Seasonal trend ; c) contour plot showing changes in seasonality with time. (Trends extracted using mixed GAM model, contour plot using GAM model)

4.3 Total Oxidised Nitrogen (TON)

There is relatively limited data for TON in Hoveton Great Broad (Figure 24), but there is no evidence of significant change (Mann Kendall tau = -0.055 p=0.413). The concentration in the broad is substantially lower than in the river upstream of the broad (sites at Wroxham and d/s of Wroxham Broad) but follows a very similar pattern which is clearly linked to river discharge. Peaks of TON occur with peaks of river discharge. The river down steam of Hoveton Great Broad (at Horning Ferry) has lower TON than the river upstream but the concentrations are higher than they are in Hoveton Broad demonstrating that the river primarily flows past Hoveton Great Broad and not directly through it. Over the last decade there has been a slight reduction in TON in the river which is just significant (Mann Kendall tau = -0.467 p=0.037). Current concentrations in the broad are similar to those measured in the 1990s with a median concentration over the whole period of monitoring of 1.2 mgl^{-1}.

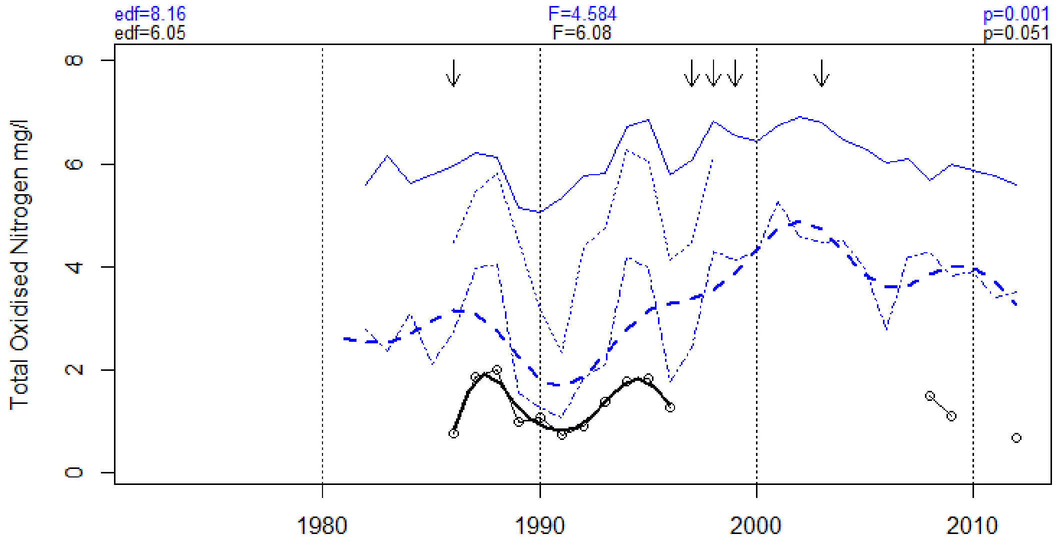


Figure 24 Trend in annual mean TON for Hoveton Great Broad (solid black line) compared with trends in River Bure at Wroxham (solid blue line), d/s Wroxham Broad (dotted blue line) and Horning Ferry (broken blue line), showing GAM smoothers for Hoveton Great Broad and river at Horning Ferry. Arrows lines mark key events,

The seasonal pattern of TON is similar to other broads with maximum values in February/March which decline to low values by June (Figure 25b & c). The rate of decline is lower than in some other broads and reflects the higher winter TON values (median winter average 3.1 mgL^{-1}) in Hoveton Great Broad and the continued supply of TON from the river. Winter TON, may also have declined, although there are too few recent data to test this statistically (Figure 26).

The ratio of SRP to TON was lowest during the particularly low flow period in 1990 (Figure 27). However, the ratio remains above 10 for the whole growing season and thus nitrogen is unlikely to become limiting (Figure 28).

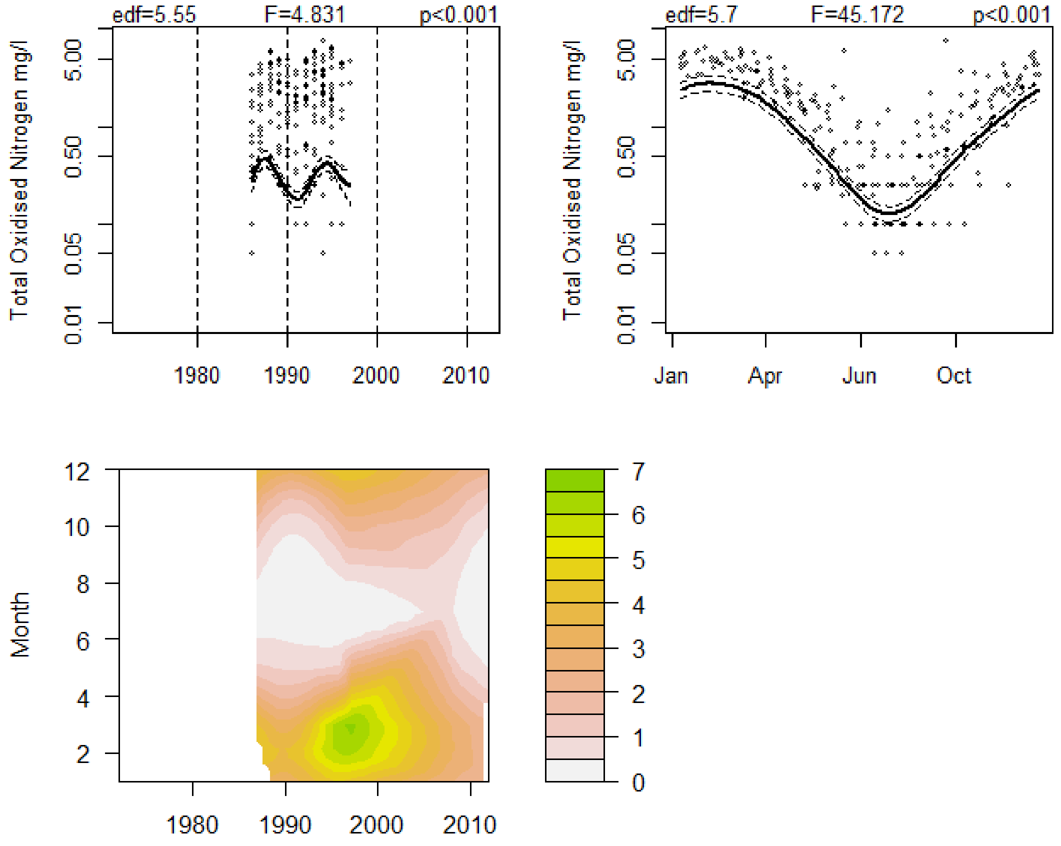


Figure 25 Changes in TON for Hoveton Great Broad: a) Long term trend (Annual); b) Seasonal trend; c) contour plot showing changes in seasonality with time. (Trends extracted using Mixed GAM model, contour plot using GAM model)

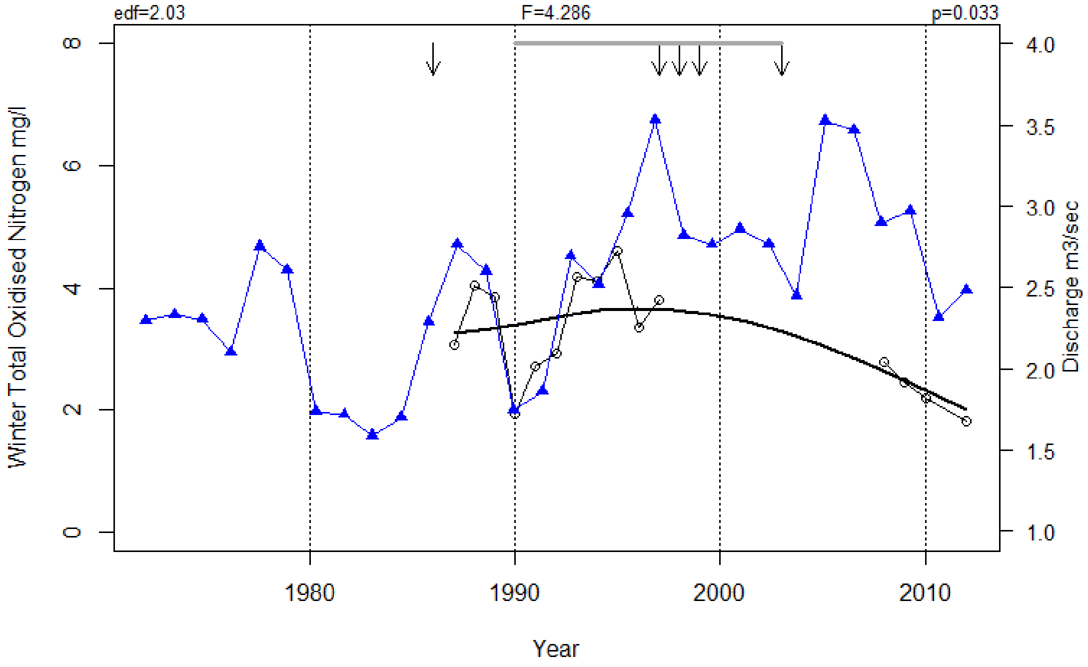


Figure 26 Trend in winter (Nov-Feb) mean TON for Hoveton Great Broad (solid black line) compared to river discharge (blue line), showing GAM smoother for TON. Arrows mark key events.

