Hoveton Great Broad Restoration Project: Seasonal Comparative Fish Surveys Summary Report

"The Hoveton Wetlands Restoration project aims to deliver the restoration of Hoveton Great Broad and Hudson's Bay. This will be achieved through a combination of sediment removal and biomanipulation, restoring them to Favourable Condition / Good Ecological Status. The project will also improve the existing access to and on the site, create new access through the adjacent Hoveton Marshes and host a number of activities and events for volunteers, local people, visitors and lake restoration specialists. Its aim is to enable more people to visit the site, become actively involved in its management and learn about the project and the importance of lake restoration.

This project is part of the Bure LIFE Project (LIFE14 NAT/UK/000054), which is financially supported by LIFE, a financial instrument of the European Community. It is also supported by the National Lottery through the Heritage Lottery Fund."

April 2017

Andy Hindes, Fishtrack Ltd

Bringing the Bure back to LIFE: Hoveton Wetland Restoration Project - LIFE14 NAT/UK/000054

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1 Introduction

The Hoveton Wetlands Restoration project aims to deliver the restoration of Hoveton Great Broad and Hudson's Bay. This will be achieved through a combination of sediment removal and biomanipulation, restoring them to Favourable Condition / Good Ecological Status. The project will also improve the existing access to and onto the site, create new access through the adjacent Hoveton Marshes and host a number of activities and events for volunteers, local people, visitors and lake restoration specialists. The overall aim is to enable more people to visit the site, become actively involved in its management, learn about the project and the importance of lake restoration.

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In the UK the two statutory bodies responsible for looking after the environmental and ecological health of the countryside are Natural England (NE) and the Environment Agency (EA). NE is responsible for protecting sites designated for their conservation importance ie Sites of Special Scientific Interest (SSSI), as well as protecting habitats through the designation process. NE has identified a number of shallow lakes and broads that are not in favourable condition. The EA are the lead organisation responsible for the identification and classification of water bodies failing under the European Directive and the Water Framework Directive (WFD). The WFD requires these sites to be in improving or favourable condition by 2015, extended to 2027 as a maximum deadline. The restoration of Hoveton Great Broad (HGB) is part of a wider strategy to improve shallow lakes and broads and attain compliance with WFD requirements.

In 2013 NE began a series of inter agency consultations between the EA and NE to investigate the feasibility of lake restoration, provisionally based at HGB. The outcome of these discussions and background work resulted in HGB being selected as the principal candidate lake for restoration pending wider consultation.

A consultation with anglers from the Broads Angling Strategy Group (BASG) within the Environmental Sub-Group (ESG) and was held on the 27th August 2013 to present the outline plan for the HGB Restoration Project (HGBRP) and to discuss and record any concerns that the

anglers had. Comments from this group resulted in a number of actions for consideration by NE and partners.

Chris Bielby, Broads WFD Specialist, currently HGBRP manager for NE, commissioned a paper (Hindes, 2013) to address and record the concerns raised at the BASG ESG meeting, as well as developing and outlining actions to take forward to address these concerns. The contract was awarded to Fishtrack and was carried out by Andy Hindes, Principal Scientist. This paper included a record of those concerns, an outline justification as to why HGB was the most suitable Broad to restore, a list of fishery-related issues that required further consideration and proposals for projects to answer those outstanding questions. It was circulated to the BASG ESG members and agreed upon. Over the proceeding 2 years (2013-2015) a series of 10 multi-method seasonal fish surveys, comprising physical and multi-beam sonar surveys; Point Abundance Sampling by Electrofishing (PASE) and Fixed Station Sonar Assessment (FSSA) and included Mobile High Resolution Sonar Survey (MHRSA) were conducted. In addition to daytime surveys a series of night surveys were also undertaken. These surveys were undertaken to provide a baseline from which the project could move forward from, underpinned by sound science. Outputs from these surveys indicated strong seasonal relationships and substantial fish populations within HGB.

The seasonal surveys (2013-2015) and resultant data are directly linked to the outline proposals influenced by the consultation process involving the BASG and in consultation with NE. However, the overall aim was not to look at suitability of fish and fisheries data for biomanipulation in isolation, but rather to ensure the system was better understood, prior to biomanipulation. The two approaches are fundamentally different. The former is both singular and insular, paying little heed to the effects of such actions upon the wider fishery or those concerns of the wider public and angling groups. The latter is more holistic, enabling biomanipulation to be targeted with the knowledge of the effects of such work upon the wider fish community within this section of the River Bure system and taking into account concerns from local residents and anglers who have considerable experience of the HGB system. This holistic approach permits NE to meet their responsibilities to the wider environment when undertaking projects, and also enables partners such as the EA to discharge their statutory duties with regard to Salmon and Freshwater Fisheries Act (SAFFA) 1975, whereby the duty is to *maintain, improve and develop* fisheries in a way that, amongst other things, *enhances the*

socio-economic contribution of fisheries and puts people at the centre. This is particularly pertinent with regard to the Norfolk Broads, which are known to attract >1.18 million angling visits per annum and support an annual contribution to the local economy of between £88 and £100m from angling related activities (STEAM Report, Broads Hire Boat Federation Survey, S. Lane Per. Comm.).

In order to ensure the fishery as a whole was taken into account with potential impact assessment of biomanipulation, the HGB and Hudson's Bay (HB) seasonal surveys required context from within the locality. A series of locations were selected for comparative purposes from criteria that encompassed hydroacoustic survey data and fish density distribution within the Bure river system, geographic location and proximity of other broads, geophysical similarities, anthropogenic use and influence, access and navigation. The results of this process were a series of broads recommended for surveying in conjunction with HGB and HB for a comparison. Five broads were selected:

Salhouse

Decoy

Hoveton Little

Pound End

Wroxham

Timeframes were tight, all broads to be surveyed within a 2-week window in order to reduce effects of seasonal and external environmental parameter changes, which in turn could influence the fish distribution and behaviours. In order to accomplish the survey programme, it was necessary for survey staff to remain on site day and night for the duration of the surveys, enabling early starts, late finishes, and providing a degree of security, maintenance and survey continuity for fixed station equipment, ensuring contiguous running and monitoring.

2 Fisheries Survey Methods

Fishery surveys were conducted on a seasonal basis to determine seasonal usage of all 7 broads (including HGB and HB) to provide abundance and biomass estimates and distribution, related to the fish community and its composition.

The multi-method survey approach comprised of two principal elements, physical fish surveys involving capture of fish and virtual monitoring using multi-beam sonar in both traditional and novel ways. These 2 principal methods were Point Abundance Sampling by Electrofishing (PASE) (Nelva et al., 1979; Persat and Copp, 1988; Copp and Garner 1995) and multi-beam sonar assessment respectively, the later being sub-divided into two methods, Fixed Station Sonar Assessment (FSSA) and Mobile High Resolution Sonar Assessment (MHRSA) (Hindes et al, *in Prep.*).

Comparative seasonal surveys were conducted from Spring 2016 to February 2017, encompassing spring, summer, autumn, and winter.

All broads were spit into zones according to habitat and water depth and in-stream structure. Flow characteristics were also taken into account where it was judged to influence fish distribution. The categorisation of zones was habitat based, but also incorporated water body structure and depth, ie where the HGB complex was split into 4 habitat zones, the Dam was differentiated from the main HGB due to characteristically uniform depth (often greater than that of the main broad), distinct flow characteristics and the cannalesque edges to the channel, likewise with HBC featuring overhanging scrub canopy and channel-like features when compared to either of the 2 broads.

Table 1. Comparative broads and their respective habitat zones. 2016-2017

Broad	Habitat Zone I	Habitat Zone II	Habitat Zone III	Habitat Zone IV
Hoveton Great Broad (HGB)	Littoral margin (HGBLM)	Limnetic zone open water (HGBOW)	Dam	Hoveton Marsh Dyke (HMD)
Hudson's Bay (HB)	Littoral margin (HBLM)	Limnetic zone open water (HBOW)	Hudon's Bay Channel (HBC)	
Salhouse	Littoral margin (SLM)	Limnetic zone open water (SOW)	Salhouse Channel (SC)	

Decoy	Littoral margin (DLM)	Limnetic zone open water (DOW)	Decoy Channel (DC)	
Pound End (PE)	Littoral margin (PELM)	Limnetic zone open water (PEOW)		
Wroxham	Littoral margin (WLM)	Limnetic zone open water (WOW)		
Hoveton Little Broad (HLB)	Littoral margin (HLBLM)	Limnetic zone open water (HLBOW)	HLBC Channel (HLBC)	

The area of each zone was calculated using Geographic Information System (GIS) software, QGIS. This enabled whole area estimates including all zones to be generated for all of the comparative broads as well as the target broad, the HGB complex, which in-turn enables estimates with a measure of variance to be generated for each zone as well as provision of whole lake estimates, which give a better overall picture of the fish community, and with regard to decisions based upon future biomanipulation and fish removal operations. In addition to this, the wetted extent of the littoral margins was also comprehensively estimated.

Each zone was covered systematically by electrofishing points/sample points, both for limnetic (open water) as well as littoral margin habitats, providing comprehensive geographical coverage. The number of points/zone between seasons was kept relatively constant.

2.1 PASE Method and Technique:

Point Abundance Sampling by Electrofishing (PASE) (Nelva et al., 1979; Persat and Copp, 1988; Copp and Garner 1995), originally adapted from fractional sampling of bird populations (Point Abundance Sampling (PAS)) (Blondel et al., 1970) was the method employed for fish capture during the littoral and limnetic fishery surveys in conjunction with MHRSA complimenting the PASE for limnetic zone quantification. PASE is a widely used method of fish capture (Copp & Penaz, 1988; Garner, 1995; Tomanova et al., 2013). Deployment of PASE within HB, HBC, HMD Salhouse, Decoy and HLB channels utilising small electrofishing boats is particularly suitable in small watercourses (Janac 2007; Copp 2010) as well as being effective in the littoral margins of HGB (Hindes, 2015).

The method comprises fishing from a small, dedicated fishing boat, suitable for negotiating confines and small watercourses as well as open water, and is operated by two personnel. The boat is propelled by 'push rowing' the boat backwards through the water in the direction of travel (Nelva et al., 1979; Copp & Penaz, 1988). This enables the oarsman to observe the operative deploying the electrofishing equipment. The electrofishing operative stands fishing off the stern, rapidly submerging the anode (a fiberglass rod with waterproof switching and incorporating an anode head of stainless steel) through the water column each time the boat is stopped in the water at the sampling point. A long handled, hand held net is then swept through the 'point' and any fish present captured. Progressing in this way the boat hops along the watercourse sampling a series of 'points'. The boat is fitted with sound deadening material to reduce conduction of generator and operator noise through the water column, which will otherwise influence fish behaviour and distribution, QPASE (Lane, Hindes, & Reeds, *in Prep*) and thus producing more accurate results than conventional PASE. This method has been quality assured using the MHRSA method (Hindes et al., *in Prep*) (see also MHRSA section).

The electrofishing equipment comprises of a dedicated electrofishing box (Electrafish FC300GP25, 250v 3kw, output 0-250v, 50-100 p/sec^{-1}), fishing at a frequency of 50-100Hz. A pulsed dc electric current is passed into the water through a hand held anode with an anode ring of 380-450mm diameter. The larger sized anode ring reduces voltage gradient, causing less harm to the fish. The area of influence is estimated from determining the distance, from the outer edge of the anode ring, at which the voltage gradient decreases to 0.12v. Power to the electrofishing box is provided by a specialist electrofishing generator, Honda 2.7 Kva, 240v, (conforming to EA electrofishing codes). It is incorrect application to 'stun' fish by application of excessive current into the water column at the sampling point or applying the current for an extended duration, since this also influences the sampling by drawing fish from outside the zone of influence into the sampling point and biasing the estimate. The correct application is; upon initial immersion of the anode and simultaneous flow of current, fish orientate themselves in the direction of the electrical current, known as alignment (Beaumont et al. 2002). Fish that are within the sphere of influence of the anode are drawn towards the operator by involuntary muscle spasm (galvanotaxis), which inhibits swimming. This enables the operator to use a hand held net to capture the fish for processing within the boat. All fish are processed for biometric data whereupon they are finally returned at the initial point of capture.

Where PASE was deployed along littoral margins, sampling took place at the interface between water and margin. Where margins were deep, the point boat was rowed into the margin enabling sampling of the margin depths. Where margins were shallow, sampling took place at the interface. At each sampling point the wetted margin depth was recorded. Sampling was repeated systematically along the entire margin, stopping approximately every 8-10 oar strokes to sample a point. This spaces sampling appoints approximately a minimum of 10m apart (dependant upon littoral margin habitat) and reduces the influence of the energised anode upon the resident fish (Tomanova et al. 2013). All fish captured at each point were identified, measured by fork length for length frequency and age class calculation. Scale samples were taken of older fish for growth rates and age analysis. Data on individual fish were recorded to enable length frequency curves to be generated, which provide information relevant to growth, size of individuals and year class when combined with age data. Furthermore, the fish assemblage can be determined using this approach. Any noticeable ectoparasites, lesions, lip and mouth damage etc were also noted. Large individuals were also sexed where practicable. Dependant on the season of sampling, pre or spawning condition is also noted. At each sampling point a grid reference/GPS coordinate was taken to enable identification of individual points and to provide general distribution of fish via Geographic Information Systems (GIS). The limnetic zone was also sampled in a systematic way, with 2 sets of 75 points in different areas of the HGB and all of HB being selected. A similar approach was adopted for other broads. Limnetic surveys were supported with MHRSA data (see below). All fish captured by PASE were individually measured, or a thorough sample measured, to provide size class information, estimates of young of year (YOY), and growth rates for those species with high densities that are considered to be principal components of the fish assemblage.

In previous seasonal surveys (2013-2015), and in recognition of the limitations of PASE to effectively sample open water, and to capture sparsely distributed species such as northern pike, *Esox lucius*, where capture of a few individuals can produce estimates with high confidence limits or measures of error surrounding them, a comparative survey was undertaken. This second daytime survey method, to validate and support daytime PASE, was MHRSA requiring the deployment of multi-beam sonar equipment in an unconventional approach.

2.2 MHRSA

Mobile High Resolution Sonar Assessment (MHRSA) data is currently used to provide evidence

of limnetic zone fish populations and may serve to support limnetic PASE data assumptions, depending upon prevailing conditions and timing of the surveys. MHRSA comprises of multi beam sonar equipment attached to articulating fixtures at the bow of a stable boat specifically adapted for this purpose, powered by a quiet running electric outboard. The advantages of such equipment and resultant data are that individual samples that are larger than PASE, determination of fish attitude and behavior, as well as fish numbers and sizes to be estimated. A comparative, quantitative version of this method is currently being developed (Hindes et al., *in prep*). Fishtrack have helped develop this method in collaboration with EA Fisheries over the past 2 years and it was our intention to ensure that this continued alongside the PASE in the comparative seasonal surveys, as both methods should not be considered discretely, but collectively, providing a holistic assessment of the fish populations of the broads in the comparative survey program. This method concentrates surveying fish in open water, along a series of transects which are plotted using GPS software to enable repetition and effective geographic coverage.

