River Wensum Restoration

Fish Monitoring Report

Client: Environment Agency
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EXECUTIVE SUMMARY

The River Wensum is a chalk river of significant value for its wildlife, as well as being an important landscape feature of rural Norfolk. The river is recognised nationally through its designation as a Site of Special Scientific Interest (SSSI), and internationally through its designation as a Special Area of Conservation (SAC). In addition, chalk rivers such as the Wensum are a priority habitat of the UK Biodiversity Action Plan (BAP). Unfortunately, the river is not in a pristine state and was classified as 'bad' by the Water Framework Directive (WFD) in 2010/2011, and the SSSI is in unfavourable ecological condition. The reasons for unfavourable condition include inappropriate water levels, water pollution – agriculture/run-off, water abstraction, inappropriate weirs, dams and other structures, invasive freshwater species, and physical modifications to the channel (deepening, widening, and straightening) that impede the river's hydrological functioning.

The River Wensum Restoration Strategy has been developed by Natural England, in partnership with the Environment Agency (EA) and the Water Management Alliance, with the aim to restore the physical functioning of the river so that it can sustain the wildlife and fisheries characteristic of a Norfolk chalk river, across numerous sites in Norfolk (11 so far). The main restoration works implemented within the strategy included narrowing the channel, restoring gravel beds (through gravel introductions and mobilising fine sediments to clean historic gravel beds by increasing velocities), reductions in impoundment, reconnecting the floodplain, improving channel sinuosity, and increasing the amount of large woody material in the channel. Following restoration work, the Wensum has been classified as 'moderate' by the WFD.

The EA commissioned Fishtek to undertake an analysis of the EA fish survey data to determine if it was possible to identify improvements in stocks following the restoration works.

Through analysis of EA fish survey data from within the restored reaches, it appears that most species of fish were generally more abundant post restoration. Trout, dace, bullhead, stone loach and minnows appear to have benefited the most from the restoration schemes, with bullhead increasing in abundance and biomass at 86% of the sites. It is likely the works have improved the area of suitable habitat for the above species, by providing more cover from predators, food, juvenile and spawning habitat that has in turn improved their populations.

The gains were however not ubiquitous; eel, pike, roach and perch tended to decrease in abundance following restoration works, and chub, pike and perch tended to decrease in biomass. Looking at the changes in standing crop (biomass) following restoration in isolation may come as a surprise as at 60% of the sites standing crop biomass was lower than before restoration took place. This reduction in biomass however should not be taken as the restoration works having a negative impact on fish as there are many variables that help determine fish populations.

These results should be interpreted cautiously; it is not possible to isolate the impact of restoration works from wider, catchment scale changes or other variables, due to the nature of the data that was available.

Despite this, these results are consistent with comparable river rehabilitation initiatives elsewhere, and although mostly positive, they suggest that larger-scale rehabilitations are probably needed to produce greater increases in fish density and diversity. It is likely that a greater response in changes to fish communities will be observed following the completion of the catchment-scale initiatives currently taking place on the Wensum, which will likely enable and enhance ecosystem recovery.

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1. INTRODUCTION

The Environment Agency (EA) has commissioned Fishtek Consulting to produce a technical report assessing the changes to fish communities across eleven river restoration sites on the River Wensum and River Tat.

The specific aims of the study are to:

- Where possible, produce an assessment of the fish community present at each site before and after restoration works took place, including:
    - Changes in the diversity or species composition
    - Identification of which species may have benefited (or dis-benefited) in relation to the restoration work
    - Changes in biomass and/or numbers of fish
    - Evidence of breeding success / recruitment
    - Comparison between restoration sites and nearby “control” sites
- Assessment of the aspect of the works that are likely to have caused the change in fish community.

2. BACKGROUND

The River Wensum is a chalk river of significant value for its wildlife, as well as being an important landscape feature of rural Norfolk. The river is recognised nationally through its designation as a Site of Special Scientific Interest (SSSI), and internationally through its designation as a Special Area of Conservation (SAC). In addition, chalk rivers such as the Wensum are a priority habitat of the UK Biodiversity Action Plan (BAP). Unfortunately, the river is not in a pristine state and is classified as bad by the Water Framework Directive (WFD), and the SSSI is in unfavourable ecological condition. The reasons for unfavourable condition include inappropriate water levels, water pollution – agriculture/run-off, water abstraction, inappropriate weirs, dams and other structures, invasive freshwater species, and physical modifications to the channel (deepening, widening, and straightening) that impede the river’s hydrological functioning.

Consequently, a number of projects/initiatives are in place to remedy these pressures. Water quality issues are being addressed by phosphate removal at sewage treatment works. Plans have been put in place to reduce the impacts of water abstraction on the river. The issue of agricultural run-off is being tackled by a Catchment Sensitive Farming project (lead by Natural England) and a Demonstration Test Catchment project lead by the University of East Anglia. The Norfolk non-native Species Initiative is taking steps to control invasive freshwater species. Remediation of the physical modifications to the river are being addressed by the River Wensum Restoration Strategy.

The River Wensum Restoration Strategy has been developed by Natural England (NE), in partnership with the Environment Agency (EA) and the Water Management Alliance, with the aim to restore the physical functioning of the river so that it can sustain the wildlife and fisheries characteristic of a Norfolk chalk river.

To summarise, as a result of historic interventions, parts of the river are too wide, too deep, and too straightened, in addition to being heavily impounded by water control structures. The Wensum is also largely disconnected from its floodplain. The main restoration works implemented within the strategy included narrowing the channel, restoring gravel beds (through gravel introductions and mobilisation of fine sediments to clean historic gravel beds by increasing velocities), reductions in impoundment, reconnecting the floodplain, improving channel sinuosity and increasing the amount of large woody material in the channel.

The following report documents the observed changes within the restored reaches and attempts to highlight how increasing habitat heterogeneity and flow variation may impact fish communities in a lowland chalk stream habitat.

3. METHODS

Fish survey data from the EA National Fisheries Population Database was interrogated to quantify how fish populations within the restored reaches have changed post–restoration. For each site the data was analysed and presented in a series of four charts:

- Abundance per unit area (change in numbers) – presented as a bar chart for individual species over all survey years available.
- Weight per unit area (change in biomass) – presented as a bar chart for individual species over all survey years available.
- Species composition – Biomass was used to produce pie charts for each survey analysed to assess the change in species composition based on the weight of fish captured.
- Total standing crop (biomass) over all survey years available.

Additional length-frequency graphs were produced for certain species and sites in an effort to determine whether recruitment was occurring; however these were determined to have limited use as the low numbers of fish caught in some years meant that little or nothing could be inferred.

Graphs were produced with abundance and density estimations (95% confidence limits), which for consistency were calculated using the Carle and Strub (1978) population model.

For clarity, fish species were categorised into three groups and graphed separately – “coarse fish” (chub, pike, dace, etc.), “minor species” (bullhead, stone loach, minnow, sticklebacks) and “other” (brown trout, lamprey, eel).

Where possible, data for fish >99 mm was used due to the inefficiency of electrofishing small fish. In some instances, all fish were used where no separation had been made within the provided EA data, or where the reach was dominated by minor species.

4. SITE DETAILS

Details of the River Wensum and River Tat restoration projects are provided in Table 4-1 and the locations of the EA fisheries survey sites are given in Figure 4-1. Finer scale maps of the fish survey locations are provided in the Appendix I.

Table 4-1. Summary of the restoration sites on the River Wensum/Tat, including location, a description of the measures implemented and the year when works were completed.

Site	Site name	Description of restoration	NGR u/s	NGR d/s	Year of implementation
1	Bintree (County school)	Bed raising, gravel introduction, change to planform	TF 99067 23263	TF 99202 22743.	2009
2	Gt. Ryburgh Common	Restoring historic river channel, flow deflectors, gravel glides, berms.	TF 93666 29206	TF 94015 29064	2010
3	Gt. Ryburgh End	Re-connecting to historic river channel + flow deflectors, gravel glides and berms	TF 96420 26962	TF 97398 826110	2011
4	Swanton Morley	Gravel glides, pools, berms, woody debris & partial removal of spoil banks to improve floodplain connectivity	TG 02031 18359	TG 02760 17770	2012
5	Sculthorpe Moor	Channel narrowing, reconnection to flood plain, gravel glides created	TF 89690 29869	TF 91287 29661	2012-14
6	River Tat	Channel narrowing, woody debris, reduced shading. Connection to drainage ditches.	TF 85044 28814	TF 86701 27978	2013
7	Tatterford common	Unknown			
8	Pensthorpe Hall	Unknown (TBC if scheme was carried out here)			
9	South Mill Farm	Bed raising, glide creation, berms, woody debris, reinstatement of two meanders.	TF 87323 27935	TF 88232 29056	2015
10	Dunton Bridge				2016
11	Costessey	Lateral berms, introduction of glide-pool sequences, woody debris, creation of off-channel refuge areas and tree planting	TG 16437 13334	TG 16641 12307	2018

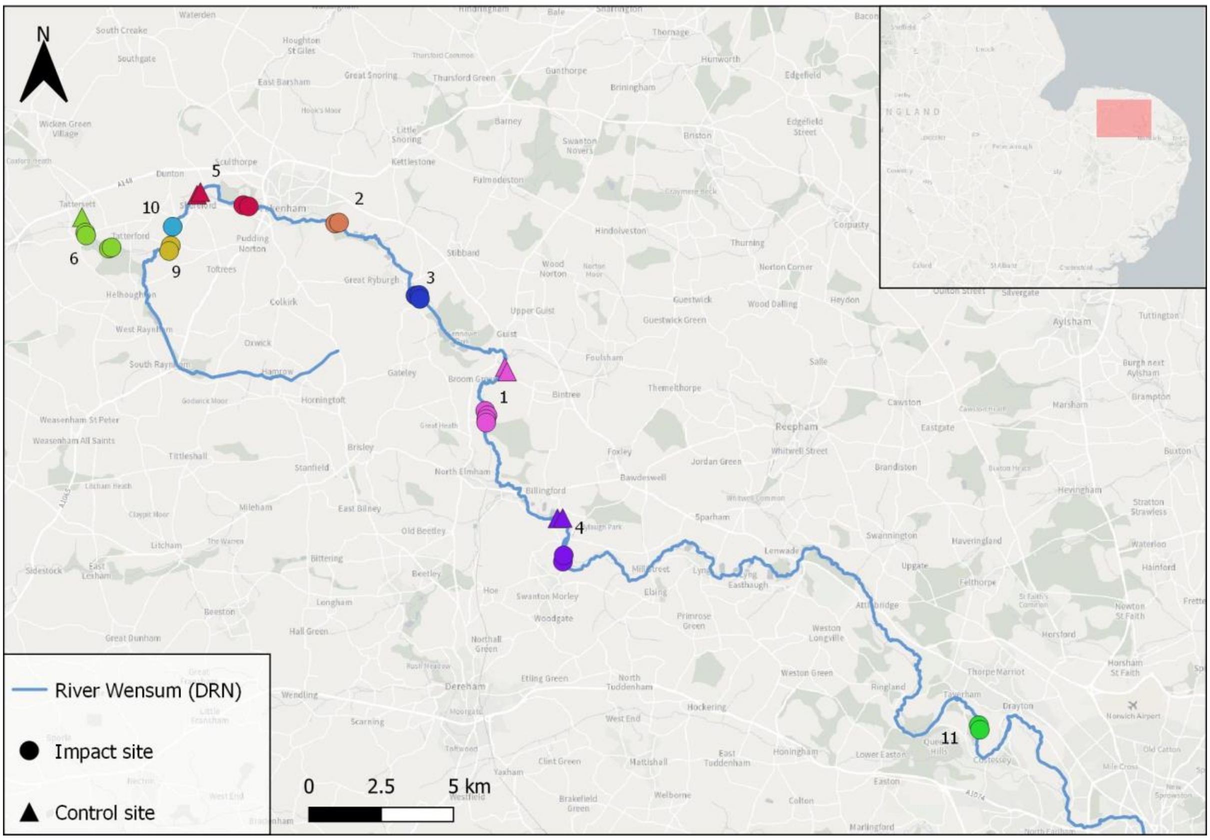


Figure 4-1. Overview of the EA fisheries monitoring sites on the River Wensum.

5. RESTORATION REACHES

5.1. Site 1. *Bintree Restoration Scheme – Reach 19*

5.1.1. *Scheme summary*

The restored reach at Bintree is located between Yarrow Bridge and County School Bridge, approximately 1.5 km downstream of Bintree Mill (NGR TF 99067 23263 to TF 99202 22743). The restoration works (which primarily included bed raising, gravel introduction and change to planform) were completed between September and December 2009.

Flow diversification throughout the reach was achieved through large scale bed raising of up to 1m in places, using locally sourced gravel reject. In certain locations additional raising to produce four glide habitats was achieved through the addition of graded gravels. Further habitat improvements were produced by altering the river planform by re-sectioning and channel narrowing works, using brushwood mattresses and large woody debris flow deflectors. Improved connectivity of the river to its floodplain was also achieved, by lowering the adjacent spoil embankment in selected locations on the true right-hand bank.

Figure 5-1. LH- Construction during November 2009, shows woody debris flow deflectors and berm creation. RH- Restored reach in August 2010. Source: EA RWRS fact sheets combined

5.1.2. *Fish survey data*

One year of pre-construction EA fish survey data information is available for the restoration reach itself (U/S County School, 2009. NGR: TF 99162 22963 - TF 99243 22814). Three additional post-restoration surveys are available for 2010, 2012 and 2019. The survey site “U/S County School” is located within the restored reach.

Data from an additional nearby, unrestored site is presented in Table 4-2 and section 4.1.4 below, for comparison (County school, NGR: TF 99208 22681 - TF 99210 22558).

Table 5-1. General overview of changes in the fish community at 'U/S County School' observed following restoration work. "+" indicates clear increase, "-" indicates a clear decline. = indicates no clear changes.

		Abundance change post - restoration	Biomass change post-restoration
3-spined stickleback	*Gasterosteus aculeatus*	=	=
Stone loach	*Barbatula barbatula*	+	+
Brown / sea trout	*Salmo trutta*	+	+
Chub	*Leuciscus cephalus*	+	=
Dace	*Leuciscus leuciscus*	+	+
Roach	*Rutilus rutilus*	-	=
Pike	*Esox lucius*	-	-
Bullhead	*Cottus gobio*	+	+
Minnow	*Phoxinus phoxinus*	+	+
Gudgeon	*Gobio gobio*	=	=
Perch	*Perca fluviatilis*	-	-
European eels	*Anguilla anguilla*	=	-
Brook lamprey ammocoetes	*Lampetra planeri*	=	=
Rudd	*Scardinius erythrophthalmus*	+	=

Table 5-2. General overview of changes in fish community at 'County School' observed following nearby restoration work upstream. "+" indicates clear increase, "-" indicates a clear decline. = indicates no clear changes.

		Abundance change post - restoration	Biomass change post-restoration
Brown / sea trout	*Salmo trutta*	+	=
Chub	*Leuciscus cephalus*	+	=
Dace	*Leuciscus leuciscus*	+	=
Roach	*Rutilus rutilus*	+	+
Pike	*Esox lucius*	-	+
Gudgeon	*Gobio gobio*	+	=
European eels > elvers	*Anguilla anguilla*	+	+
Lamprey sp. > ammocoete	*Petromyzontidae*	-	=
Perch	*Perca fluviatilis*	-	-

5.1.3. US County School, Fish survey data – Abundance

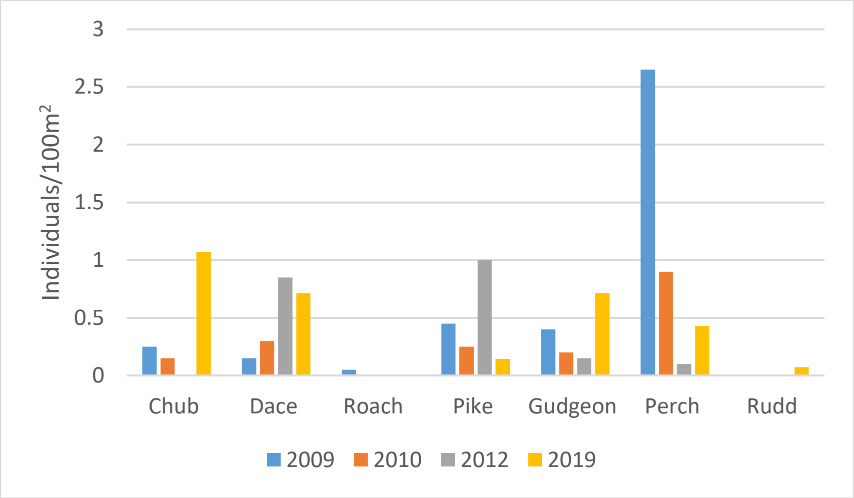


Figure 5-2. Abundance of coarse fish species within the restoration reach, 2009-2019. Includes data for all fish caught.

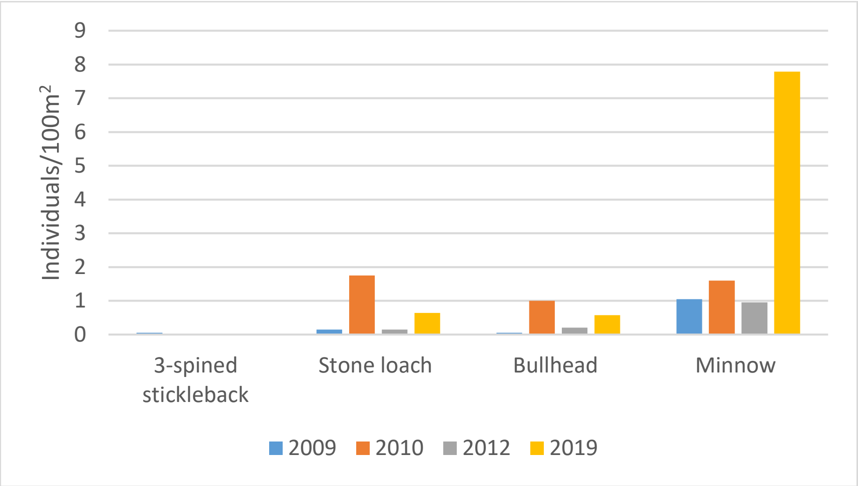


Figure 5-3. Abundance of minor fish species caught within the restoration reach, 2009-2019. Includes data for all fish caught.

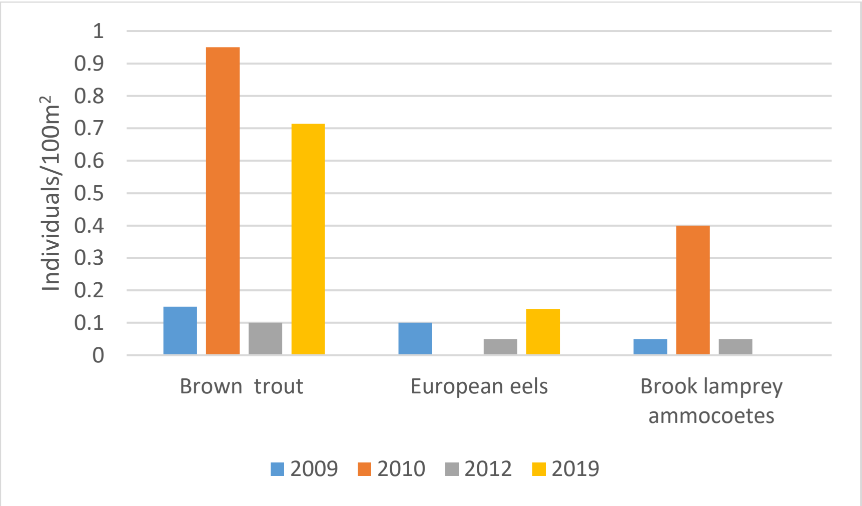


Figure 5-4. Abundance of other fish species caught within the restoration reach, 2009-2019. Includes data for all fish caught.

US County School, Fish survey data – Biomass

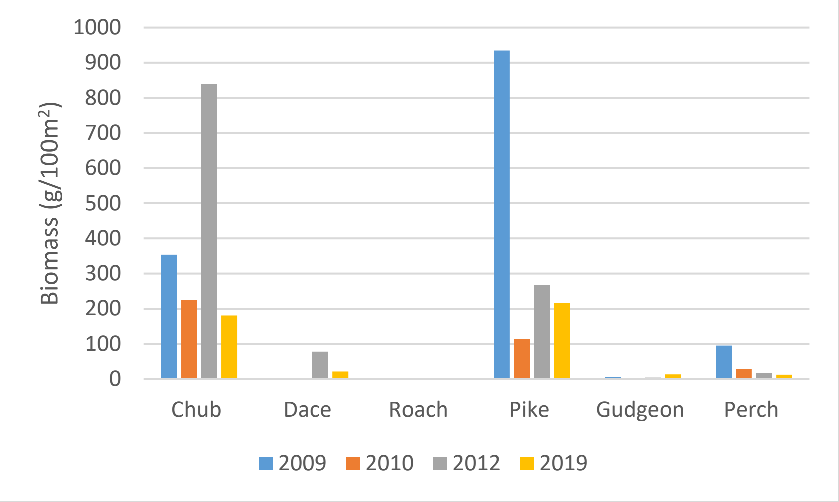


***Figure 5-5** Biomass of coarse fish species within the restoration reach, 2009-2019. Includes data for all fish caught.*

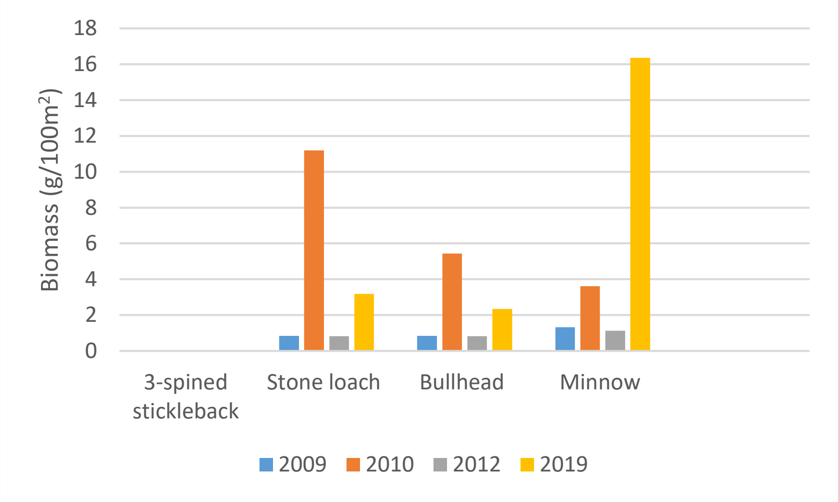


Figure 5-6. Biomass of minor fish species within the restoration reach, 2009-2019. Includes data for all fish caught.

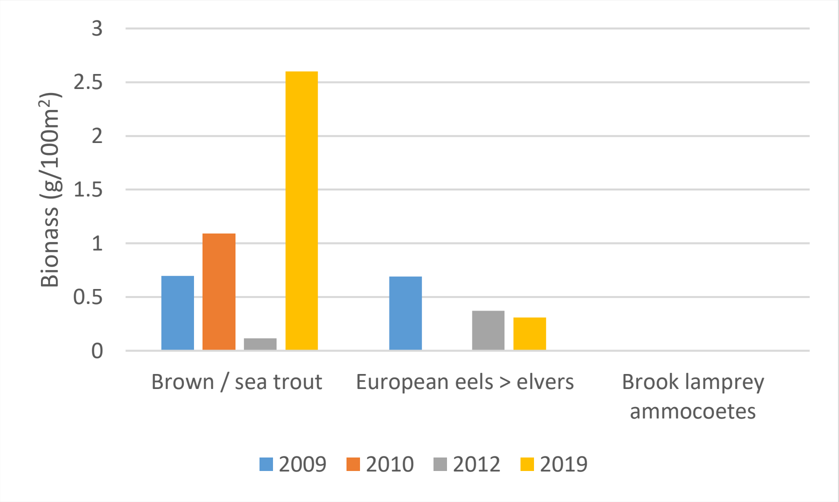


Figure 5-7. Biomass of other fish species within the restoration reach, 2009-2019. Includes data for all fish caught.

US County School, community composition in terms of biomass

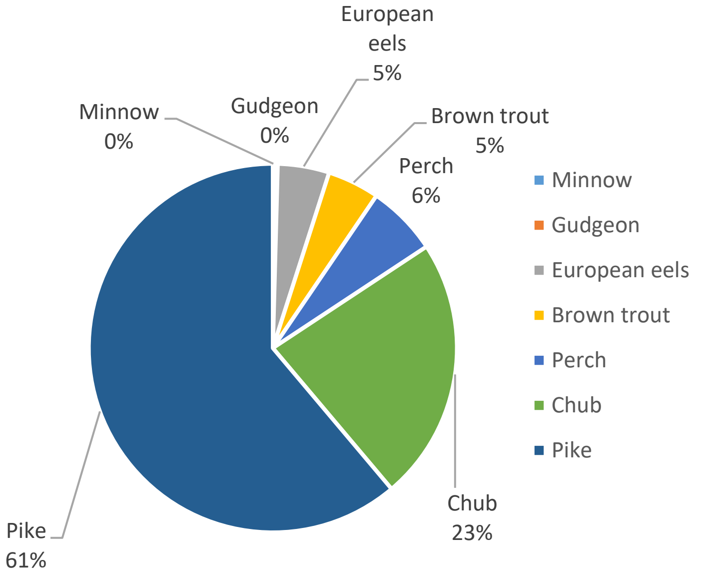


Figure 5-8. 2009 community composition in terms of biomass.

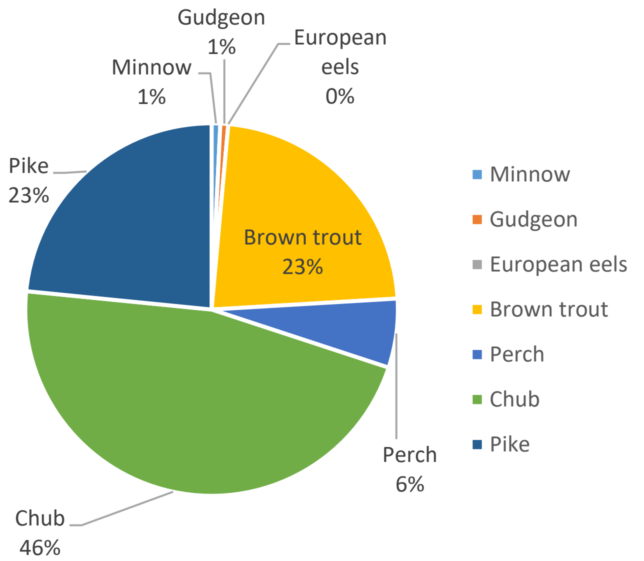


Figure 5-9. 2010 community composition in terms of biomass.

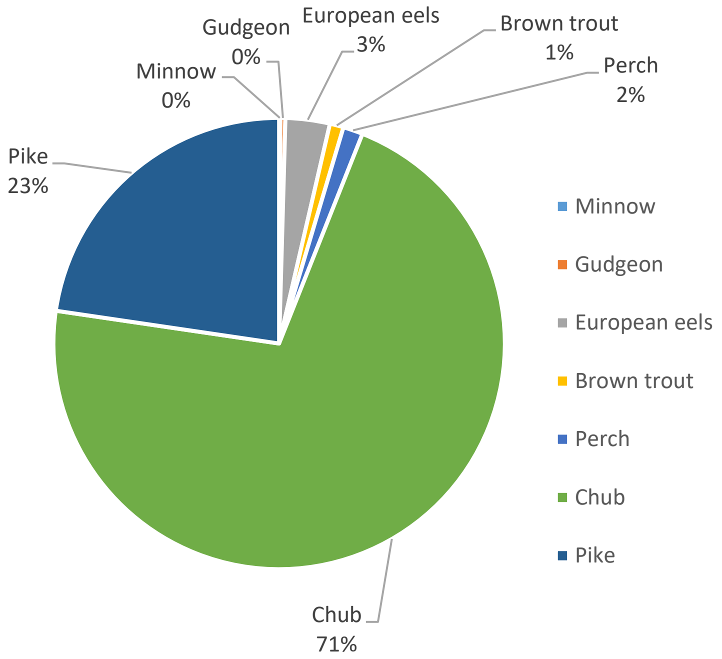


Figure 5-10. 2012 community composition in terms of biomass.