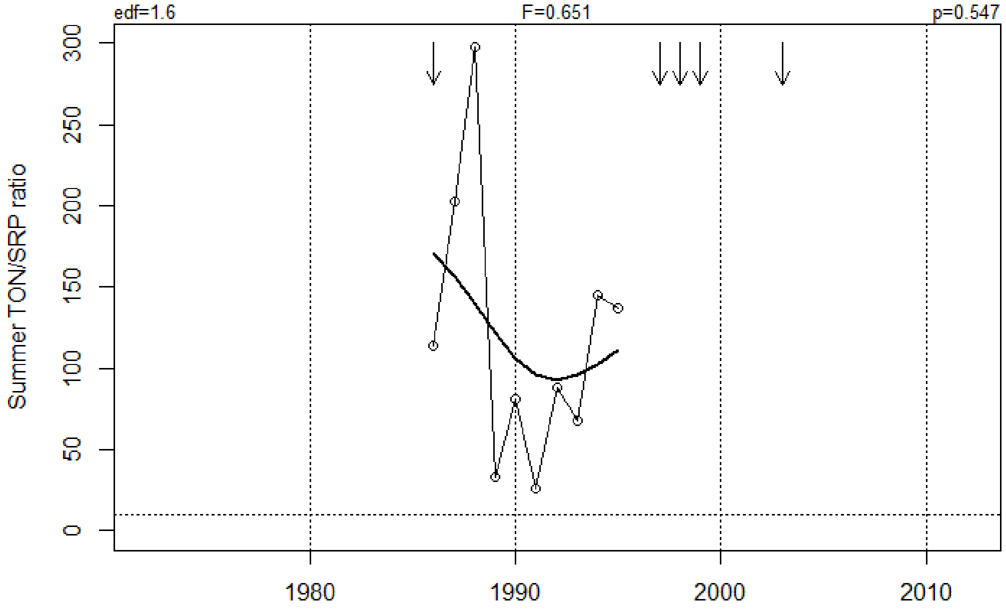


Figure 27 Trend in ratio of summer mean TON/SRP in Hoveton Great Broad. Horizontal line marks Redfield ratio (10.0). Arrows mark key events.

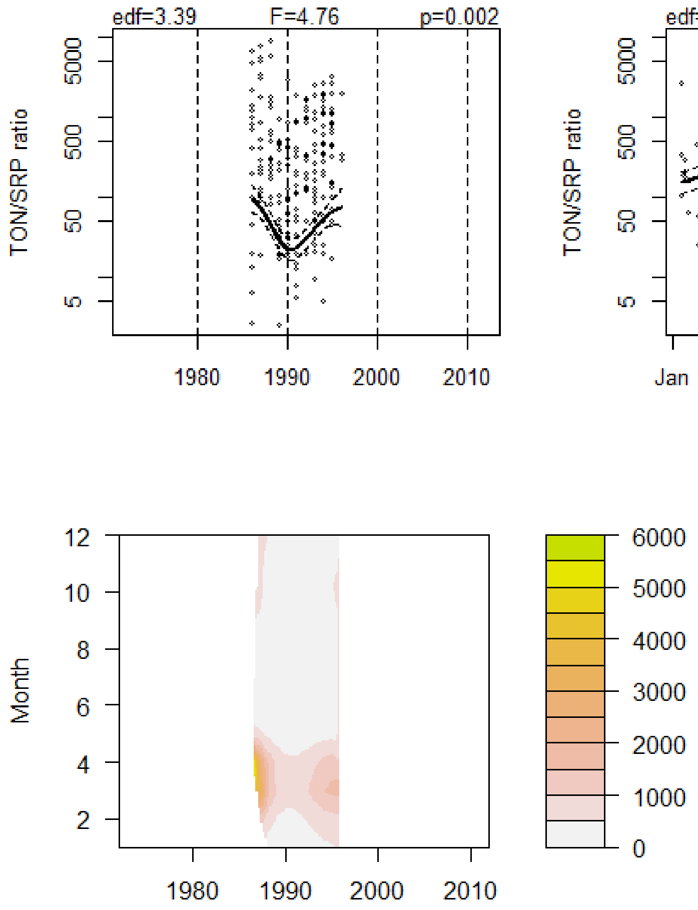


Figure 28 Changes in ratio of SRP/TON ratio for Hoveton Great Broad: a)Long-term trend (Annual); b)Seasonal trend; c)contour plot showing changes in seasonality with time. (Trends extracted using mixed GAM model, contour plot using bivariate GAM model)

4.4 Chloride

Chloride concentrations in Hoveton Great Broad would normally be low as the broad is in the upper reaches of the tidal River Bure. However, during the period of monitoring in the early 1990s river flows were particularly low and in combination with a series of winter surge tide events this resulted in elevated chloride levels in the Broad during 1990 and 1991 (Figure 29). Levels were not particularly high, even during the surge events (see scatter in Figure 30b) and apart from these events Hoveton Great Broad has minimal seasonal change in Chloride. However, the relatively long time period (3 years) suggests that flushing rates in the broad are slow, at least in lower flow years.

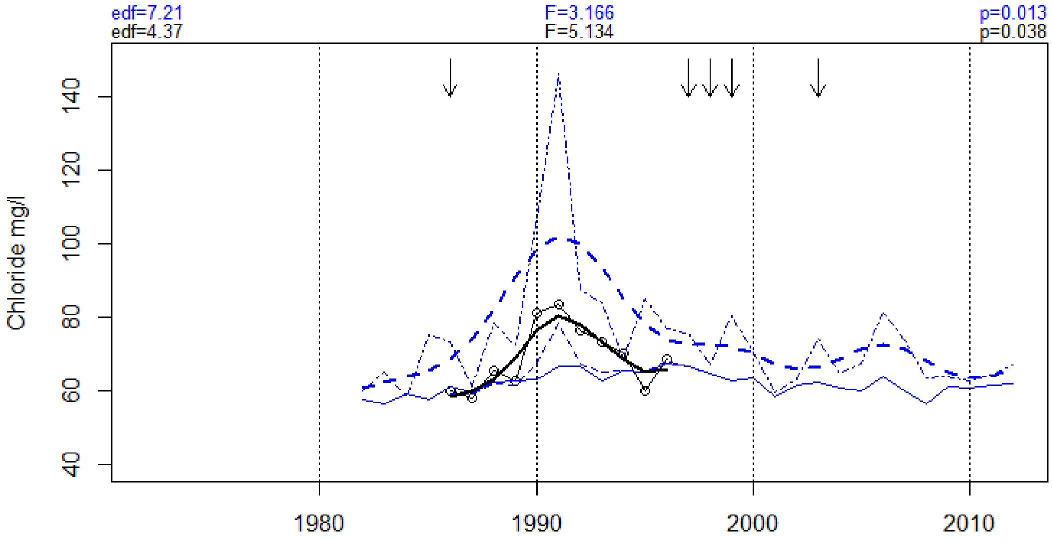


Figure 29 Trend in annual mean chloride for Hoveton Great Broad (solid black line) compared to trends in River Bure at Wroxham (solid blue line),d/s Wroxham Broad (dotted blue line) and Horning Ferry (broken blue line), showing GAM smoothers for Hoveton Great Broad and river at Horning Ferry. Arrows mark key events.

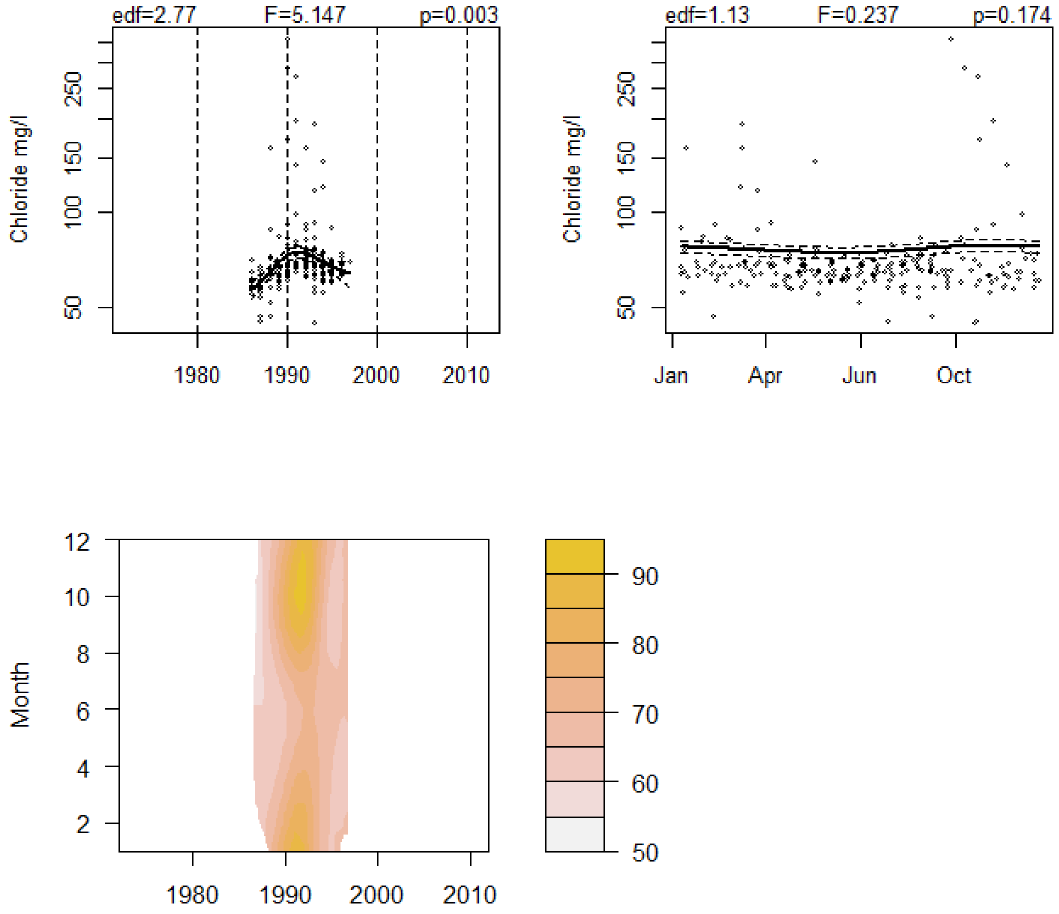


Figure 30 Changes in chloride for Hoveton Great Broad: a) Long term trend (Annual); b) Seasonal trend (Julian Days); c) contour plot showing changes in seasonality with time. (Trends extracted using GAM model, contour plot using GAM model).