2.3 FSSA

Fixed Station Sonar Assessment (FSSA) was deployed using multi-beam sonar DIDSON and ARIS (Sound Metrics, USA) at two main locations on HGB (the Gate & the Dam), 2 on Salhouse (entrances to the river), 3 on Decoy (river entrances and entrance to Woodbastwick marsh system), 3 on HLB (river entrance, channel to Burnt Fen, entrance to PE) and 2 on Wroxham (river entrances) reflecting the perceived importance of these locations for fish moving on or off the broads. These locations were commonly surveyed for 24hrs/day-[1] over the duration of each survey period on each respective broad in order to provide a contiguous sampling period to compare with other broads. Deployment comprises of the installation of suitable floating framework anchored to the lakebed or shore and containing self contained monitoring modules co-developed by Fishtrack and the EA. The sonar is either suspended beneath the structure to allow for rotation, pan and tilt of the unit and without interference of the field of view or suspended via tripod with likewise ease of movement. Powering of the units were a departure form the norm. In place of conventional generators the units were powered by a fuel cells, which were incorporated into the FSSA monitoring modules and a departure from conventional shore based equipment. Computer data capture and backup, were incorporated into the modules as well as energy storage via batteries to permit additional running for 2 hours without power, should system failure occur. The pontoon-based structures and modules were incorporated into weatherproof ventilated enclosures that provided additional security. The sonar was focused

towards the area of interest. This enabled monitoring of the area for fish movements 24hrs/day-[1] for the duration of the broad specific comparative seasonal survey.

3 Results and Discussion

This report focuses exclusively on the results from the PASE surveys and their data sets, which are presented below. FSSA and MHRSA datasets are integral to the overall assessment of the fish assemblage, as well as fish density, biomass and distribution, and for identifying key movements and revealing diel behaviour. However, due to the lack of availability of both FSSA and MHRSA datasets they are not incorporated into the results of this report. Since in depth focus on the fish assemblage and distribution within HGB/HB has been carried out over previous surveys and reports, this comparative work looks to evaluate the principal components of the fish assemblage in relation to neighbouring broads and seek some context for the results of the HGB/HB surveys. Previous work has identified roach and bream and the principal cyprinids and the most significant components of the fish assemblage that require further focus prior to moving forward with the planned restoration.

The data are presented from an 'All season' perspective in order to provide an overview. The individual seasons are then presented in order, providing further detail and illuminating key points. All broads are compared during the comparisons and key performance elements are highlighted and discussed.

3.1 PASE

3.1.1 Species richness

The total number of fish species captured during PASE surveys varied between seasons, with a general trend of decline in species richness as the seasons progressed towards winter (Table. 2). An overall total of 14 species (inc. 1 hybrid) were represented between Spring 2016 to Winter 2017 (Table. 2). HGB/HB complex scored the highest combined species richness ($\sum n$ 37) and Decoy the lowest ($\sum n$ 17). HGB/HB was consistently the highest scoring broad throughout all seasons (Table. 2). HGB/HB also produced the least variation in species richness over all seasons and scored highest during the winter, suggesting there is sufficient overwintering habitat to hold various fish species. Those broads showing the highest species richness seasonal variation overall were Wroxham and PE, (7 & 6 respectively).

Table 2. Seasonal species richness within broads of the comparative surveys. 2016-2017

Species and season (spring, summer, autumn & winter (s,s,a,w))	Salhouse Broad				Pound End Broad				Wroxham Broad				Hoveton Little Broad				Hoveton Great Broad/HB				Decoy Broad			
	s	s	a	w	s	s	a	w	s	s	a	w	s	s	a	w	s	s	a	w	s	s	a	w
Dace (*Leuciscus leuciscus*)																								
Sea trout (*Salmo trutta*)																								
Atlantic Flounder (*Platichthys flesus*)																								
3-spined stickleback (*Gasterosteus aculeatus*)																								
Common Bream (*Abramis brama*)																								
Gudgeon (*Gobio gobio*)																								
Perch (*Perca fluviatilis*)																								
Northern Pike (*Esox lucius*)																								
Ruff (*Gymnocephalus cernus*)																								
Roach *(Rutilus rutilus*)																								
Rudd (*Scardinius erythrophthalmus*																								
Roach /Bream hybrid																								
Tench (*Tinca tinca*)																								
Eel (*Anguilla anguilla*)																								

3.1.2 Overall whole broad estimates

Elevated fish densities are a feature of this section of the tidal River Bure, from upstream of Horning to downstream of Wroxham. Hydroacoustic reports from 2004 onwards consistently identify this section as the most prolific in the entire tidal river from 5-mile house to Coltishall common, approximately 40Km (Hindes 2004-2011, Crompton, 2014). These elevated densities often exhibit pockets of higher density within them. These occur opposite entrances to broads such as HGB/HB or Wroxham broad (Hindes, 2004-2011), indicating the association of fish with both the river and the neighbouring interconnected broads. Thus, this section of the River Bure and its associated broads could be regarded as the honey pot for fish populations. Therefore, the importance of the fish community, both in terms of structure and scale will have widespread influence and implication on the rest of the system. It is fair to assume that any impacts upon

the fish community within this section of the system would therefore, have a consequential affect upon the wider fish community of the River Bure.

Season variances have a profound influence on fish distribution and population levels. Accordingly, all comparisons are made on a seasonal basis.

3.1.3 Littoral zone

The majority of smaller fish reside within the littoral zone during daylight where PASE is more effective in such typically shallow, complex habitats (Copp XXXX). Estimates of the principal components of the fish assemblage relating to the littoral zone are a fair indicator of the holding capacity or attractiveness of such habitat for smaller fish and hence the potential carrying capacity of the broad. Therefore, focusing on this habitat zone in isolation as well as part of the integral habitat make up of each broad would appear to have merit.

The HGB/HB complex is sub divided for the purposes of presenting littoral zone estimates and all broads and their respective zones have a measure of variance surrounding their estimated mean density and biomass. The principal cyprinids, roach and bream, which are also the principal components of the fish assemblage, are presented in isolation as well as alongside combined category of 'other' species'. Other species of note are discussed where relevant.

3.1.4 Limnetic zone

The open water component of the 6 comparative broads are relatively featureless with regard to macrophyte growth or submerged structure, though even here there is variance within this group. To all intensive purposes they can be regarded as slit plains, especially true for the function of habitat and holding ability of particular locations with regard to fish populations and distribution. Nevertheless, they do form an important element of the broad habitat zones and fish do use these habitats for foraging. For example, pike patrol this habitat in search of larger prey fish, and bream forage in the soft sediments for macro invertebrates. During hours of darkness, small fish and YOY including roach and perch also forage in open water, feeding off zooplankton in the pelagic zone (Hindes, 2015). Despite the functional use of the limnetic zone, for many species and size class of fish, this area is largely avoided during daylight and so devoid of these size classes of fish. This is attributable to exposure to predation, particularly piscivorous and avian, as well as reduced feeding opportunities during daylight hours related to zooplankton

avoidance of fish predation by strong association with cover (Moss XXX). Encounters within this zone may have a profound influence on the overall fish population estimates due to the large contribution to the overall size of the function habitat of the broad. It is precisely due to uncertainty surrounding such estimates that MHRSA was developed, providing another level of measure of such a large component of the broad habitat structure.

3.1.5 All Zones

All broads are zoned according to their habitat and incorporate a variety of other factors that are taken into account where they are considered to influence fish distribution and density. For example, HGB/HB complex is sub divided into two separate broads with discreet limnetic and littoral zones. Further zonation takes into account differing channels and dykes that might be within the system; examples such as The Dam, Hoveton Marsh Dyke (HMD) and Hudson's Bay Channel (HBC) illustrate the point that these areas have features or characteristic that will influence fish distribution. For example, HBC is a sinuous channel of relatively deep water with distinctive flow characteristics that fish find attractive and safe. Therefore, it is often a zone that has high concentrations of fish at specific time of the year, forming clumped distributions. The data presented within the 'All zone' sections are mean estimates of each respective zone along with a measure of variance surrounding the mean (standard error).

3.1.6 Relative representation

The proportion of each fish species' contribution to the overall density and biomass estimates makes up the fish assemblage and their relative position within that assemblage. For instance, it is common for northern pike to feature strongly on the biomass component of the estimates due to their relatively large size, but conversely so with density estimates due to their comparatively solitary nature and their status as a top predator within the food chain.

3.1.7 All seasons

3.2 Overall

The HGB/HB complex dominated the overall mean density estimates for all broads in all seasons (Fig. 1a), indicating the usage of the broad by the fish community throughout all seasons and its importance to this part of the River Bure system. Biomass estimates also reflect the status of the HGB/HB complex (Fig. 1b), particularly regarding spring and summer. The spring estimates are

indicative of use of the broad during the spawning season. Comparison of HGB/HB during spring versus the next top performing broad, PE, show density differences in favour of HGB/HB (0.58 ind. m^{-2} vs 0.3 ind. m^{-2}). Biomass estimates reveal that these differences are related to not just more fish present in the HGB/HB complex per unit area, but also that the individual sizes are larger too. The elevated biomass estimate (22.58g.m^{-2} vs 2.27g.m^{-2}) equate to higher weights per individual per unit area (circa 38.93g/ind.m^{-2} vs 7.8g/ind.m^{-2}) is indicative of larger, adult fish, conducive to usage of the broad by mature adult spawning fish.

The summer densities also dominated by HGB/HB, suggest that the effect from the site being a favoured spawning site is carried through to the summer recruitment phase, resulting in higher density estimates than all the other comparative broads. This is further supported by examination of the biomass estimates in conjunction with the density estimates. The size of fish by weight changes from the spring high to a more modest summer figure (12.92g./ind.m^{-2}), conducive of YOY present within the community, diluting the effect of larger adult fish, but increasing the density estimates.

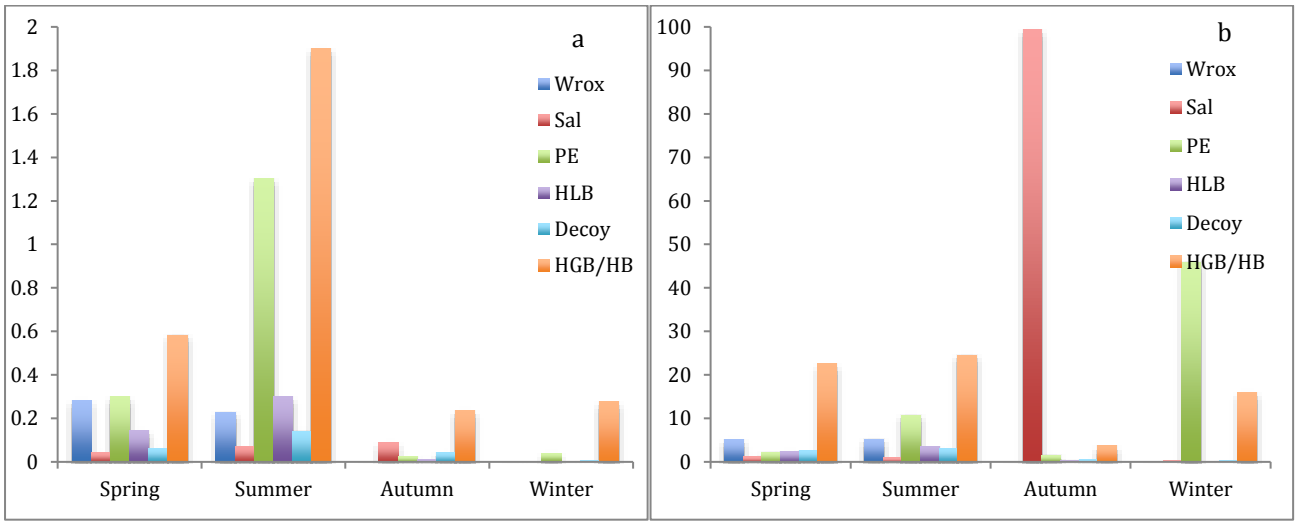

Figure 1a & 1b. Overall, whole broad density (ind. m^{-2}) and biomass (g m^{-2}) estimates by season. All broads. 2016-2017

Overall mean density estimates for all species combined, including roach and bream, on a broad-by-broad basis varied widely. HGB/HB complex produced the highest density estimates of all the broads in all seasons (Fig. 1a), clearly demonstrating it's importance to the fish community of this section of the River Bure and adjacent broads.

3.3 Spring

3.3.1 Overall

HGB/HB dominated the overall mean density estimates for the 'all species' combined category (0.57 ind. m^{-2}), as well as for the principal cyprinid fish species categories, roach and bream (Fig. 2a). Wroxham and PE produced similar estimates (0.28 ind. m^{-2} & 0.30 ind. m^{-2}) respectively, whilst lowest estimates were from Salhouse (0.04 ind. m^{-2}), perhaps reflecting the paucity of habitat suitable for spawning fish which would be assembling in broads during this time of the year. From the overall mean bream density estimates, it is clear that they preferentially select HGB/HB complex during spring over all the other broads in the comparative surveys and hence the importance for this site for spawning purposes. The same is also true for roach. Biomass estimates also support this, with HGB/HB dominating all biomass estimates for the all species combined category as well as for bream (Fig. 2b). The scale of bream dominance in the overall mean biomass estimates (15.1 g m^{-2} vs all other broads mean 0.13 g/m^{-2}), is indicative of the numbers of large adults present on the complex during this time, something which is supported by previous spring surveys (2013-2015) and evidenced by littoral margin investigation as well as from ARIS data sets. Roach overall mean biomass estimates were strongest on Wroxham broad, followed by PE and HGB/HB (4.97 g m^{-2}, 2.02 g m^{-2}, 1.91 g m^{-2} respectively).

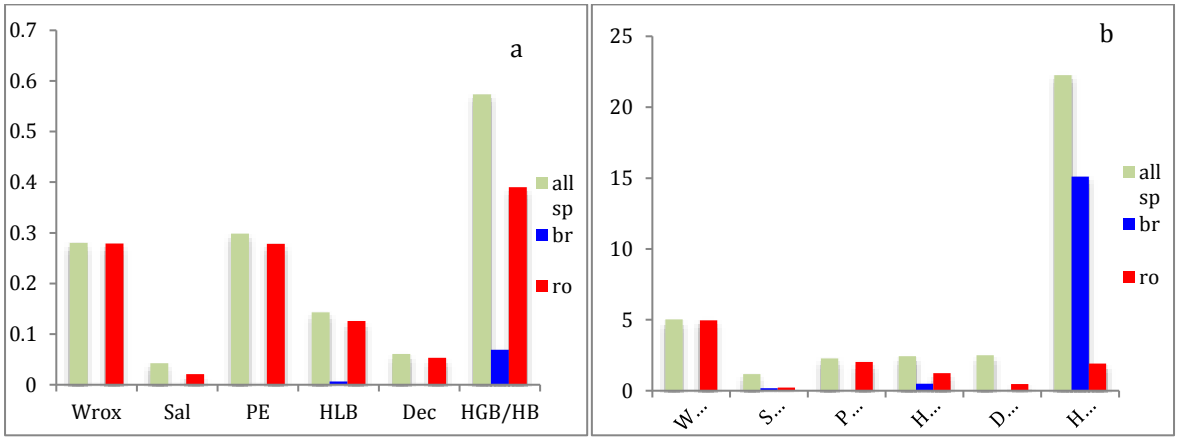

Figure 2a & 2b. Overall mean density (ind. m^{-2}) (a) and biomass (g m^{-2}) (b), roach, bream and all species combined, all broads Spring 2016.