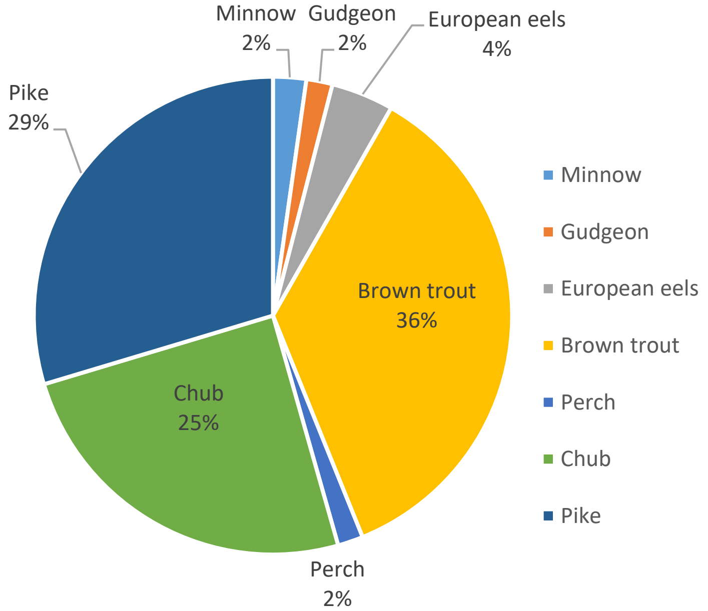


Figure 5-11. 2019 community composition in terms of biomass.

Standing crop estimate

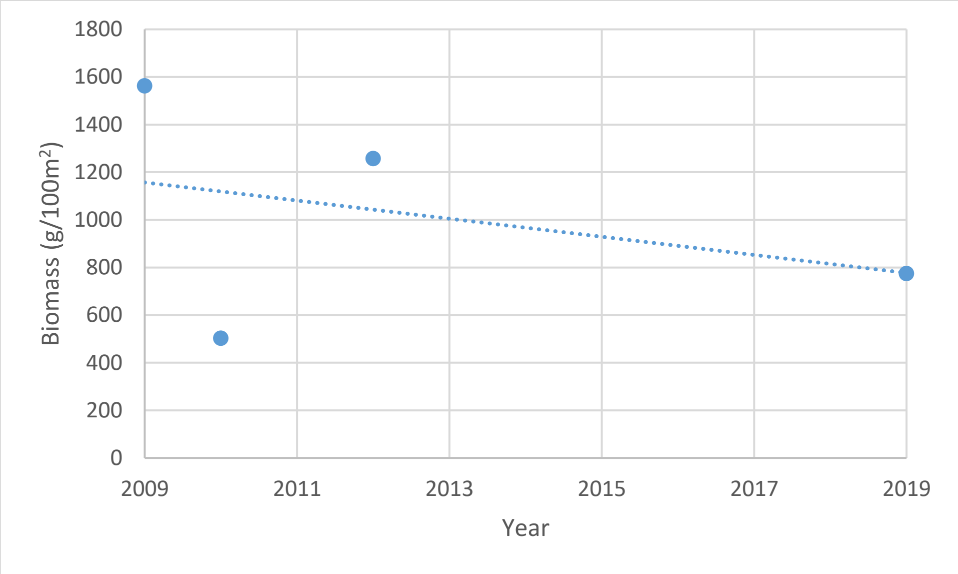


Figure 5-12. Standing crop estimate over time in terms of biomass/100m^2 of all fish species present. 2009-2019.

5.1.4. County School (control), Fish survey data

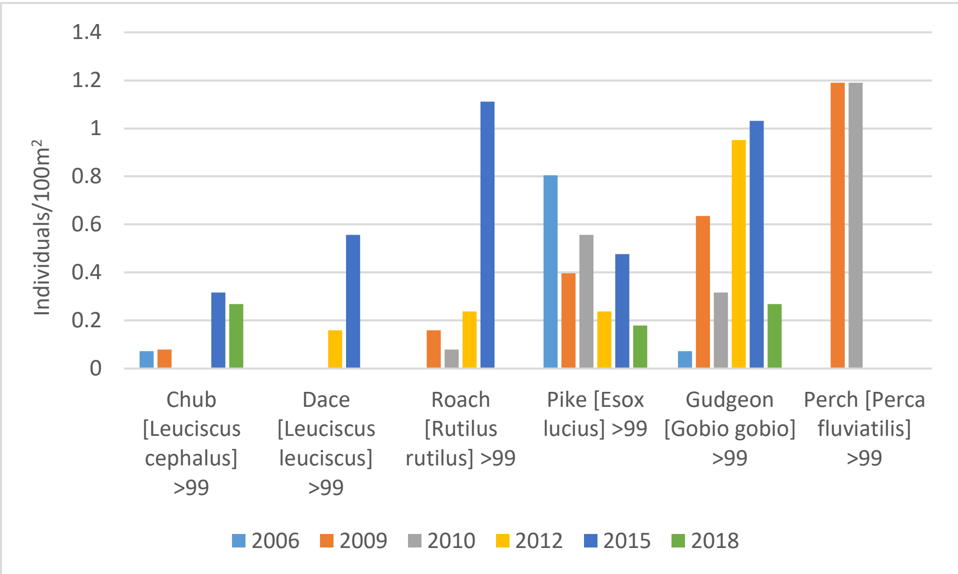


Figure 5-13 Carle and Strub estimates for the abundance of coarse fish species within the County School reach, 2006-2018. Includes data for all fish caught >99mm.

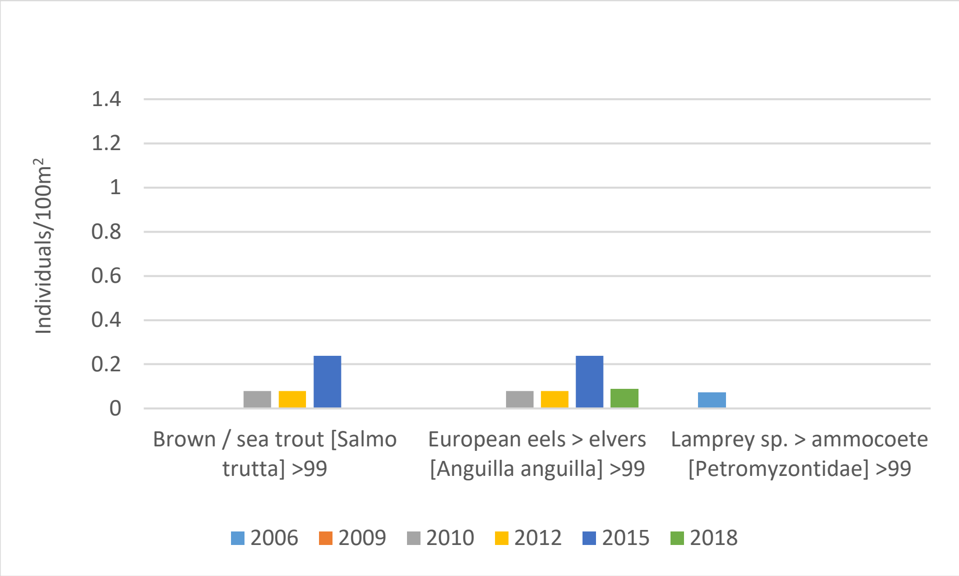


Figure 5-14. ***Carle and Strub estimates for the biomass of other fish species within the County School reach, 2006-2018. Includes data for all fish caught >99mm.***

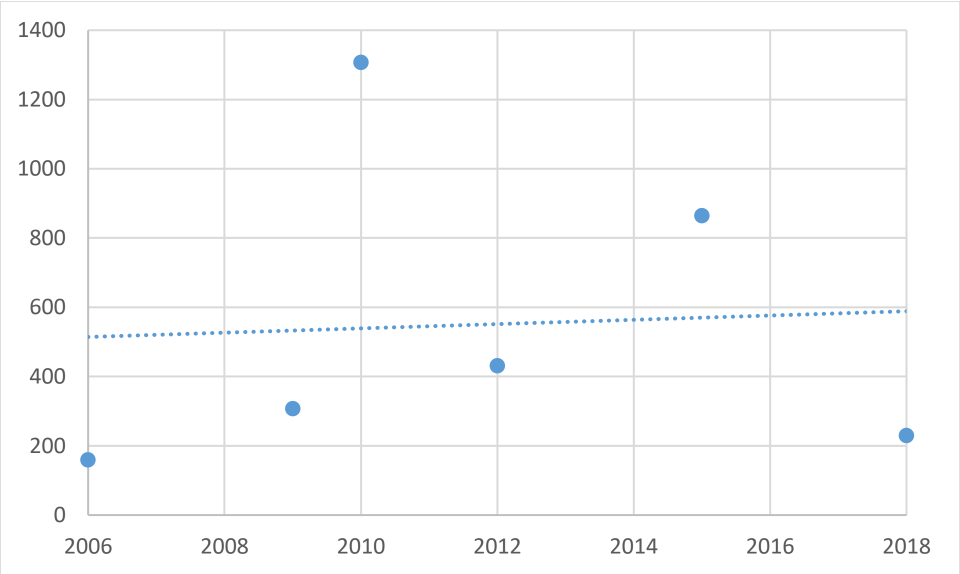


Figure 5-15. ***Standing crop estimate over time in terms of biomass/100^2 of all fish species present (>99mm) within the County School survey reach (2006-2018).***

Community composition in terms of biomass in the County School (control) reach.

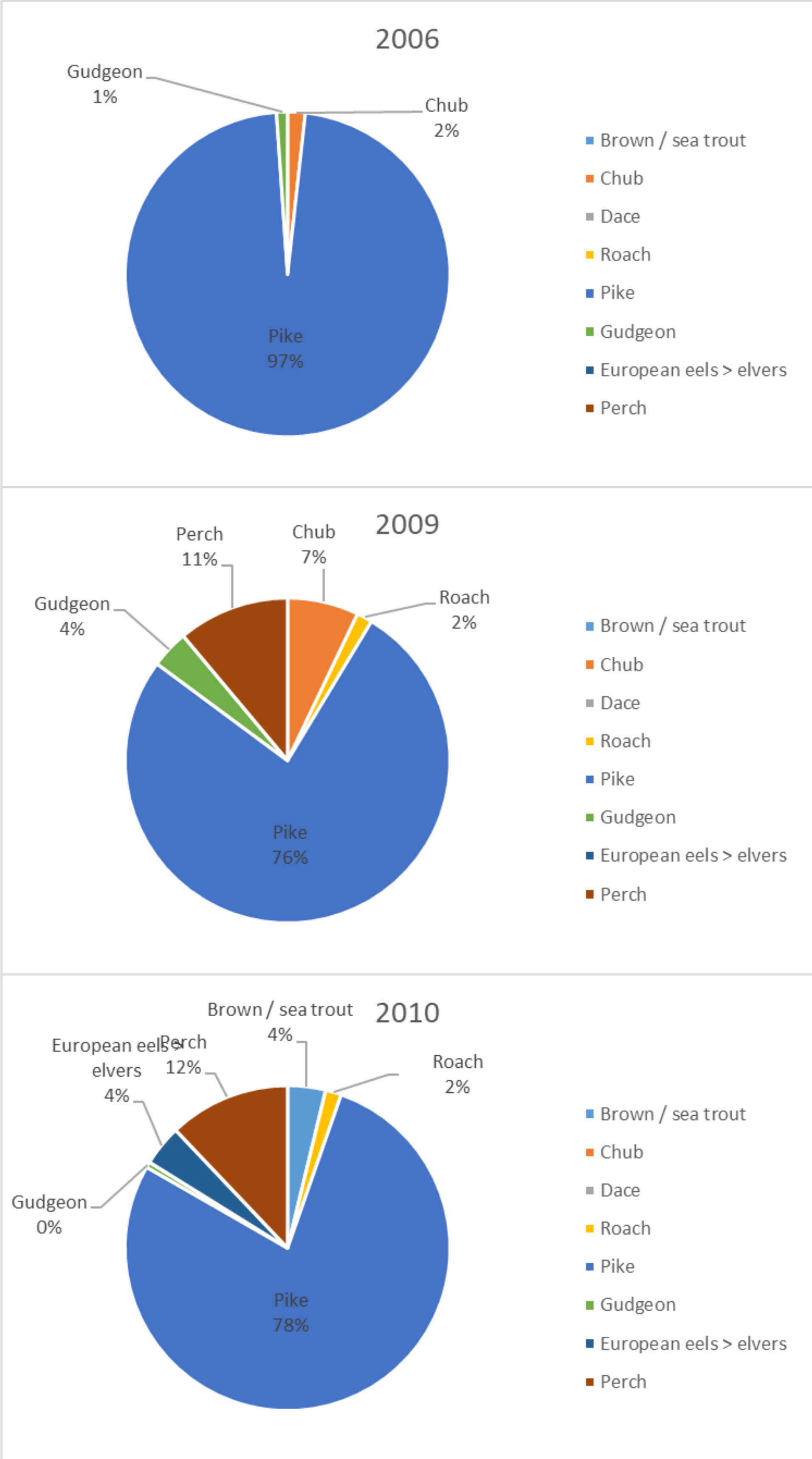


Figure 5-16. Community composition in terms of biomass. 2006/9/10

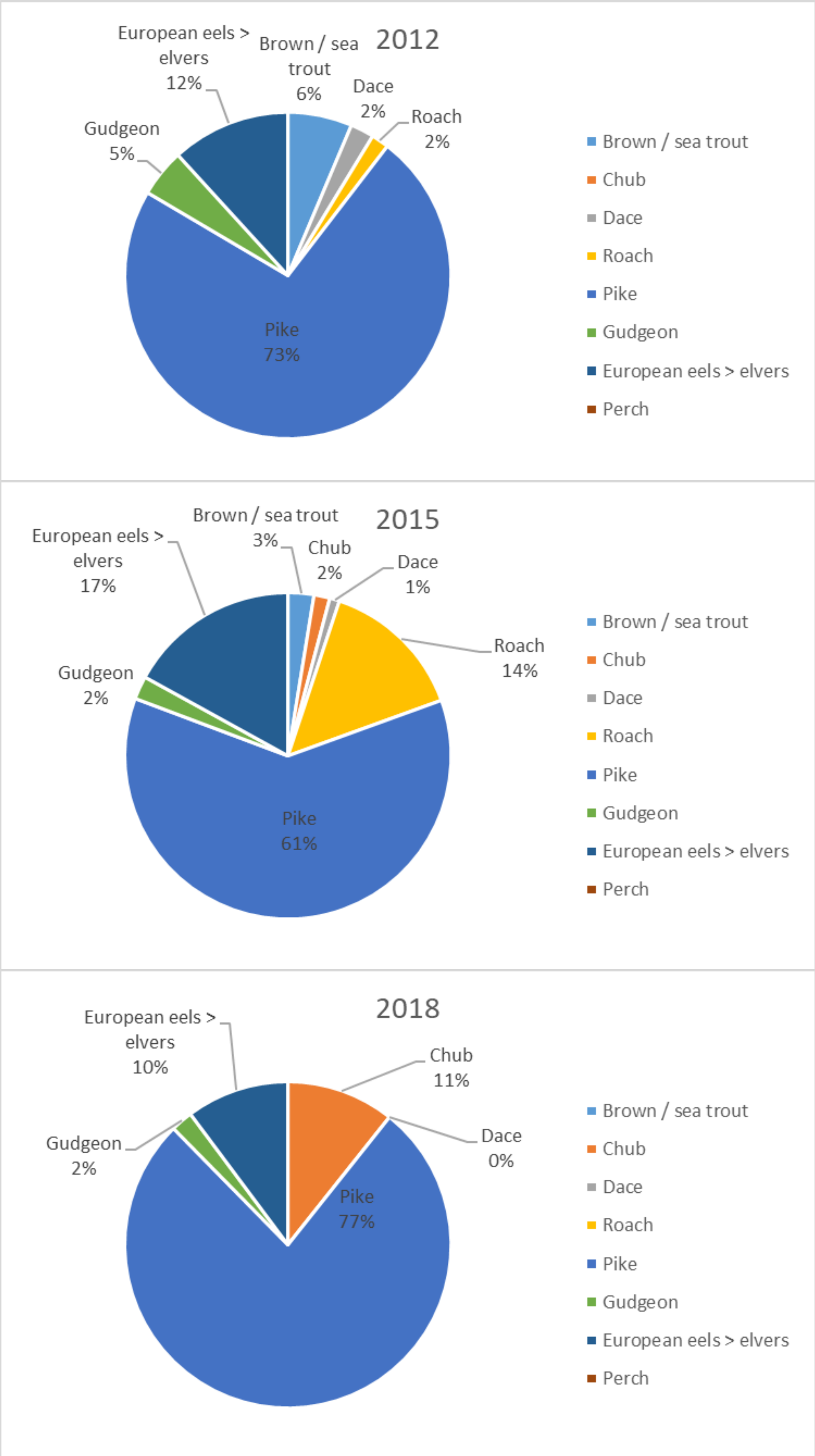


Figure 5-17. Community composition in terms of biomass. 2012/15/18

5.1.5. *Summary of results*

Notable changes in abundance were observed for seven out of the fourteen species recorded at the site (50%). The most significant increases were for chub, dace, trout, minnows, and gudgeon (Figure 5-2,Figure 5-3,Figure 5-4). Trout numbers have increased across a range of year classes, suggesting spawning is taking place (see Appendix II for Length-frequency graphs).

These increases are likely a result of the restoration works which have increased habitat heterogeneity and provided more spawning habitat. Chub, dace and gudgeon also increased in abundance within the control reach. This may have resulted from individuals moving between the reaches as they are close (<100m apart) and are not separated by an impassable barrier, however it is impossible to prove whether the restoration work was the cause behind the increase or not. Three species decline in abundance following restoration (pike, roach and perch). Pike and perch also declined within the control reach; however, it is not possible to put the decline down to local change in habitat or larger catchment scale factors such as pollution and water quality.

Biomass increases were recorded within the restoration reach for 5/14 species (35%). These increases were recorded for stone loach, brown trout, dace, bullhead and minnow. Declines in biomass occurred for pike, perch and eel. Decline in eel and perch biomass also occurred within the control reach.

It appears that the carrying capacity of the restored reach is far higher than the control site. In 2019, the standing crop estimate (biomass/100m^2) for the restoration site was almost 4 times greater than the control site (Figure 5-12, Figure 5-15).

Species richness increased in the restoration reach, with the addition of rudd to the electrofishing survey data results in 2019.

Further discussion of these results is presented in section 8.

5.2. Scheme 2 – Great Ryburgh common /Reach 24

5.2.1. *Scheme summary*

The restored reach at Great Ryburgh common is located between Fakenham and Great Ryburgh (NGR: TF 93666 29206 to TF 94015 29064). The restoration works (which primarily involved restoring the historic channel) were completed between October and December 2010.

A substantial length of the historic river channel at Gt. Ryburgh common was disconnected from the Wensum in the 1950's. A straight engineered channel was cut through the floodplain, allowing most of the river flow to bypass a sequence of meanders. Before restoration, flows through this section were sluggish and uniform, resulting in siltation of the gravel bed.

In the Autumn of 2010, the historic meander loop was reinstated to restore the natural form and geomorphological processes of the river (Figure 5-18). The upstream end of the engineered channel has been plugged to ensure flow passes into the meander. It has been set at a level below the existing bank height to enable the straight channel to be utilised as a route for flood relief during high flow events. The section of channel immediately downstream of the plug now provides ecologically important backwater habitat.

The meander loop and parts of the existing channel downstream of the meander loop have been further ameliorated with the addition of several features including flow deflectors, gravel glides and berms.

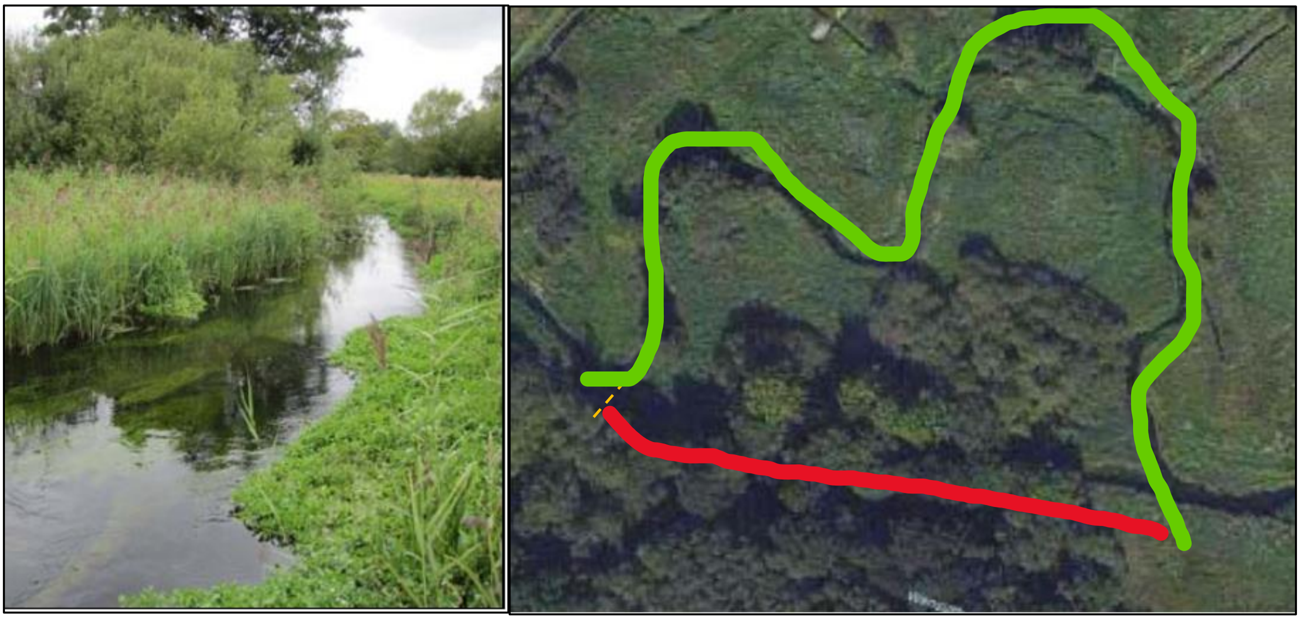


Figure 5-18. LH- Reinstated meander loop. Source: EA RWRS fact sheets combined RH- Green line indicates the reinstated historic channel. Yellow dashed line marks the location of the plug. Red line indicates the straight, engineered channel which has now become a backwater habitat.

5.2.2. *Fish survey data*

There is no pre-restoration data available for the new meander loop so no comparison can be made. Two years of post-completion data are available for the new channel (Great Ryburgh New loop, 2011, 2013. NGR: TF 93727 29204 - TF 93856 29240) which indicate which species benefit from this river restoration technique.

Two years of electro fishing data exists for sites upstream and downstream of the new meander loop on the existing river channel, however these are insufficient for a robust comparison to be made in relation to how the restoration work has impacted nearby fish populations. As such, the following analysis aims to describe how the new channel habitat is being used by fish instead.

Great Ryburgh new loop, abundance

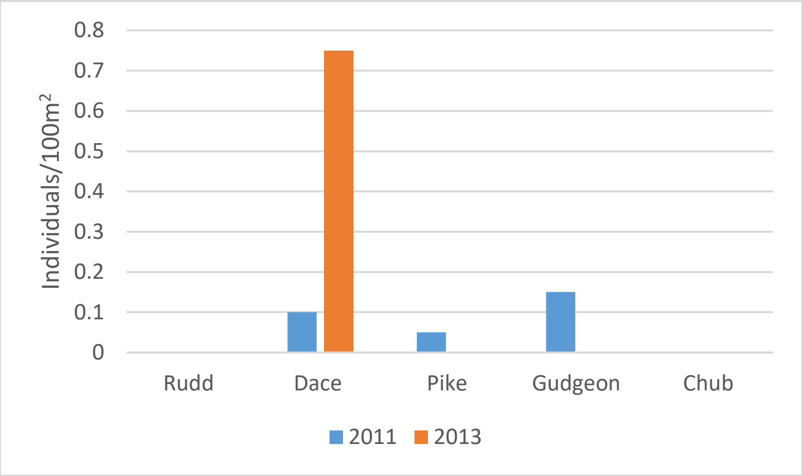


Figure 5-19. Abundance of coarse fish species within the restoration reach, 2009-2019. Data is for fish >99mm.

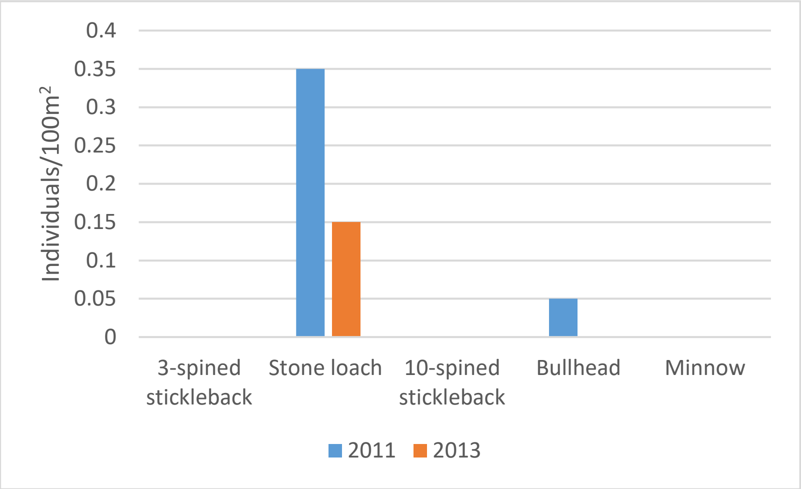


Figure 5-20. Abundance of minor fish species within the restoration reach, 2009-2019. Data is for fish >99mm.

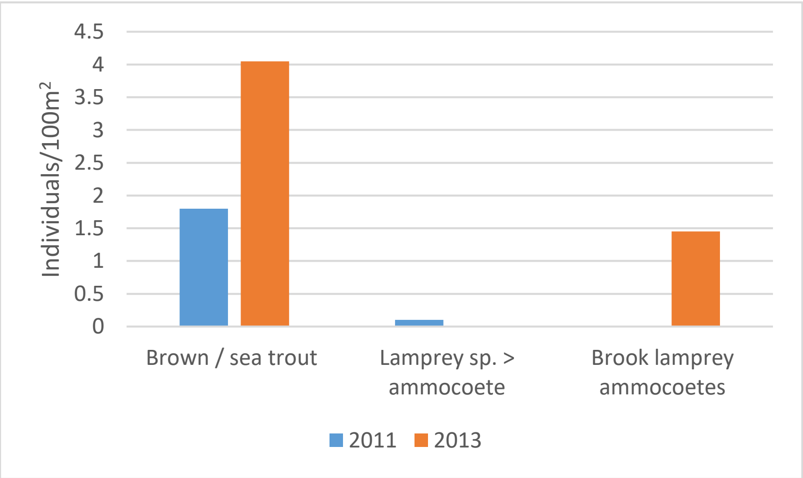


Figure 5-21. Abundance of other fish species within the restoration reach, 2009-2019. Data is of fish >99mm.

Great Ryburgh new loop, biomass

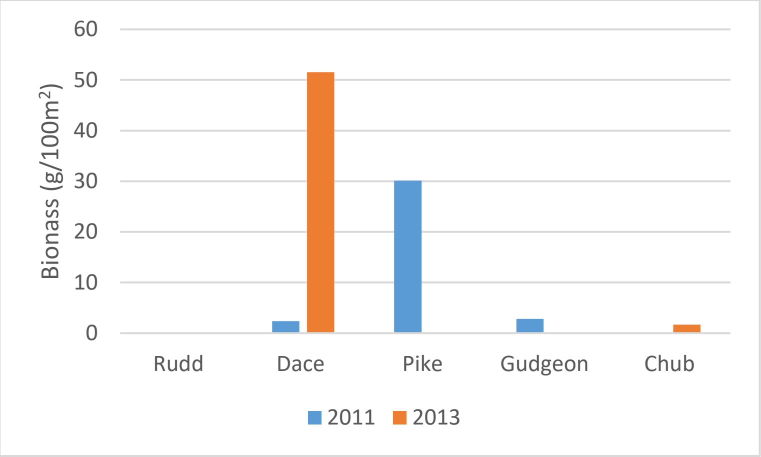


Figure 5-22. Biomass of coarse fish species within the restoration reach, 2009-2019. Data is for fish >99mm.