4.5 Chlorophyll a

Annual mean chlorophyll concentration in Hoveton Great Broad has reduced substantially (Mann Kendall tau = -0.615 p=0.002), most of the change occurring in the early 1990s. As for total phosphorus, recent values are slightly higher than the lowest values recorded in 1993 and 1994 (Figure 31). The median for the last decade is 44 µgl^{-1} which would place the broad in Poor status, although close to the Poor/Moderate boundary, under the WFD.

Chlorophyll levels in the River Bure just downstream of the broad and several kilometres downstream at Horning Ferry (Figure 30) are similar to those in the broad demonstrating that this section of the tidal River Bure is effectively a long linear lake, at least during periods of lower flow when the bulk of the Hoveton Great Broad monitoring was undertaken. Over the last decade the chlorophyll level in the river at Horning Ferry has only decreased very slightly and this change is not statistically significant (Mann Kendall tau = -0.333 p=0.110).

Within the fish exclosure chlorophyll levels were lower than those in the broad, particularly during 1992 when large cladocera dominated the zooplankton during the whole of the summer period (Stansfield et al 1999). However, it was difficult to prevent fish from entering the exclosure due to tidal overtopping and by 1994 chlorophyll levels in the exclosure were only marginally lower than they were in the main broad.

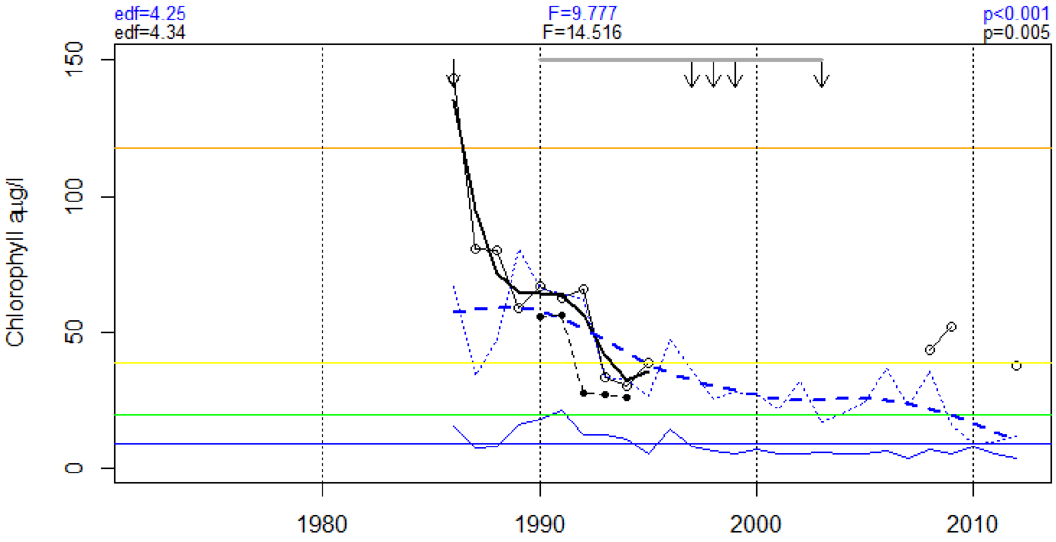


Figure 31 Trend in annual mean chlorophyll a for Hoveton Great Broad (solid black line), compared to trend in River Bure at Wroxham (solid blue line), and Horning Ferry (dotted blue line) and in fish exclosure (dotted black line, black dots), showing GAM smoothers for Hoveton Great Broad and river at Horning Ferry. Arrows lines mark key events, grey line period of fish exclosure.

The seasonal cycle of chlorophyll in Hoveton Great Broad is similar to other broads with connections to the main river. There is a spring phytoplankton peak in April, followed by a clear water period during May before a much larger summer peak in late August or September (Figure 32). Although the general pattern remains similar, the magnitude of the summer peak has reduced substantially when compared to levels prior to 1990, while the spring peak remains unchanged (Figure 33). It is likely that at least part of this change is related to the particularly low river flows in 1989 and the generally lower flows prior to this, although the much higher summer phosphorus levels would also have contributed to the differences.

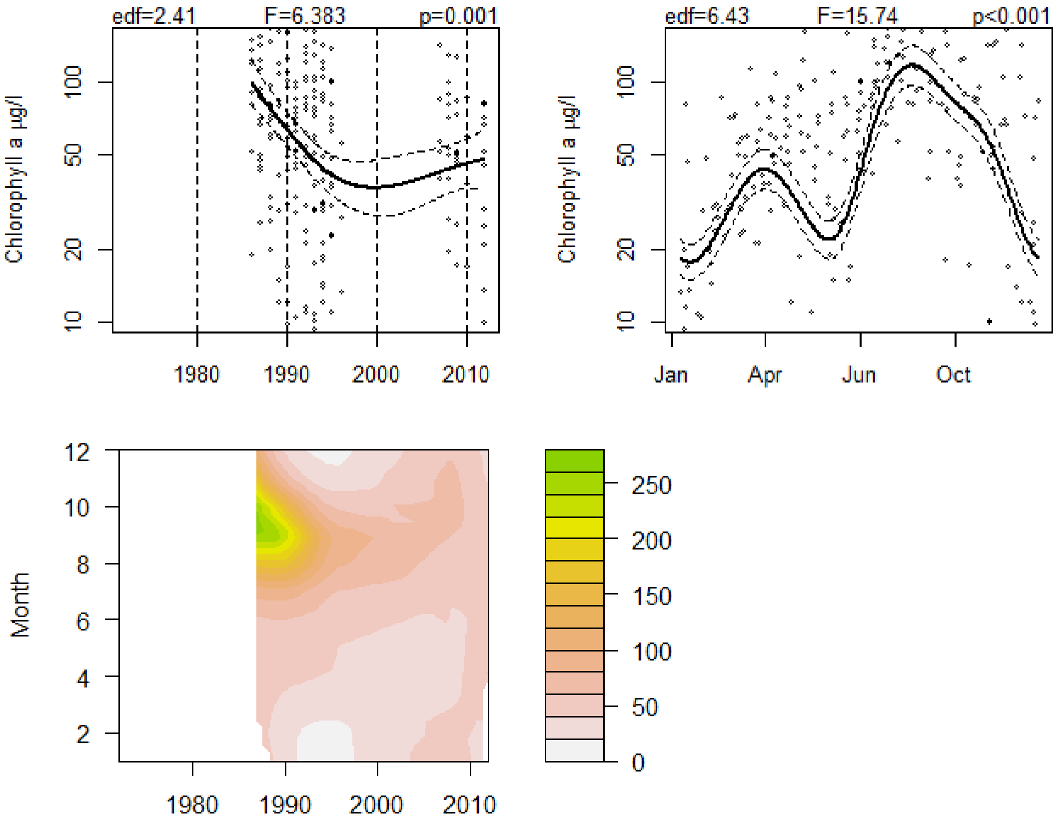


Figure 32 Changes in Chlorophyll a for Hoveton Great Broad: a) Long term trend (Annual); b) Seasonal trend c) contour plot showing changes in seasonality with time. (Trends extracted using Mixed GAM model, contour plot using GAM model)

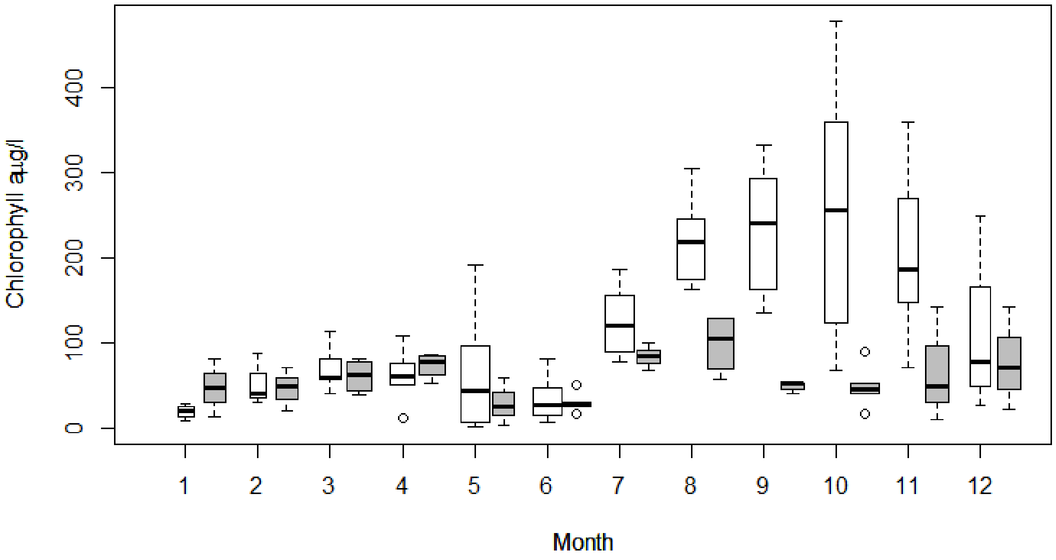


Figure 33 Comparison of monthly range of Chlorophyll a in Hoveton Great Broad for last decade (open bars) with those prior to 1990 (grey bars). Bar width proportional to number of samples.

4.6 Chlorophyll a:Total Phosphorus ratio

The ratio of chlorophyll to total phosphorus declined during the monitoring period and with the exception of 1991 was lower in the fish exclosure than in the broad (Figure 34. During 1993 and 1994 values in the broad were close to or below 0.4, suggesting zooplankton grazing or other factors such as flushing may have reduced phytoplankton growth. However, more recent values are above this threshold and thus there are no indications of any top-down control of phytoplankton growth in Hoveton Great Broad.