3.3.2 Littoral zone

During spring there is little difference between littoral margin density estimates of roach from HGB, Hoveton Little Broad (HLB) and Pound End (PE) (Fig 3a). However, HLB dominated the littoral margin biomass estimates for roach, indicating, this broad attracts a larger stamp of roach compared to HGB and HB.

Despite the modest density estimates for bream across HLB, HGB and HB during spring (Fig. 3a), their biomass estimates were substantially higher than all other broads (Fig. 3b), indicating that those fish present were larger adults present in the littoral margin, which is not their normal habitat.

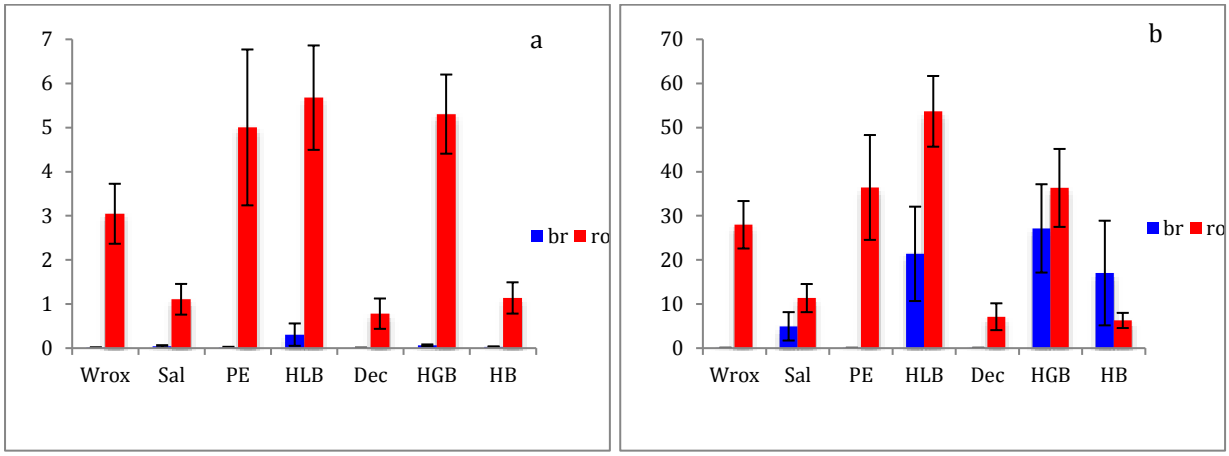

Figure 3a & 3b. Roach and bream littoral margin mean density (ind. m^{-2}) and biomass (g m^{-2}) (± 1 S.E.), all broads. Spring 2016.

Given the season, the presence of large adults, and the previous years data where biomass estimates were some of the highest recorded (255.805 g m^{-2} (± 146.753) (Hindes 2015), and evidence regarding spawning bream, this is clearly a spring spawning population present on HLB, HGB and HB, with HGB producing the highest biomass estimates of all the broads during the spring season. Thus, it's reasonable to conclude that the HGB/HB complex has the most suitable bream spawning habitat in comparison to the other broads, though its marginal habitats are less unique for roach during the spring spawning period.

3.3.3 Limnetic zone

Most broads had no fish captured in the open water habitats during the spring survey with exception of HGB/HB complex and Wroxham Broad. The HGB/HB complex produced two estimates, with HB limnetic zone scoring higher than the main HGB itself (2.099 ind. m^{-2} ±1.776 & 0.028 ind. m^{-2} ±0.011 respectively). The higher HB limnetic estimate was boosted by the presence of adult bream in the catch, as evidenced by the biomass values (53.12 g. m^{-2} ±34.95). The high measure of variance surrounding the mean estimate being indicative of a clumped distribution. In other words a number of adult bream were captured in two or three sampling points and augmented with capture of a shoal of smaller fish. Wroxham Borad produced much

lower estimates than the HGB/HB complex (0.267 ind. m^{-2} ±0.124 & 4.87 g. m^{-2} ±2.25) and these were attributed to the capture of roach over 6-7 points in a relatively small area of the broad.

3.3.4 All zones

Spring density estimates are dominated by Hudson's Bay channel (HBC), a sinuous tree shaded channel with areas of deep water and flow characteristics atypical of a broad. The density estimates were substantially larger than any other broad's habitat zone density estimate (Fig. 4a). Even with the wide variance surrounding the mean estimate, indicative of a clumped distribution, the zone is substantially above all other estimates. This suggests that either fish are using this location for spawning, something not observed, or are aggregating prior to spawning and utilising the overhead cover during hours of daylight. Subsequent visits during the surveys and over the past 3 years also strongly support this hypothesis. Previous surveys (2013-2015) have shown the migration of substantial numbers of fish (>20000) migrating out of HBC and into the main HGB during periods of dusk, which further supports the overhead cover hypothesis.

Other habitat zones within the HGB/HB complex also perform well, with littoral margin estimates of the HGB and the Hoveton Marsh Dyke (HMD) system amongst the other highest density estimates, only outperformed by HLB littoral margin (Fig. 4a). Wroxham and Salhouse littoral margins produced low density estimates, (3.31ind. m^{-2} (± 0.68) & 1.48ind. m^{-2} (± 0.38) respectively). This is not surprising, considering the poorly developed margins. Decoy produced the lowest littoral margin density estimate (1.09ind. m^{-2} (± 0.38)), despite having slightly better developed margins than both Wroxham and Salhouse. However, perhaps more surprisingly, HB littoral margin zone produced the second lowest of all marginal estimates (1.34ind. m^{-2} (± 0.36)) despite having better developed margins than most other broads. The likely explanation for this is related t the silting up of the broad and access to margins being hampered by very shallow water, especially so during low tidal cycles. During the previous spring survey (2015), this margin was densely populated with spawning adult bream, something that did not occur during the surveys this year.

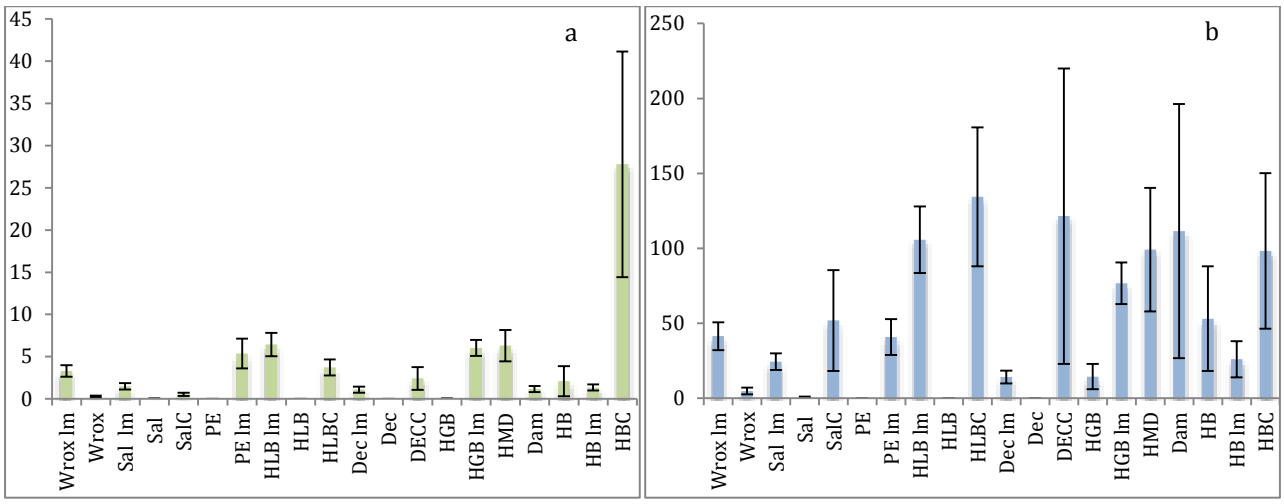

Figure 4a & 4b. All habitat zones mean density (ind. m^{-2}) and biomass (g m^{-2}) (±1 S.E.), all species for all broads. Spring 2016.

Overall, Wroxham, Salhouse, and Decoy performed poorly during the spring fish habitat zone density estimates, possibly indicating their unfavourable status for spawning fish and as a consequence of poorly developed littoral margins. Although Decoy habitat is considered to be slightly better than Salhouse and Wroxham, it performed worse than both (1.09 ind. m^{-2} (± 0.37) vs 1.48 ind. m^{-2} (±0.38) & 3.31 ind. m^{-2} (± 0.68) respectively). Surprisingly, Hudson's Bay also performed poorly, with the second lowest littoral zone estimate (1.34 ind. m^{-2} (± 0.36)), despite having better margins than other zones and broads, suggesting that fish were elsewhere during the survey, very probably in HBC (see above). Biomass estimates appear to be influenced by habitat and location. The majority of the higher estimates being associated with channels joining broads to the River Bure or as off broad connections (Fig. 4b). the comparatively narrower measures of variance surrounding mean biomass estimates for the non channel habitats indicates there more uniform distribution compared to the clumped distribution of the channel habitats. (Fig. 4b).

3.3.5 Relative representation

Roach density dominated all broads during the spring surveys (Fig. 5a). Salhouse broad was the most marginal when including the limnetic zone trout catch (see below). However, when this component was excluded, roach retained the margin over all other species (Fig. 5a). Relative roach biomass was highest for Wroxham (a roach dominated broad (Fig. 5b)), PE and HLB (Fig. 5b). Larger bream dominated the relative biomass estimates in HGB/HB complex, confirming

their spawning preference for this complex. Decoy produced 'other species' category dominance within the broad.

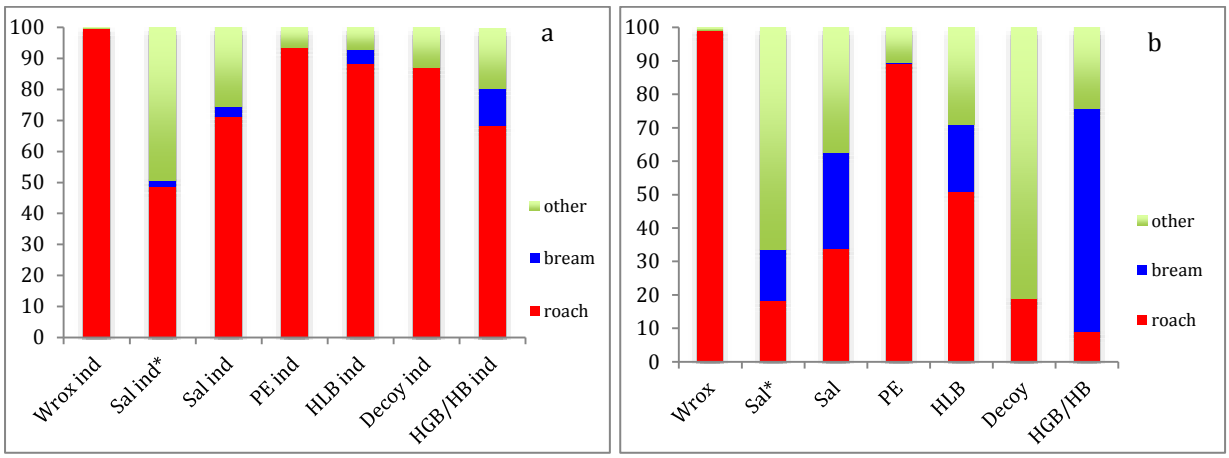

Figure 5a & 5b. Relative (%) overall density and biomass of roach, bream and all 'other' species category. All broads Spring 2016.

The spring survey turned up a few surprises in Salhouse relative density estimates in the form of a sea trout captured in the limnetic zone. This was the only fish capture in this habitat zone and the influence in the fish assemblage relative density estimates is notable (Fig 6a).

The data are presented with and without the sea trout catch since this is not the natural habitat for a sea trout and its influence upon the estimates causes a degree of confusion, being atypical. Accordingly, we draw attention to the second figure related to the fish assemblage (Fig. 6b). In both cases, however, roach remain dominant, though at a higher level without the open water sea trout present.

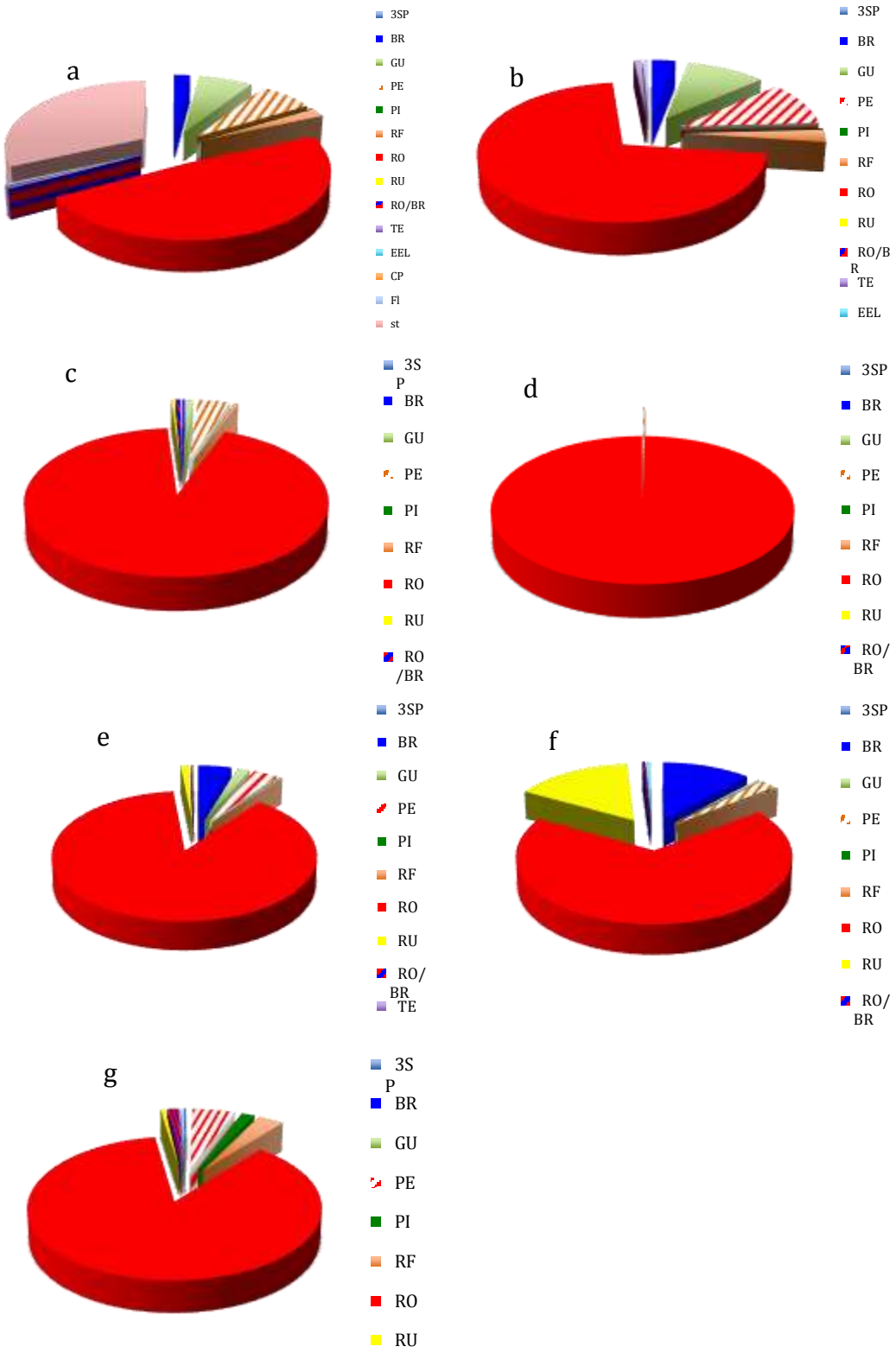

Figure 6a - 6g. Composition of the fish assemblage by relative (%) density. Salhouse with(a) and without(b) sea trout, Pound End(c), Wroxham(d), Hoveton Little Broad(e), Hoveton Great Broad(f), and Decoy(g). Spring 2016.