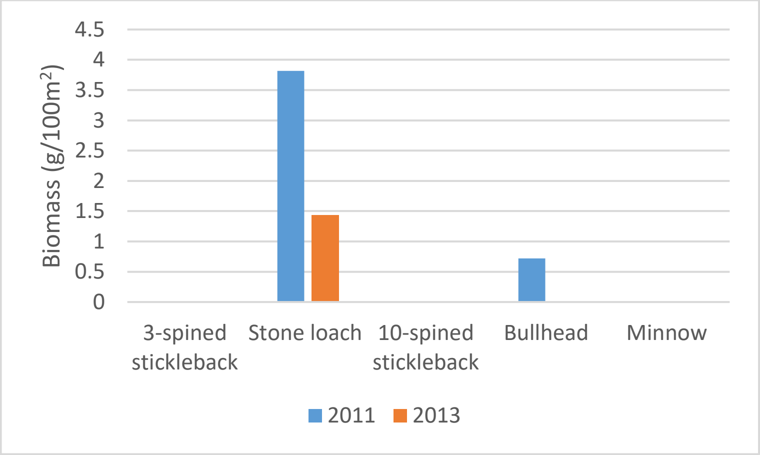


Figure 5-23.Abundance of minor fish species within the restoration reach, 2009-2019. Data is for fish >99mm.

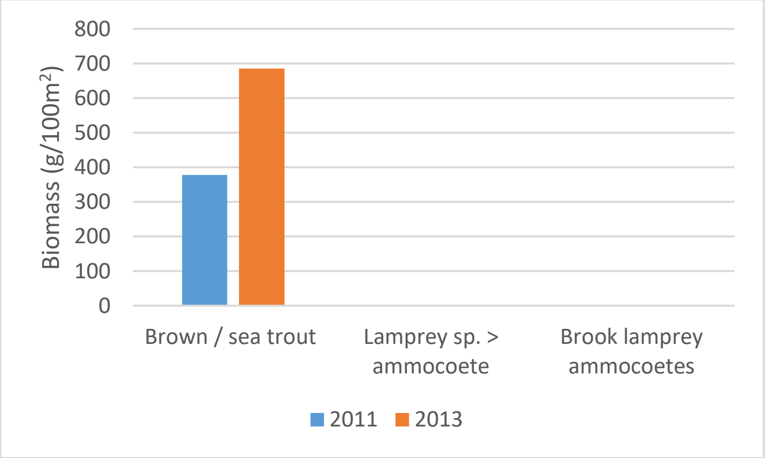


Figure 5-24. Abundance of other fish species within the restoration reach, 2009-2019. Data is for fish >99mm.

Great Ryburgh new loop- Community composition in terms of biomass (fish >99mm)

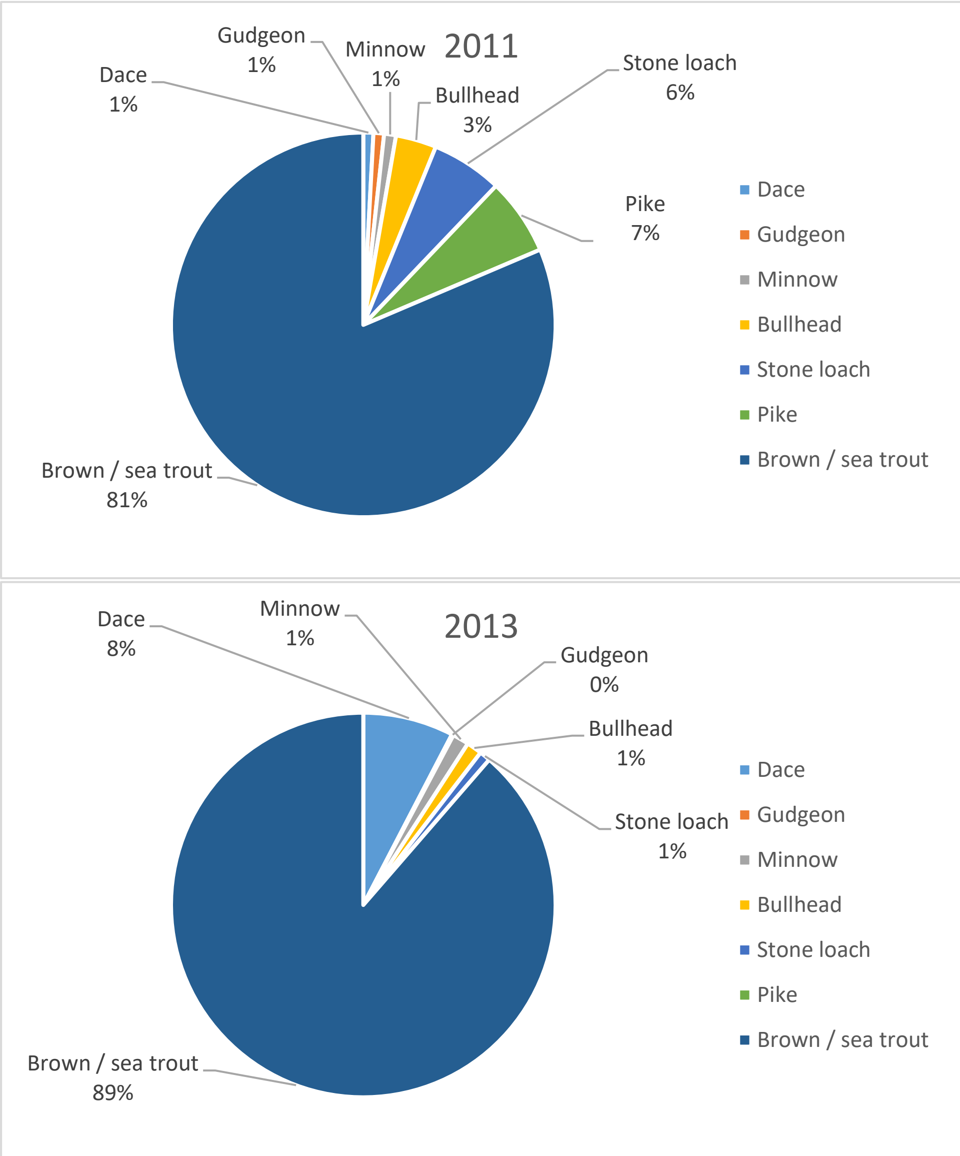


Figure 5-25. Percentage biomass of fish >99mm inhabiting the new meander loop (all species present) in 2011 and 2013.

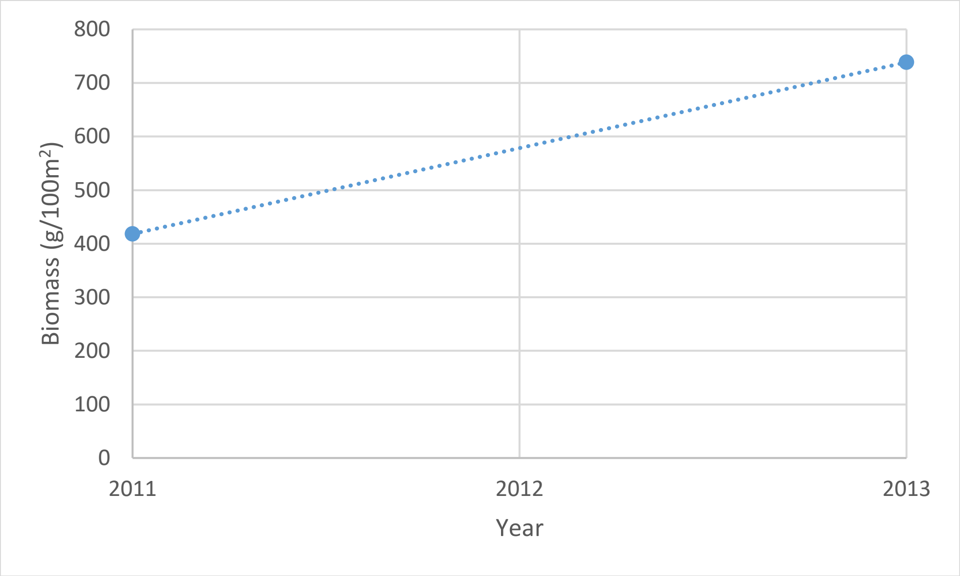


Figure 5-26. Carle and Strub standing crop estimate, all fish >99mm.

5.2.3. *Summary of results*

The above data shows which fish have colonised the new meander loop habitat.

Brown trout dominates the restoration reach, with the species accounting for 81% and 86% of the total biomass in 2011 and 2013 respectively. Seven other species make up the remainder of the biomass. Length frequency data (presented in the Appendix II) suggests that the trout are also using the reach to spawn as juvenile year classes are present as well as larger individuals (range 50- 500 mm). Trout biomass appears to be increasing over time with almost a 100% increase observed between 2011 and 2013. This may be attributed to an improvement in food supply, in terms of more juvenile fish and invertebrates which are using the newly created habitat.

Dace also use the new meander loop habitat, increasing from 1% of the total biomass in 2011 to 8% in 2013.

Brook lamprey ammocetes were recorded in 2013, suggesting that some silt deposition has occurred providing juvenile lamprey habitat.

The standing crop estimate for all fish > 99mm has increased substantially from 418 g / 100m^2 in 2011, to 728 g / 100m^2 in 2013. This suggests the habitat was still improving in 2013, with vegetation establishing and invertebrate communities colonising the new reach.

Ideally additional data is required to see how the community has settled 5-10 years post restoration and to confirm that the restoration techniques have a long term impact on the physical environment.

5.3. Scheme 3 – Grear Ryburgh End/Reach 21a

5.3.1. *Scheme summary*

The Ryburgh End restoration scheme encompasses 1.32km of river channel between Great Ryburgh Mill and Sennowe Bridge (TF 96420 26962 to TF 97398 826110). The restoration works (which primarily involved restoring the historic channel) were completed between September and December 2011.

During the late 1800s, the historic river course was bypassed by a new channel. This straight, engineered channel was deep and lacked flow and habitat diversity, and as a result of its incised form, had minimal connection to the floodplain. A key part of this restoration scheme was to excavate a new channel to connect the river to its former, historic channel (Figure 5-27). The straightened channel was also plugged to divert flows into the new river course. The old river course now provides backwater habitat and acts as a secondary channel in high flow events.

Within the new meandering channel, deeper pools have been created on many of the bends to provide slower water for preferential deposition, increasing the functionality of the glides by reducing sediment flow across them. Deep sections also help limit encroachment by marginal vegetation and providing refuges for fish and other wildlife. The restored reach also includes areas of shallow water at the channel edge and a number of bays and backwaters connected to the main channel. In-channel woody debris has been installed to vary the flow and planform, creating physical habitat for many species of plants, invertebrates, and fish. Native species of tree and shrub have been planted (and fenced from livestock) in strategic locations to provide areas of riparian shade. Lateral berms and gravel glides have also been introduced within the straightened channel, upstream of the new link to the historic channel, to provide a more diverse environment.

Figure 5-27 Green line indicates the reinstated historic channel. Yellow dashed line marks the location of the plug. Red line indicates the straight, engineered channel which has now become a backwater habitat.

5.3.2. Fish survey data

Fourteen years of fish population data has been collected within the restoration reach ('DS Gt. Ryburgh bridge', EA fish survey site id 1476. TF 96593 26837 - TF 96751 26725). This represents 6 years of pre-restoration data and 8 years of post-restoration data. Following the restoration work, the downstream grid reference of the surveyed reach was moved to TF 96721 26859, which is located approximately 130m into the new channel, as the previously surveyed reach has been plugged to divert flows to the historic channel.

Although five additional surveys have taken place within and around the restoration reach (Site ids: 39704, 44201, 39588, 44203), these are standalone surveys post restoration surveys which cannot be used to display trends over time. As such they have been excluded from the following graphs.

***Table 5-3** General overview of changes in the fish community at Great Ryburgh end, observed following restoration work. "+" indicates clear increase, "-" indicates a clear decline. = indicates no clear changes.*

Species		Abundance change post -restoration	Biomass change post- restoration
3-spined stickleback	*Gasterosteus aculeatus*	=	+
Stone loach	*Barbatula barbatula*	+	+
Brown / sea trout	*Salmo trutta*	+	+
Chub	*Leuciscus cephalus*	=	=
Dace	*Leuciscus leuciscus*	=	=
Roach	*Rutilus rutilus*	+	=
Pike	*Esox lucius*	-	=
Bullhead	*Cottus gobio*	+	+
Minnow	*Phoxinus phoxinus*	+	+
Brook lamprey > ammocoete	*Lampetra planeri*	+	=
Gudgeon	*Gobio gobio*	+	+
European eels > elvers	*Anguilla anguilla*	-	-
Perch	*Perca fluviatilis*	-	-
Lamprey sp. ammocoete	*Petromyzontidae*	+	=
10-spined stickleback	*Pungitius pungitius*	=	=
Tench	*Tinca tinca*	=	=
Rudd	*Scardinius erythrophthalmus*	=	=

DS Great Ryburgh Bridge, abundance

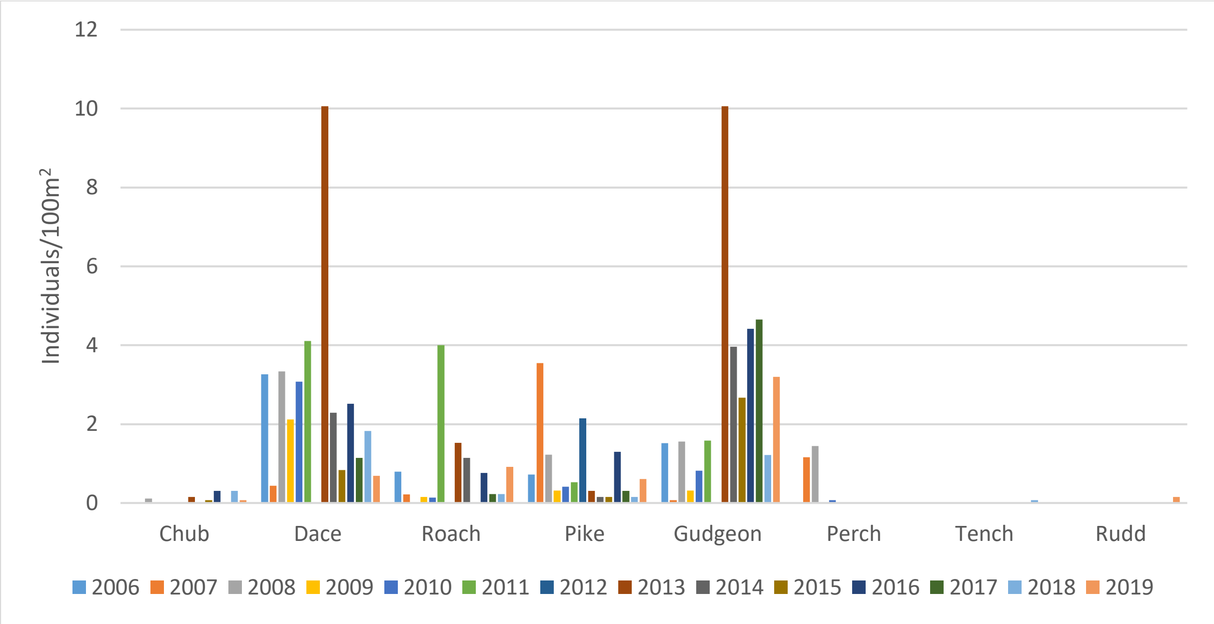


Figure 5-28. Abundance estimates of coarse fish species within the survey reach, 2006-2019.

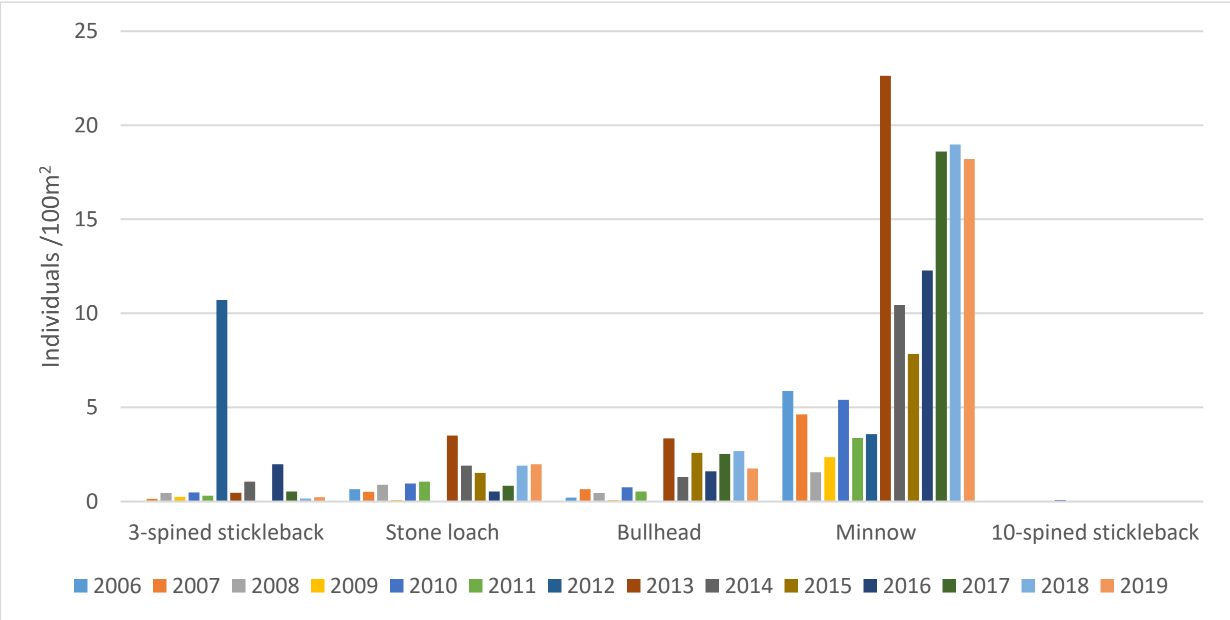


Figure 5-29. Abundance estimates of minor fish species within the survey reach, 2006-2019

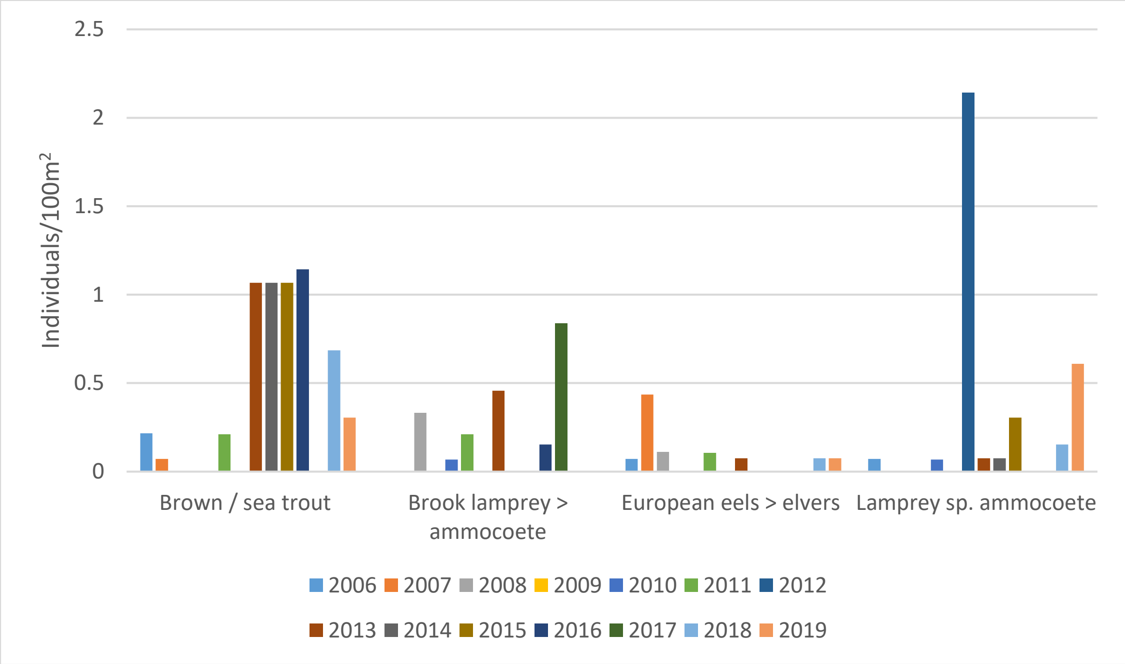


Figure 5-30. Abundance estimates of other fish species within the survey reach, 2006-2019

DS Great Ryburgh Bridge, Biomass

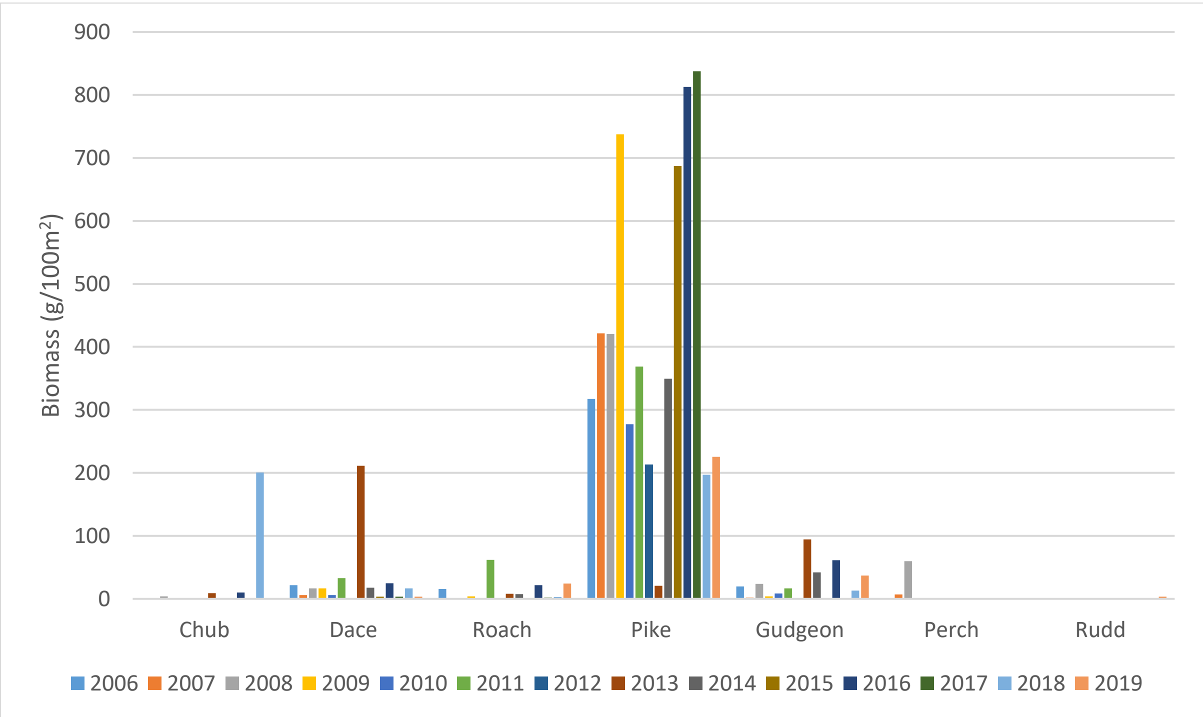


Figure 5-31. Biomass estimates of coarse fish species within the survey reach, 2006-2019

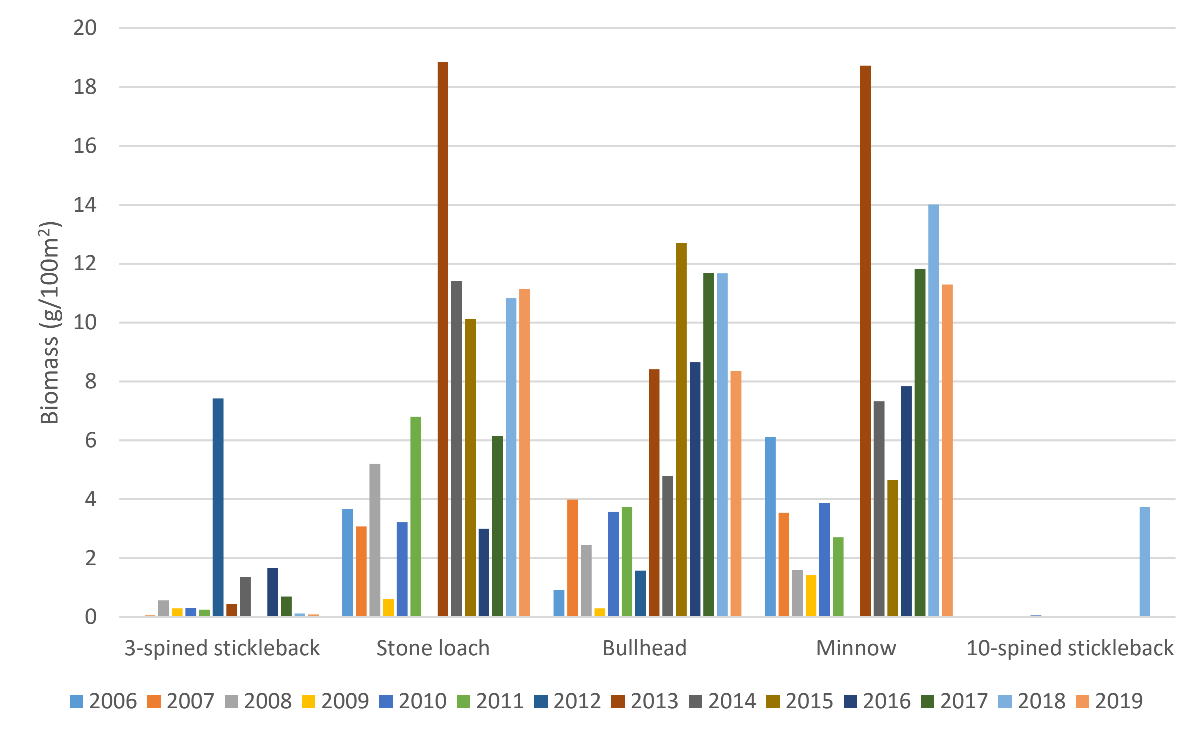


Figure 5-32. Biomass estimates of minor fish species within the survey reach, 2006-2019