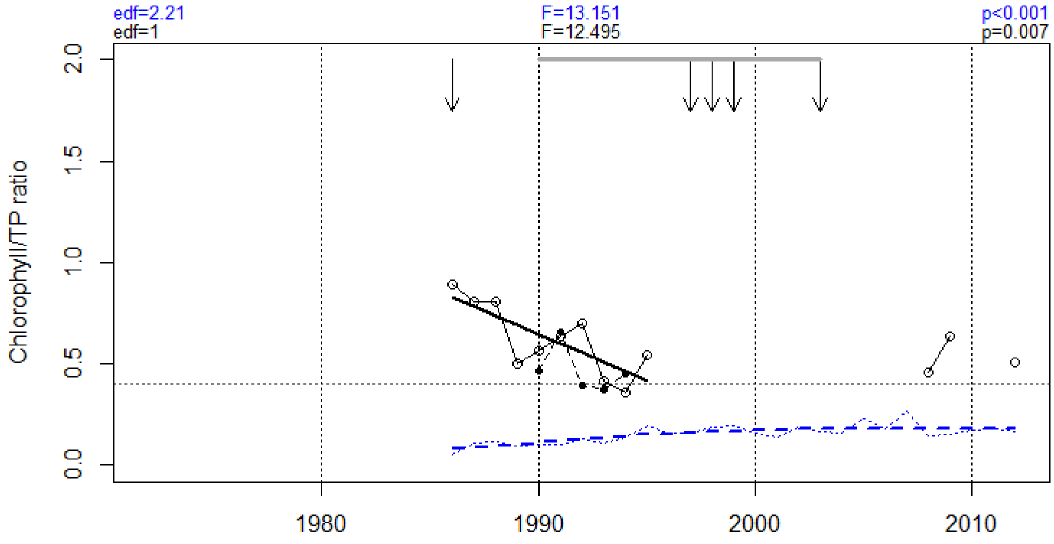


Figure 34 Trend in annual mean chlorophyll a/TP ratio for Hoveton Great Broad (solid black line) compared to trend in River Bure d/s Wroxham Broad (dotted blue line) and fish exclosure (dotted black line, black solid circles) showing GAM smoothers for Hoveton Great Broad and river d/s Wroxham Broad. Arrows and line mark key events.

4.7 Secchi Depth

Secchi depth values increased in the broad (Figure 35), as would be expected given the significant reduction in chlorophyll concentration and the good relationship between chlorophyll and Secchi depth (Figure 36). The latter relationship indicates that the chlorophyll-Secchi depth relationship in Hoveton is typical of the Broads as a whole.

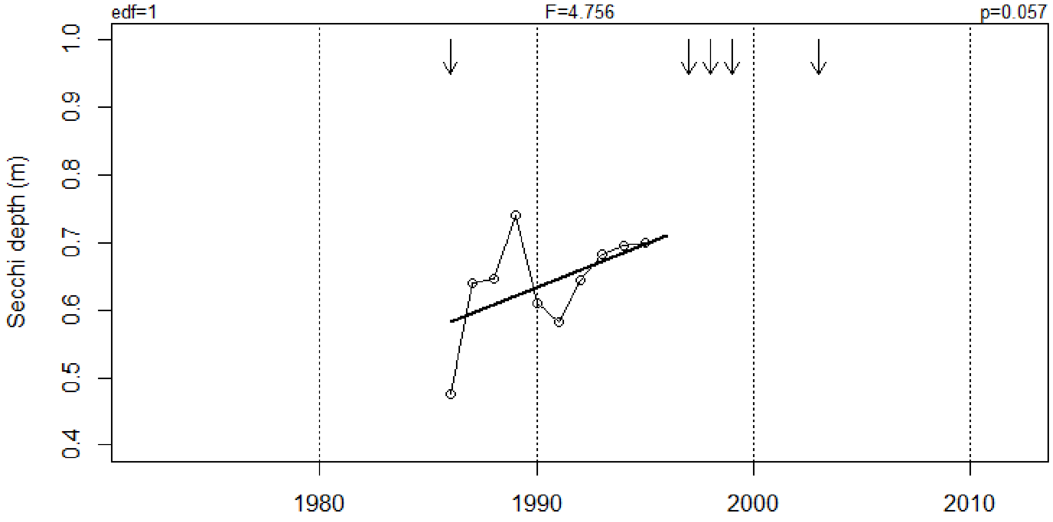


Figure 35 Trend in annual mean Secchi depth for Hoveton Great Broad (sold black line) showing GAM smoother. Arrows mark key events.

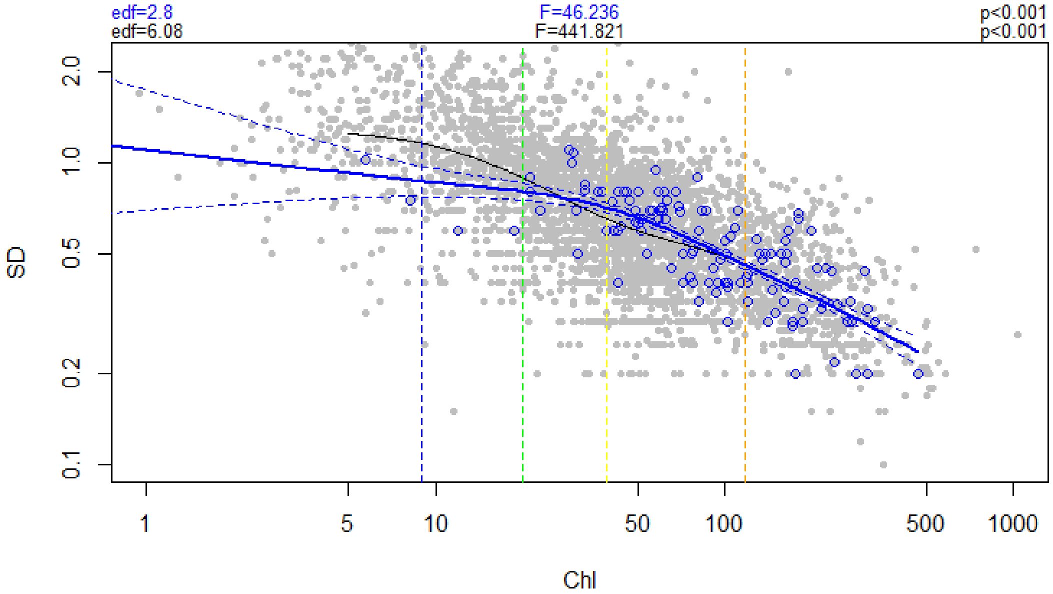


Figure 36 Relationship between water transparency (Secchi depth) and chlorophyll a in Hoveton Great Broad. Lines show GAM smoothers for all broads (black) and for Hoveton Great (blue). (Data shown are only for samples where secchi depth is < water depth).

5 Sediment chemistry

5.4 Review of available data on sediment P and P release

Available data on sediment P from 1993 were originally reported by Pitt et al. (1997) Sediment TP data from 1993 were produced from analysis of sediment slurries collected at 1 cm intervals to 12 cm sediment depth. Data on pore water chemistry and associated estimates of sediment P release from cores collected between April and September 1989 used in this report were originally reported by Jackson (1991). Recent data on sediment TP concentrations (2013) were provided by the Broads Authority (Andrea Kelly, 16th September 2013). Recent data included values from sediment slurries across three sediment depth ranges (0 cm to 3 cm; 9 cm to 11 cm; and 19 cm to 21 cm).

5.5 Review of historical data (i.e. pre 2012)

Between April and September 1989, estimates of P flux (n = 4 dates) from sediments of Hoveton Great Broad ranged from 1.4 mg P m^{-2} d^{-1} to 26.6 mg P m^{-2} d^{-1} (Jackson 1991). During the same sample period, significant variation in pore water SRP and Fe^{2+} concentrations were reported with sediment depth indicating variation in P release processes, perhaps due to changes in redox potentials. In general, concentrations of both SRP and Fe^{2+} increased with decreasing sediment depth to about 2 cm to 3 cm sediment depth. Maximum concentrations of SRP in the upper 12 cm of sediment across the 4 sample dates ranged from around 0.15 mg L^{-1} to 2.48 mg L^{-1}. For Fe^{2+}, maximum concentrations ranged between 1.95 mg L^{-1} and 5.25 mg L^{-1}.

Sediment P composition varied with depth and between April and October 1993 ((Pitt et al. 1997); p21; Figure 1.7). In April 1993, TP concentrations decreased gradually (from in upper 1 cm) from 1 cm (about 1.4 mg TP g^{-1} dw) sediment depth to about 10 cm sediment depth (about 0.7 mg TP g^{-1} dw). In October, sediment TP concentrations increased from 1 cm sediment depth (1.4 mg TP g^{-1} dw) to 2 cm sediment depth (about 1.6 mg TP g^{-1} dw) before gradually decreasing towards 11 cm sediment depth (1.0 mg TP g^{-1} dw). Pitt et al. (1997) attribute the increase in organic sediment P, the main pool responsible for variation in sediment TP between the two sample dates, to an increased load of particulate organic P from the water column following summer phytoplankton growth. However, it is unlikely that variation in water column conditions between the two sample dates will have impacted on an increase in sediment P concentrations at 10 cm depth, perhaps with the exception of bioturbation by macroinvertebrates acting to homogenise upper sediments to these depths. The average TP concentration across the upper 10 cm of sediment was reported as 1.02 mg TP g^{-1} dw in 1993 (Pitt et al., 1997).

5.6 Current baseline sediment phosphorus

Variation in sediment TP concentrations with sediment depth in 2013 up to 21 cm is shown (Figure 37). The average TP concentration across the upper 21 cm of sediment was 0.66 mg TP g^{-1} dw in 2013. It should be noted that the sampling methods employed in 2013 were different to those employed in 1993 in that different sediment sections were collected for analysis across the two sample periods. If we consider the TP concentration across the upper 11 cm of sediment sampled in 2013 (i.e. from 0cm - 3cm and 9 cm - 11 cm slurries) then the mean value is 0.79 mg TP g^{-1} dw, and for the surface sediment layer, only, the mean is 1.03 mg TP g^{-1} dw in 2013. Taken collectively, these recent data suggest a drop in sediment TP concentration in Hoveton Great Broad between 1993 and 2013, and that this decrease has been manifest within the upper sediment layers.