The other stand out fish of the survey was a flounder, captured in a shallow, sheltered, muddy side bay of the Salhouse littoral margin (Plate 1). Flounder are a transitional and coastal zone species, able to tolerate both marine and freshwater conditions, but in fresh and brackish water usually occurring in the lower tidal reaches of rivers and estuaries.

Plate 1. Flounder from Salhouse littoral margin

HGB/HB complex featured rudd (16%) in the relative density estimates (Fig. 6f). These were captured in the channel leading to the broad from the river in the tree shaded littoral margins. Rudd also feature in the relative density estimates of HLB (Fig.6e), though at lower levels (1.2%) than Salhouse. Rudd are a feature of the broads fish community, but usually at low levels, and periodically found in areas of good habitat.

Pike typically feature strongly in biomass estimates and the relative biomass of the fish assemblage in relation to the numbers captured. However, this was only observed on Decoy, whereby a representation of 2% in relative density (Fig. 6g) produced an estimate of 76% biomass (Fig. 7g). Roach biomass dominated half the broads (PE, Wroxham, HLB, 89%, 99% & 53% respectively) (Figs 7c-d). Bream dominated the relative biomass for HGB/HB (67%) (Fig. 7f). Although roach on Salhouse performed better than all other species, this was more modest (34%) (Fig. 7b) than other comparative broads.

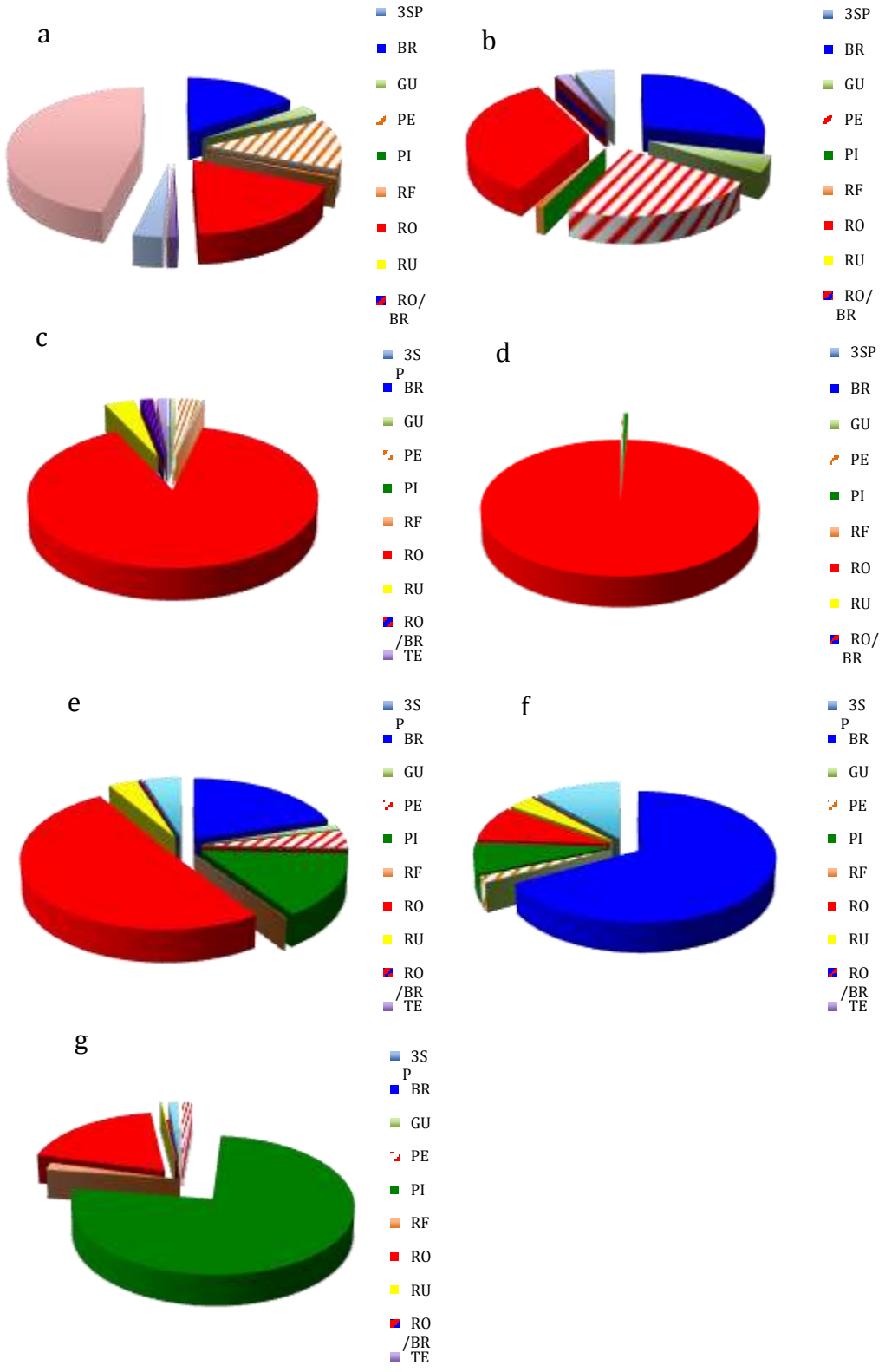

Figure 7a - 7g. Composition of the fish assemblage by relative (%) biomass. Salhouse with(a) and without(b) sea trout, Pound End(c), Wroxham(d), Hoveton Little Broad(e), Hoveton Great Broad(f), and Decoy(g). Spring 2016.

3.4 Summer

3.4.1 Overall

The highest recorded density was HGB/HB (1.9 ind. m^{-2}) during the summer surveys (Fig. 8a). Most broads (67%) exhibited a high point during the summer surveys, augmented by the presence of new young of the year (YOY) following the spring spawning and subsequent summer recruitment phase. Exceptions to the summer high point were Wroxham and Salhouse, which produced their highest densities during spring and autumn respectively (Figs. 2a & 14a).

Considering summer surveys are conducted at the end of the summer (September) the majority of these fish are predominantly juveniles or YOY. Sampling at summers end presents a realistic portrayal of the likely fish community that may recruit into the larger population after the overwintering period and a true representation of the summer fish population. This is primarily due to the high mortality rates facing YOY over the summer period, especially so after hatching ad entering the fry stage. Thus, sampling mid summer will inadvertently sample those fish due to succumb to mortality over this period and present inflated estimates. In actuality, there are two principal mortality periods, the first during summer and the second during the winter period, when reserves may be low and predation and/or food supply and low temperatures will contribute to higher mortalities of younger age classes.

The highest scoring mean density estimate for roach was PE (Fig. 8a), and it is the roach density that strongly influenced the all species combined category, contributing 96% overall, indicating the paucity of other species present in any numbers within the broad. HGB/HB dominated the bream density estimates, clearly showing that bream favour this broad over all the comparative broads, even long after spawning season has finished (Fig. 8a). This feature of the assemblage is also seen in the biomass estimates, where the HGB/HB bream biomass dominates all the other comparative broads (Fig 8b) and contributes substantially (69.5%) to the overall combined all species biomass estimate. Salhouse performed poorly in both mean density and biomass estimates (Figs 8a & 8b) attributable to heavy usage by boat traffic during the peak holiday season, paucity of habitat and poorly developed littoral margins with little off-broad refuge with exception being the Salhouse Channel, though this has limited value during summer due to lower water levels restricting both its length and usability for fish.

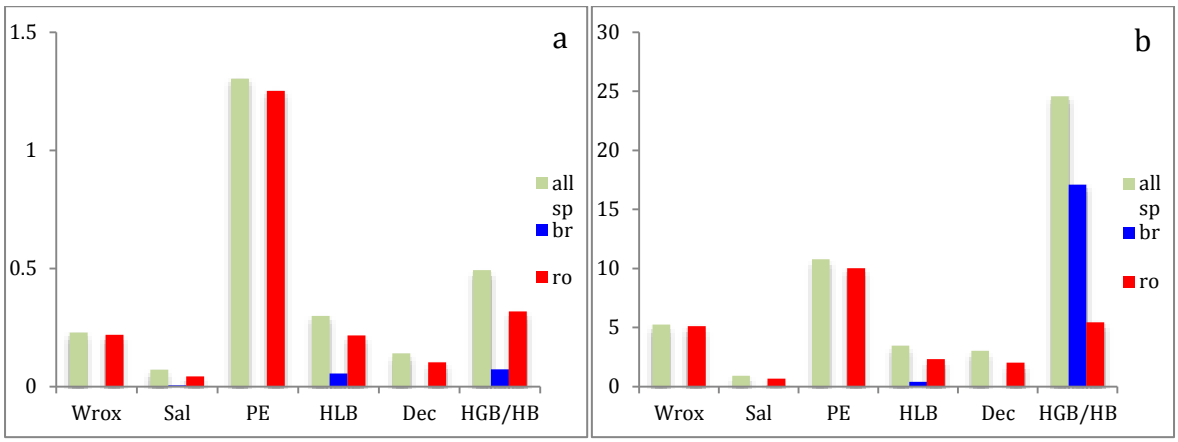

Figure 8a & 8b. Overall mean density (ind. m^{-2}) (a) and biomass (g m^{-2}) (b), roach, bream and all species combined, all broads Summer 2016.

3.4.2 Littoral zone

Roach littoral zone mean density estimates were dominated by HLB, outperforming HGB (Fig. 9a). The same is true for bream during this survey. The segregation of HB from HGB in the estimates reveals that the main broad (HGB) provided most of the roach from the littoral margin habitat zone to the overall roach estimates (Fig. 8a). Few bream were found in the littoral margins of HGB during this period.

The HGB/HB segregation also shows that broad mean bream estimates were influenced by bream present within the HB littoral margin, though these were clearly smaller size class than those present on HLB contributing correspondingly less to their respective biomass estimates (Fig. 9b).

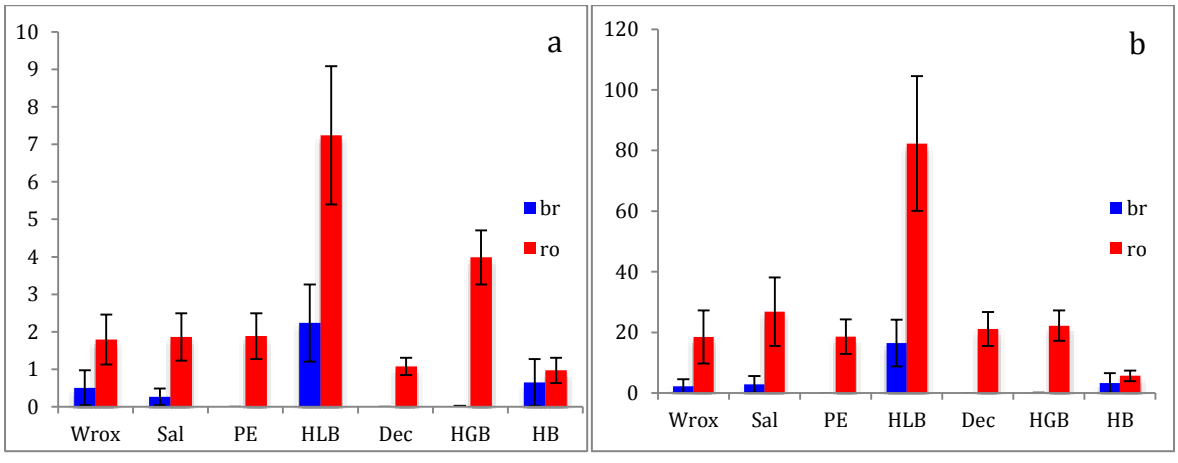

Figure 9a & 9b. Roach and bream mean littoral margin density (ind. m^{-2}) and biomass (g m^{-2}) (± 1 S.E.), all broads. Summer 2016.

3.4.3 Limnetic zone

HGB limnetic zone dominates open water habitat zone biomass estimates (20.08g. m^{-2} ±11.97) with the nearest comparative broad estimate produced from PE (9.53g. m^{-2} ±8.00). The key difference between the estimates is the species that comprise the majority of their respective estimates. In the former, bream are responsible for 98% of the open water biomass estimate, whereas in PE this is totally (100%) attributable roach. PE also produced the highest density estimate (1.214 ind. m^{-2} ± 1.107). Both HLB and Salhouse produced no fish from the open water surveys.

3.4.4 All zones

The channel between the River Bure and HLB (HLBC) produced very high mean density estimates (>52 ind. m^{-2}), dominating the mean density habitat zone all species estimates (Fig. 10a). The littoral margin (HLBLM) was also well represented. Other high densities were provided from the Dam on HGB and HBC. Indeed, the Dam produced the second highest density estimate (>18 ind. m^{-2}) out of all the habitat zones during the summer. The pattern relating to biomass estimates was similar, with HLBC and the Dam dominating mean biomass estimates (Fig. 10b), with HLBC producing the highest of all biomass estimates during the comparative surveys. (580.9g m^{-2} ±201.8).

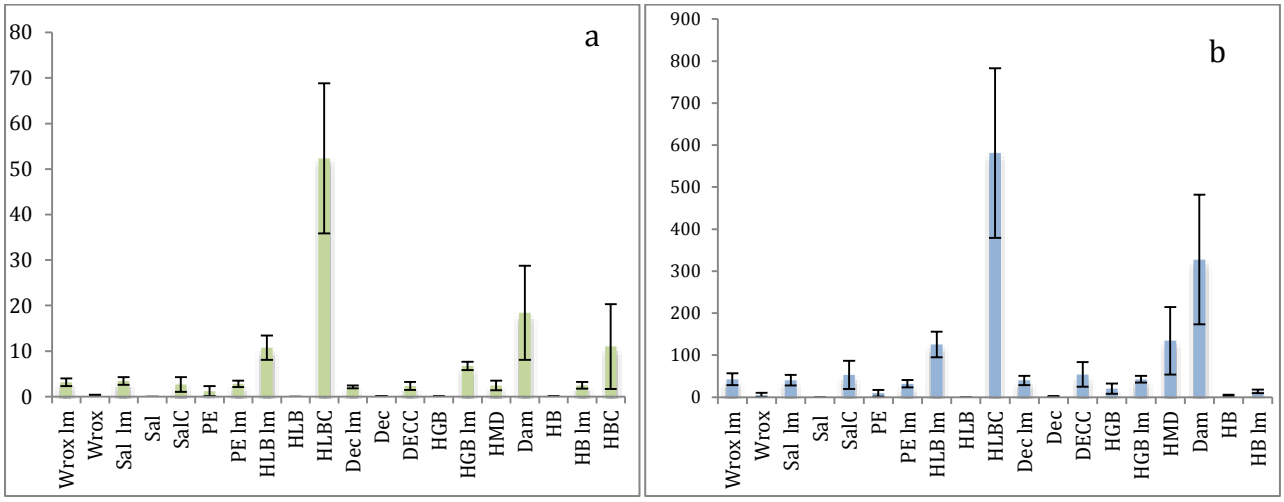

Figure 10a & 10b. All habitat zones mean density (ind. m^{-2}) and biomass (g m^{-2}) (±1 S.E.), all species for all broads. Summer 2016.