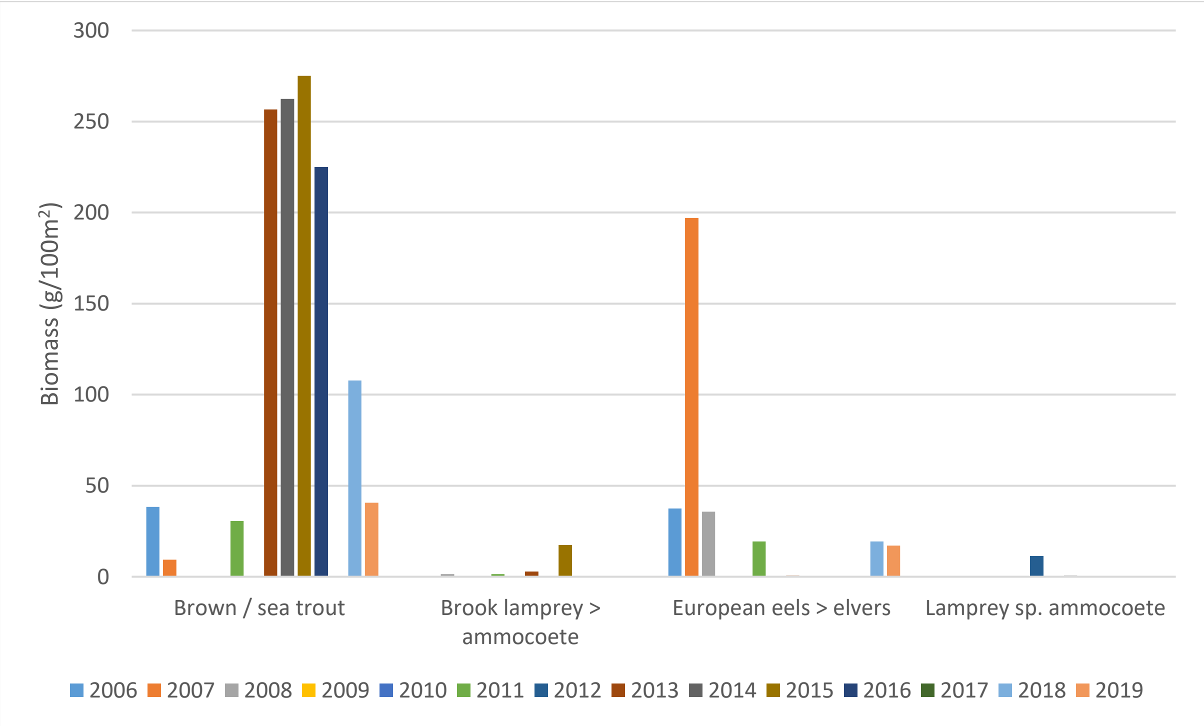
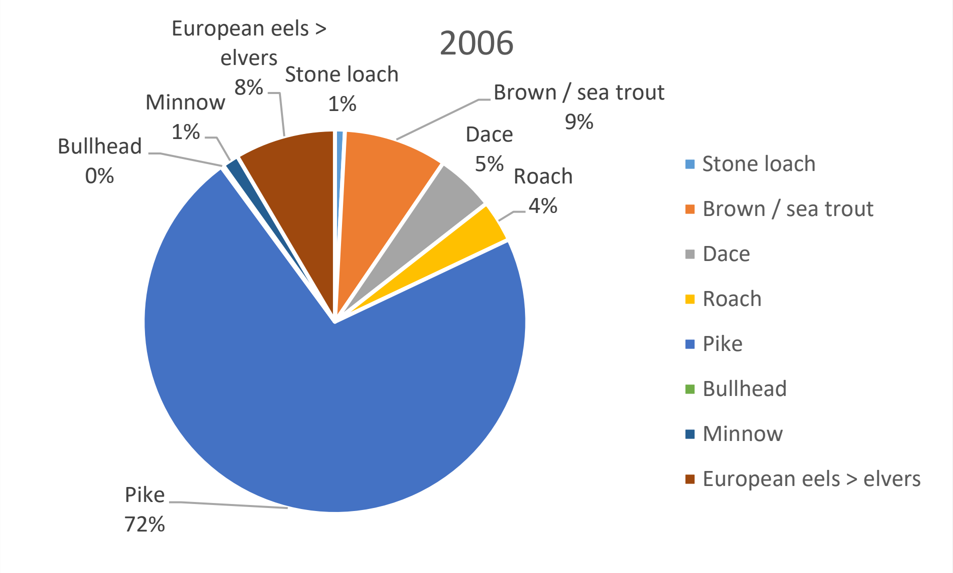
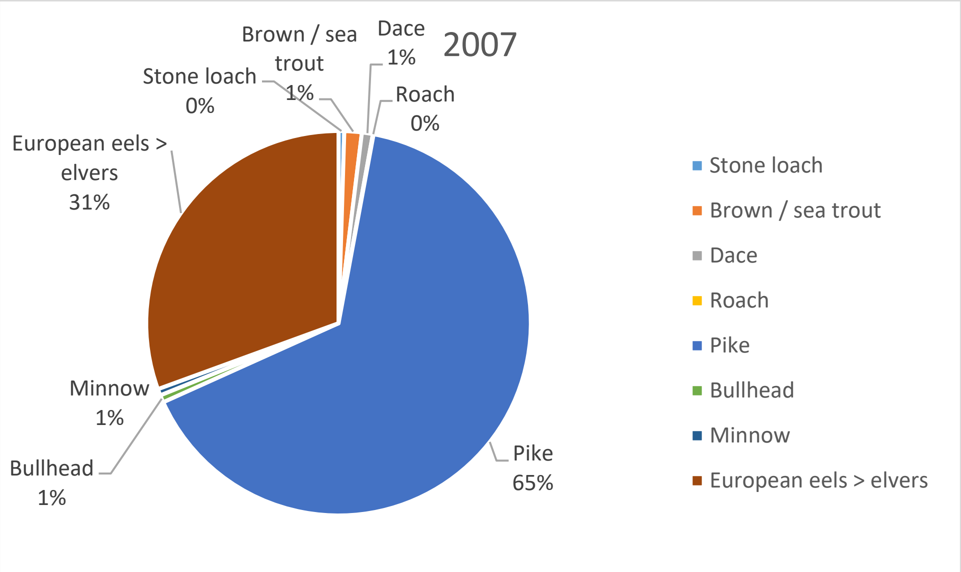
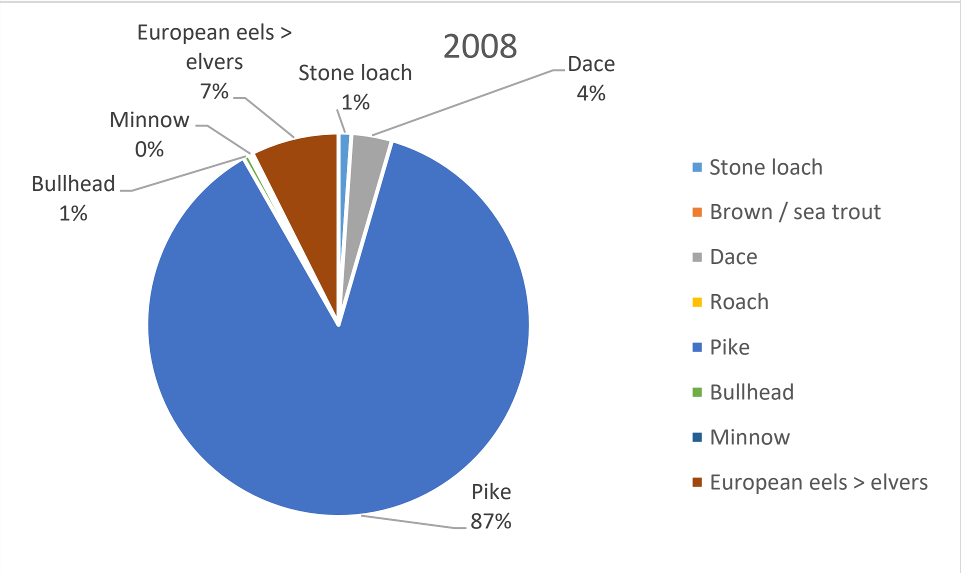


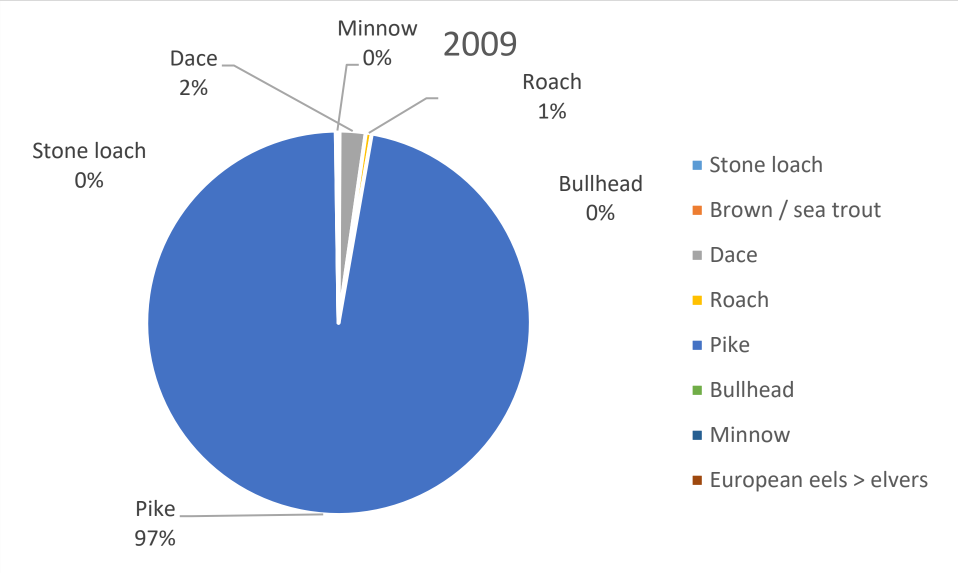
Figure 5-33. Biomass estimates of other fish species within the survey reach, 2006-2019

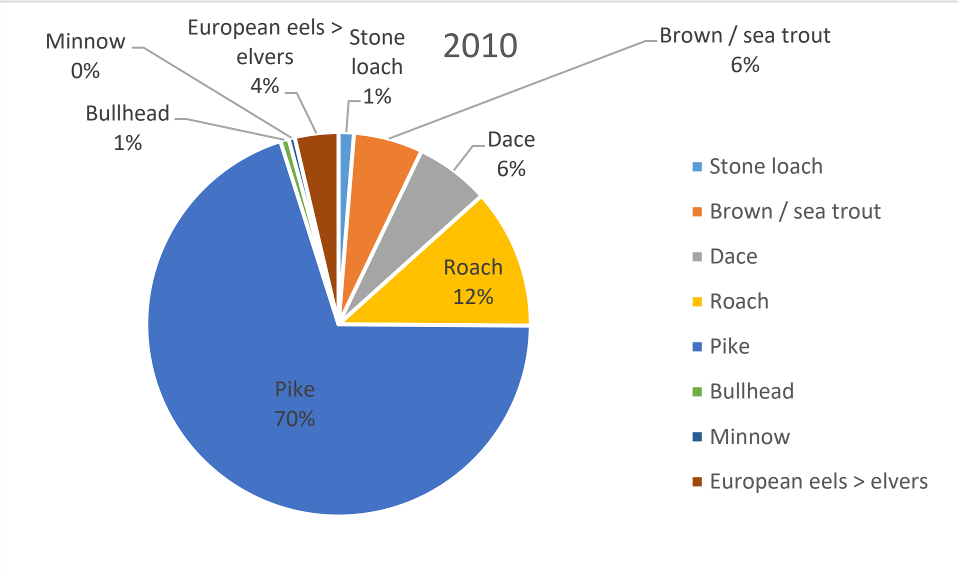
Community composition in terms of biomass

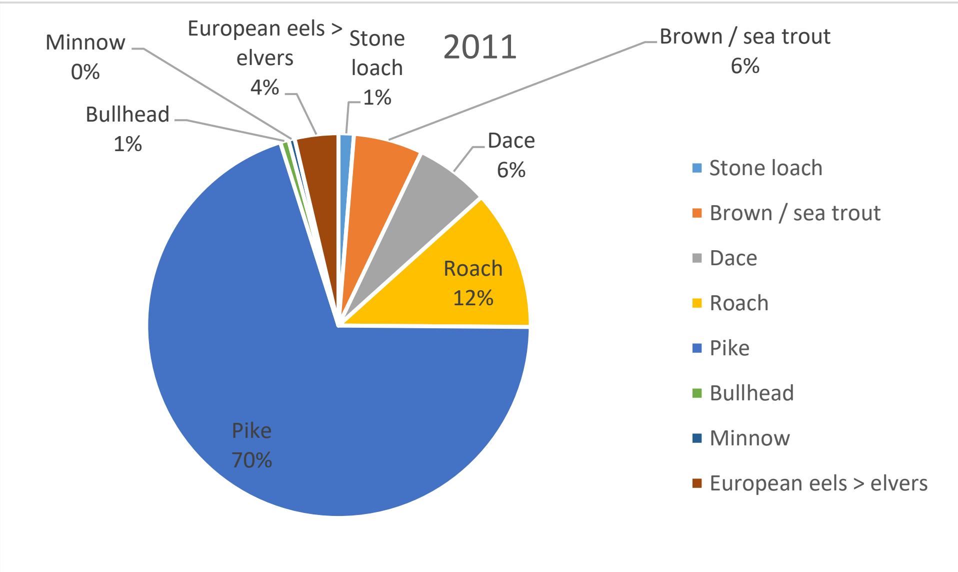


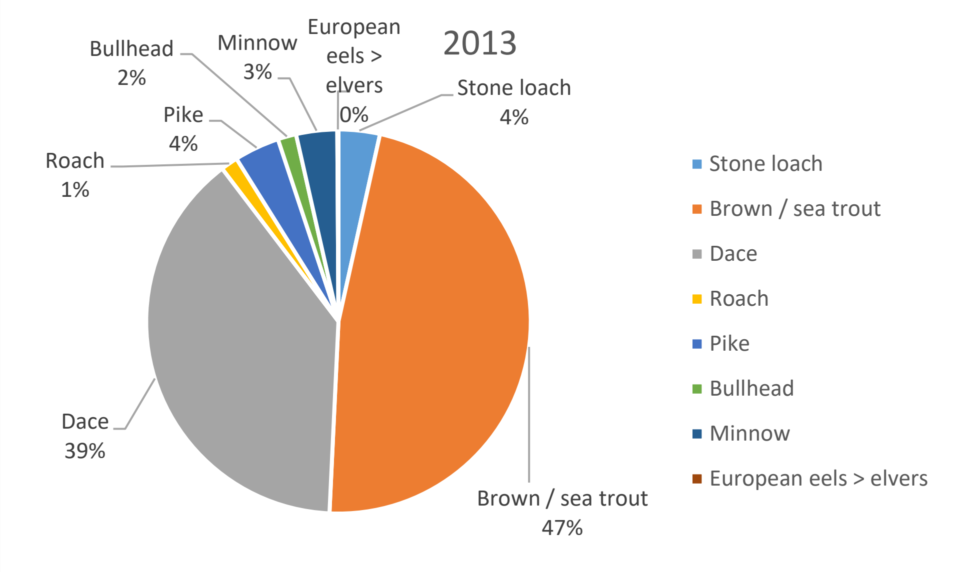


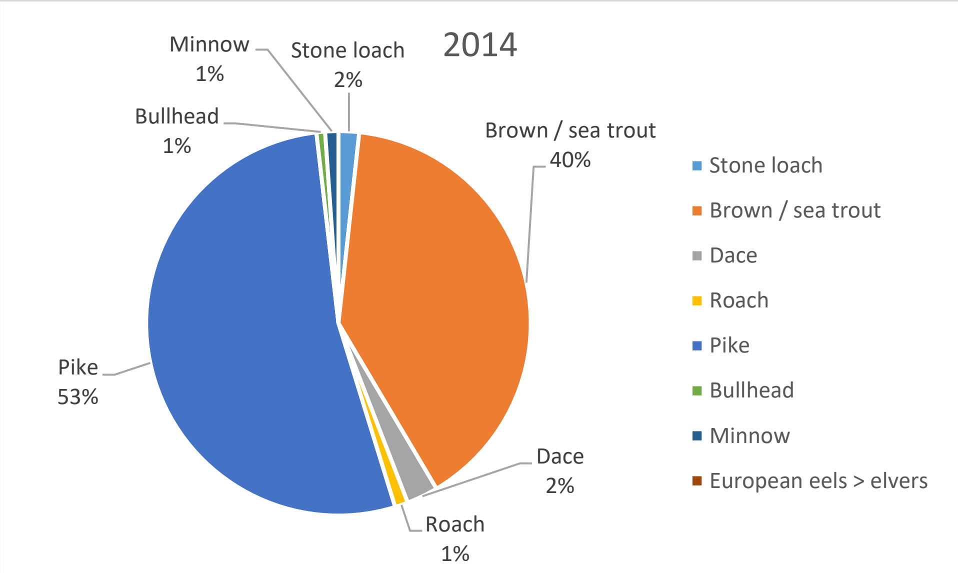


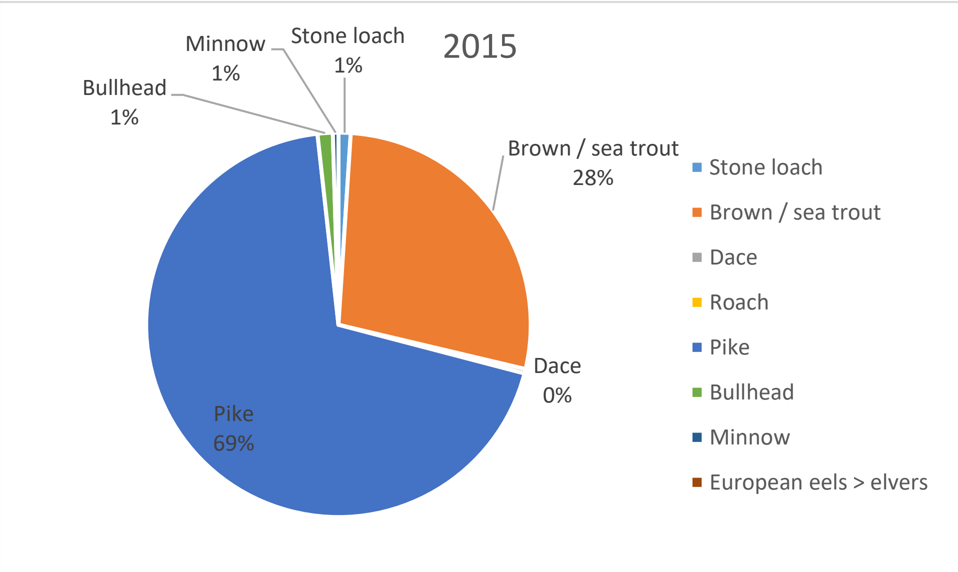

2009
Minnow 0%
Dace 2%
Roach 1%
Stone loach 0%
Bullhead 0%
Pike 97%
Stone loach
Brown / sea trout
Dace
Roach
Pike
Bullhead
Minnow
European eels > elvers

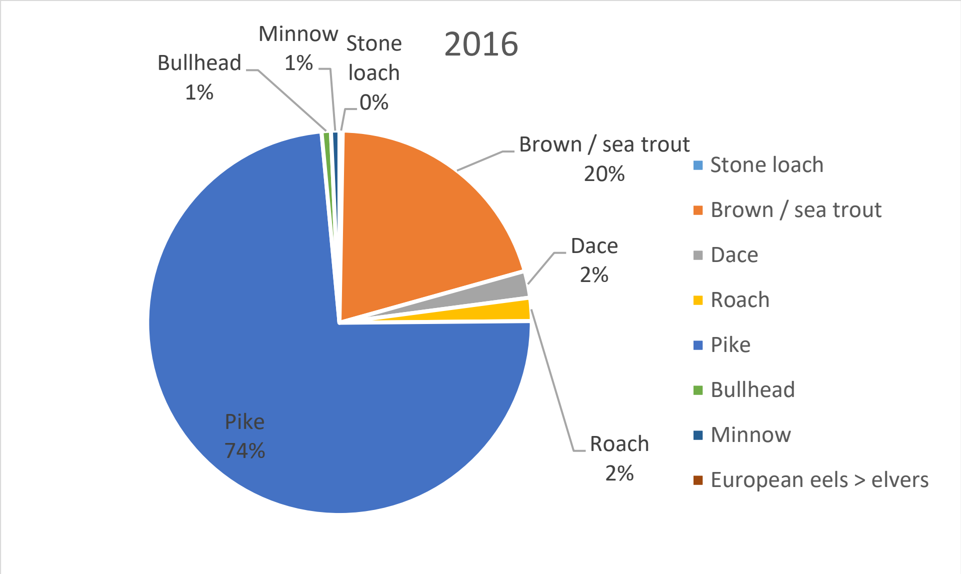

2010
Minnow 0%
European eels > elvers 4%
Stone loach 1%
Brown / sea trout 6%
Bullhead 1%
Dace 6%
Roach 12%
Pike 70%
Stone loach
Brown / sea trout
Dace
Roach
Pike
Bullhead
Minnow
European eels > elvers

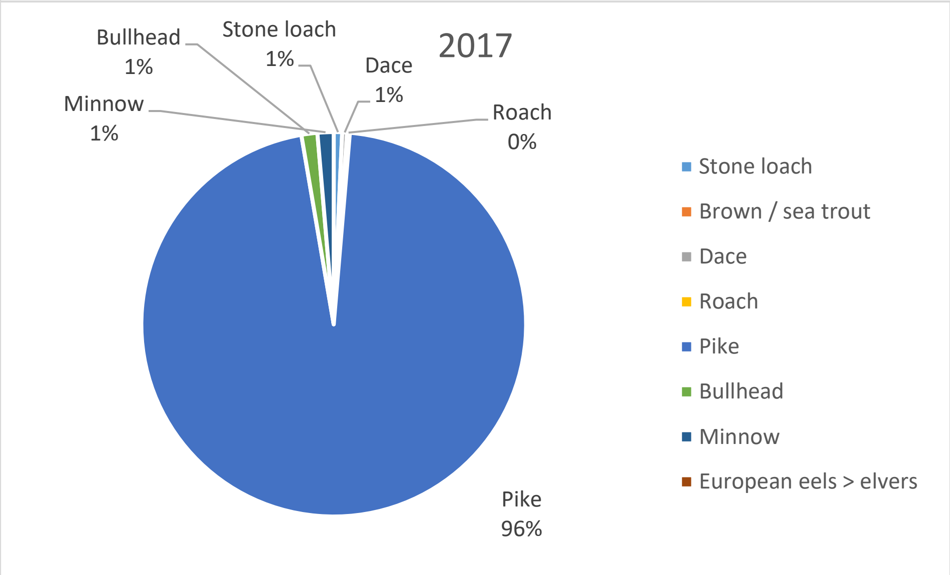

2011
Minnow 0%
European eels > elvers 4%
Stone loach 1%
Brown / sea trout 6%
Bullhead 1%
Dace 6%
Roach 12%
Pike 70%
Stone loach
Brown / sea trout
Dace
Roach
Pike
Bullhead
Minnow
European eels > elvers

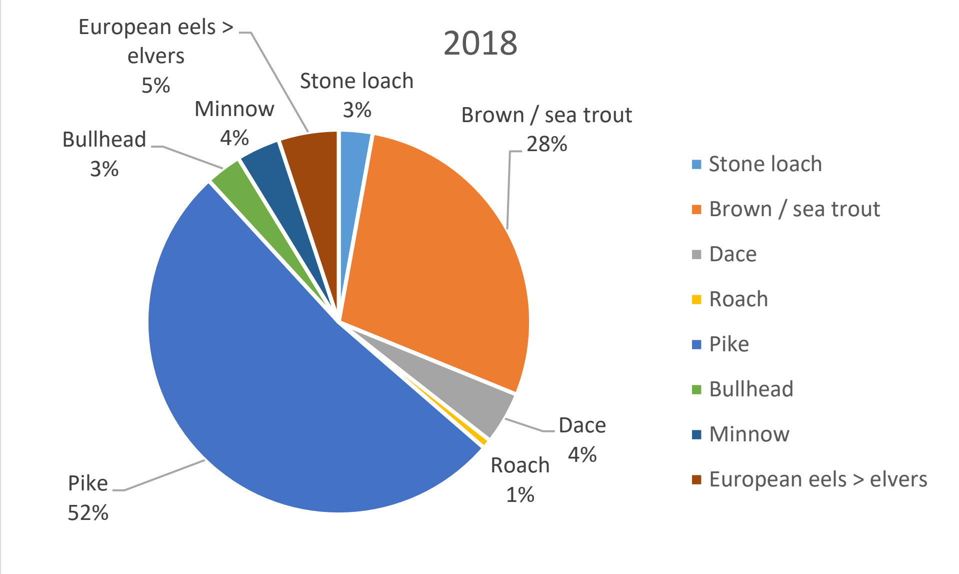

2013
Stone loach 4%
Brown / sea trout 47%
Dace 39%
Roach 1%
Pike 4%
Bullhead 2%
Minnow 3%
European eels > elvers 0%
Stone loach
Brown / sea trout
Dace
Roach
Pike
Bullhead
Minnow
European eels > elvers

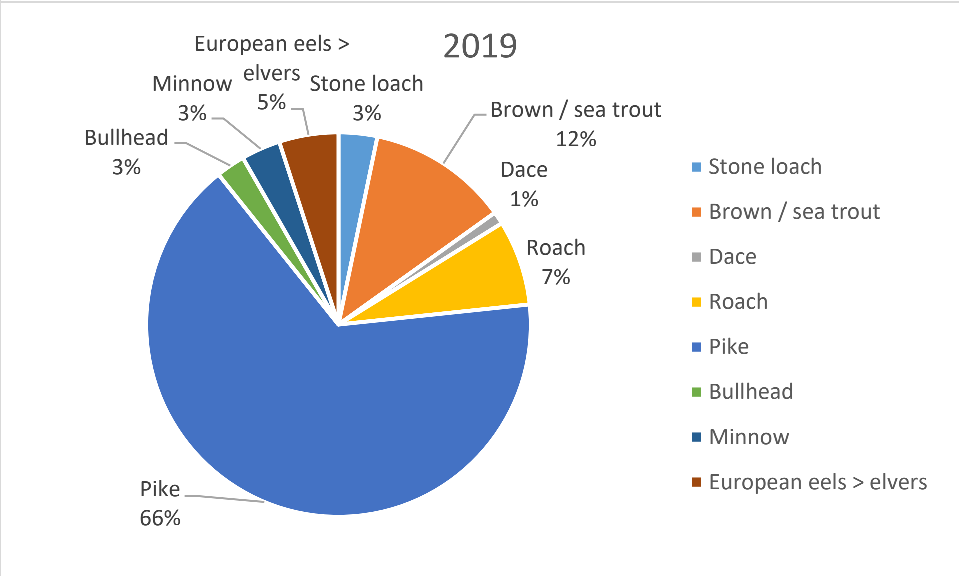

2014
Minnow 1%
Stone loach 2%
Bullhead 1%
Brown / sea trout 40%
Pike 53%
Dace 2%
Roach 1%
Stone loach
Brown / sea trout
Dace
Roach
Pike
Bullhead
Minnow
European eels > elvers


2015
Minnow 1%
Stone loach 1%
Bullhead 1%
Brown / sea trout 28%
Dace 0%
Pike 69%
Stone loach
Brown / sea trout
Dace
Roach
Pike
Bullhead
Minnow
European eels > elvers


2016
Bullhead 1%
Minnow 1%
Stone loach 0%
Brown / sea trout 20%
Dace 2%
Roach 2%
Pike 74%
Stone loach
Brown / sea trout
Dace
Roach
Pike
Bullhead
Minnow
European eels > elvers


2017
Bullhead 1%
Stone loach 1%
Dace 1%
Minnow 1%
Roach 0%
Pike 96%
Stone loach
Brown / sea trout
Dace
Roach
Pike
Bullhead
Minnow
European eels > elvers


2018
European eels > elvers 5%
Stone loach 3%
Minnow 4%
Brown / sea trout 28%
Bullhead 3%
Dace 4%
Roach 1%
Pike 52%
Stone loach
Brown / sea trout
Dace
Roach
Pike
Bullhead
Minnow
European eels > elvers


2019
European eels > elvers 5%
Minnow 3%
Stone loach 3%
Brown / sea trout 12%
Bullhead 3%
Dace 1%
Roach 7%
Pike 66%
Stone loach
Brown / sea trout
Dace
Roach
Pike
Bullhead
Minnow
European eels > elvers

Standing crop estimate - Biomass

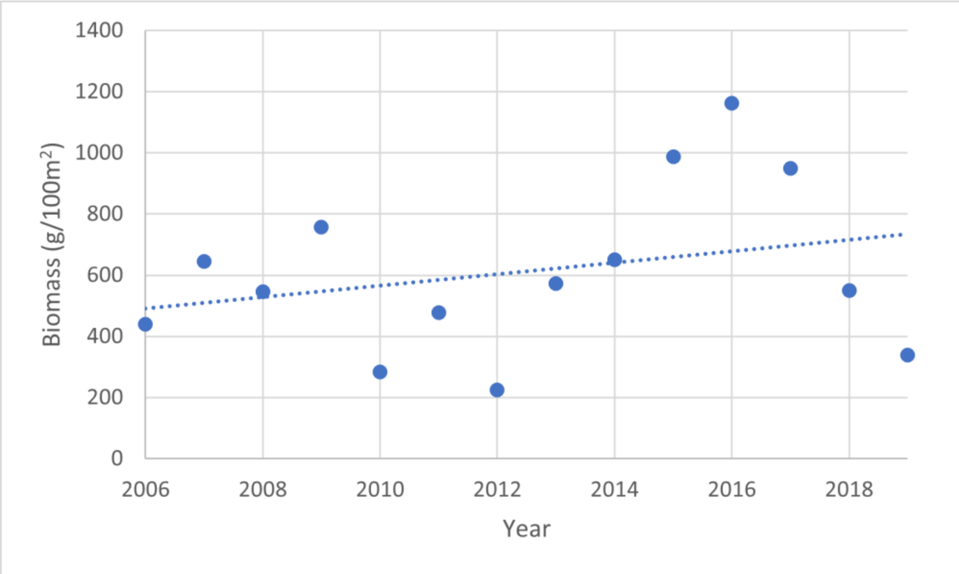


Figure 5-34.Carle and Strub standing crop estimate, all fish >99mm

5.3.3. *Summary of results*

Notable changes in abundance were observed for eight out of the seventeen species recorded at the site (47%). The most significant increases were for brown trout, gudgeon and all minor species (Figure 5-29 & Figure 5-30). Trout biomass increased from 6% in 2010/2011, to almost half the biomass following the restoration works in 2013, highlighting the significant increase in suitable habitat for this species.