In the context of recommendations made by Sas (1989) the reported decrease in sediment TP concentrations between 1993 and 2013 indicate a shift in the internal loading potential in the broad. In 1993, concentrations indicated moderate internal loading potential with recovery following significant reduction in catchment P loading being likely within 5 years. However, the lower sediment TP concentrations reported in 2013 indicate that recovery would be rapid following any further catchment management.

The relationship between sediment TP concentration and sediment depth is shown (Figure 37) and indicates a gradual decrease in sediment TP concentration with increasing sediment depth up to about 15 cm to 20 cm. This relationship is commonly reported in lakes suffering from elevated catchment P loading as described by Carey and Rydin (2011). The gradient of the slope in the relationship between $\log_e$ sediment TP and sediment depth can be used to estimate the potential for sediment P release following reduction of catchment P loading where a strongly negative slopes indicate the strongest P release potential. The slope for Hoveton Great Broad across the upper 20 cm of sediment in 2013 was – 0.023. Similar relationships calculated using data from 96 lakes ranging in TP concentrations from 3 to 1162 µg TP L^{-1} indicate that TP accumulation in the upper 20 cm of sediment in Hoveton Great Broad is similar to other moderately eutrophic lakes.

There is some degree of discrepancy between the indications for internal loading based on interpretation of water and sediment chemistry. It seems fairly unequivocal from both sediment and water chemistry that during the 1990s P release from sediments was occurring during the summer on a regular basis. The limited available water chemistry data from 2008 suggest this pattern is reduced but likely to still be continuing whereas the 2013 sediment chemistry seems to imply limited potential for internal loading. The comparison of surface sediment P between 1993 and 2013 suggests that internal loading potential has reduced.

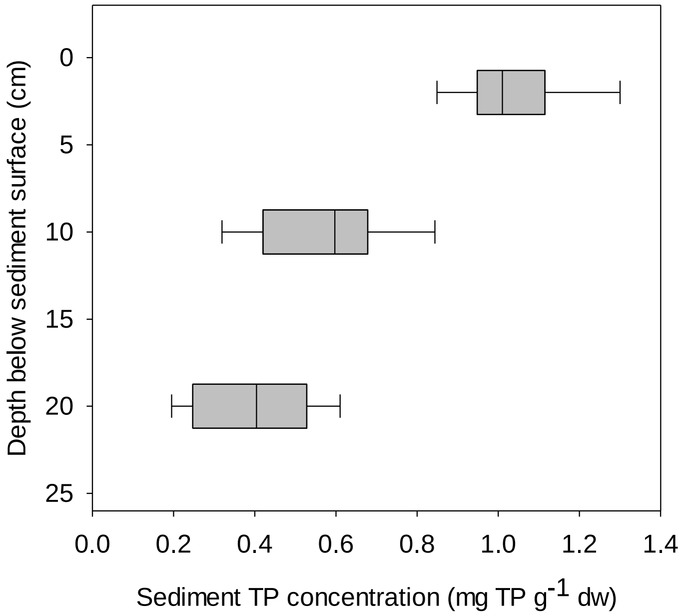


Figure 37 Variation in sediment TP concentration with sediment depth in Hoveton Great Broad in 2013. Sediment samples were collected from 0 cm to 3 cm; 9 cm to 11 cm and 19 to 21 cm sediment depth ranges.

6 Macrophytes

6.1 Cover: macrophytes and algae

Cover is low over the duration of monitoring in Hoveton Great Broad, with only two years, 1998 and 2000, showing more extensive cover (Figure 38). Plant cover increases from the mid-1980s to reach a stable value of ~10% by 2000. This overall pattern mirrors the decline in TP in both Hoveton Little and Hoveton Great Broads over the same period

Filamentous alga cover is perennially low, although it exhibits higher spikes at approximately 10-year intervals from 1991 onwards (Figure 39). Whether these spikes have any environmental basis is unclear due to the lack of data, and nothing obvious connects these years climatically. The increased algal cover in 2000 was coincident with an increase in cover of *Ceratophyllum* suggesting that much of the recorded algal cover was epiphytic. In principle the sudden changes in cover might suggest phases of reduced grazing control by snails. In 2010 the exceptionally cold winter may have promoted algal cover by delaying the onset of snail grazing. While algal cover is low in global terms it should be noted that within Hoveton Great Broad it represents a significant proportion, indeed occasionally the majority of total plant cover

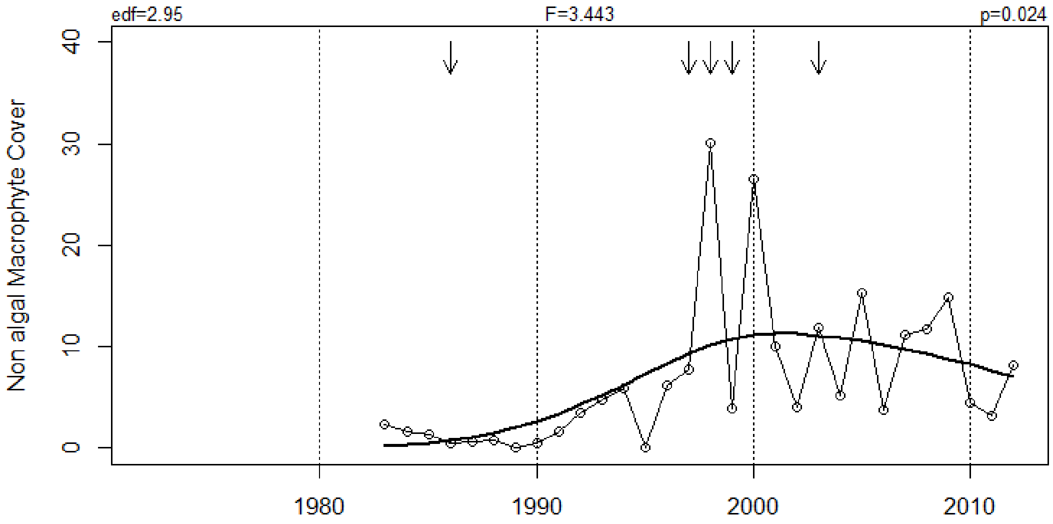


Figure 38 Trend in cover of non-algal macrophytes for Hoveton Great Broad (solid black line), showing GAM smoother. Vertical lines mark key events.

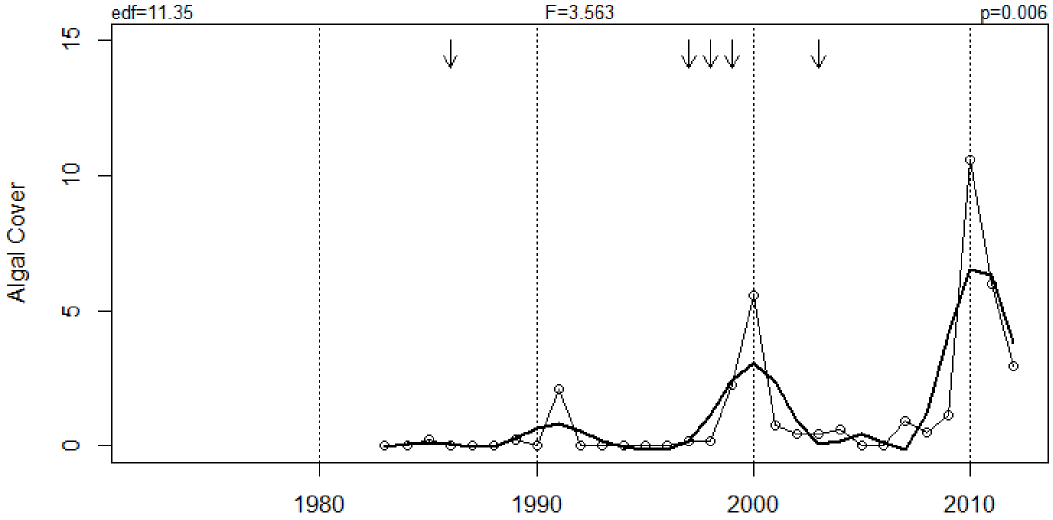


Figure 39 Trend in algal macrophytes cover for Hoveton Great Broad (solid black line), showing GAM smoother. Vertical lines mark key events.

6.2 Species richness

There has been a significant general increase in plant richness from 3 to 5 species over the last 30 years, with a recorded maxima of 6 species (Figure 40). There is a basic core of *Ceratophyllum*, *Potamogeton pectinatus* plus isolated patches of *Nymphaea alba* and

Nuphar lutea, that have been increasingly joined by species such as *Zannichellia*, *Potamogeton crispus* and *Elodea nuttallii* (Figure 41), although in all cases the latter species only occur at very low cover.

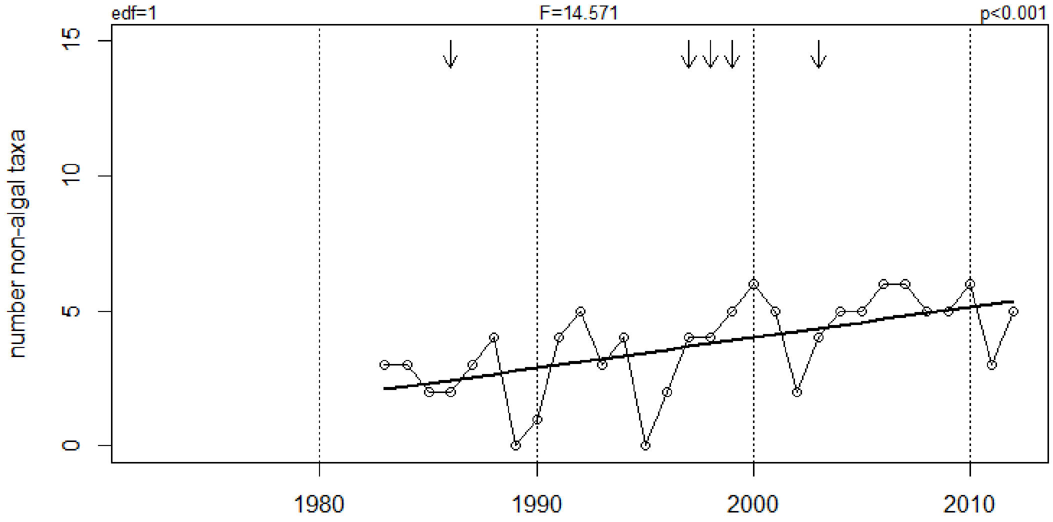


Figure 40 Trend in macrophyte species richness for Hoveton Great Broad (solid black line), showing GAM smoother. Arrows and lines mark key events.