Since both the Dam and HLBC are routes onto their respective broads, with flow regimes atypical of the broads themselves, their respective performance, both in terms of density and biomass, would suggest that fish preferentially select these habitat zones above others. This is likely due

to food source transport, reducing metabolic activity during foraging. The deeper water and flow also providing a relatively consistently cooler water temperature, thereby reducing temperature control measures and the necessity of avoidance of elevated high temperatures that can develop within the shallow broads during daytime during the summer.

3.4.5 Relative representation

Roach continue to dominate the all broads community structure in terms of relative density estimates (Fig. 11a). Wroxham maintains its overall highest roach dominance when compared to the proportion of roach in other broads during this period. This is also supported by correspondingly high biomass representation too (Fig. 11b), the highest of all the broads during the summer. The HGB/HB complex maintained overall bream dominance of relative biomass (Fig. 11b), 14% of the relative density (Fig. 11a) producing >69% of the relative biomass, representing a slight shift in bream population from the spring survey (11.9% for 66.9%) (Figs. 5a & b).

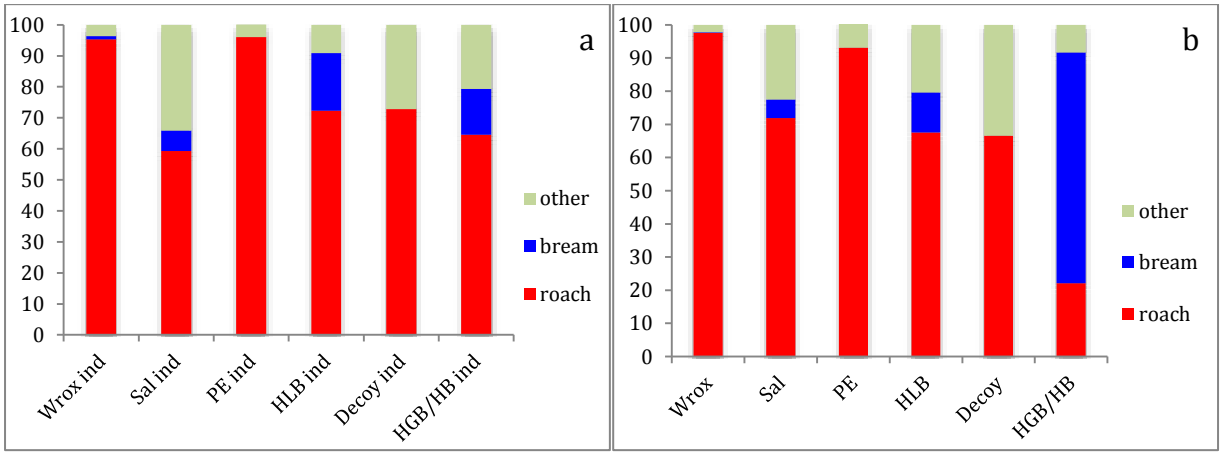

Figure 11a & 11b. Relative (%) overall density and biomass of roach, bream and all 'other' species category. All broads Summer 2016.

Roach dominance of the relative broad fish community ranges from 59% in Salhouse to between 95 & 96%, Wroxham & PE respectively (Figs. 12a, b & c). Perch produced good representation in Salhouse, probably more suited to the alder scrub lined littoral margins than other species. A surprise catch of 8 rudd in the littoral margins produced their representation within the assemblage. Despite being captured deep in the tree covered margin this is atypical for the species, preferring better quality habitat and there appears to be no reason why they would be found in this particular broad, given the reduced habitat opportunities it provides.

Bream representation was quite good in HLB, where they comprised 18% of the fish community by relative density (Fig. 12d). The channel leading onto the broad produced half the catch of bream of the littoral margin.

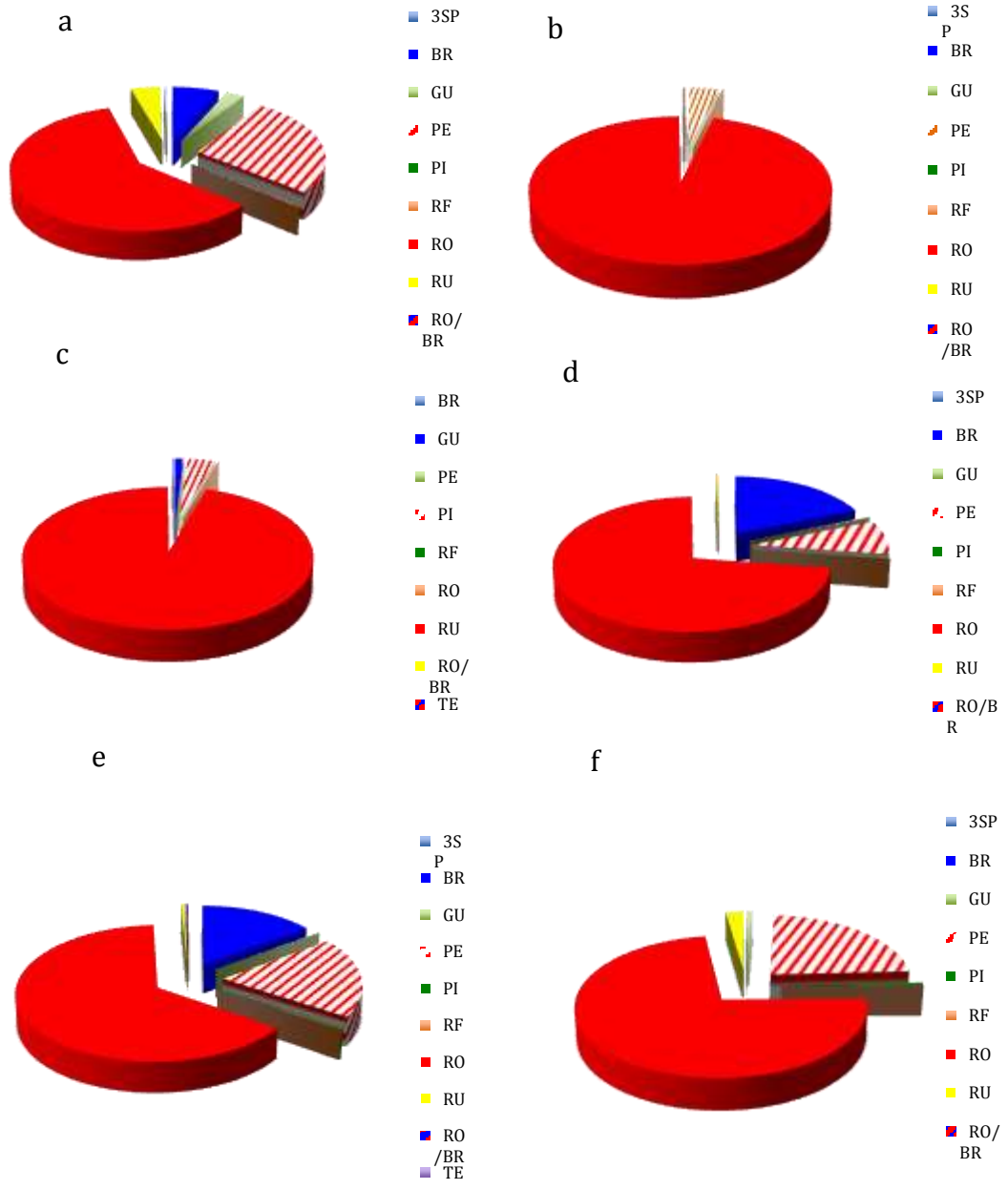

Figure 12a -12f. Composition of the fish assemblage by relative (%) density. Salhouse(a), Pound End(b), Wroxham(c), Hoveton Little Broad(d), Hoveton Great Broad(e), and Decoy(f). Summer 2016.

HGB/HB complex also produced a fair representation of bream in relative density estimates for the fish community (14.7%) (Fig. 12e). However, the relative biomass figures demonstrate the difference between HGB/HB and HLB in their usage by the bream community. HGB/HB produce higher estimates of biomass for a given density in comparison to HLB (69% vs 12% relative biomass (Figs. 12d & e)), showing that adult bream prefer HGB/HB complex and are less commonly found in HLB, despite the presence of smaller conspecifics on that broad (Figs. 12d & e).

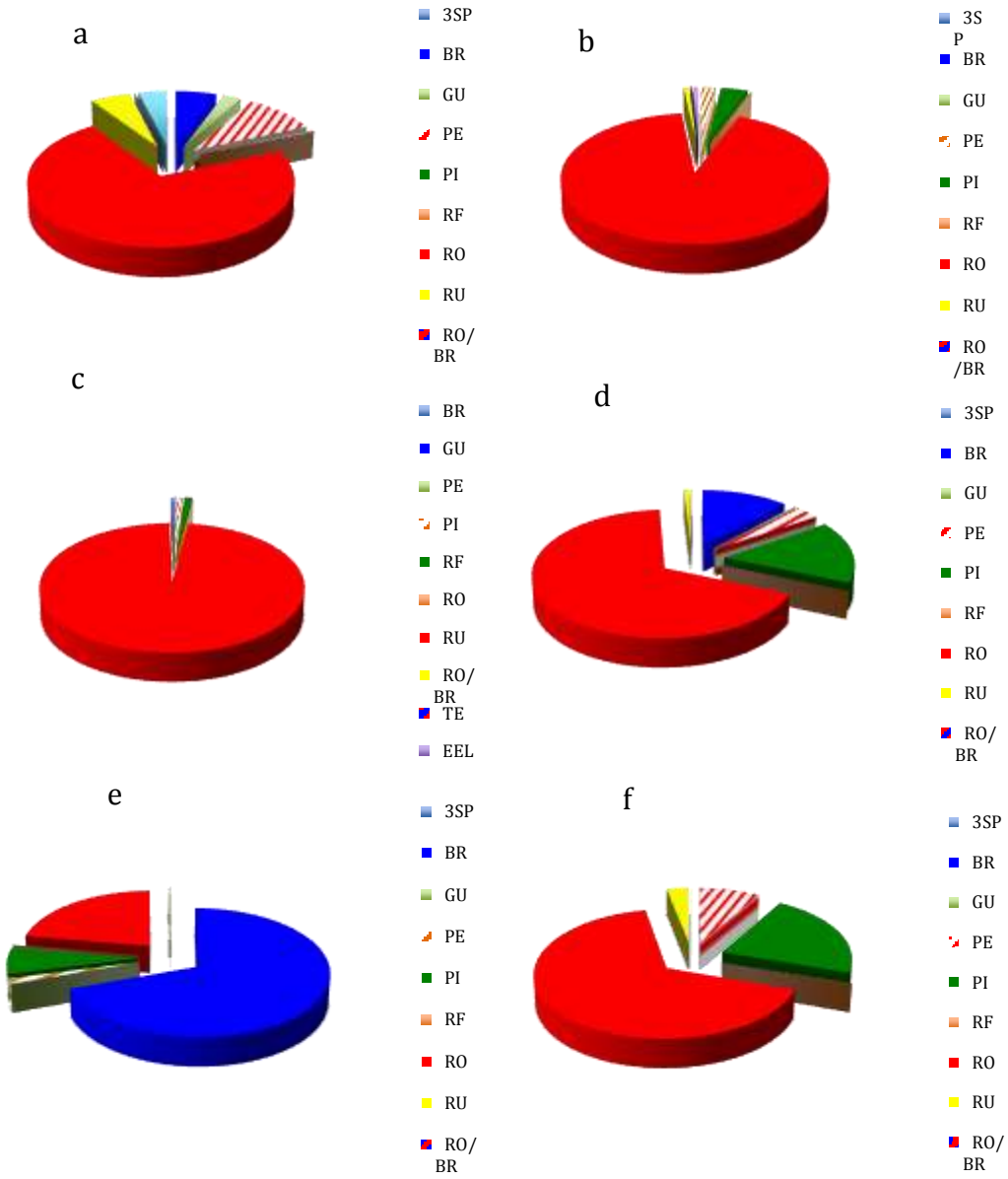

Figure 13a – 13f. Composition of the fish assemblage by relative (%) biomass. Salhouse(a), Pound End(b), Wroxham(c), Hoveton Little Broad(d), Hoveton Great Broad(e), and Decoy(f). Summer 2016.

Pike representation, always low in relative and actual density estimates, often produce disproportionately elevated biomass estimates due to their relatively large body size. In HLB and Decoy they produce 16-22% relative biomass (Figs. 13d & e) from relative density of 0.16% & 0.69% respectively (Figs. 13 d & e).

The surprise catch of the summer surveys were dace. Wroxham littoral margin produced 5 dace between 91-106mm (fork length) from a single spot adjacent to the upstream entrance to the broad, tight against the margin. Dace are not a regular fish in the wider broads assemblage. They usually occur in relatively fast flowing sections of rivers with clear water conditions and gravel substrates on which to spawn (Wellby in Davies et al, 2004), conditions contrasting with the habitat of the Broads. Records of Broads' surveys (EA) reveal no dace captured over the past 20+ years, indicating the uniqueness of this capture. Apart from the stony substrate over which they were captured, no explanation as to why they were there can be ventured, since they are an early spawner and long past their spawning season.

3.5 Autumn

3.5.1 Overall

HGB/HB dominated the all species combined mean density estimates as well as those for roach (Fig. 14a). Indeed, it is clear that the all species category was heavily influenced by the presence of roach (90%). Such strong roach density estimates on HGB/HB during this time of year when most broads are showing a drop of in density, would suggest that these fish are likely to remain within the complex, seeking out secure habitat in which to overwinter. The exception, or partial exception, to this hypothesis is Salhouse, where an elevated bream density and better roach density than all the other remaining broads would suggest a similar situation occurring. However, given the paucity of habitat in Salhouse broad, this is extremely unlikely to be so for bream. Autumnal elevated bream densities, typically considered being as a result of fish not yet left for overwintering areas, would suggest this is true for the bream present in Salhouse.

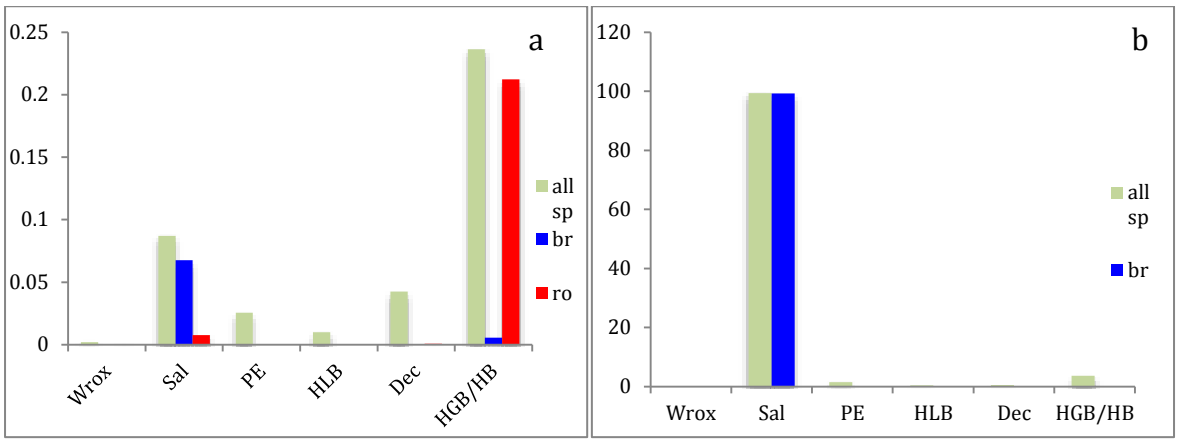

Figure 14a & 14b. Overall mean density (ind. m^{-2}) (a) and biomass (g m^{-2}) (b), roach, bream and all species combined, all broads Autumn 2016.