Post-restoration declines in abundance were recorded for pike, eels and perch. Despite the decline in pike abundance, pike biomass remained fairly constant post restoration, potentially indicating that the new habitat is more suitable for larger pike to take up residence in than the former which was dominated by juvenile pike. Pre restoration, few pike were recorded >700mm (see Appendix II), however post 2015 they were caught on a yearly basis.

The pronounced lack of fish recorded in 2012 is likely due to the proximity of this survey to the completion date of the scheme. The new channel between the straightened Wensum and the reinstated historic channel was likely bare, lacking vegetation. Fish numbers quickly rebounded from 2013 onwards, suggesting the channel margins became vegetated and invertebrate communities re-established themselves.

Figure 5-34 shows a substantial increase in biomass from 2013 to 2016, with total standing crop almost 1200g/100m^2, compared to <500 g/100m^2 in 2011. Standing crop then declines again over the following 3 years to <400 g/100m^2 in 2019. The reason behind this decline cannot be inferred from the EA fish survey data, ideally changes in the physical habitat are recorded to determine whether any changes have occurred that may have led to this drastic reduction.

Species richness appears to have increased post – restoration, with both rudd and tench being recorded in surveys following the completion of the works.

Further discussion of these results is presented in section 8.

5.4. Scheme 4 – Swanton Morley/Reach 14a

5.4.1. *Scheme summary*

The Swanton Morley restoration scheme encompasses 0.88 km of river Wensum from downstream of Swanton Morley weirs to Castle Farm (TG 02031 18359 to TG 02760 17770). The restoration works were completed between June and September 2012.

Pre-restoration, historic dredging had left the river channel in this reach wider and deeper than what would be considered natural. The river was also largely disconnected from the floodplain by large spoil embankments on both banks. Furthermore, the reach lacked tree cover and in-channel woody debris, which are likely to have impacted successful fish recruitment and increase predation rates.

Restoration in this reach primarily entailed the installation of gravel glides, pools, lateral shelves (berms) and woody debris. Some partial removal of spoil embankments was also undertaken to improve floodplain connectivity. A small meander loop, bypassed as part of a land drainage scheme in the 1950s, has also been reinstated by plugging the existing straight channel to divert flows around the loop. Once de-silted, the meander returned to the natural hard bed, consisting of pockets of gravel and chalk, providing excellent habitat. Selective planting of native species of tree and shrub has also taken place on the open stretches of channel to complement the other restoration features.

Figure 5-35. Restored reach, post restoration, August 2012. (Source: EA RWRS fact sheets combined)

5.4.2. *Fish survey data*

Three years of fish population data collected within the restoration reach exist. This represents one year pre-restoration data and 2 years post-restoration ('Swanton Morley (Restoration reach 14)', EA fish survey site ID 42981. TG 02076 18094 - TG 02058 17877).

There is a nearby 'control' site with a longer-term data set (11 years), approximately 1.25 km upstream of the restoration reach which may provide some insight into the background condition of the river ('Swanton Morely', Site ID 1482, TG 01807 19361 - TG 01988 19382). However, as the 'control' site is geographically separate from the restoration reach (separated by weirs), it is not appropriate to use this data for a robust comparison to be made, in relation to how the restoration work has impacted fish populations within the restoration reach. The habitat may have been fundamentally different and therefore supported a different community of fish than in the restoration reach (pre-restoration). Graphs of the control site are included in the Appendix III.

Table 5-4. General overview of changes in the fish community at Swanton Morley restoration reach 14, observed following restoration work. "+" indicates clear increase, "-" indicates a clear decline. = indicates no clear changes.

Species		Abundance change post - restoration	Biomass change post-restoration
3-spined stickleback	*Gasterosteus aculeatus*	=	=
Stone loach	*Barbatula barbatula*	+	+
Brown / sea trout	*Salmo trutta*	+	+
Chub	*Leuciscus cephalus*	=	-
Dace	*Leuciscus leuciscus*	+	+
Pike	*Esox lucius*	=	-
Minnow	*Phoxinus phoxinus*	+	+
Lamprey sp. ammocoetes	*Petromyzontidae*	=	=
Gudgeon	*Gobio gobio*	+	=
Perch	*Perca fluviatilis*	+	+
European eels > elvers	*Anguilla anguilla*	=	+
Roach chub hybrid	*Leuciscus cephalus x Rutilus rutilus*	=	=
Roach	*Rutilus rutilus*	=	=

Abundance- Swanton Morley, Restoration reach 14.

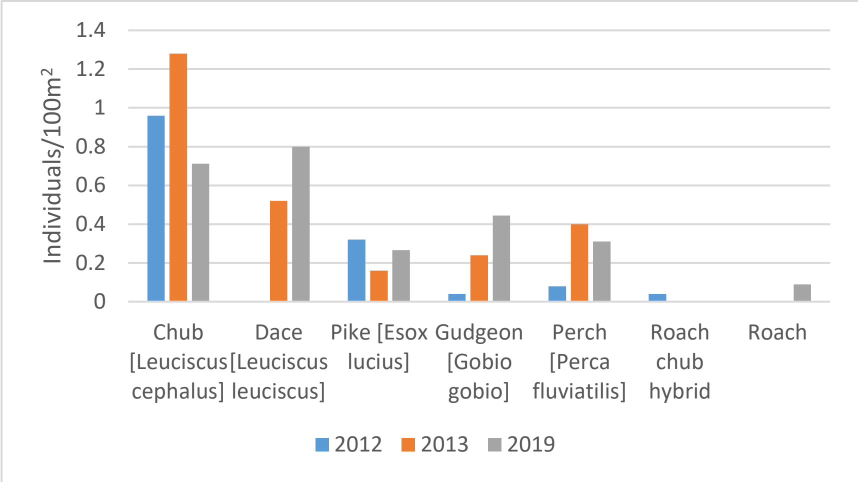


Figure 5-36. Abundance estimates of coarse fish species within the restoration reach, 2012, 2013, 2019. Data is for all lengths of fish caught.

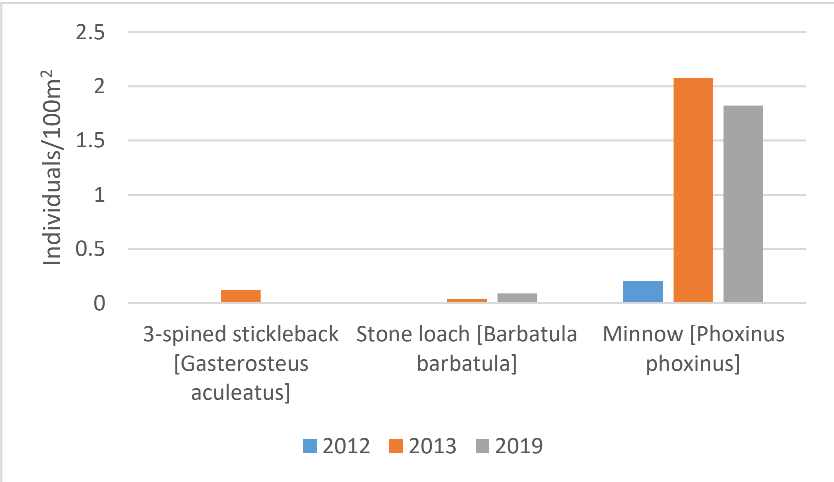


Figure 5-37.Abundance estimate of minor fish species within the restoration reach, 2012, 2013, 2019. Data is for fish all lengths of fish.

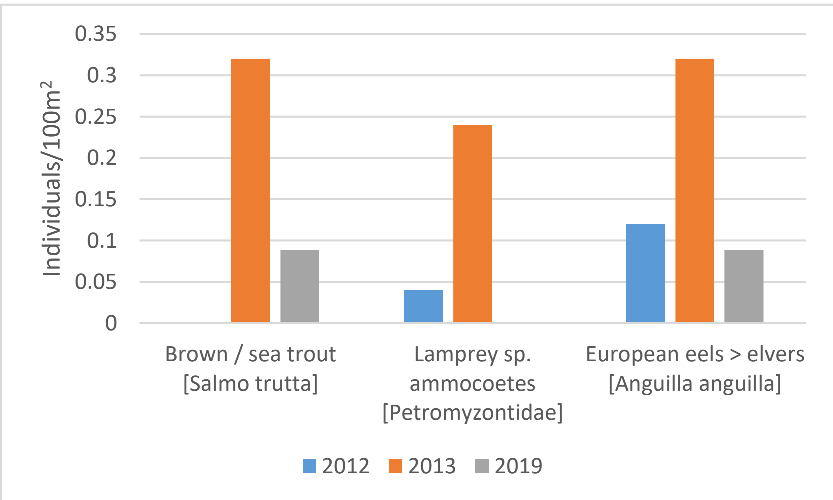


Figure 5-38. Abundance of other fish species within the restoration reach, 2012, 2013, 2019. Data is for fish all lengths of fish.

Biomass – Swanton Morley

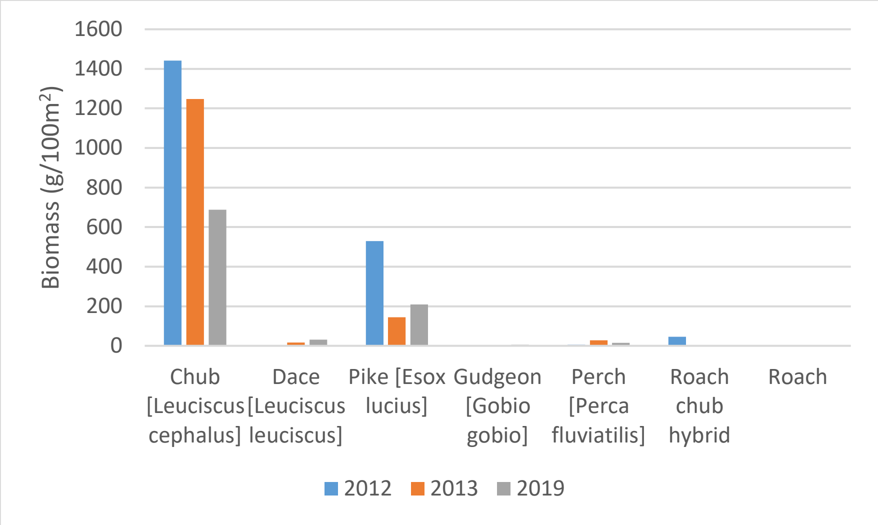


Figure 5-39. Biomass estimates of coarse fish species within the survey reach, 2012, 2013, 2019

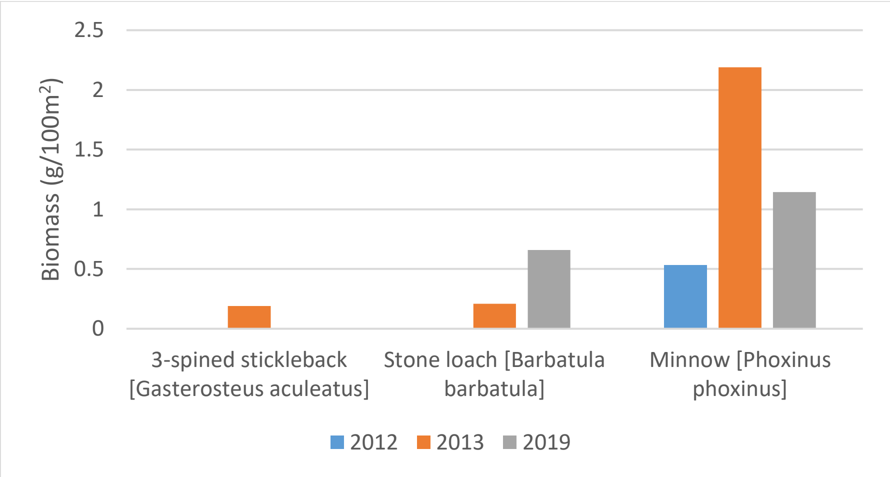


Figure 5-40. Biomass estimates of minor fish species within the survey reach, 2012, 2013, 2019

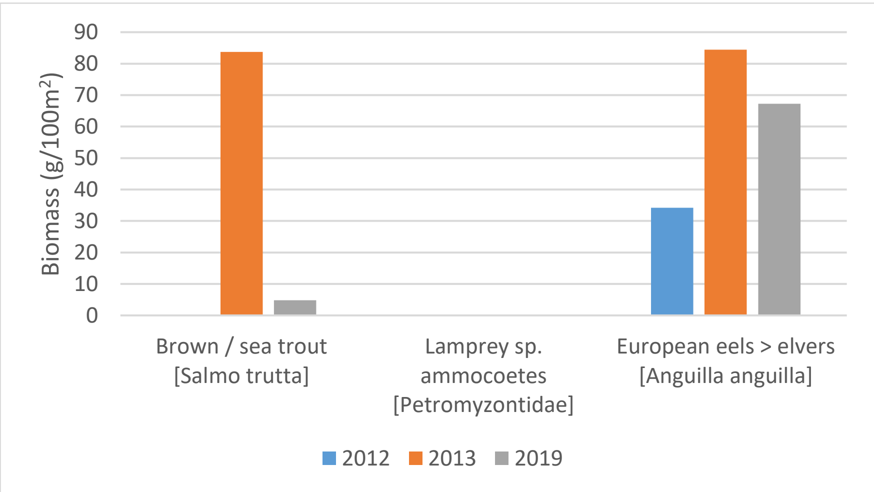
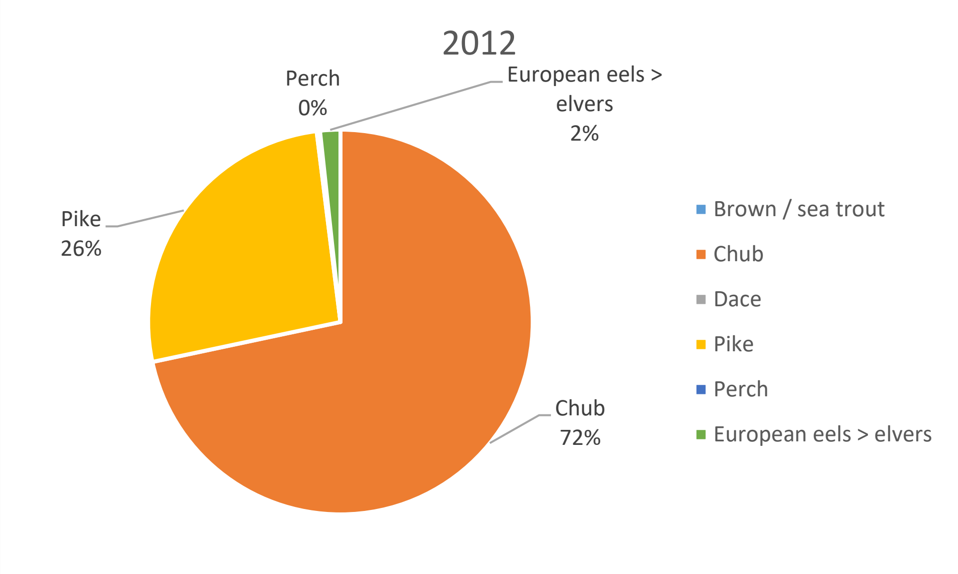
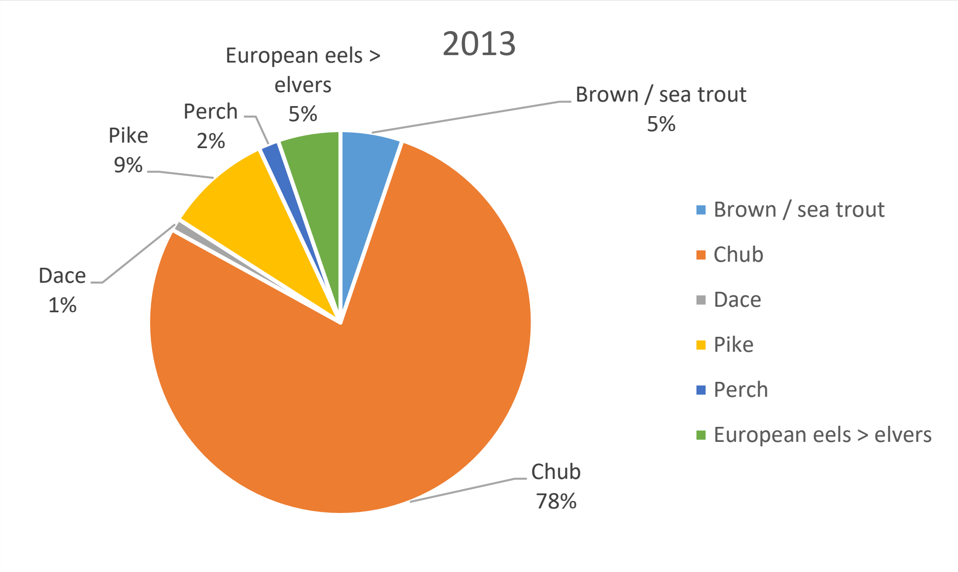
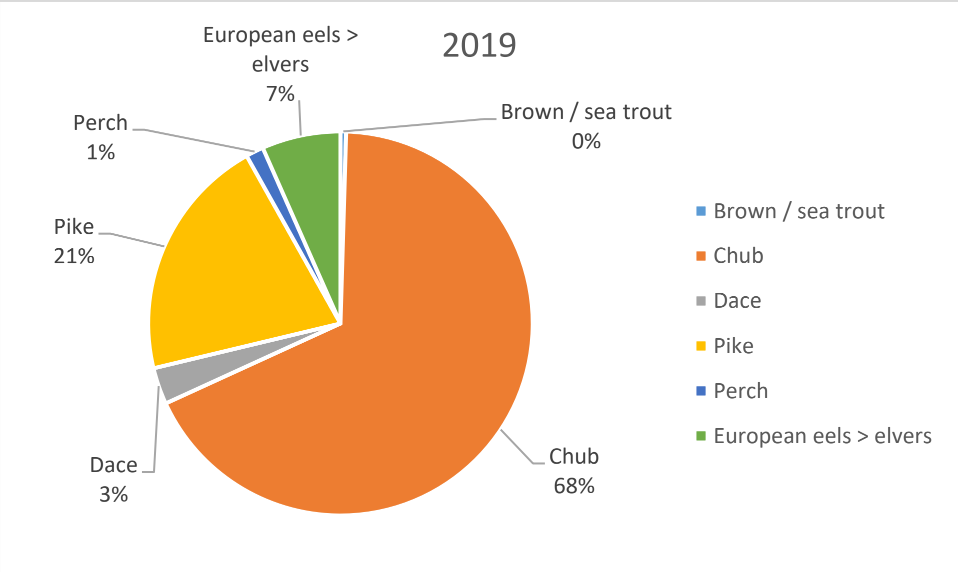


Figure 5-41. Biomass estimates of other fish species within the survey reach, 2012, 2013, 2019

Community composition in terms of biomass







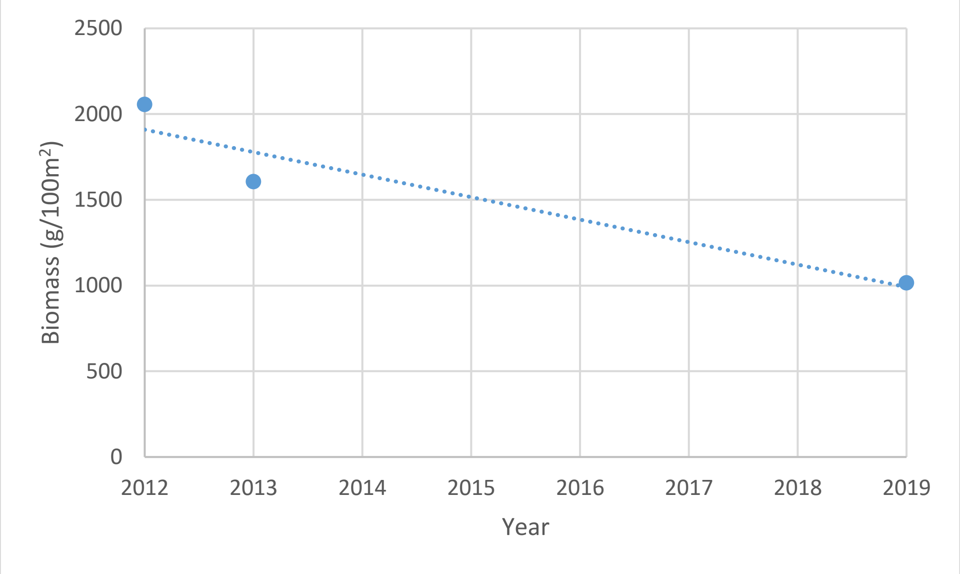


Figure 5-42. Standing crop estimate in terms of biomass for the restoration reach

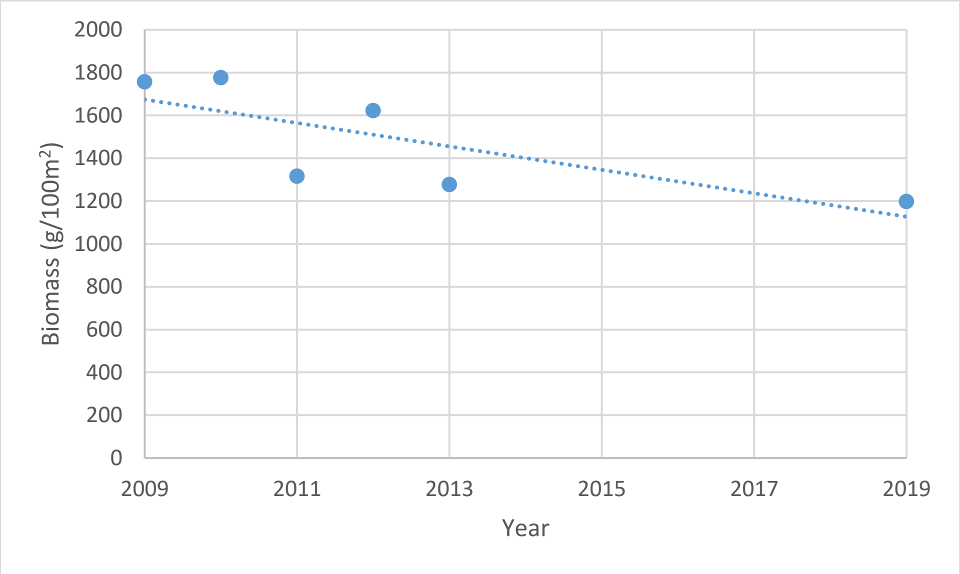


Figure 5-43. Standing crop estimate in terms of biomass for the control site

5.4.3. *Summary of results*

It appears that the restoration works had a positive impact on the fish community present within the survey reach. The abundance of all species recorded either remained similar to pre-restoration levels or increased post restoration. No declines in abundance were observed over the thirteen species recorded.

Biomass also increased or remained similar post restoration for all species aside from pike and chub. Pike biomass in 2019 was approximately two-thirds of the 2012 level. The recorded chub biomass in 2019 was half of the 2012 level.

In terms of community composition, chub still account for approximately 70% of the biomass, similarly to before restoration works took place. Eel biomass has increased, with higher proportions of the total biomass recorded in 2013/2019 than 2012. The dace population also increased from representing

<1% of the total biomass in 2012 to 1% and 3% in 2013 and 2019 respectively. All minor species (3-spined stickleback, stone loach and minnow) also increased in biomass post-restoration.

Since 2012 there has been a decline in standing crop estimate, with biomass/100m^2 reducing year on year (Figure 5-42). However, this decline also took place in the control reach (Figure 5-43) so it is unlikely that this is as a result of the restoration work.

Further discussion of these results is presented in section 8.

5.5. Scheme 5 – Sculthorpe/Hempton Moor// Reach 27 and Reach 28c

5.5.1. *Scheme summary*

The Sculthorpe Moor restoration scheme encompasses 2.125 km of river Wensum approximately 900m downstream of Sculthorpe Mill down to Night Common where the river passes beneath the A1065 Fakenham Bypass (National Grid Reference TF 89690 29869 to TF 91287 29661). The restoration works spanned two years and were completed in November 2013.

The planform and channel geometry of this reach had been subjected to past modifications including divisions, straightening and significant dredging, impacting the function of the river. The creation of gravel glides was identified as a highly important measure to improve the reach, with channel re-sectioning also being identified as a priority measure.

Several gravel glides have been created along the reach by importing material from a local source. The glide locations were selected in areas with appropriate channel dimensions to ensure all silt and sand material remains mobile under a wide range of flows. Woody debris and pinned willows were used to help improve silted gravel beds. By constricting the flow in this way has ensured fine sediments remain on the move and the gravels remain exposed, providing spawning habitat for trout and habitat for a range of invertebrates which depend on clean gravel substrate.

Figure 5-44. Restored river channel with clean gravel beds visible. Note sinuosity and flow diversity. (Source: EA RWRS fact sheets combined)

5.5.1. *Fish survey data*

Three years of fish population data collected within the restoration reach exist. This represents one year pre-restoration data and 2 years post-restoration ‘Hempton Moor u/s Fakenham bypass’, EA fish survey site ID 43603. NGR: TF 90532 29708 – TF 90724 29671). Another survey site is located within the restoration reach (site ID: 43791), however there is only one year of pre-restoration data that cannot be used for a comparison.

There is also a nearby ‘control’ site upstream with 4-year dataset, approximately 1 km upstream of the restoration reach which may provide some insight into the background condition of the river (‘u/s Sculthorpe Mill’, Site ID 1467, TF 8892830003 – TF 8904030102). However, as the control site is geographically separate from the restoration reach (separated by a mill), it is not appropriate to use this data for a robust comparison to be made, in relation to how the restoration work has impacted fish populations within the restoration reach. The habitat may have been fundamentally different and therefore supported a different community of fish than in the restoration reach (pre-restoration), and/or respond to other variables in a different way. Graphs of the control site are included in the Appendix III.

Figure 5-45. General overview of changes in fish community (>99mm) within the Sculthorpe restoration reach, observed following restoration work. "+" indicates clear increase, "-" indicates a clear decline. = indicates no clear changes.

Species		Abundance change post -restoration	Biomass change post- restoration
Rudd	*Scardinius erythrophthalmus*	=	=
Stone loach	*Barbatula barbatula*	n/a	n/a
Brown / sea trout	*Salmo trutta*	+	+
Dace	*Leuciscus leuciscus*	+	+
Bullhead	*Cottus gobio*	n/a	n/a
Minnow	*Phoxinus phoxinus*	n/a	n/a
Brook lamprey > ammocoete	*Lampetra planeri*	+	=
Gudgeon	*Gobio gobio*	-	-
3-spined stickleback	*Gasterosteus aculeatus*	n/a	n/a
Roach	*Rutilus rutilus*	-	-

Abundance – Hempton Moor u/s Fakenham bypass (fish >99mm)

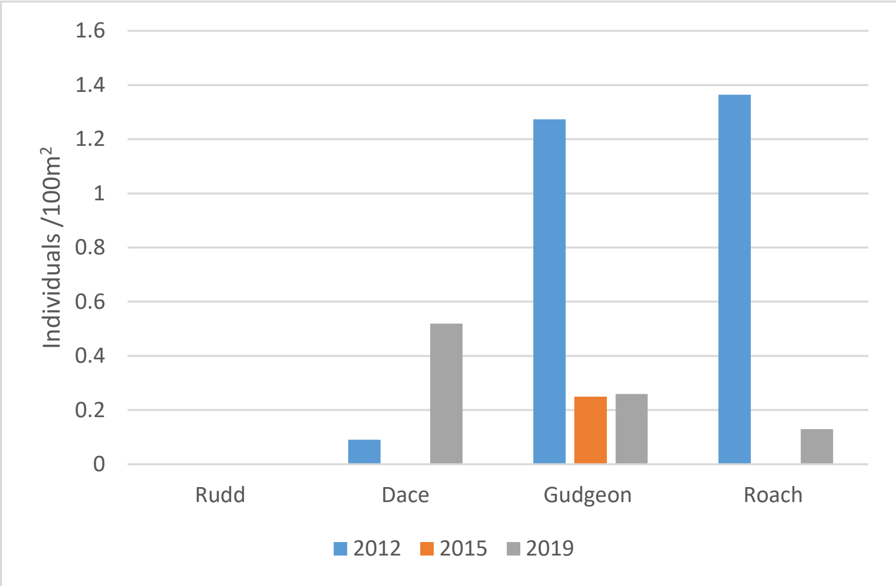


Figure 5-46. Abundance estimates of coarse fish species within the restoration reach, 2012, 2015, 2019. Data is for fish >99mm.