6.3 Compositional change (Major growth forms; Change Index and LMNI)

Compositionally, in terms of summary indices (Figure 41 and Figure 43), Hoveton Great Broad has shown no directional change over the last 30 years and both the Change Index and LMNI imply a significant departure from the historic baseline.

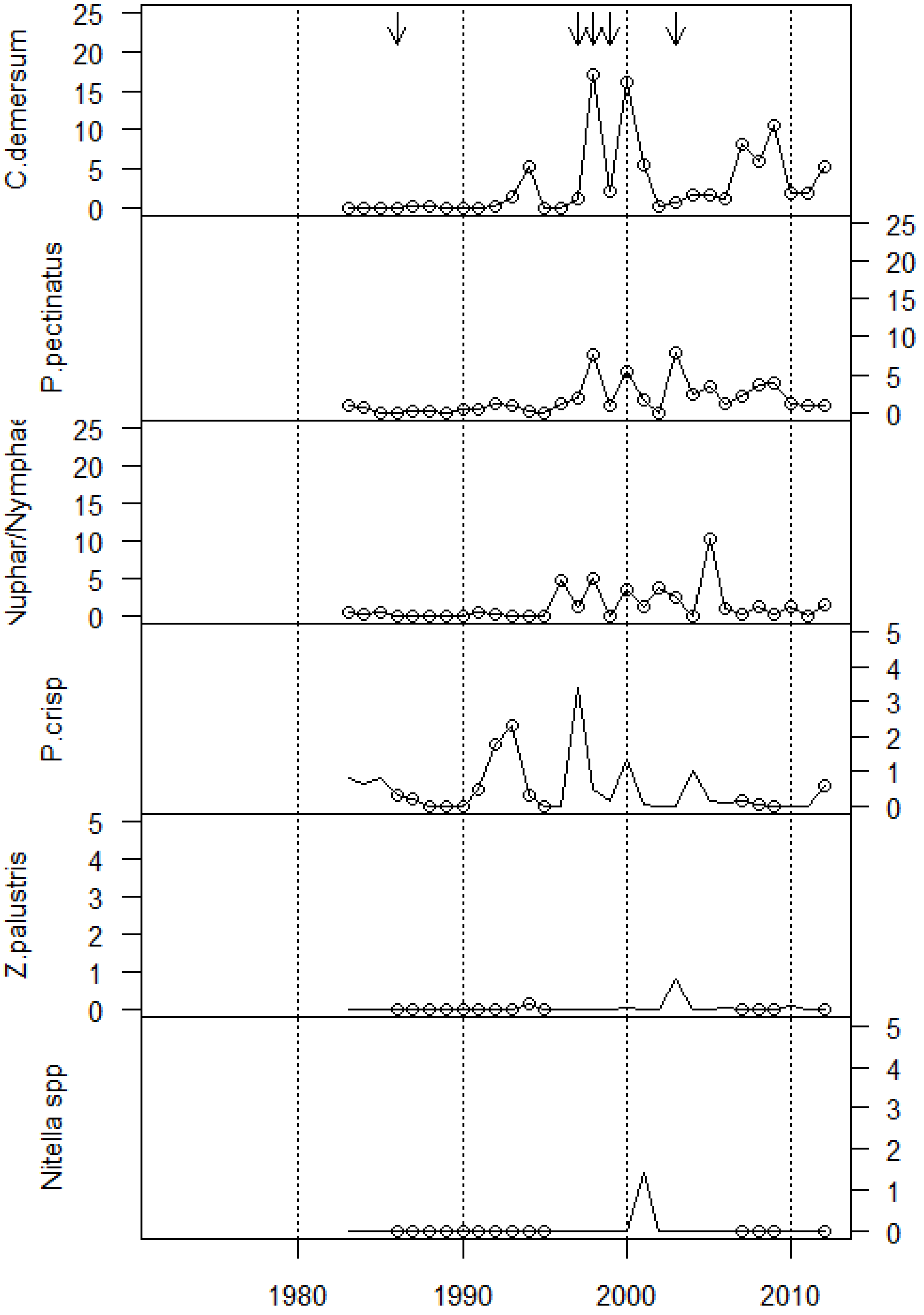


Figure 41 Trend in macrophyte species in Hoveton Great Broad. Vertical lines mark key management events.

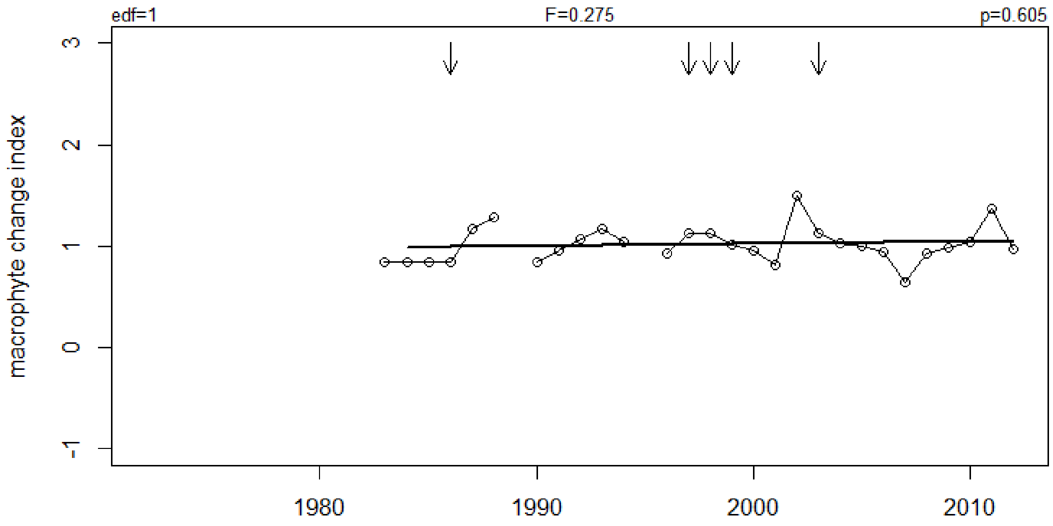


Figure 42 Trend in macrophyte Change Index for Hoveton Great Broad (solid black line), showing GAM smoother. Vertical lines mark key events.

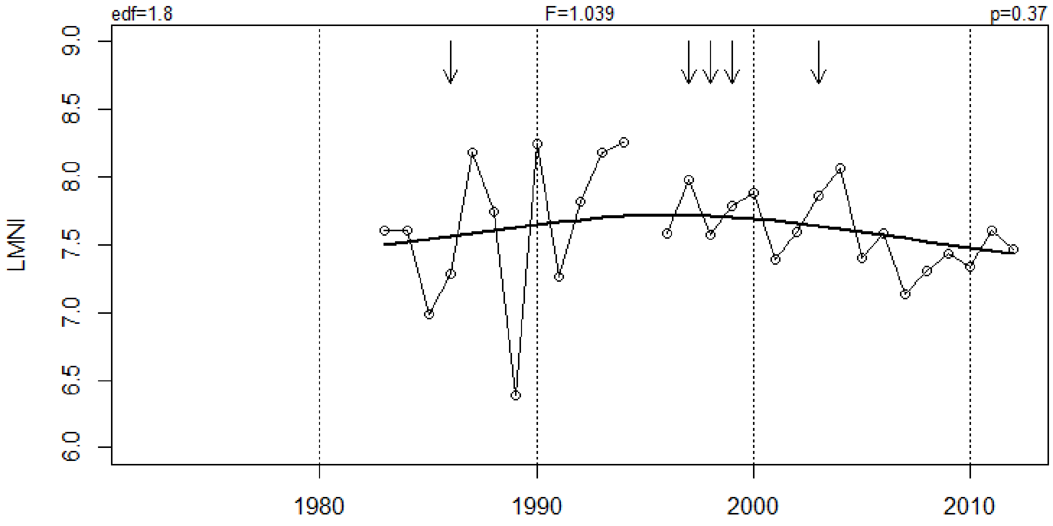


Figure 43 Trend in lake macrophyte nutrient index (LMNI) for Hoveton Great Broad (solid black line), showing GAM smoother. Vertical lines mark key events.

7 Fish

7.1 Abundance and composition

The Hoveton Great Broad system, including the main broad, Hudson's Bay and Hoveton Hall Marshes, was surveyed by PASE in December 1999 by ECON. The survey revealed that nine species were present within the system. In order of abundance, these were: Roach, Perch, European eel, Common bream, Gudgeon, Pike, Ruffe, Roach x bream hybrid and Rudd. In the main broad, six of these were present (Roach, European eel, Gudgeon, Perch, Pike and hybrid), eight were present within Hudson's Bay (Hybrids were not captured) and the Marshes (Rudd was absent).

The capture of these fish in the combined system resulted in abundance and biomass estimates of 0.14 ind. m^{-2} and 5.68 g m^{-2} respectively. Few fish were present within the main broad (0.01 ind. m^{-2}). The highest abundance estimate was recorded in the surveyed dykes within the Hoveton Marshes (1.35 ind. m^{-2}). The overall density estimates were considered low, particularly given the eutrophic nature of the broad at the time of surveying. Moreover, the dyke systems within the Marshes may support large aggregations of fish (e.g. dykes within the Trinity system regularly support densities >10 ind. m^{-2}), thus it was surmised that part of the fish community, particularly Roach and Common bream, over-wintered away from the immediate system. It is possible that the fish used the riverine connection to refuge in other suitable habitats such as boatyards in nearby locations such as Wroxham and Horning. This theory was supported by the presence of predominantly young-of-the-year (YOY) Roach (31 – 58 mm in fork length) within the Marshes, the entrance dyke and the small dyke in the northwest of Hudson's Bay. A small proportion of 1+ Roach (67 – 86 mm) were also captured in these habitats but no fish of older age classes. The generally poor growth rate of the cyprinid species was also indicative of greater densities and resulting in greater competition for resources. The general absence of YOY Common bream within the system, despite the presence of adult fish (see below), suggested these fish were also elsewhere. Whilst particularly poor recruitment could have been a factor, this would point to a lower than average overall abundance estimate for the species, thus affecting the overall estimate.