Given the paucity of suitable deeper water fish habitat for larger fish, it is more likely that these are generally adults with a lack of deeper habitat in which to retreat to during autumn and winter, and therefore more susceptible to capture from PASE and present in open water habitats. The chance capture of 5 adults (mean fork length 421mm, mean weight >1.4kg; range 388-452mm, 1.1-1.8kg) would tend to support this. The open water capture of bream contributed >99% of the overall mean all species combined biomass estimate (Fig. 14b) Alternatively, presence of these fish could be explained that these particular fish are foraging wider and not overwintering. This is a choice that older, larger fish are able to make and still survive the winter, unlike their smaller conspecifics.

Roach density estimates in Salhouse are generated by the presence of numbers of roach present in the Salhouse channel, a heavily over-shaded dyke leading off the main broad, providing suitable overwintering cover for limited numbers of fish. Water depth decreases notably along this channel, reducing the attractiveness as an overwintering habitat and also the survival chances for overwintering fish during cold weather. The shallowing water physically prevents larger fish, such as adult bream, taking advantage of the habitat further upstream. Fish tend to aggregate in pockets of good habitat and it is encounters with these that produce high variance around mean estimates. Where clumped distributions exist there is always a possibility of missing these during the structured sampling regime. Sampling a wider distribution results in more even sampling encounters, lower variance and sometimes, a higher overall mean density estimate.

3.5.2 Littoral zone

During the autumn surveys HB dominates the roach littoral zone mean density and biomass estimates (Figs. 15a & b). Both PE and HLB perform poorly during this season. It is perhaps surprising that PE was outperformed by Salhouse and this is attributed to the shallow water conditions that prevail along the majority of the littoral margin in PE. The lack of water depth and the comparative lack of cover during this time provide poor refuge from predation, and it is perhaps this that drives the shift in littoral margin roach distribution. Salhouse's, also poor marginal habitats do provide a degree of overhead cover in some locations.

In general, bream were largely absent or poorly represented in the autumn surveys, both in terms of density and biomass. Salhouse and HGB were the only two broads producing modest littoral margin estimates, the remainder being poor performers (Figs. 15a & b).

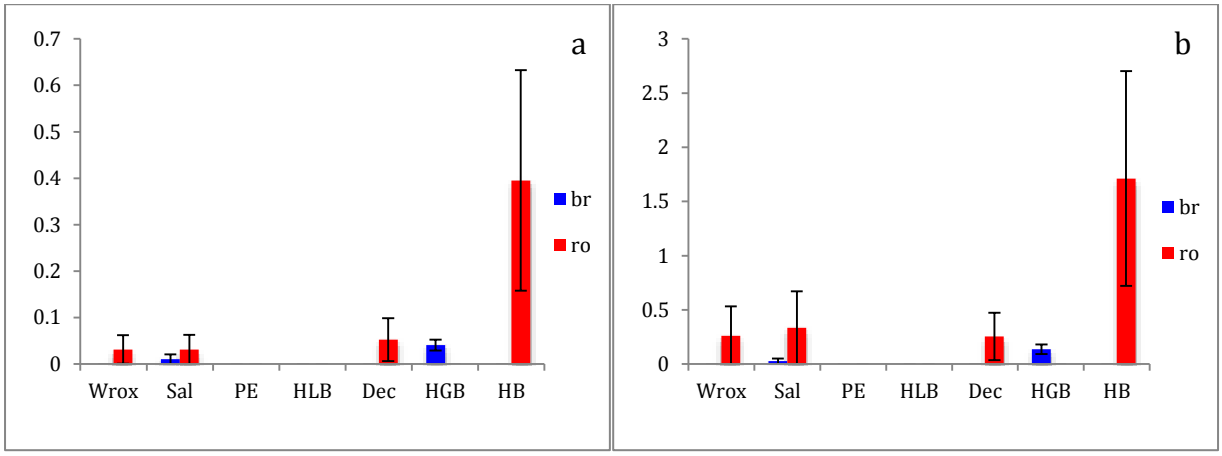

Figure 15a & 15b. Roach and bream littoral margin mean density (ind. m^{-2}) and biomass (g m^{-2}) (± 1 S.E.), all broads. Autumn 2016.

3.5.3 Limnetic zone

Only a third of the broads produced density and biomass estimates from their limnetic zones. Salhouse produced the highest density (0.069 ind. m^{-2} ±0.069) and biomass (101.47g. m^{-2} ±101.47) estimates. The measure of variance surrounding the mean estimates indicating the catch was achieved in only a few sampling points. In this case all fish were caught in a single point. They were adult bream ranging between 388mm-452mm fork length. Decoy produced estimates of density and biomass that were totally comprised of perch.

3.5.4 All zones

During autumn, HGB habitat zones dominated the mean density estimates, specifically the Dam and HBC (Fig. 16a). Distribution was clumped, often indicative of this time of year when fish are either overwintering or preparing to do so. Smaller size classes of fish typically shoal in tighter formation during the overwintering period, often in mixed species shoals. Habitat also influences fish distribution and shrinking habitats due to the early onset of winter from vegetation die-back will further exacerbate this. Increased predation also induces such behaviour, though in this case it is probably the least likely scenario. All other zones showed relatively poor estimates. Biomass estimates for the Dam and HBC were also the highest of all the zones, with HBC showing a larger number of smaller fish (Figs. 16a & b).

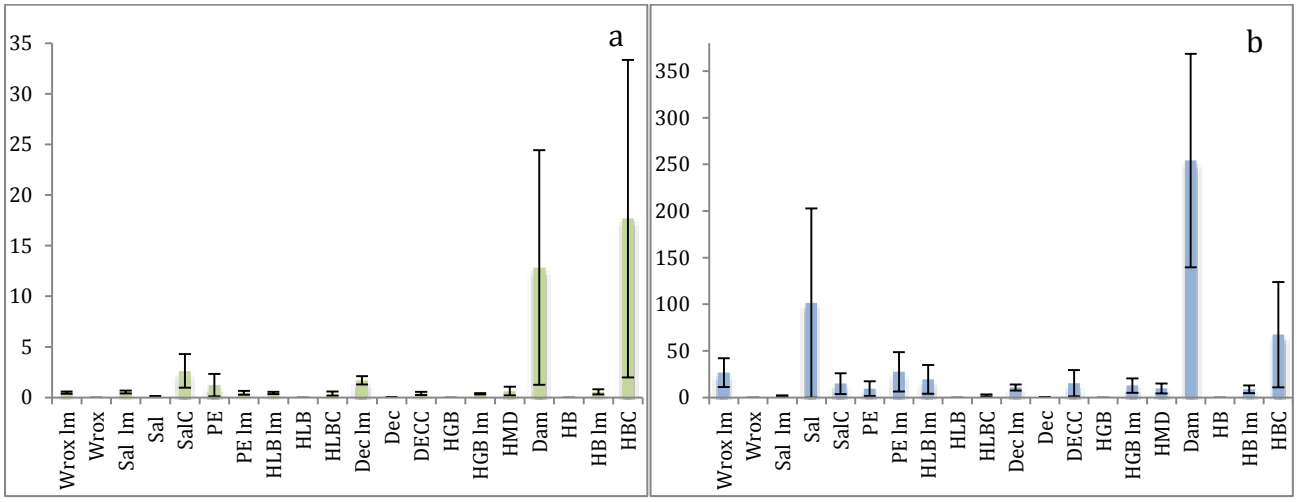

Figure 16a & 16b. All habitat zones mean density (ind. m^{-2}) and biomass (g m^{-2}) (±1 S.E.), all species for all broads. Autumn 2016.

Salhouse produced low density estimates for the various habitats present on the broad, but showed better biomass for the limnetic zone, whereby a number of large adult bream were captured, skewing the mean biomass estimates (Fig. 16b).

3.5.5 Relative representation

The other species category dominated relative density estimates for most broads during the autumn (Fig. 17a), with exception of Salhouse and HGB/HB complex, which were dominated by bream (78%) and roach (90%) respectively.

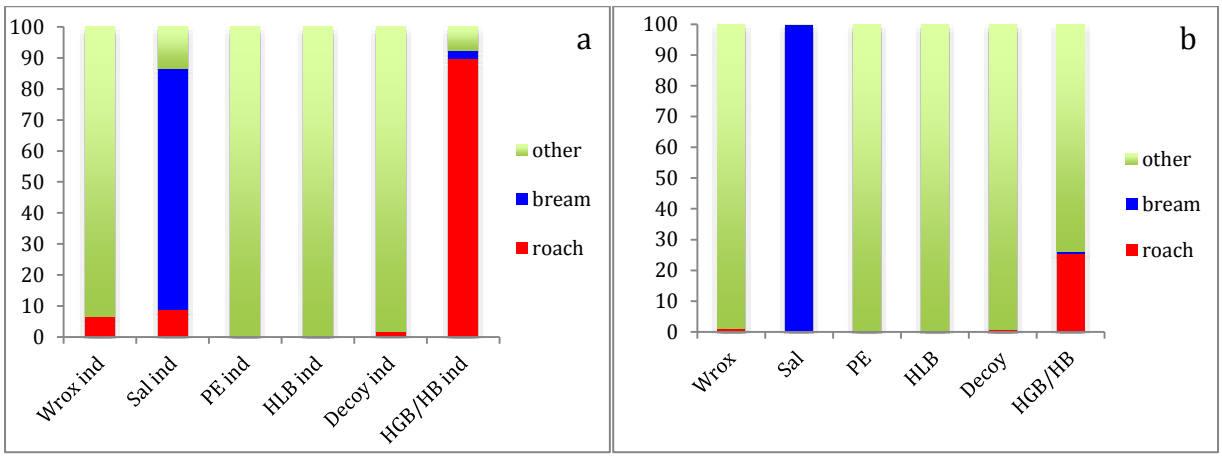

Figure 17a & 17b. Relative (%) overall density and biomass of roach, bream and all 'other' species category. All broads Autumn 2016.

Biomass representation was a similar picture, the exception was HGB/HB where a shift in dominance of roach in relative density to domination of other species in biomass indicates these roach were smaller YOY or juvenile fish, and or the other species were larger, hence increasing their contribution to this aspect of the community. The all species relative assemblage composition reveals perch to be a significant feature of the density representation for other species (Figs. 18b,c,d & f).

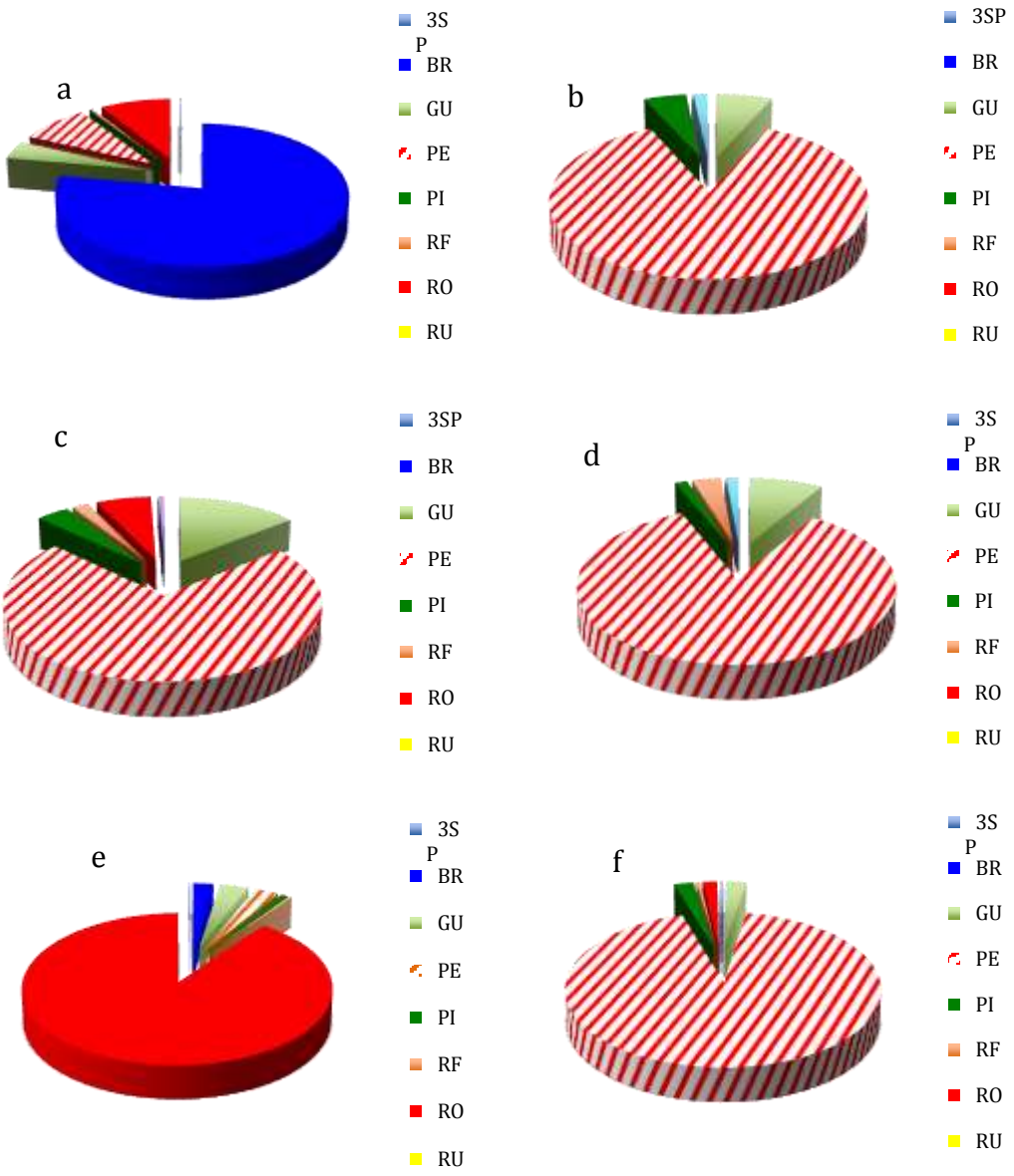

Figure 18a - 18f. Composition of the fish assemblage by relative (%) density. Salhouse(a), Pound End(b), Wroxham(c), Hoveton Little Broad(d), Hoveton Great Broad(e), and Decoy(f). Autumn 2016.

Salhouse fish community, as described by biomass representation, was dominated by bream (>99%) (Fig. 19a). Pike dominated all other relative biomass estimates, ranging from 43% to 90% and contributing, along with perch, substantially to the other species category.