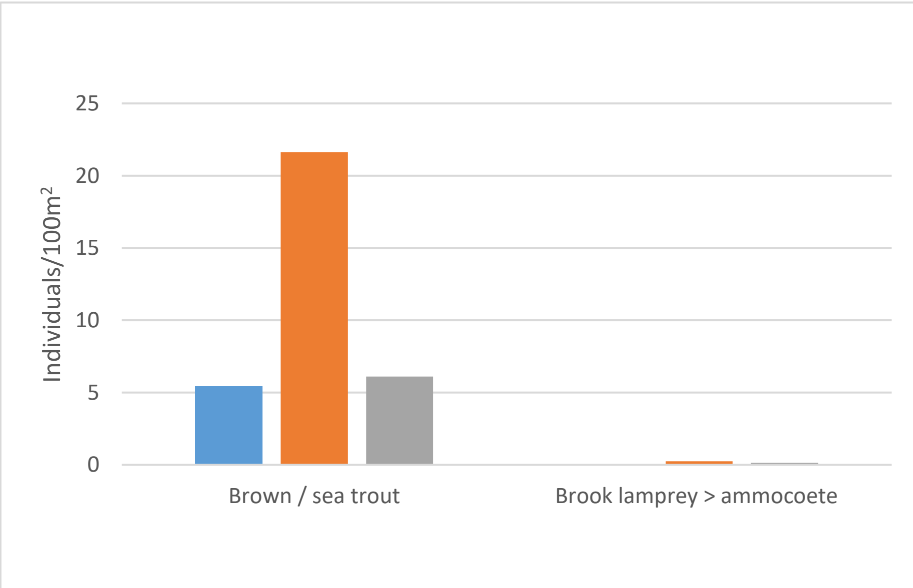


Figure 5-47. Abundance estimates of other fish species within the restoration reach, 2012, 2015, 2019. Data is for fish >99mm.

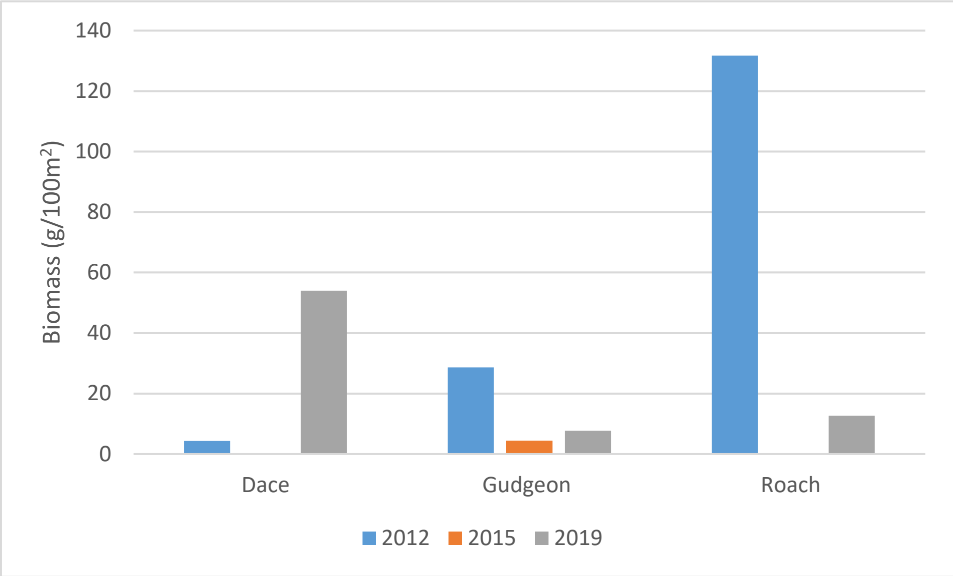


Figure 5-48. Biomass estimates of coarse fish species within the survey reach, 2012, 2015, 2019

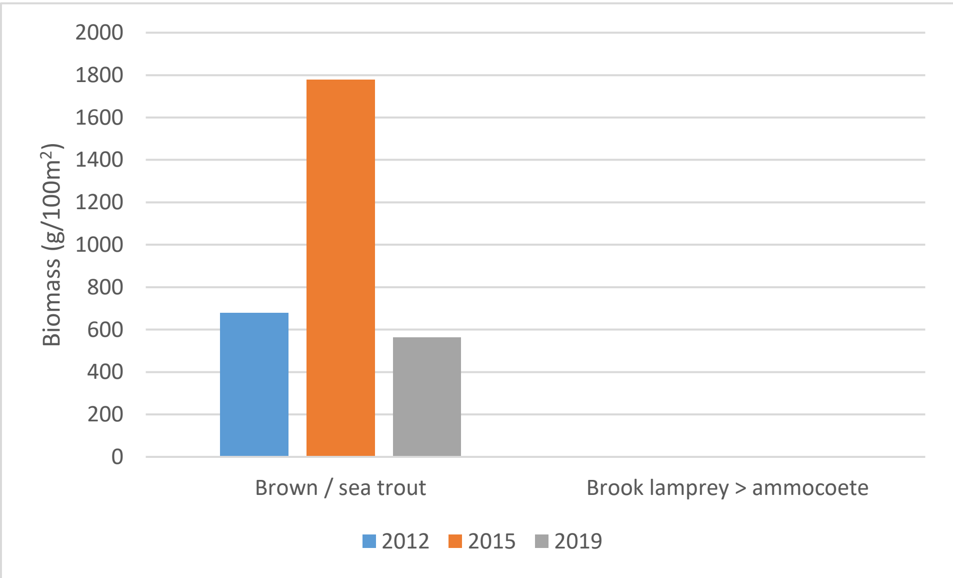
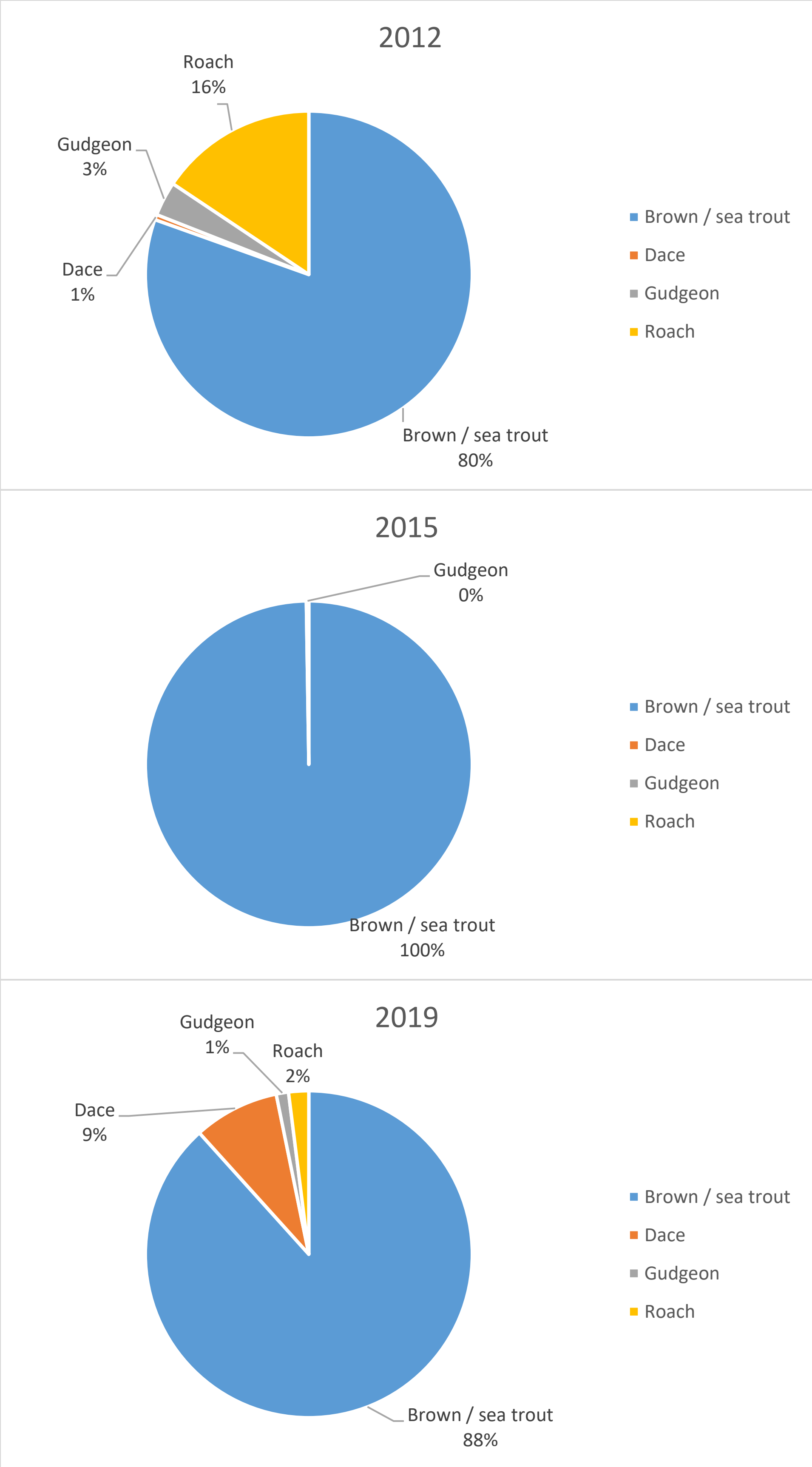


Figure 5-49. Biomass estimates of other fish species within the survey reach, 2012, 2015, 2019


2012
Roach
16%
Gudgeon
3%
Dace
1%
Brown / sea trout
80%
Brown / sea trout
Dace
Gudgeon
Roach
2015
Gudgeon
0%
Brown / sea trout
100%
Brown / sea trout
Dace
Gudgeon
Roach
2019
Gudgeon
1%
Roach
2%
Dace
9%
Brown / sea trout
88%
Brown / sea trout
Dace
Gudgeon
Roach

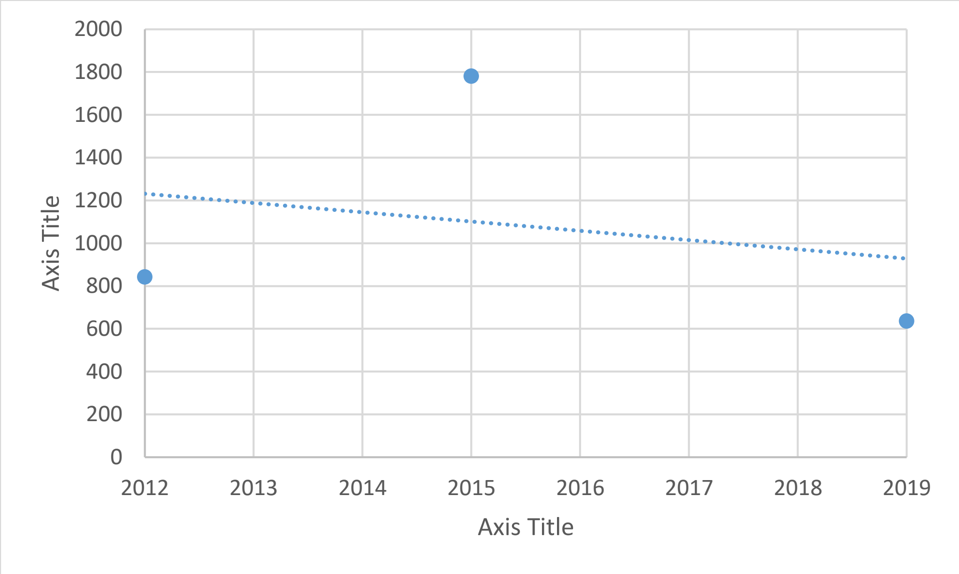


Figure 5-50. Standing crop estimate in terms of biomass for the restoration reach (fish >99mm)

5.5.2. *Summary of results*

The impact of the restoration work at this site appears to be mixed, with both increases and decreases in abundances and biomass of fish being recorded.

Trout were recorded as being the dominant species prior to the restoration work, however in 2015, (3 years post completion) abundance increased almost 400% from 2012 levels (5.4 /100m^2) to almost twenty-two individuals /100m^2. It is unclear as to whether this was caused by natural variation or as a result of the work, as trout abundance had dropped to around six individuals /100m^2 in 2019, only marginally higher than pre-restoration levels.

Dace appear to have replaced roach within the survey reach. Dace increased from 1% of the total biomass in 2012 to 9% in 2019. Pre-restoration, roach represented 16% of the total biomass within the survey reach. This has however since dropped to just 2% in 2019. The proportion of gudgeon has also declined, from 3% of the total biomass in 2012 to 1% in 2019.

5.6. Scheme 6 – River Tat restoration (reaches 41-45)

5.6.1. *Scheme summary*

The River Tat is a tributary of the upper Wensum and forms part of the River Wensum Site of Special Scientific Interest (SSSI). The river Tat scheme encompasses 2.19 km of River Tat from approximately 380m upstream of the Broomsthorpe Road Bridge extending downstream to the Tatterford Road Bridge (NGR: TF 85044 28814 to TF 86701 27978). The works took place between May and August 2013.

The planform and channel geometry of this reach has been subjected to significant historic modifications including divisions, straightening and the construction of an online lake system. Although much of the river has a gravel bed substrate, its gradient is fairly constant and as such, the watercourse is homogeneous in character and the gravels are silted. Despite the presence of riparian woodland, the river is also believed to be lacking in-channel timber.

Restoration primarily aimed to increase flow to keep the gravel silt free. This was achieved by narrowing the channel, either through installing Large Woody Debris (LWD) features or re-distributing bed material to create pool and glide sequences. Woody debris not only increases the local water velocity, helping keep the gravel bed free from silt, but also provides cover for fish and provides habitat for invertebrates.

On the upper reach of the scheme, large spoil embankments have been removed and the material used to create berms narrowing the river channel. The removal of the bank material encourages floodplain wetting during periods of high flow. This has the combined benefits of increasing floodplain biodiversity and providing a sink for suspended sediment, as well as reducing flood risk to people and property in the downstream catchment.

Additionally, several floodplain drainage ditches have been reconnected to the main river channel. These provide both refuge areas in flood events and increase the diversity of habitat available to fish

and other wildlife.

Figure 5-51. Left-hand images display the River Tat pre-restoration, and the right-hand images display the same reaches post-restoration. Note the increase in flow diversity and constriction of the channel in both locations. (Source: EA RWRS fact sheets combined)

5.6.2. *Fish survey data*

Two survey sites are located within the restoration reach (Broomsthorpe Bridge, EA fish survey site ID: 1463, NGR: TF 85128 28553 – TF 85159 28458 & Pynkney Hall, EA site ID: 47583, NGR: TF8596128034 - TF8605128078). The Broomsthorpe Bridge site has 4 years of data available, one survey pre-restoration in March 2013, and additional data for 2014/16/18. No length data is available for this site. The Pynkney hall site was also surveyed in 2013, prior to restoration work commencing. Post-restoration data is available for 2014/15/16/18.

A nearby control site exists (Coxford Abbey farm, Site ID: 32412, NGR: TF 84993 29080) with two years of pre-restoration data available. The 2009 survey was unfortunately a single run survey so does not represent a population estimate and should only be used as a reference for species present.

Broomsthorpe Bridge- Abundance and biomass

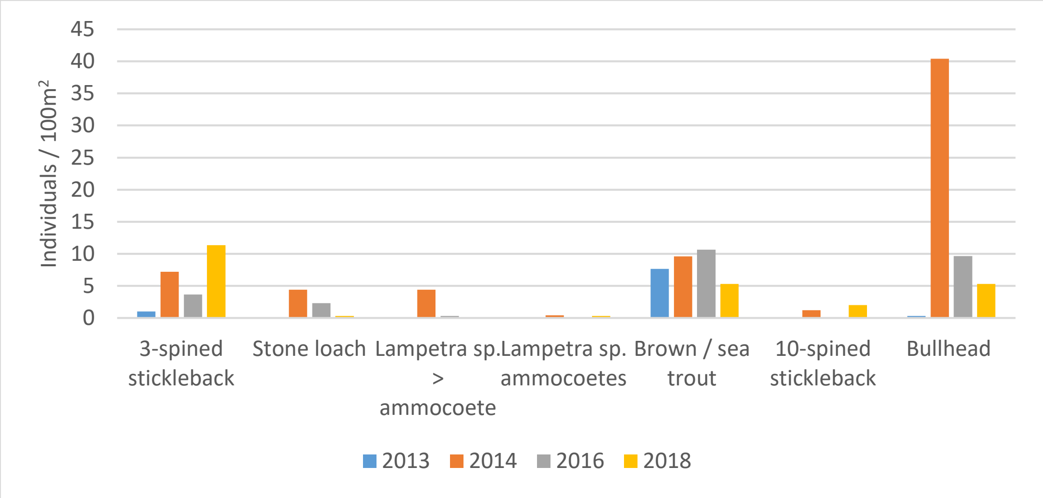


Figure 5-52. Abundance estimates of all fish species within the Broomsthorpe survey reach, 2013, 2014, 2016, 2018.

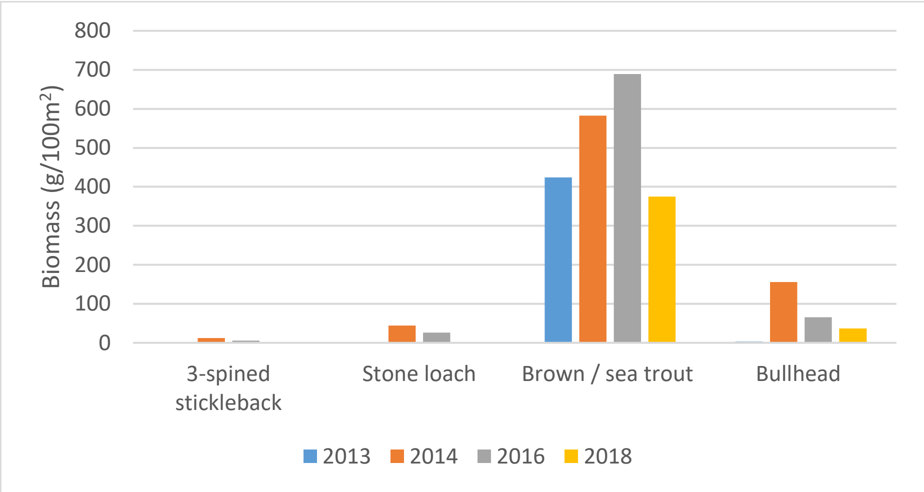


Figure 5-53. Biomass estimates of all fish species within the Broomsthorpe survey reach, 2013, 2014, 2016, 2018.

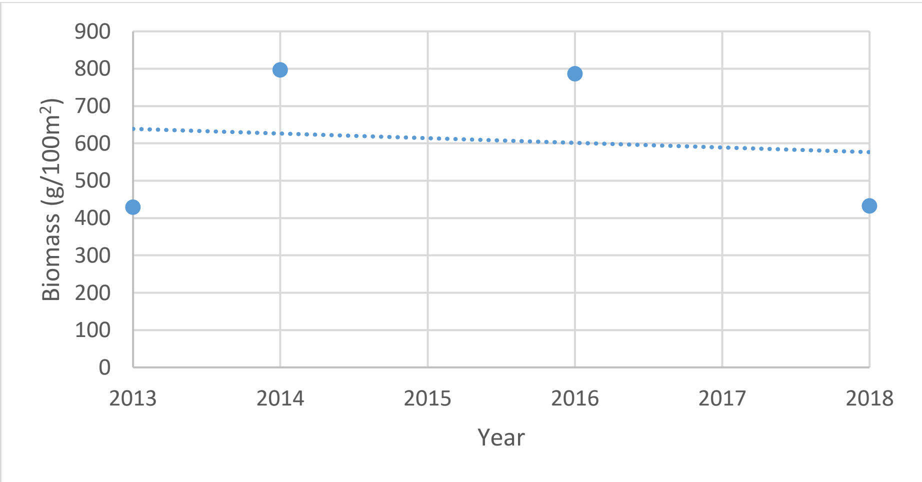


Figure 5-54. Standing crop estimate for the Broomsthorpe reach in terms of biomass

Community composition in terms of biomass - Broomsthorpe Bridge

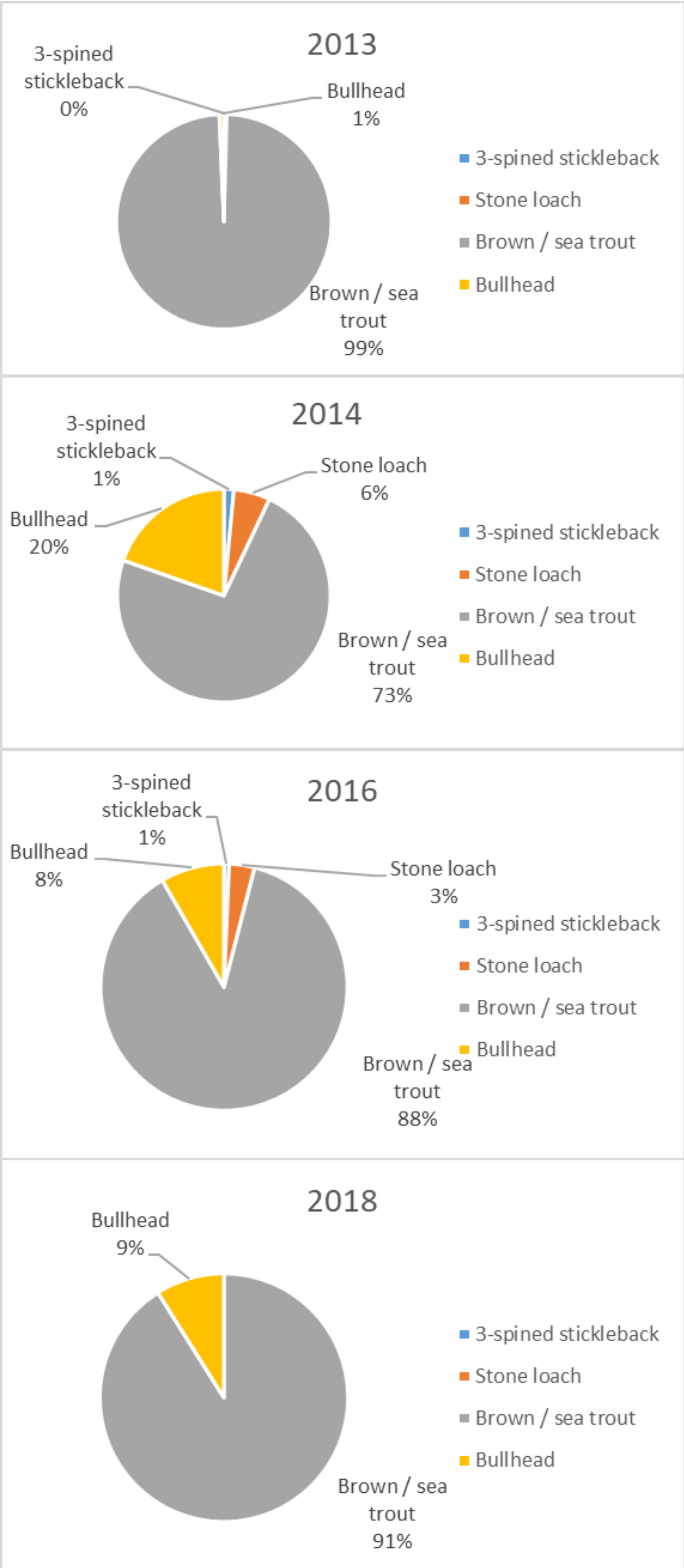


Figure 5-55. Change in fish community composition at Broomsthorope bridge in terms of biomass, 2013-2018.

Pynkney Hall – abundance and biomass

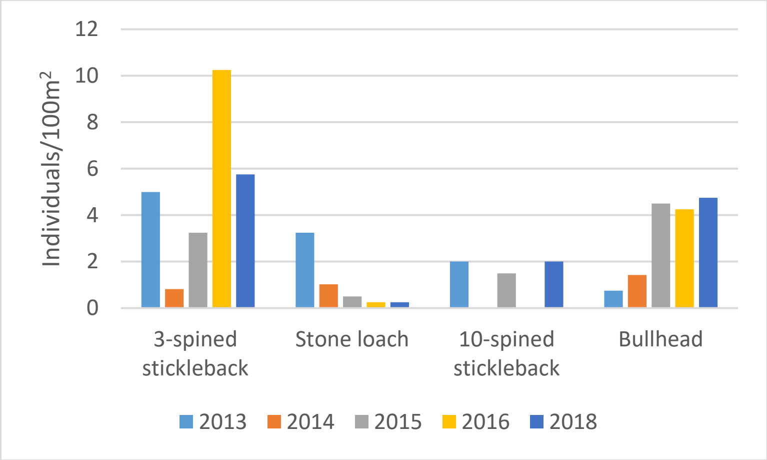


Figure 5-56. Abundance estimates for minor fish species within the Pynkney Hall survey reach, 2013, 2014, 2015, 2016, 2018.

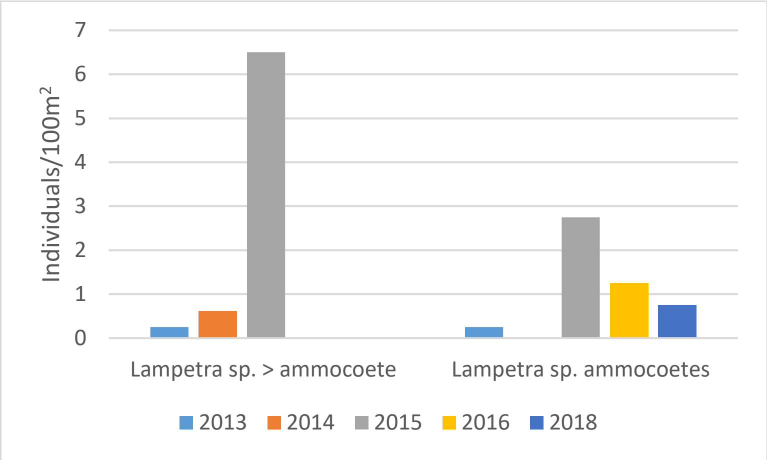


Figure 5-57. Abundance estimates for lamprey within the Pynkney Hall survey reach, 2013, 2014, 2015, 2016, 2018.

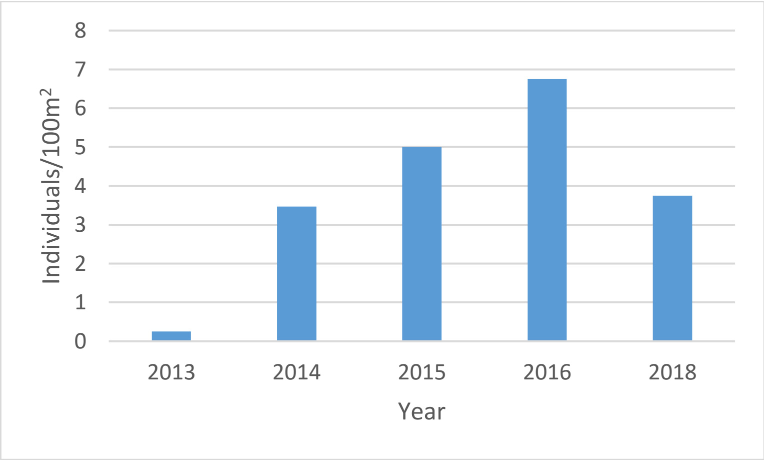


Figure 5-58.Abundance estimates for brown trout within the Pynkney Hall survey reach, 2013, 2014, 2015, 2016, 2018.0

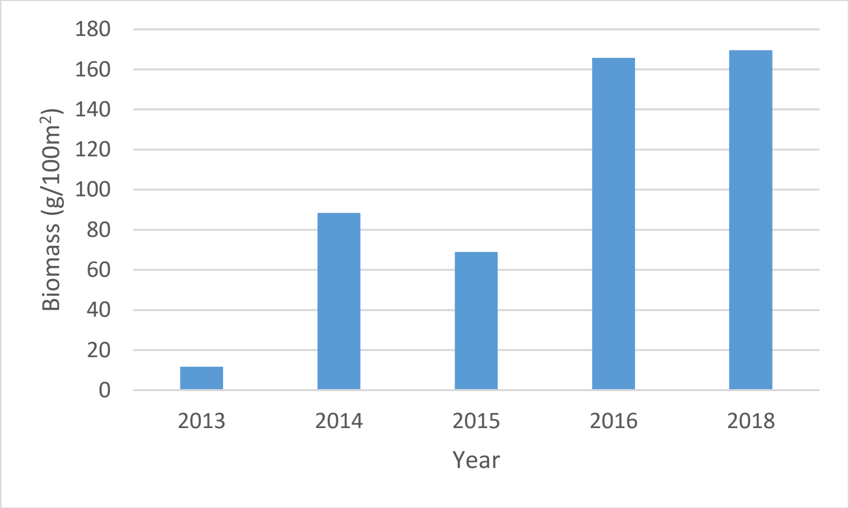


Figure 5-59. Biomass estimates for brown trout within the Pynkney Hall survey reach, 2013, 2014, 2015, 2016, 2018.