The capture of an adult Common bream (and observation of a shoal) in Hudson's Bay was clear evidence of their presence in the system. The estimated biomass for adult fish alone within Hudson's Bay was 25.7 g m^{-2}, or 257 kg ha^{-1} and 3.9 g m^{-2} (39 kg ha^{-1}) for the whole system. These densities would equate to c.650 adult fish in the system, whereas a typical value of 100 kg ha-1 for a eutrophic broad, based on the weight of the individual captured would equate to an adult population of c. 1,500.

7.2 Fish feeding guild changes

The composition of the fish community as derived from feeding guilds for the Hoveton Great Broad system is typical of a eutrophic broad. Zooplanktivorous fish dominated the system by number, representing 93% of the overall abundance estimate, whereas benthivores dominated by biomass (68%), with piscivorous Pike and European eel contributing 29% to the overall biomass total.

8 Water birds

Count data were available for Hoveton Great Broad only for October - March in the period autumn 1999 to spring 2008. Gadwall is the dominant water bird species with typical winter peaks of 100-300 birds. Numbers have remained stable over the count period and in some years have reached the threshold for national importance. The broad also supports winter peaks of typically 70-100 Tufted Duck. Along with the less numerous Pochard, diving duck numbers have remained stable. Hoveton also supports modest winter numbers (peaks of 20-30 birds) of Great Crested Grebe, although their numbers, along with those of coot, have shown a general decline over the 10 year period for which data was available. Numbers of dabbling duck (Mallard, Teal, Shoveller) have also tended to decrease. Unlike many other broads the numbers of feral geese are low.

9 Summary of interactions

9.1 Macrophytes and Chlorophyll

Chlorophyll dictates the light climate for plant growth and not surprisingly chlorophyll and macrophyte cover are tightly coupled in Hoveton Great Broad, with observed chlorophyll being at the upper end of that recorded for the broads as a whole, and recorded macrophyte cover being correspondingly very low (Figure 44).

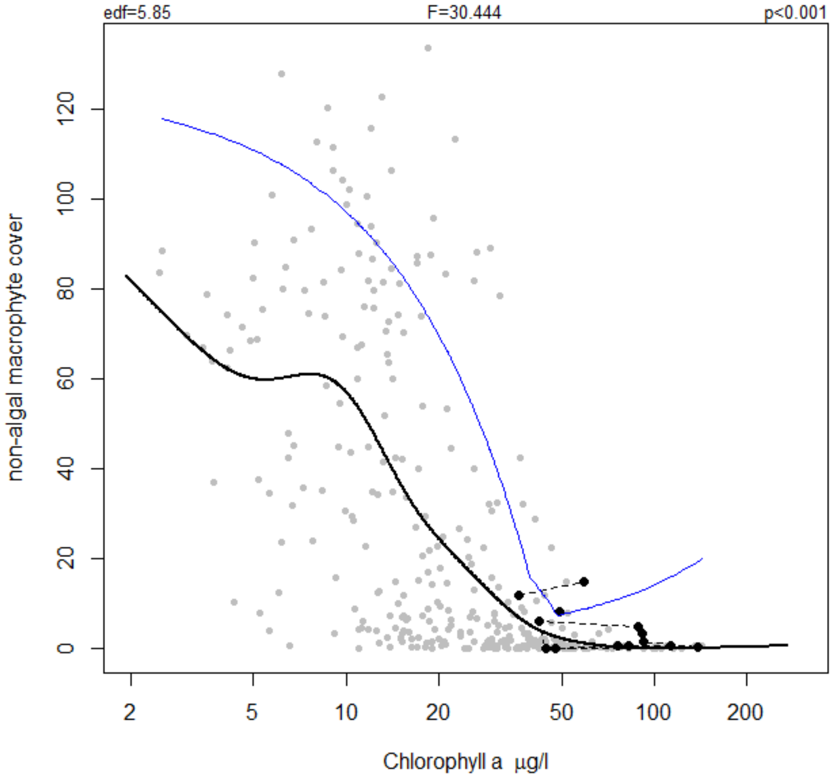


Figure 44 Relationship between non-algal macrophye cover and mean chlorophyll a, showing trajectory of change in Hoveton Great Broad. Grey points mark values for all other broads. Blue line represents 90th%tile of a quantile regression.

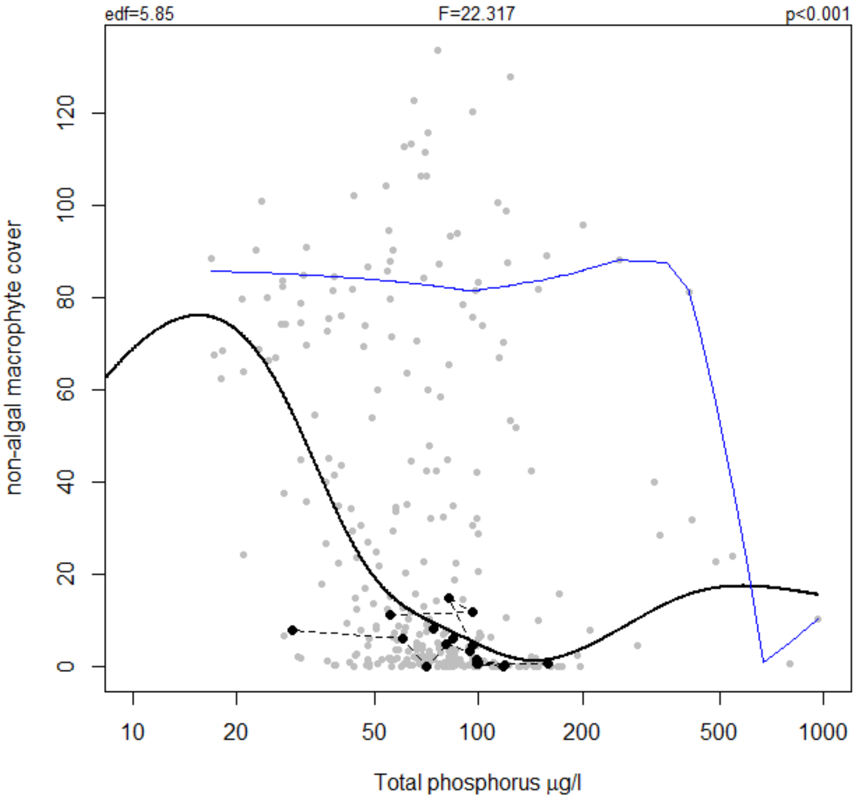


Figure 45 Relationship between non-algal macrophye cover and total phosphorus, showing trajectory of change in Hoveton Great Broad. Grey points mark values for all other broads. Blue line represents 90th%tile of a quantile regression.

9.2 Chlorophyll v TP

In the absence of any significant top down control chlorophyll yields are high per unit TP putting them at the upper limits of a global chlorophyll-TP relationship. If it is impossible to restore top down control as a means of promoting macrophyte re-establishment this relationship implies that TP needs to still reduced significant to achieve chlorophyll levels that will afford a suitable light climate for macrophyte growth. It is evident from Figure 46 that Hoveton Great Broad supports chlorophyll levels that are high on a cross-broad scale.

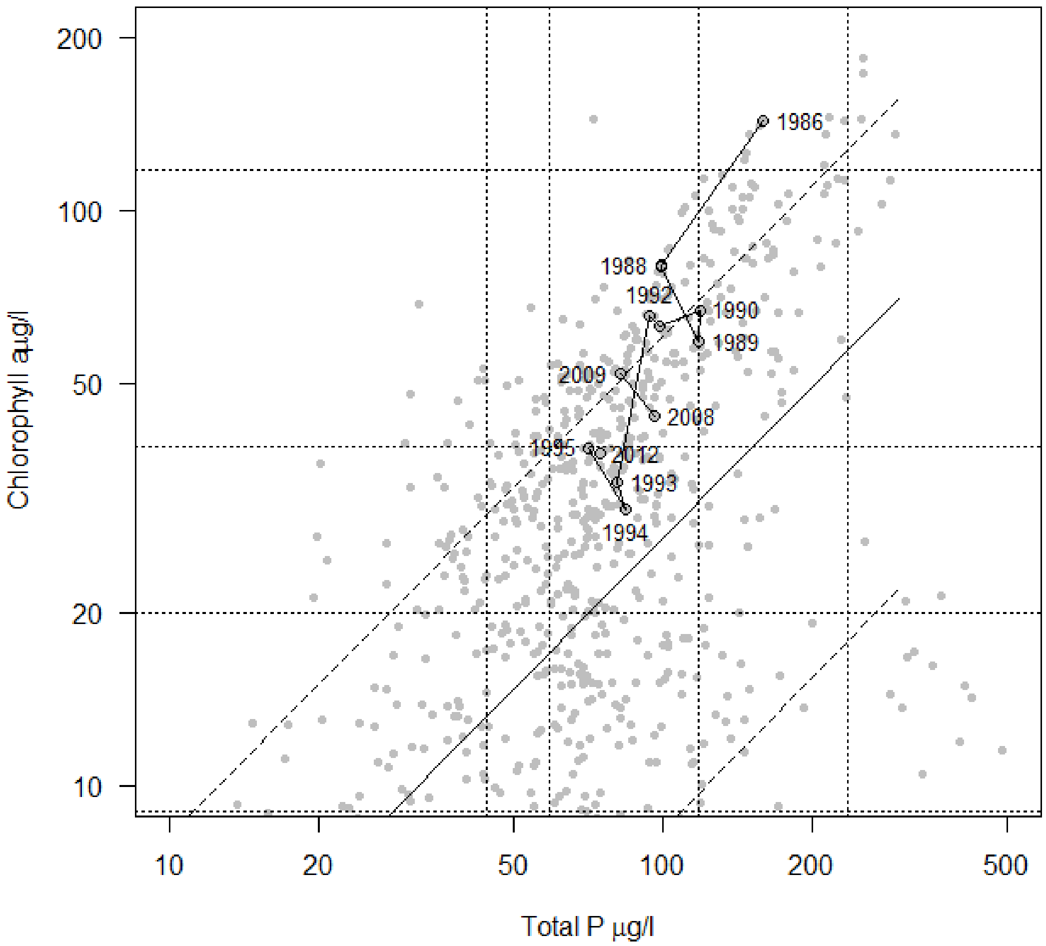


Figure 46 Relationship between annual mean chlorophyll a and total phosphorus, showing trajectory of change in Hoveton Great Broad Grey points mark values for all other broads, horizontal and vertical dotted lines show WFD boundary values, diagonal dotted lines show relationship for European lakes (Phillips et al. 2008).