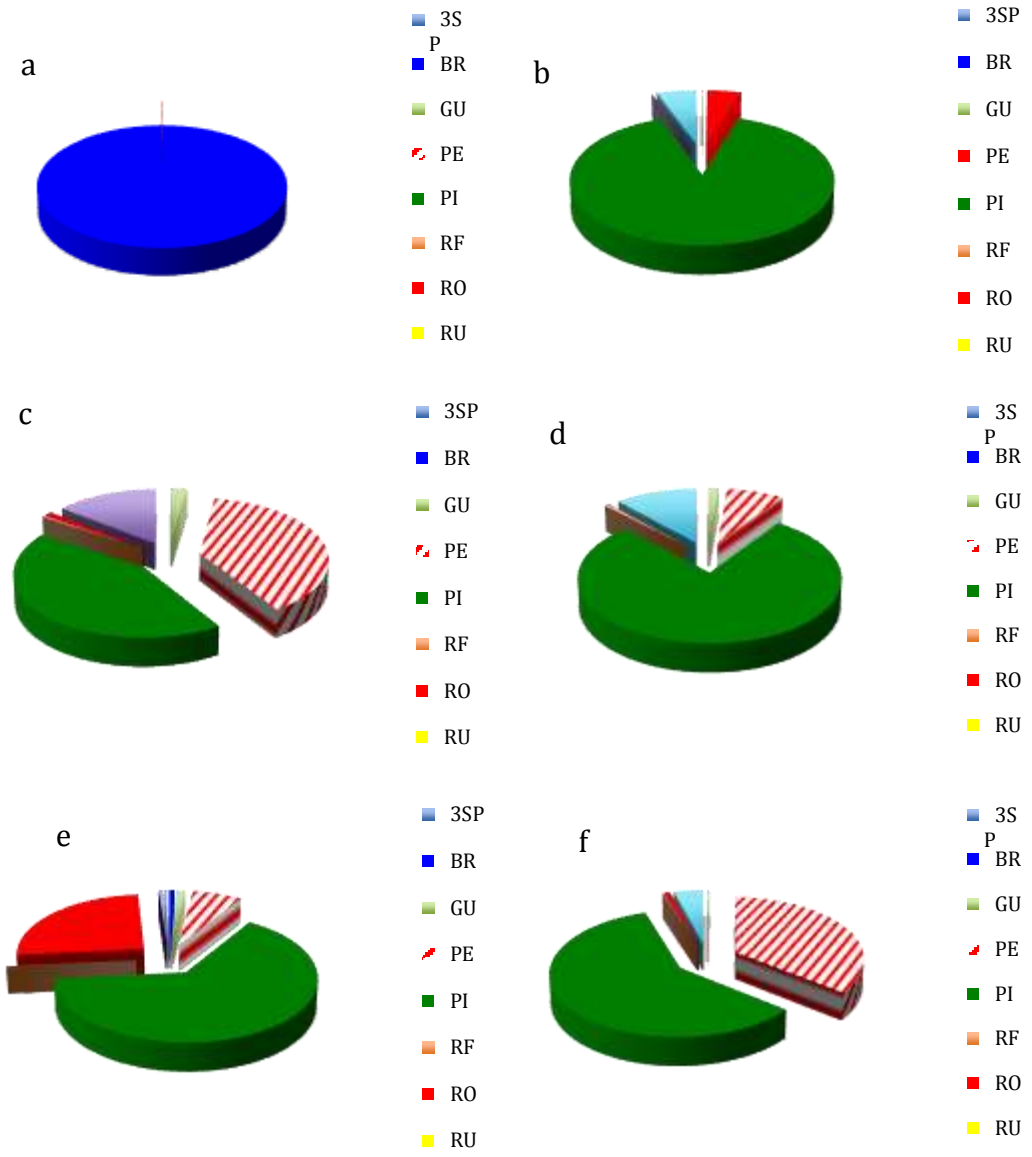

Figure 19a - 19f. Composition of the fish assemblage by relative (%) biomass. Salhouse(a), Pound End(b), Wroxham(c), Hoveton Little Broad(d), Hoveton Great Broad(e), and Decoy(f). Autumn 2016.

The capture of tench on Wroxham, in an area with good macrophyte development at the far north end of the broad, contributed 14% to relative representation in estimated biomass for the broad community (Fig. 19c). Tench, although present within the overall broads fish assemblage, are not a prominent species in terms of their representation.

3.6 Winter

Significant changes occurred prior to the inception of the winter survey specifically on HGB/HB. Land and Water, contracted for the dredging component were on the broad, having established a base and a series of work pontoons and platforms. Early dredging and piling operations had commenced and areas of the littoral margin were not accessible during this time. During this process, there were substantially more boat movements by powered craft operating in the Gate section of the broad and some localised changes to the margins in discrete areas. Further changes were in place around the Dam, where the wood stakes had been removed and steel gates installed. The in-stream structure of woody debri provided by fallen trees had also been cleared. In addition to this some tree trimming had taken place on HBC. The net results of this work were: impacts upon the fish community accessing some marginal areas. Impacts upon fish from noise, disturbance and sediment re-suspension during operations. Noise and disturbance from powered craft, though difficult to quantify, does impact upon fish behaviour and movements. Previous work identified disturbance of adult bream in open water from around 3 meters (Hindes et al, 2015). Trimming scrub in HBC has strongly impacted both the fish population and their distribution within this channel. Fish appeared to be more clumped in their distribution, remaining faithful to a discrete area within the HB end of the channel. However, analysis of the variances reveals that with exception of spring, where variation was 48% of the mean estimate, variation remained between 81 and 81% of the mean estimates during all remaining seasons for 2016. However, fish behaviour did change. The behaviour and activity of these was fish manifestly agitated, with fish undertaking jerky, dis-coordinated movements and flipping at the water surface. Previous observations revealed unhurried steady swimming away from the boat. The former activity is costly in terms of energetics during a time (winter) when small fish are usually more torpid and less energetic to preserve energy and fat reserves by reducing metabolic activity. The later is the converse of this, and will have a detrimental affect to the overwintering survival of these fish.

3.6.1 Overall

Lowest densities were, perhaps unsurprisingly for the large part, during winter. However, notable exceptions to this were PE and HGB/HB, which produced their lowest densities during autumn, suggesting an exchange in fish for those using parts of the complex for overwintering.

The HGB/HB complex dominates the overall all species combined and roach categories of the mean density estimates (Fig.20a). Biomass estimates are also adversely influenced by season, with winter producing poor results from all broads except PE and HGB/HB complex Fig. 20b).

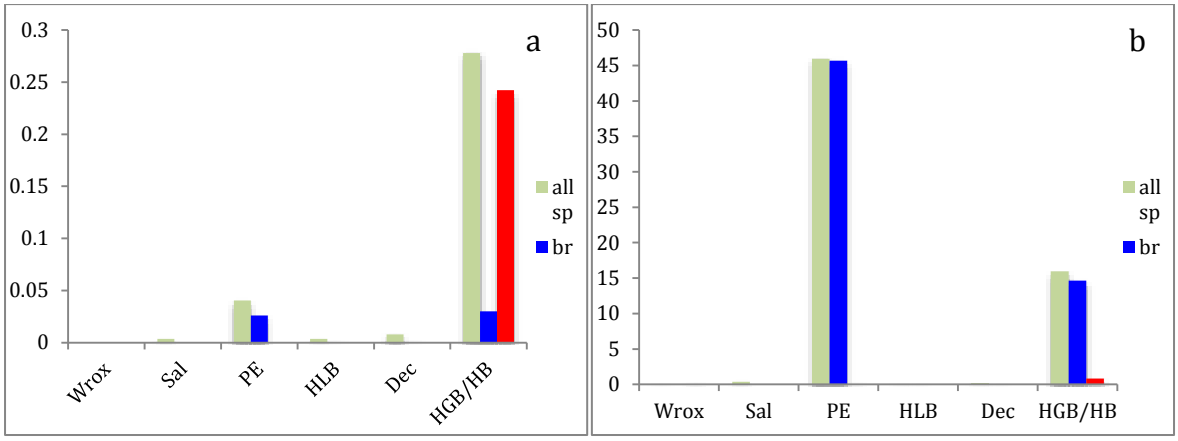

Figure 20a & 20b. Overall mean density (ind. m^{-2}) (a) and biomass (g m^{-2}) (b), roach, bream and all species combined, all broads Winter 2016.

The data suggest HGB/HB had adult bream present on the broad during this time. The same is true for PE where open water capture of large adults have a profound influence on the estimates, contributing >99% to the all species combined estimate.

3.6.2 Littoral zone

Most broads perform poorly during the winter surveys with poor density estimates for all broads with the exception of roach on HB (Fig 21a). Biomass estimates are also adversely influenced by season, with winter producing poor results from all broads except HB (Fig. 21b), and HGB, though to a much lesser extent.

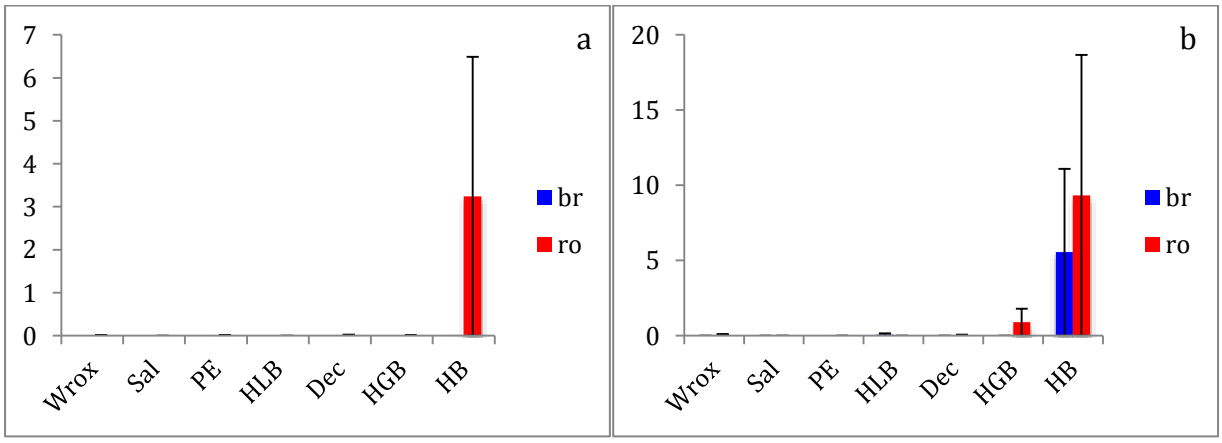

Figure 21a & 21b.. Roach and bream littoral margin mean density (ind. m^{-2}) and biomass (g m^{-2}) ($\pm$ 1 S.E.), all broads. Winter 2016.

The low-density estimate for bream during the winter survey on HB produced higher biomass estimates, indicating presence of larger adult fish.

The data suggest that with exception of HB, the broads are not widely used during the winter months, suggesting that these fish overwinter elsewhere, are within other zones of the broads, or are deeper within the system and remain undetected by PASE surveys. Thus, the HGB/HB complex would appear to be utilised by bream throughout the seasons including during winter months. It is highly likely, the fish that utilise this habitat are not overwintering fish as such, but part of the component that remains active during the winter months in all but the coldest conditions. Such large fish are capable of surviving winter in this manner, remaining modestly active, regulating their energy usage and foraging where feeding is either good or easily obtained, order to minimise energy debt in favour of net gain rather than expenditure. It is relatively unusual to find large bream in the littoral margins, their preferred habitat being the limnetic zones. It is assumed that the above strategy is deployed for their presence to be detected in this habitat.

3.6.3 Limnetic zone

Only HGB and PE open water habitats produced any density (0.009 ind. m^{-2} $\pm$ 0.009 & 0.028 ind. m^{-2} $\pm$ 0.028 respectively) or biomass (17.38g. m^{-2} $\pm$ 17.38 & 48.33. m^{-2} $\pm$ 48.33 respectively) estimates. Both were as a result of capture of adult bream in single sampling points, and in each case it was two fish at each sampling point that comprised the capture.

3.6.4 All zones

Typical broads feature of density data are the virtual absence of fish, particularly in the littoral and channel habitat zones during this time of year. Exceptions to this are the HBC data, whereby mean all species density and biomass estimates completely dominate all other broads and habitat zones (Figs. 22a & b). The large measure of variance surrounding both mean estimates indicate the clumped distribution of the fish, even within the confines of this channel. This suggests that further microhabitats do indeed exist within habitat zones in broads. Thus, fish distribution can be both specifically tied to a zone, but tightly clumped within that zone, the fish exploiting habitats and making full use of the shelter or foraging that it provides. This lends

weight to the argument for detailed assessment of broads, segregation of areas into discrete habitats where they may influence fish distribution, all in order to adequately identify key areas that may require or benefit from protection or careful, considered management in order not to adversely impact upon the fish stock.

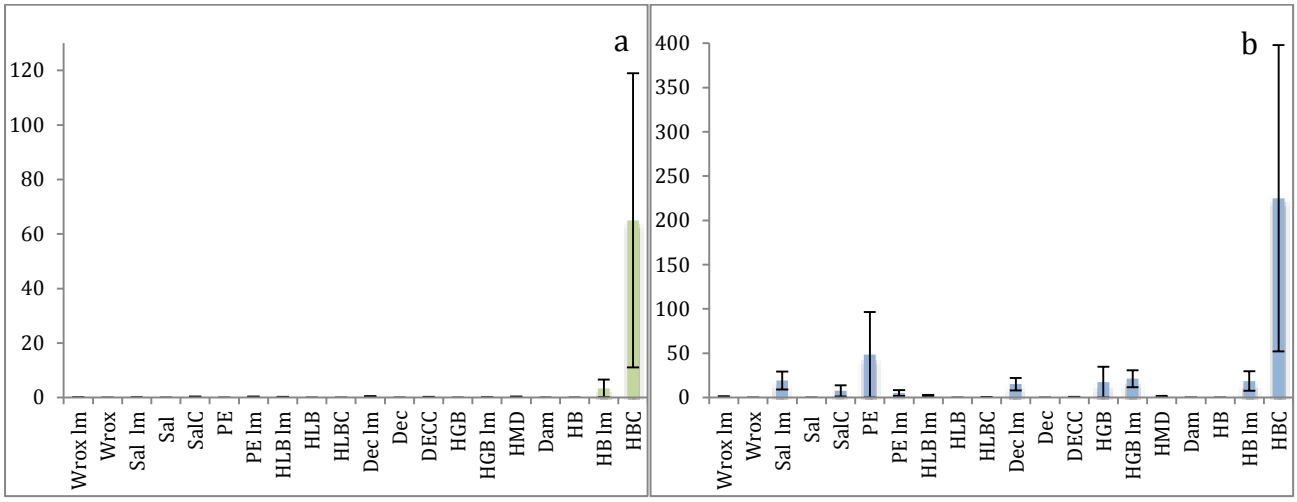

Figure 22a & 22b. All habitat zones mean density (ind. m^{-2}) and biomass (g m^{-2}) (±1 S.E.), all species for all broads. Winter 2016.