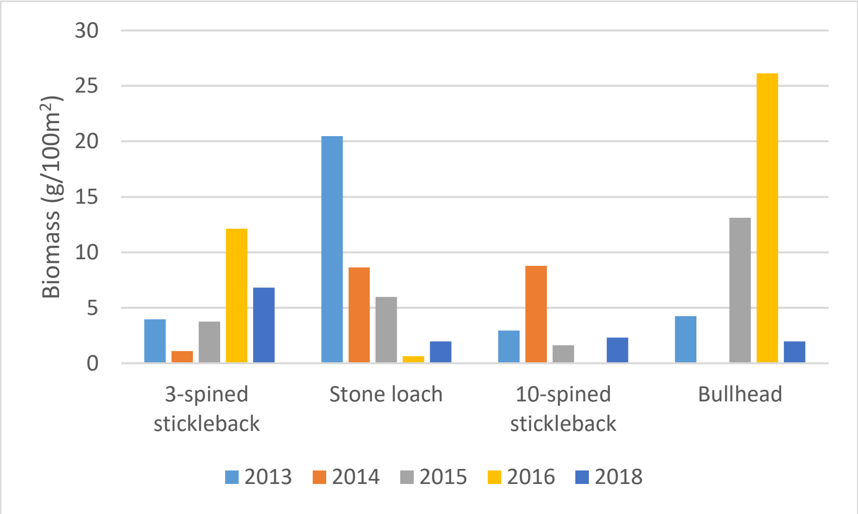


Figure 5-60. Biomass estimates for minor species within the Pynkney Hall survey reach, 2013, 2014, 2015, 2016, 2018.

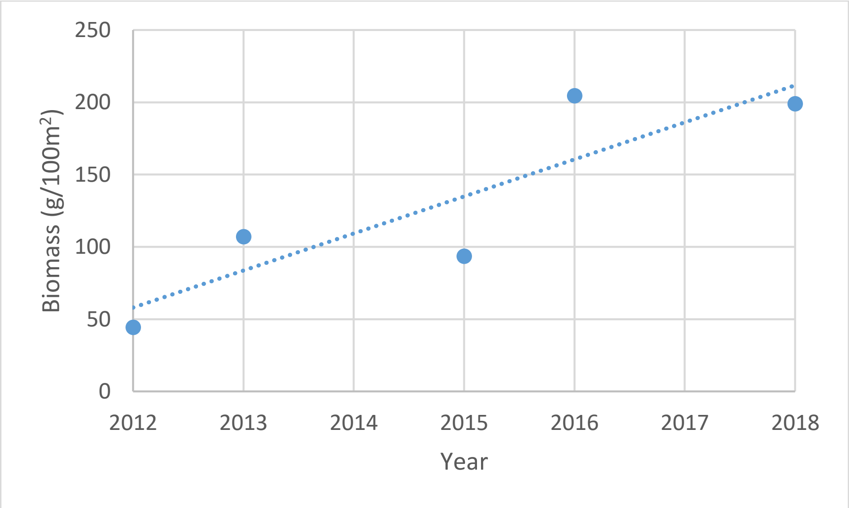


Figure 5-61. Standing crop estimate in terms of biomass for Pynkney Hall restoration reach

Coxford Abbey farm – Control

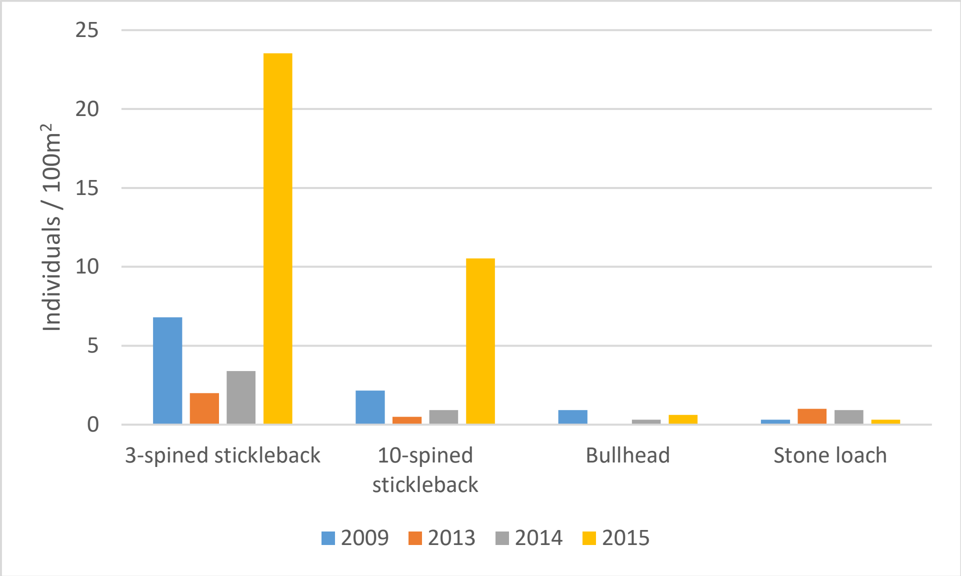


Figure 5-62. Abundance estimates for minor fish species within the Coxford Abbey Farm survey reach.

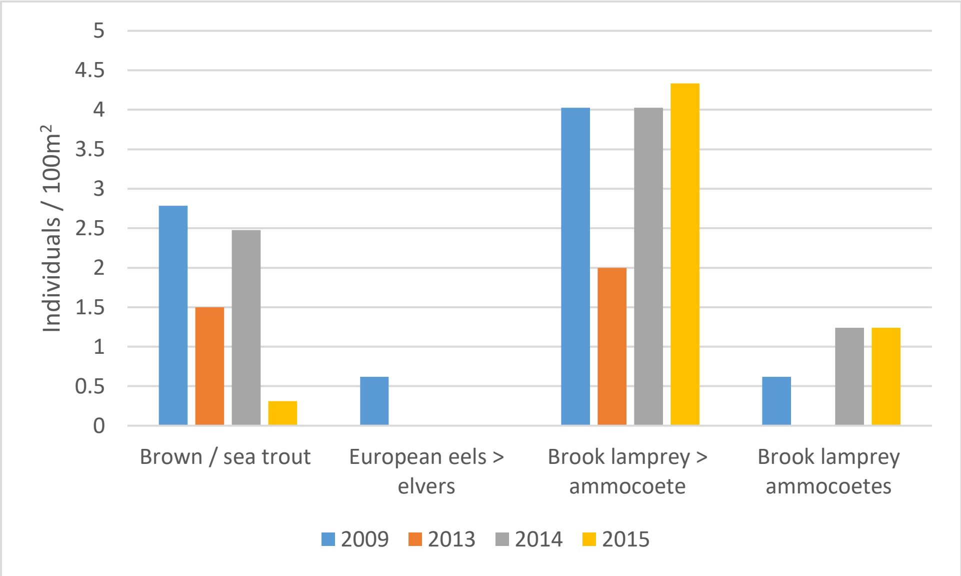


Figure 5-63. Abundance estimates for other fish species within the Coxford Abbey Farm survey reach.

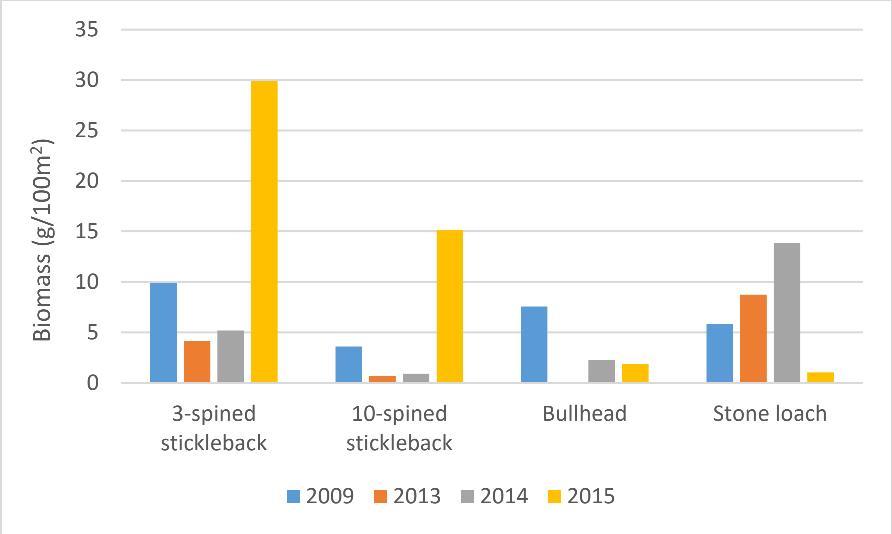


Figure 5-64. Biomass estimates for minor fish species within the Coxford Abbey Farm survey reach.

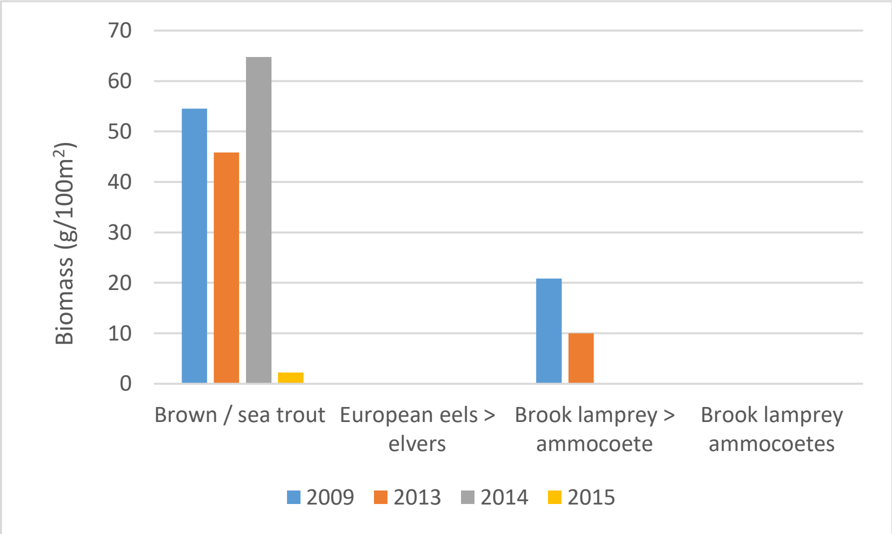


Figure 5-65. Biomass estimates for other fish species within the Coxford Abbey Farm survey reach.

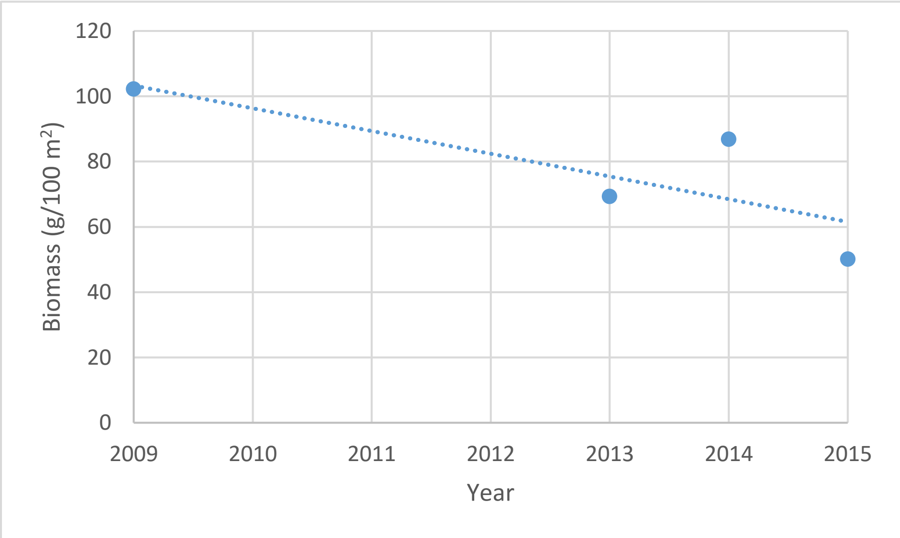


Figure 5-66. Standing crop estimate for Coxford Abbey Farm

Table 5-5. General overview of changes in fish community (all lengths) within the Broomsthorpe Bridge restoration reach, observed following restoration work. "+" indicates clear increase, "-" indicates a clear decline, = indicates no clear changes.

Species		Abundance change post -restoration	Biomass change post- restoration
3-spined stickleback	*Gasterosteus aculeatus*	+	=
Stone loach	*Barbatula barbatula*	+	+
Lampetra sp. > ammocoete	*Lampetra*	=	=
Lampetra sp. ammocoetes	*Lampetra*	=	=
Brown / sea trout	*Salmo trutta*	=	+
10-spined stickleback	*Pungitius pungitius*	=	=
Bullhead	*Cottus gobio*	+	+

Table 5-6. General overview of changes in fish community (all lengths) within the Pynkney Hall restoration reach, observed following restoration work. "+" indicates clear increase, "-" indicates a clear decline, = indicates no clear changes.

Species		Abundance change post -restoration	Biomass change post- restoration
3-spined stickleback	*Gasterosteus aculeatus*	=	+
Stone loach	*Barbatula barbatula*	-	-
Lampetra sp. > ammocoete	*Lampetra*	+	n/a
Lampetra sp. ammocoetes	*Lampetra*	+	n/a
Brown / sea trout	*Salmo trutta*	+	+
10-spined stickleback	*Pungitius pungitius*	=	=
Bullhead	*Cottus gobio*	+	+

5.6.1. *Summary of results*

Broomsthorpe Bridge

Following restoration work, significant increases in the abundance of 3 spined stickleback, stone loach and bullhead were recorded. Bullhead numbers were exceptionally high (40 individuals /100m^2) in 2014, however they subsequently dropped in following years. Prior to the works, trout accounted for 99% of the biomass within the survey reach. The increase in habitat complexity has likely caused the increase in minor species which now account for between 9% and 27% of biomass. The addition of woody debris and more gravels will have increased minor species numbers/biomass, as these features provide cover and spawning habitat respectively.
Trout biomass increased following restoration, however their abundance remained similar to pre-restoration levels.
Although there is a control site a short distance upstream from Broomsthorpe bridge, there is little use to make a comparison as the sites already differed significantly pre-restoration works. Trout biomass pre-restoration at Broomsthorpe bridge was already 400g/100m^2 (2013) as opposed to the control site where trout biomass was 45g/100m^2 (2013). Additionally, the control site data only exists up until 2015 as opposed to 2019.

Pynkeny hall

Following restoration work, an increase in abundance was recorded for half the fish species present within the reach (brown trout, bullhead and lamprey).

Bullhead and brown trout showed the most significant, sustained increases. Bullhead abundance increased from 0.75 /100m^2 in 2013 to 4.5/100m^2 in 2015 and has remained around this level since. Similarly, brown trout numbers increased from 0.25/100m^2 in 2013 to an average of 4.74/100m^2 in the following 4 years. Biomass for these two species also increased significantly. Trout biomass prior to restoration works was 11.7 g/100m^2, and since 2013 has increased steadily to 169g/100m^2. Although there was a substantial increase in lamprey > ammocete numbers in the two years following the completion of works, adult brook lamprey were absent from surveys in 2016 and 2018.

Stone loach did not appear to benefit from the scheme, with their numbers falling from 3.25/100m^2 in 2013 to 0.25/100m^2 by 2018. This was also reflected in a similar fall in biomass, from 20g /100m^2 to 2g /100m^2.

As a result of the substantial increase in trout biomass within the survey reach, total standing crop biomass in 2018 within the reach has increased 400% since pre-restoration levels.

5.7. Scheme 9 – South Mill Farm phase 1 (Reach 30 & part of 31,39,40)

5.7.1. *Scheme summary*

The South Mill scheme covers 1.9 km of river channel, running from the redundant railway line on the River Tat (NGR TF87323 27935) downstream to the confluence with the River Wensum, and then downstream along the Wensum to Dunton Road Bridge (NGR TF88232 29056). Phase 1 of the scheme was completed September 2015 (Scheme 9), and Phase 2 (Scheme 10) in August 2016.

The planform and channel geometry of this part of the River Wensum has been subject to significant modification through dredging, diversions and straightening. The channel modifications, involving widening and deepening, caused the river to deteriorate in terms of natural functioning and loss of good habitat. The over-deepening of the river's bed removed fish spawning gravels and the canalised steep edges limited the fringing vegetation that provide useful cover. Another consequence was that the river channel was unable to transport silt, which then provided conditions that facilitate the growth of common reed and bur-reed which smothered the channel during the summer months.

The chosen restoration work involved raising the bed level at selected locations in order to achieve a gradient which matches the 'natural' gradient of the Wensum prior to any physical modification. It was not practical to achieve the desired gradient along the whole reach due to the large amount of material required for wholesale bed raising

The scheme utilised a number of techniques including importing gravel to create glides, redistribution of the gravel bed to create glides and pools, construction of berms to narrow the channel and improve sinuosity, installation of woody material features and the reinstatement of two meander loops.

Figure 5-67. Before and after restoration photographs (Source: EA RWRS fact sheets combined)

5.7.2. *Fish survey data*

Four years of pre-restoration EA fish survey data is available for the restoration reach (South Mill Farm, EA survey ID: 1465, NGR: TF 88039 228031 – TF 88090 28222). One additional post-restoration survey is available for 2017.

The nearest control site is over 2 km upstream, on the main River Wensum, above the confluence with the River Tat (Hellhoughton common, ID: 1462). This stretch is likely too different in terms of discharge than the restoration reach to make any meaningful comparisons.

South Mill Farm, Abundance

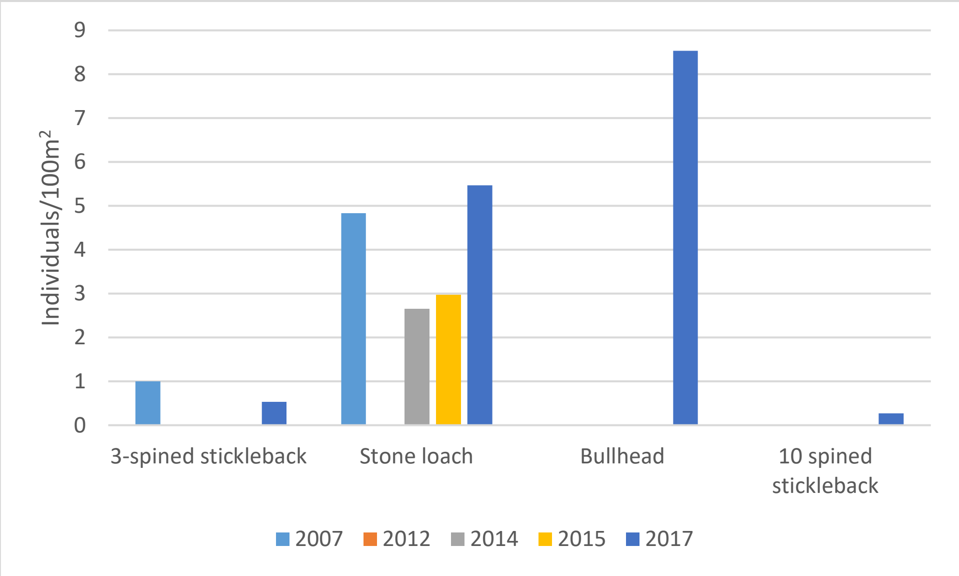


Figure 5-68. Abundance estimates of all fish species (>99mm) within the South Mill Farm survey reach.

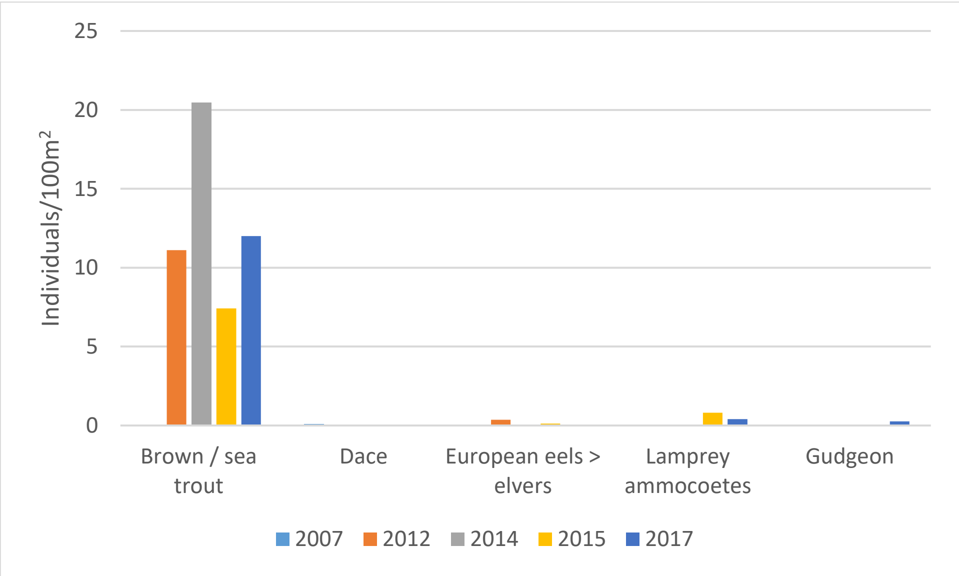


Figure 5-69. Abundance estimates of other fish species (>99mm) within the South Mill Farm survey reach.

South Mill Farm, Biomass

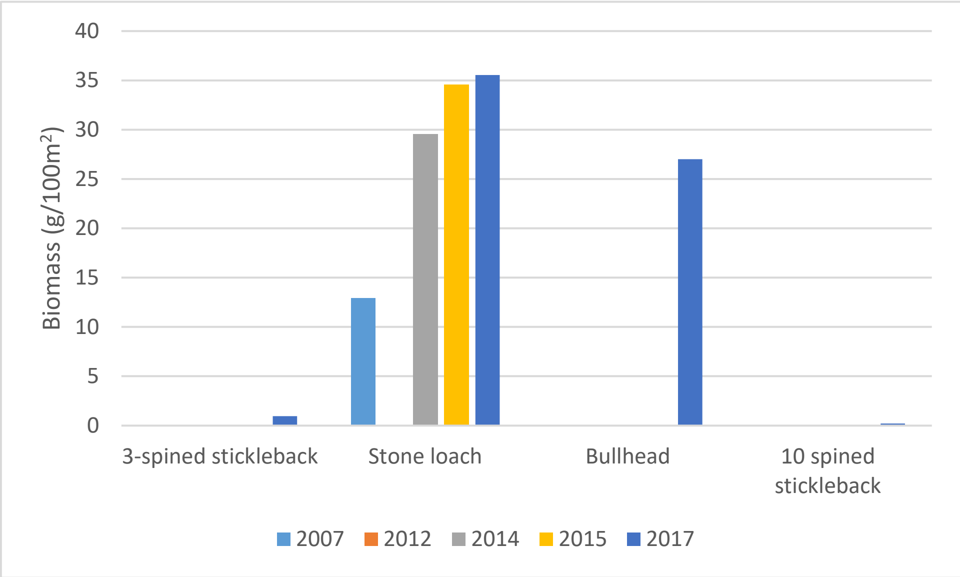


Figure 5-70. Biomass estimates of minor fish (>99mm) within the South Mill Farm survey reach.

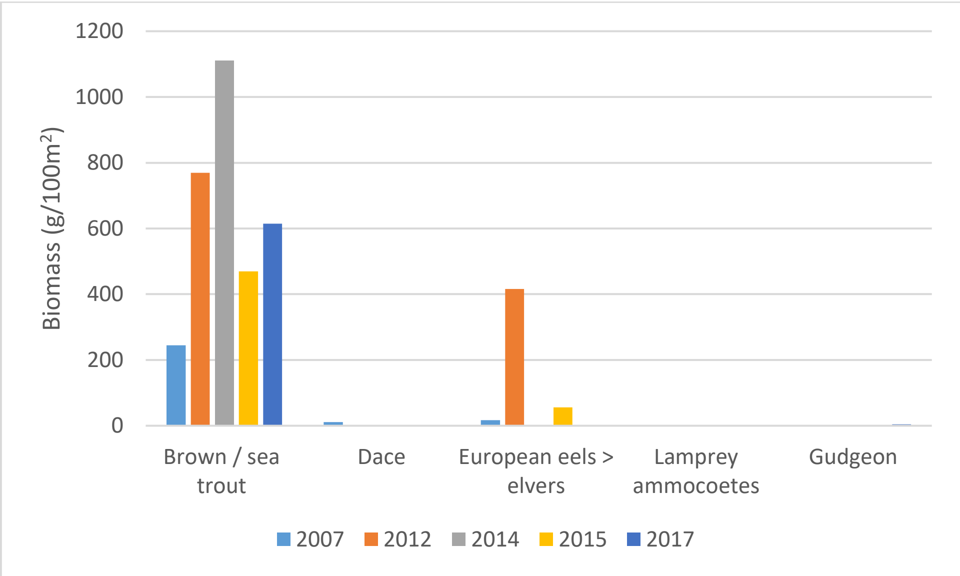


Figure 5-71. Biomass estimates of other fish (>99mm) within the South Mill Farm survey reach.

South Mill Farm community composition in terms of biomass

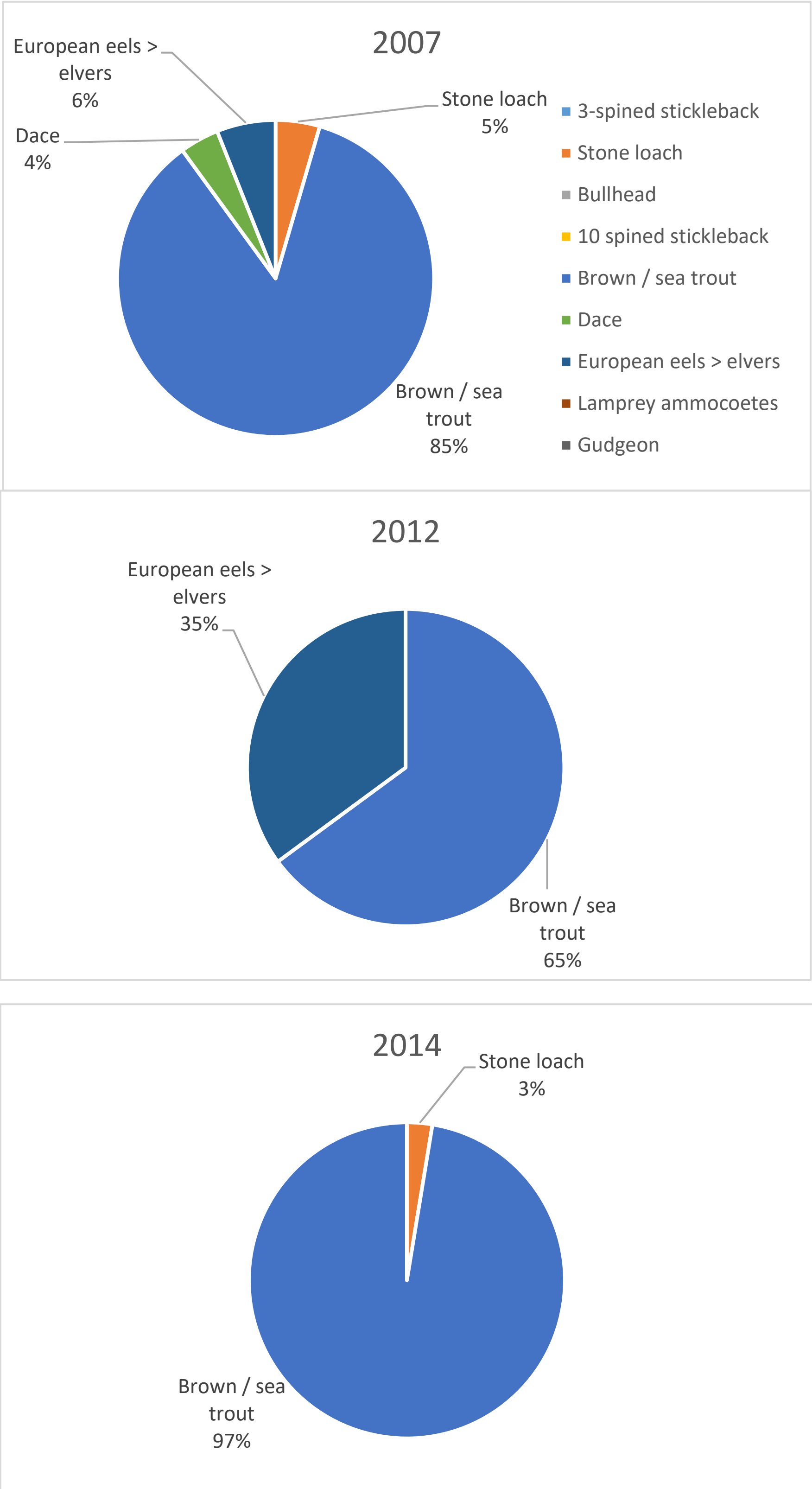


Figure 5-72. Fish community composition at South Mill Farm in terms of biomass, 2007/12/14.