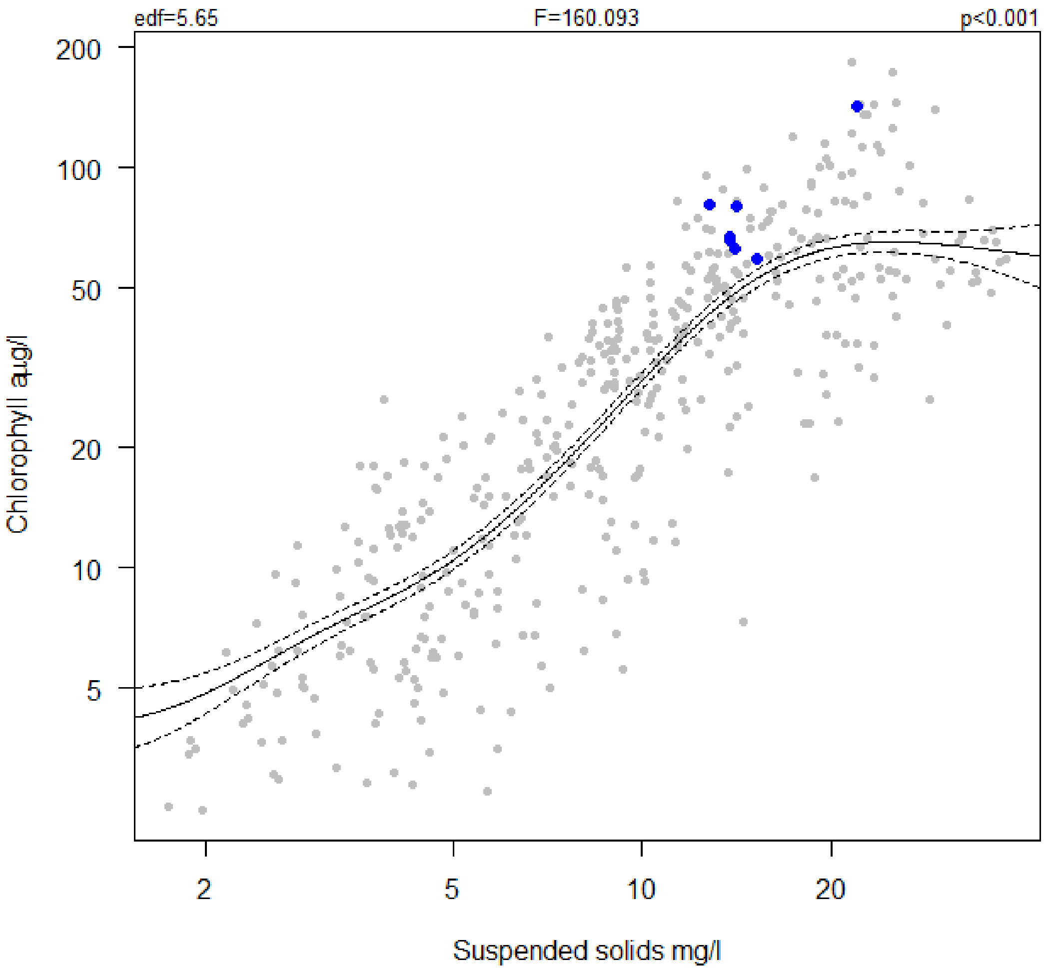


Figure 47 Relationship between chlorophyll concentration and suspended solids in Hoveton Great Broad. Grey points mark values for all other broads.

10 Evidence of overall system response to management

No evidence of sustained response to within-broad management initiatives, although there is a clear reduction in river and broad TP and chlorophyll as a result of upstream point source control. Over the brief period when these measures were effective it is clear that fish barriers established a degree of top down control resulting in clearer water although this phase too brief to stimulate macrophyte growth.

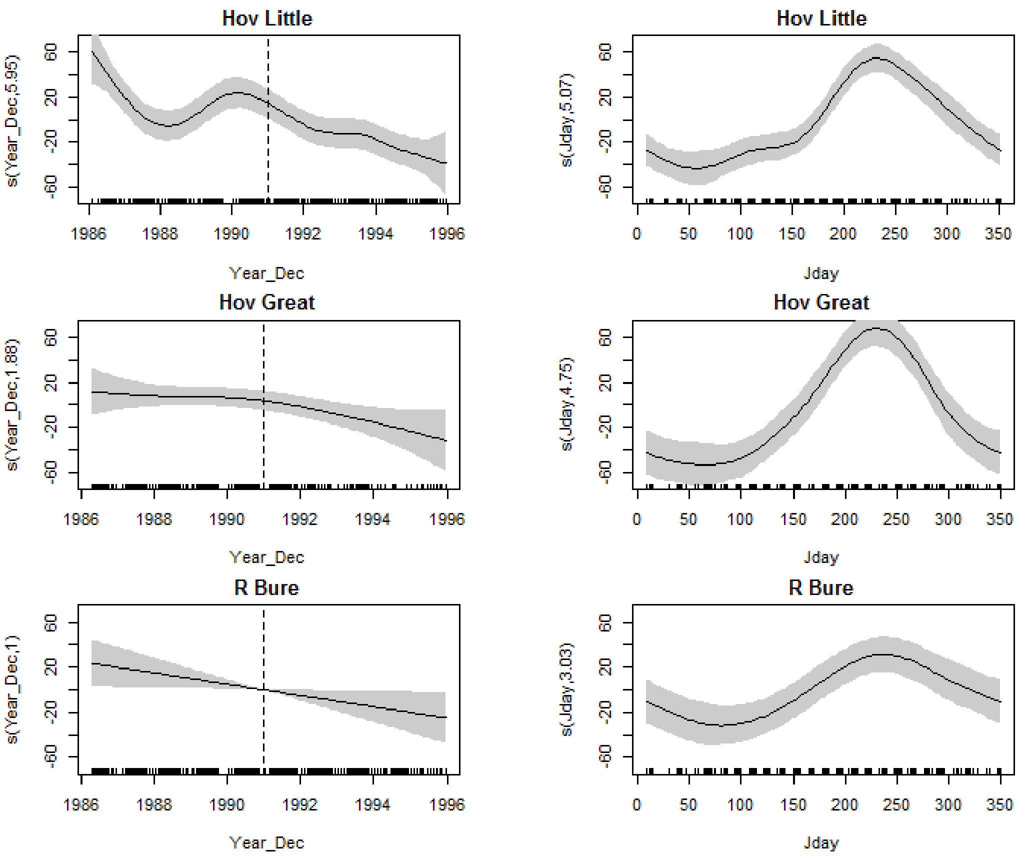


Figure 48 GAM smoothers of standardised data comparing trends in TP in Hoveton Little Broad (dredged 1989/90), Hoveton Great Broad (undredged) and the River Bure upstream at Wroxham. Left annual trend, right seasonal trend.

11 Future management options

From a future management perspective the following points are germane:

- Hoveton Great Broad is likely to support high densities of zooplanktivorous fish, at least seasonally, and there is no evidence of top down control of phytoplankton. Chlorophyll yields are therefore high relative to TP concentrations, transparency is poor and macrophyte cover is predictably low.
- Without the opportunity for effective biomanipulation in Hoveton Great Broad it is likely that ambient TP concentrations require to be almost halved (to ~40ugl^{-1}) in order to achieve chlorophyll levels that are compatible with a light regime for extensive macrophyte growth.
- Water chemistry analysis provides unequivocal evidence for sediment P release during the summer. Surface sediment P concentrations have declined but remain moderately high. The continued scale of sediment P release is uncertain. Water chemistry analysis suggests it is diminished but continuing whilst sediment P analysis suggests limited potential.

- In principle sediment removal should lower internal loading of P within Hoveton Great Broad. However, there are important lessons to be learnt from experience of Hoveton Little Broad where shallow sediment removal in 1989/90 proved ineffective at both re-establishing macrophytes or significantly changing the trajectory of water column P from that observed in the river or the undredged Hoveton Great broad (Figure 48). Recent surveys estimate a soft sediment depth of 0.4-0.5m in Hoveton Great Broad and it may be that deeper removal on a larger scale is required to achieve the benefits sought. Regardless of effects on internal loading of P removal of sediment on this scale ought to provide a more favourable rooting medium for macrophytes, will expose any buried viable propagule bank and has the added benefit of removing contaminants that may be having unknown impacts on plants or invertebrates. Potentially, sediment removal may be the action that is required to kick start macrophyte growth to establish spatial refugia for zooplankton on a sufficiently large scale that chlorophyll is reduced, while establishing the positive feedback effect of P uptake by macrophytes in constraining phytoplankton growth may be critical.
- Reduced connectivity with the Bure would lower tidal exchange of river water and may assist in lowering nutrient concentrations. It may also be critical in maintaining sedimentation at a sufficiently low level in the face of rising river flows to sustain the benefits of sediment removal.

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