3.6.5 Relative representation

As bream and roach presence on the broads decline during the winter season, the 'other species' category becomes elevated to dominate most estimates (Fig. 23a). Exceptions of PE which bream dominated due to open water capture of several fish on a single point, and roach because simply put there are more roach than most other species still on the broad

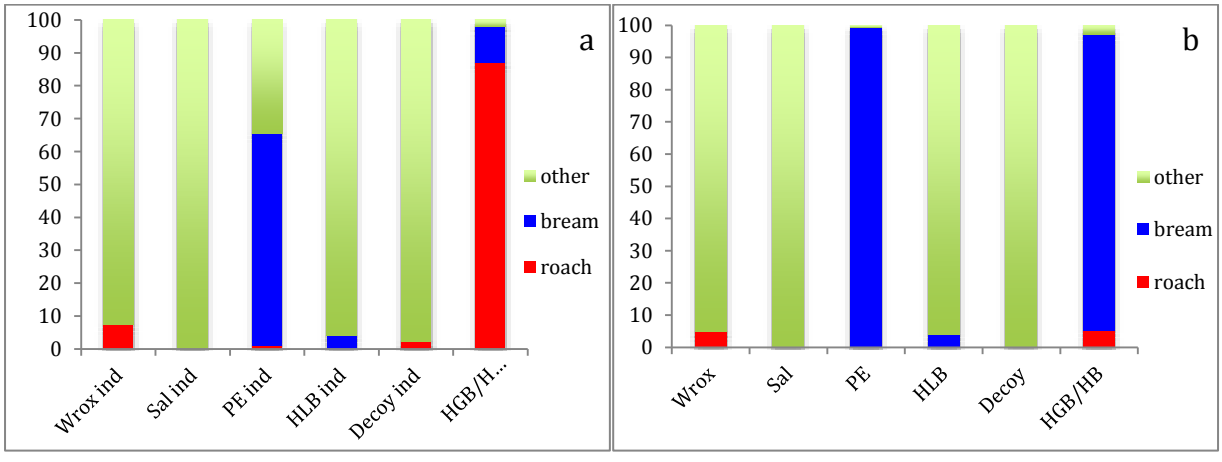

Figure 23a & 23b. Relative (%) overall density and biomass of roach, bream and all 'other' species category. All broads Winter 2016.

The PE 'other species' relative density category are strongly influenced by perch which contributed 29% to the estimate (Fig. 24b). The presence of adult bream on HGB/HB is supported by the relative representation within biomass estimates (92%)(Fig. 23b). Pike relative density representation was high on Salhouse (20%). It is more typical for pike to produce lower relative figures, typically between >1%-10%. Further analysis reveals that the declining cyprinid stocks elevate the pike presence as opposed to the pike density increasing

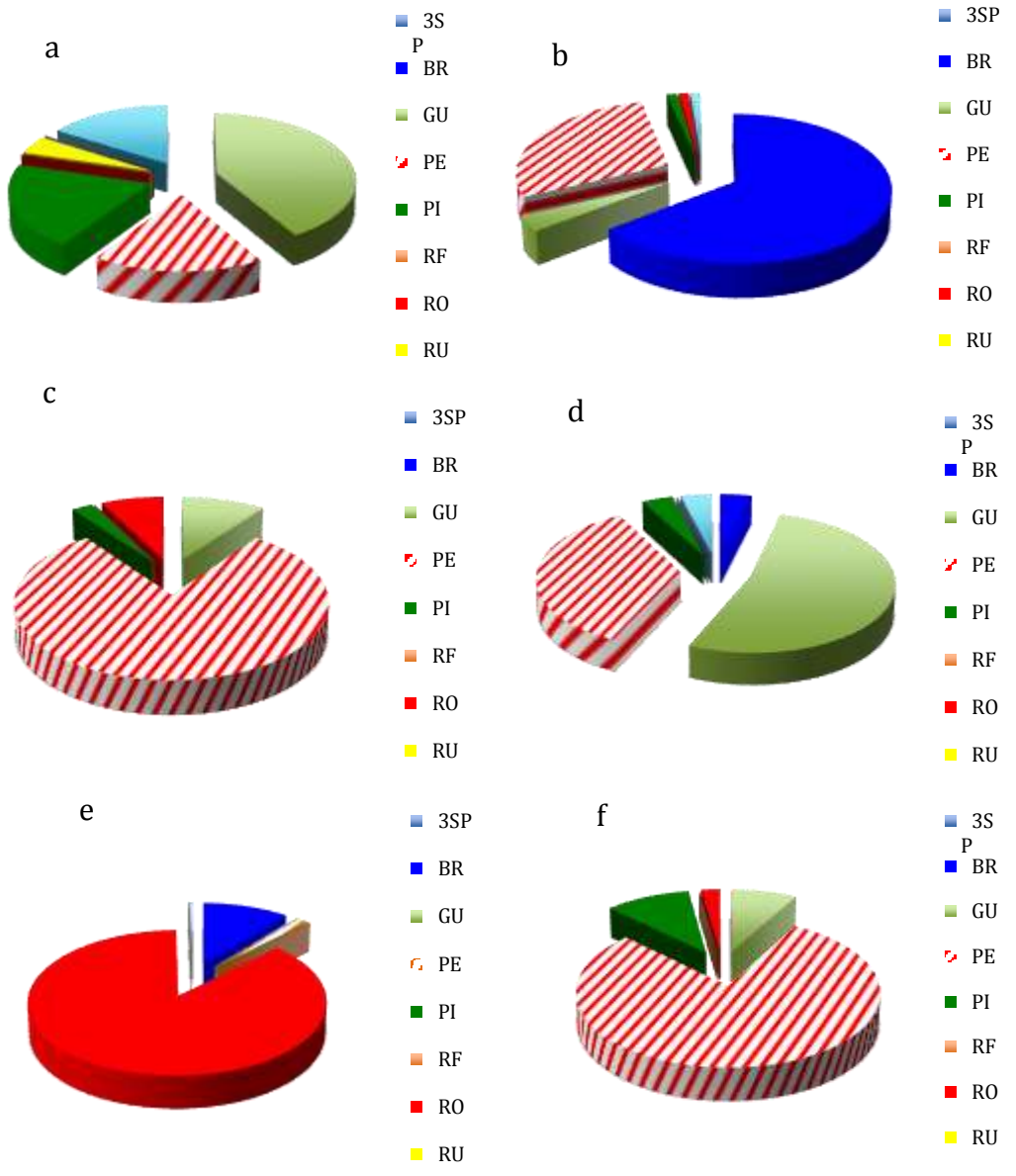

Figure 24a - 24f. Composition of the fish assemblage by relative (%) density. Salhouse(a), Pound End(b), Wroxham(c), Hoveton Little Broad(d), Hoveton Great Broad(e), and Decoy(f). Winter 2016.

The Perch dominated both Wroxham and Decoy relative density estimates during the winter (80% & 79% respectively) (Figs. 24c & f). Surprisingly, gudgeon provided robust representation in both PE and HLB, or rather the paucity of fish and the increased presence of gudgeon combined to produce the estimate (Figs. 24a & d). It is probable that the gudgeon population has not actually increased, rather their status is more likely to remain relatively static. The observed effect is more likely to be as a result of increased visibility, in the absence of cyprinids, leading to increased capture and hence elevation in relative density estimates.

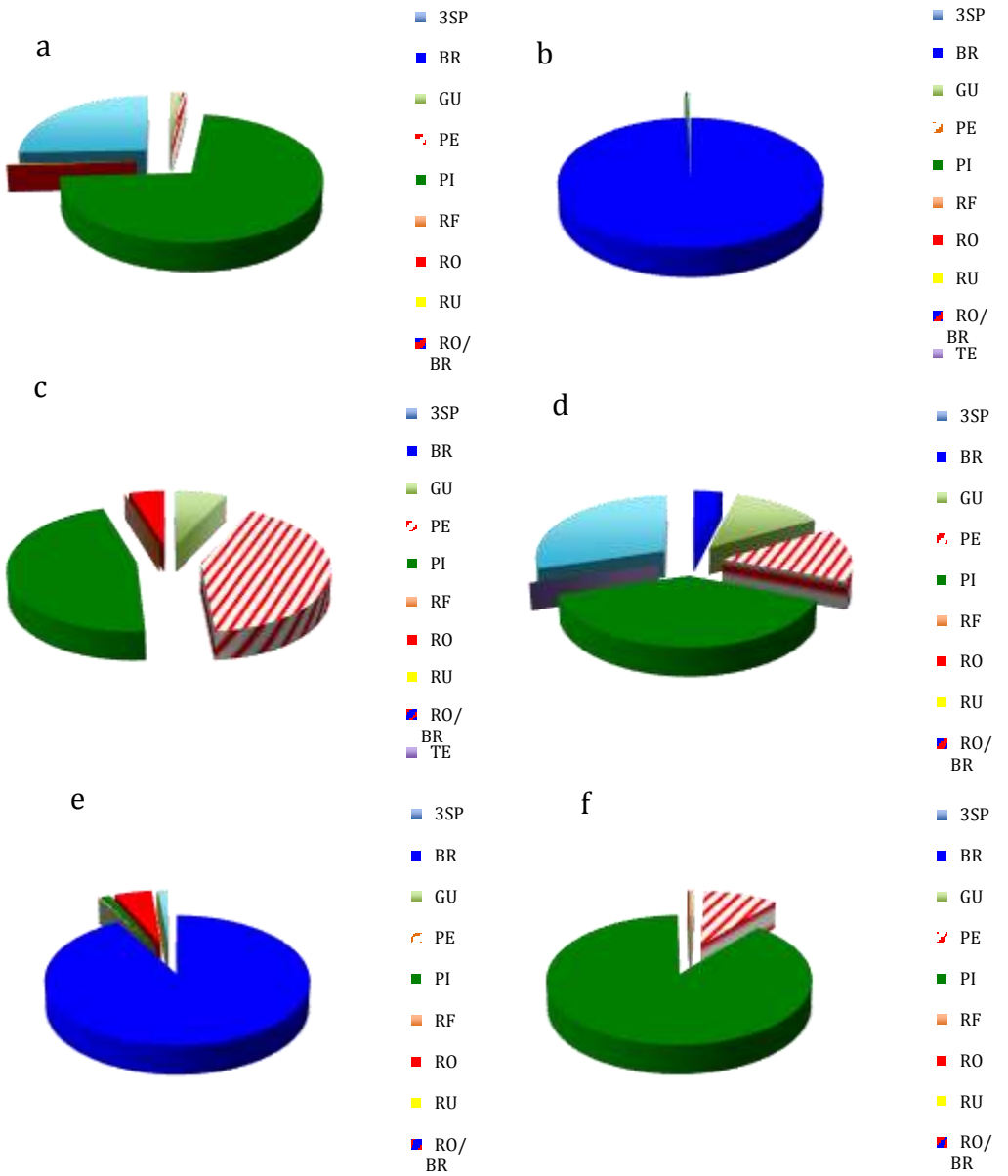

Figure 25a - 25f. Composition of the fish assemblage by relative (%) biomass. Salhouse(a), Pound End(b), Wroxham(c), Hoveton Little Broad(d), Hoveton Great Broad(e), and Decoy(f). Winter 2016.

The pike population would appear to be prevalent during winter. However, this effect is merely the paucity and small size of the silver fish elevating the status of the predatory pike. Thus, pike dominate relative biomass of Salhouse and Decoy (72% & 89& respectively (Figs. 25a & d), two broads with low density estimates, and have a substantial influence on relative biomass estimates of Wroxham and HLB (Figs. 25c & d).

4 Conclusions

- The HGB/HB complex dominates all other comparative broads for whole broad density estimates over all four seasons indicating its importance for broads fish populations

- Spring and summer whole broad density estimates are dominated by the HGB/HB complex over all the other comparative broads in the survey. Thus, the HGB/HB complex is a key spawning site for the immediate area and potentially important to the River Bure system. The picture is less clear during autumn and winter, suggesting that larger fish that can skew limnetic estimates are free to travel and frequent several broads during winter. MHRSA data would be able to determine this

- The principal components of the cyprinid community, roach and bream, are also the most numerous species during spring and summer surveys and dominate density estimates in all seasons for HGB/HB, indicating their importance and influence on the fish assemblage both within the HGB/HB complex as well as the wider system.

- HGB/HB is the most important broad for spawning bream and roach. Direct evidence substantiates bream spawning activity and indirect evidence suggest likewise for roach

- The persistent presence of roach on HGB/HB during autumn and winter suggest these fish do not leave the broad. Thus, the HGB/HB complex also serves as an overwintering location for roach and probably other smaller bodied fish species

- Loss of access to the habitats that exist within HGB/HB will impact upon the roach population which show evidence of overwintering in the complex and upon the bream community, which use the broad for spawning in substantial numbers (2014-2015)

- HGB/HB complex does not appear to be unique for pike in comparison to other broads in the dataset

- PE, HLB and HGB are important for roach during spring. This suggests that these broads are spawning sites

- Large adult roach have been captured during limnetic surveys of Wroxham broad, but in a discrete area of the limnetic zone adjacent to Wroxham House. Few large adults are seen on HGB/HB except in HMD, adjacent to the Dam stakes and Gate entrance. Despite evidence that roach spawn within the HGB/HB complex, larger adult fish are rarely seen or captured. Their distribution appears to be restricted or the timing of surveys misses their presence on the HGB/HB complex. Previous survey work (2013-2015) found larger adults present in HMD though this has not been consistently so. Thus, the roach population dynamics on HGB/HB remains partially unexplained at present

- HBC is a very important habitat zone for fish during most times of year and especially so during winter. Changes to the habitat structure have a marked influence upon fish behaviour and distribution

- Salhouse, despite the paucity of habitat, produced reasonable fish estimates, albeit with influence from chance limnetic encounters. Nevertheless, it does indicate the limnetic zone is utilised by larger adult fish on occasion during daylight hours. Paucity of littoral marginal habitat and anthropogenic disturbance reduces the ability of the broad to produce decent fish estimates

- Wroxham is roach dominated. However, data from MHRSA has revealed a large shoal of bream resident for a few days occurring during 2016. This data remains unprocessed at

present, but would suggest that bream do make use of the flow into the broad from the river or perhaps to lie up between foraging periods

- HLBC provides both refuge and foraging opportunities to fish at specific times of the year. Early season (spring) saw large adult roach, rudd and bream present in the channel margins

- HLB appears to be unattractive to adult bream, though they access PE through this broad. Only small shoals have been observed on Decoy and only by MHRSA and not PASE

5 Recommendations

5.1 Bream spawning

- Quantifying HGB/HB bream spawning activity is essential to understand the scale and distribution of the event

- Evaluating HGB/HB spawning sites to determine what bream are spawning on and to what extent, identifying preferences that may exist

- Developing and constructing artificial spawning substrate to trial on bream spawning grounds. Trialling artificial spawning substrate to evaluate selection and performance efficacy. This should be considered as any mitigation will likely require augmentation or early initial deployment whilst establishing mitigation measures for spawning substrate

- Identification of other spawning sites and broads, places the spawning effort of bream into context and shapes the extent and location of any mitigation measures

- Assess littoral marginal habitat for fish spawning in all comparative broads. Produce a model to assess habitat quality and identify habitat fragmentation

- Identify habitat creation opportunities simultaneously from marginal habitat assessments. These may be utilised in potential mitigation measures, offsetting loss of spawning habitat from the isolation of the HGB/HB complex.

5.2 Roach

- Loss of access to the habitats that exist within HGB/HB will impact upon the roach population during the winter period. Loss of overwintering habitat should be assessed for opportunities to develop new ones or increase viability of existing ones elsewhere within the system
- Determination of roach spawning effort on HGB/HB. Indirect evidence suggests that roach spawn in the complex, but at present we have no direct evidence for this. Quantifying roach spawning during spring should be considered with a similar effort on the next highest performing comparative broad, since this will place the issue into context and will shape decisions regarding whether mitigatory measures are required or not.

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