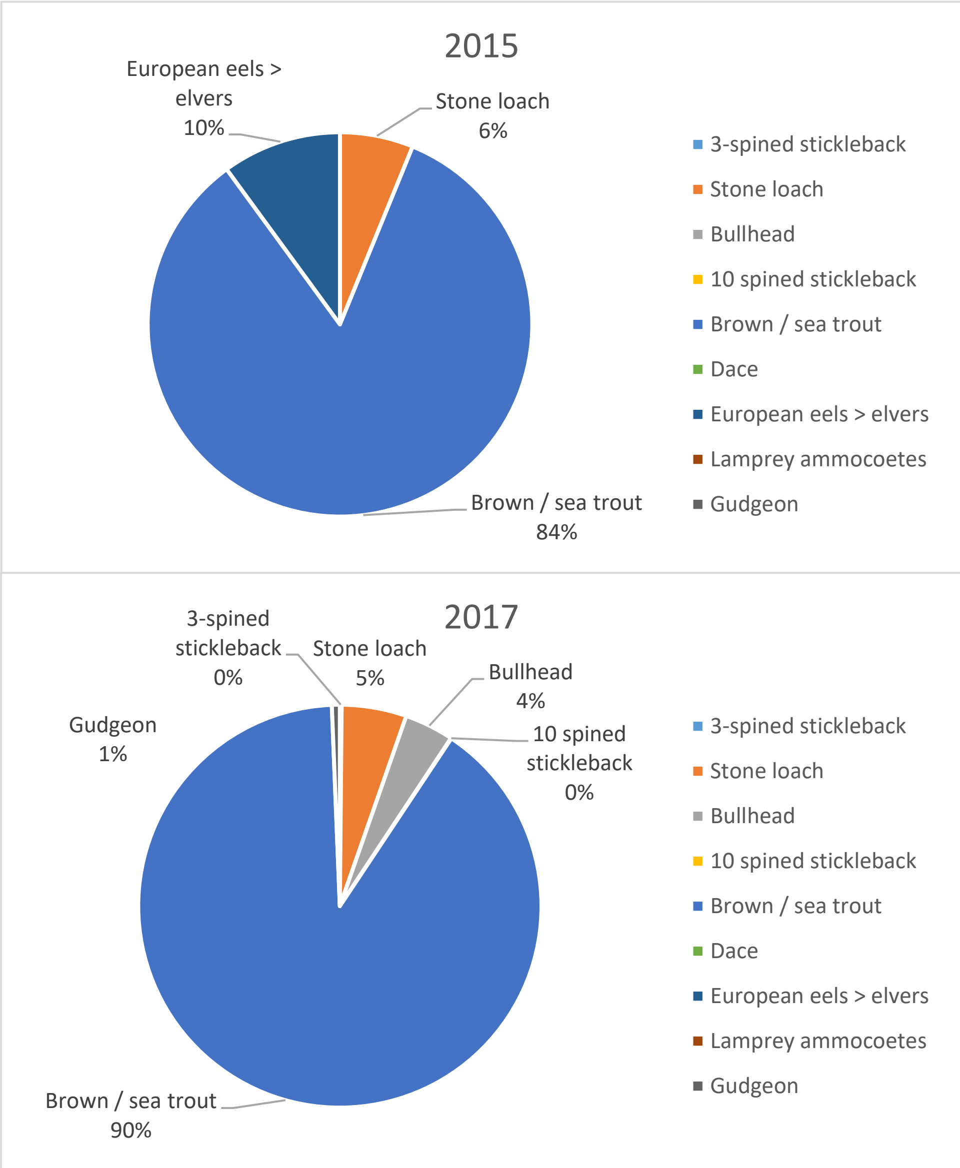


Figure 5-73. Fish community composition at South Mill Farm in terms of biomass, 2015 & 2017. Restoration work occurred shortly after the 2015 survey.

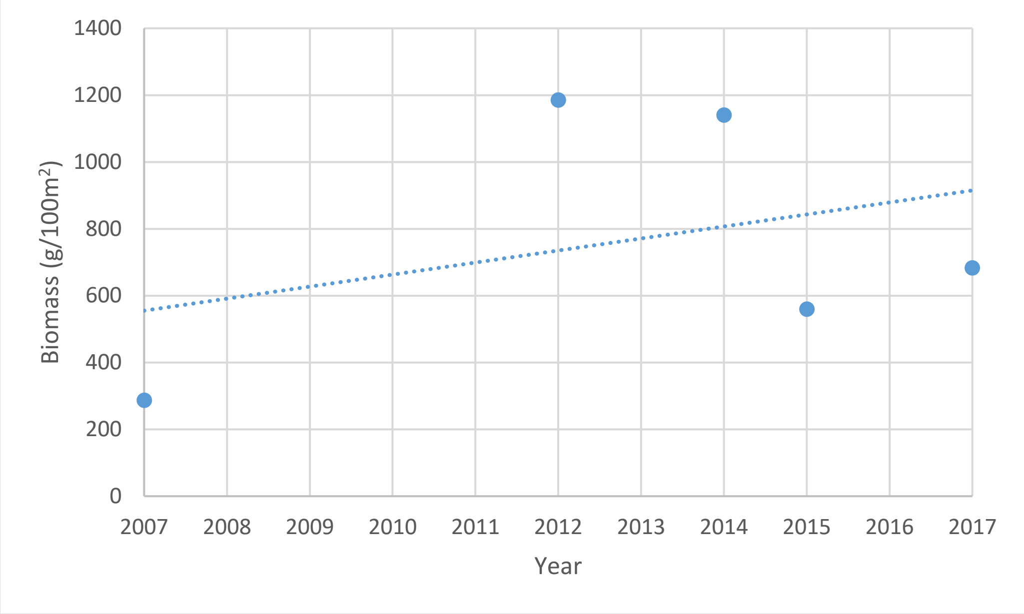


Figure 5-74. Standing crop estimate for South Mill Farm

Table 5-7. General overview of changes in fish community (all lengths) within the South Mill Farm restoration reach, observed following restoration work. "+" indicates clear increase, "-" indicates a clear decline, = indicates no clear changes

Species		Abundance change post -restoration	Biomass change post- restoration
3-spined stickleback	*Gasterosteus aculeatus*	=	+
Stone loach	*Barbatula barbatula*	+	=
Brown / sea trout	*Salmo trutta*	=	=
Dace	*Leuciscus leuciscus*	=	=
Bullhead	*Cottus gobio*	+	+
European eels > elvers	*Anguilla anguilla*	=	-
Lamprey ammocoetes	*Lampetra sp.*	=	=
10 spined stickleback	*Pungitius pungitius*	+	=
Gudgeon	*Gobio gobio*	=	=

5.7.3. *Summary of results*

As there is only one year of post-completion survey data available, only limited conclusions can be drawn from the survey data.

Since restoration took place in 2015, bullhead, 3 and 10 spined sticklebacks have been recorded (all three species were absent from the pre-restoration survey in 2015). It is likely that the new, diverse habitat is more suitable for these minor species. 4% of the total biomass recorded in 2017 was comprised of bullhead which were absent in the four previous surveys.

Trout biomass has historically fluctuated at the site so although trout biomass and abundance were higher in 2017 (610 g/100m^2) than 2015 (470 g/100m^2), it was lower than in 2014 (1111 g/100m^2).

The only species to have declined since restoration works took place were eels, however there were never many recorded in the pre-restoration surveys for this site (Figure 5-71).

Although the total standing crop estimate (all species) is higher for 2017 than 2015 (pre-restoration), it is still lower than 2014 and 2012.

5.8. Scheme 10 – South Mill Farm phase 2 (U/S Dunton Bridge)

5.8.1. *Scheme summary*

Refer to section 5.7.1 for scheme information.

5.8.2. *Fish survey data*

1 year of pre-restoration EA fish survey data is available for the restoration reach (u/s Dunton Bridge, EA survey ID: 67203, NGR: TF 88131 28873). Two additional post-restoration surveys are available for 2017 and 2019.

U/S Dunton Bridge – Abundance

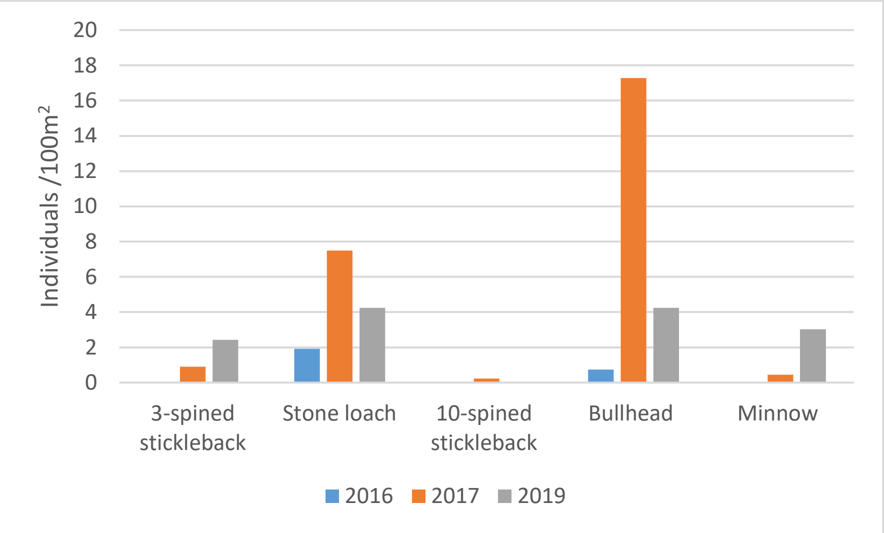


Figure 5-75. Minor species abundance estimates for fish >99mm, U/S Dunton Bridge.

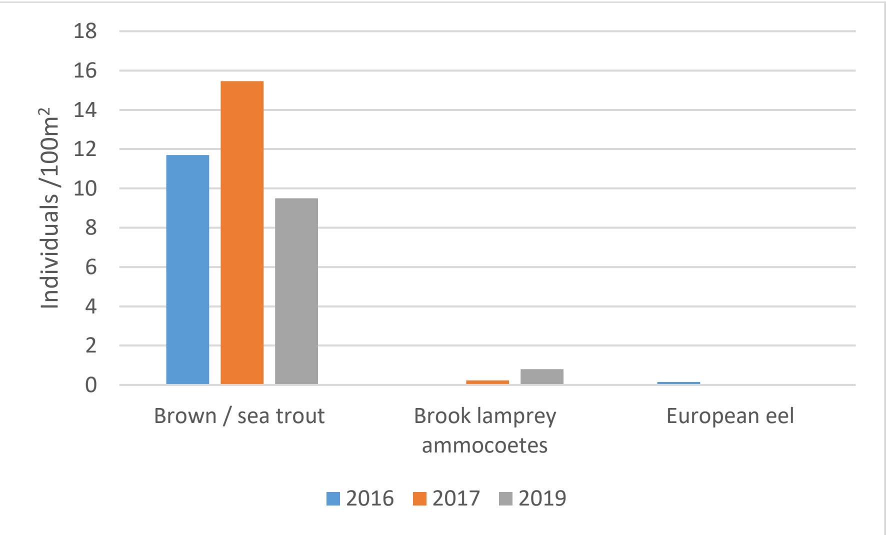


Figure 5-76. Other species abundance estimates for fish >99mm, U/S Dunton Bridge.

U/S Dunton Bridge – Biomass

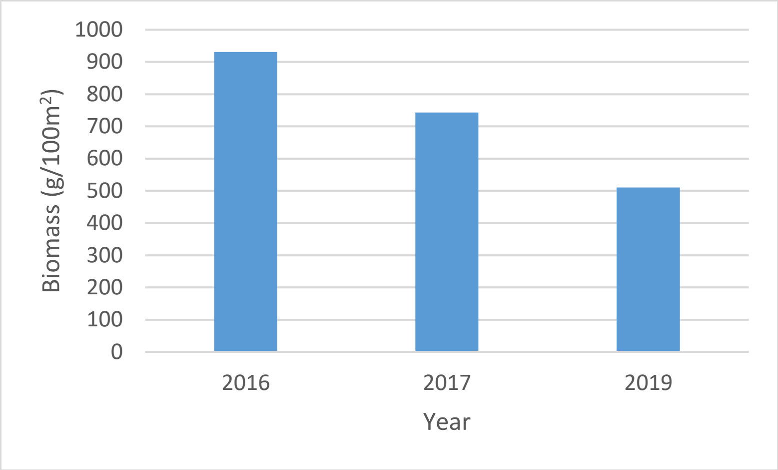


Figure 5-77. Brown trout biomass estimates for fish >99mm, U/S Dunton Bridge.

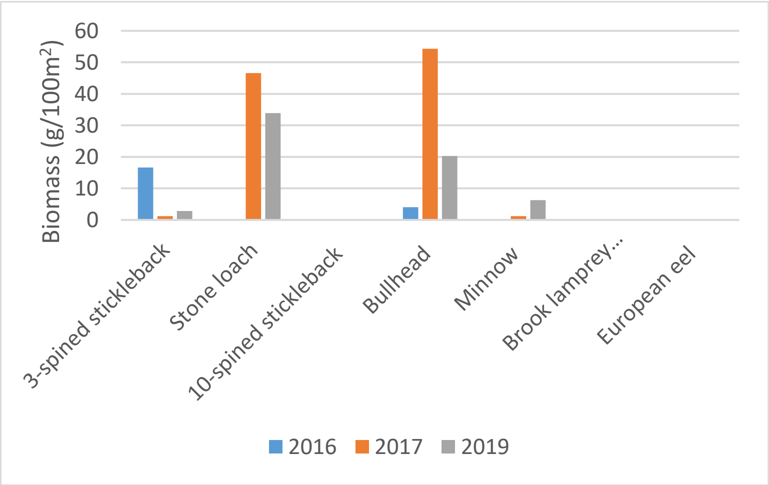


Figure 5-78. Other species biomass estimates for fish >99mm, U/S Dunton Bridge.

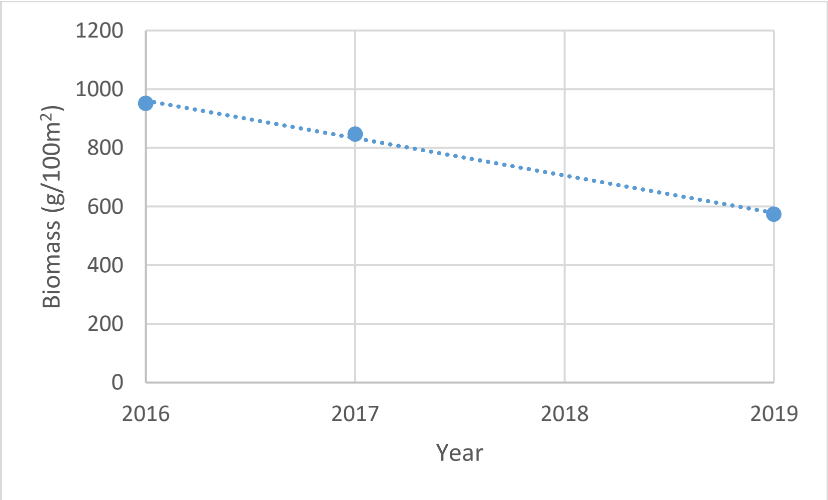


Figure 5-79. Standing crop estimate (all species) for U/S Dunton Bridge, 2016-2019.

Community composition in terms of biomass

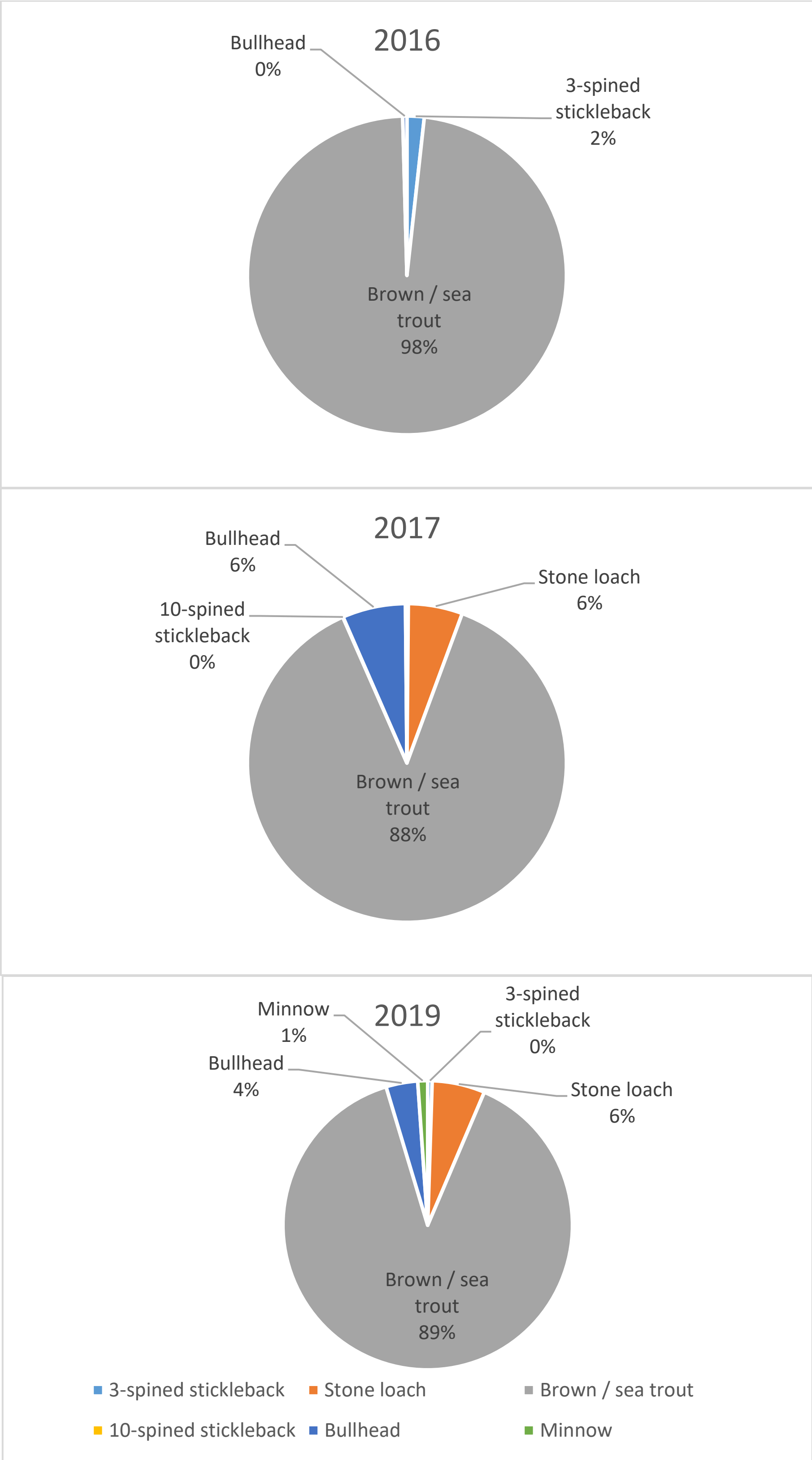


Figure 5-80. Community composition of the restoration reach U/S Dunton Bridge, 2016/17/19

Table 5-8. General overview of changes in fish community (all lengths) within the U/S Dunton Bridge restoration reach, observed following restoration work. "+" indicates clear increase, "-" indicates a clear decline, = indicates no clear changes

Species		Abundance change post -restoration	Biomass change post- restoration
3-spined stickleback	*Gasterosteus aculeatus*	+	-
Stone loach	*Barbatula barbatula*	+	+
Brown / sea trout	*Salmo trutta*	=	-
Bullhead	*Cottus gobio*	+	+
European eels > elvers	*Anguilla anguilla*	=	=
Lamprey ammocoetes	*Lampetra sp.*	+	=
10 spined stickleback	*Pungitius pungitius*	=	=
Minnow	*Phoxinus phoxinus*	+	+

5.8.3. *Summary of results*

Prior to the restoration works the reach was almost totally dominated by brown trout (98%) biomass, with bullhead and stone loach accounting for the remaining 2%. Since restoration took place, minor species now account for a greater proportion of the total biomass (12% in 2016 and 11% in 2019). Minnows, 3 and 10 spined sticklebacks have also been recorded within the survey reach following the completion of the works. This is likely due to the more heterogenous habitat, which creates more niches and therefore supports a greater diversity of species.

Brown trout biomass within the survey reach has steadily declined since 2016, from 930 g/100m^2 (pre-restoration) to 510 g /100m^2 in 2019.

5.9. Scheme 11 – Costessey

5.9.1. *Scheme summary*

The Costessey scheme covers 1.2km of channel, from seven hundred metres downstream of Taverham Road Bridge (TG 16437 13334) to the southern extent of the Wensum Fisheries lake complex (TG 16641 12307). The scheme was completed in September 2018.

Restoration measures in this reach included the construction of lateral berms, introduction of glide-pool sequences, use of woody material, creation of off-channel refuge areas and tree planting.

In four locations cattle drinking areas have been formalised using chalk to create a firm surface to reduce poaching and help minimise sediment entering the river.

One hundred native trees appropriate to the site were planted along the reach. In the long-term these are hoped to improve bank stability, create a diversity of light and shade conditions, whilst also providing a potential source of woody material to the river, improving physical habitat and providing cover for fish.


Figure 5-81. LH - Newly created glide within the restored reach. RH - Cattle drinker (Source: EA RWRS fact sheets combined).

5.9.2. *Fish survey data*

Although there is a long-term dataset for this site (11 years, 2009-2019, 'Place Farm, Costessey' EA Site ID: 1494, NGR: TG 16676 12847 – TG 16715 12695), this represents 10 years of pre-restoration data and one year of post-restoration, which does not allow for a good evaluation of the impact of the scheme on the local fish population.

Costessey – Abundance

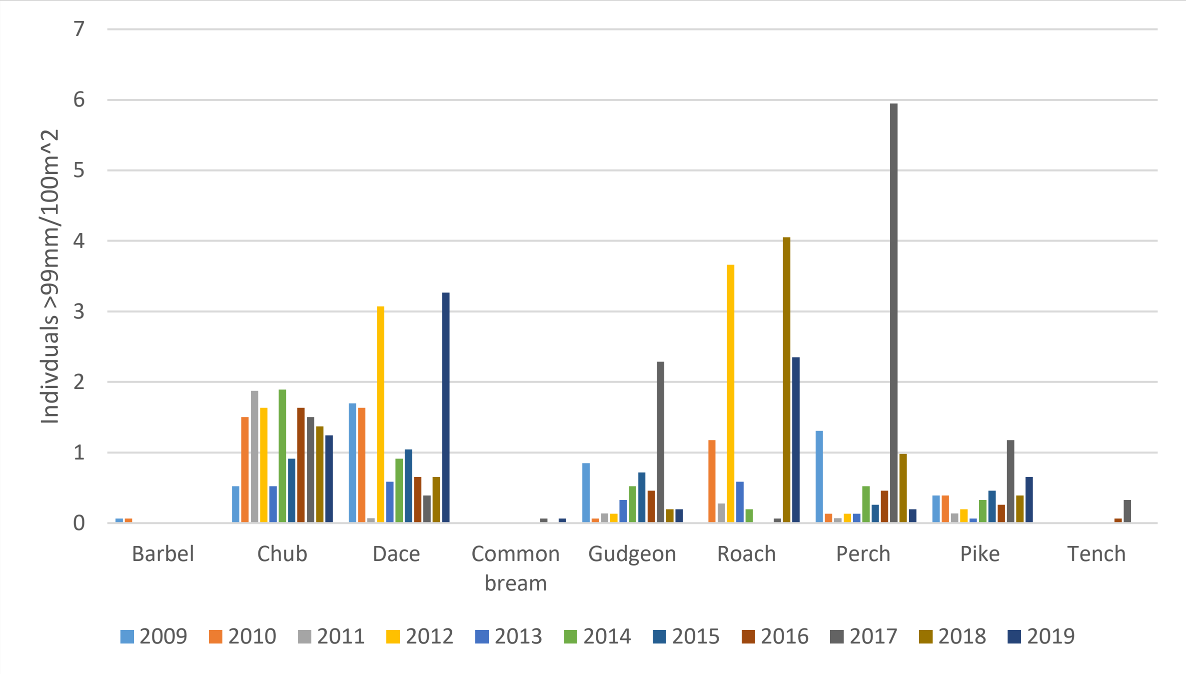


Figure 5-82. Estimated coarse fish abundance within the restoration reach (>99mm)

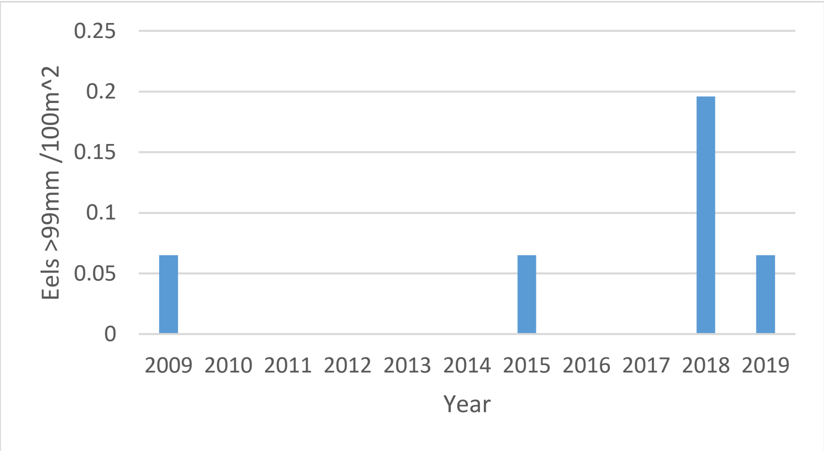


Figure 5-83. Estimated Eel abundance within the restoration reach (>99mm)

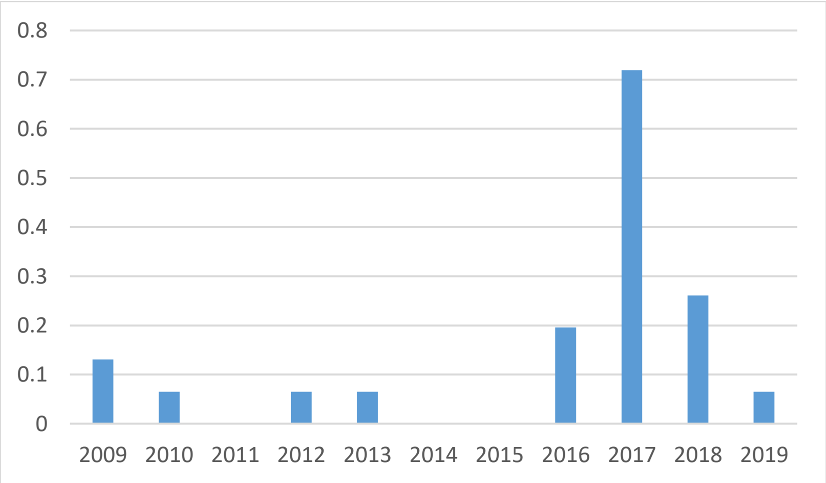


Figure 5-84. Estimated brook lamprey ammocete abundance within the restoration reach (>99mm)

Costessey – Biomass

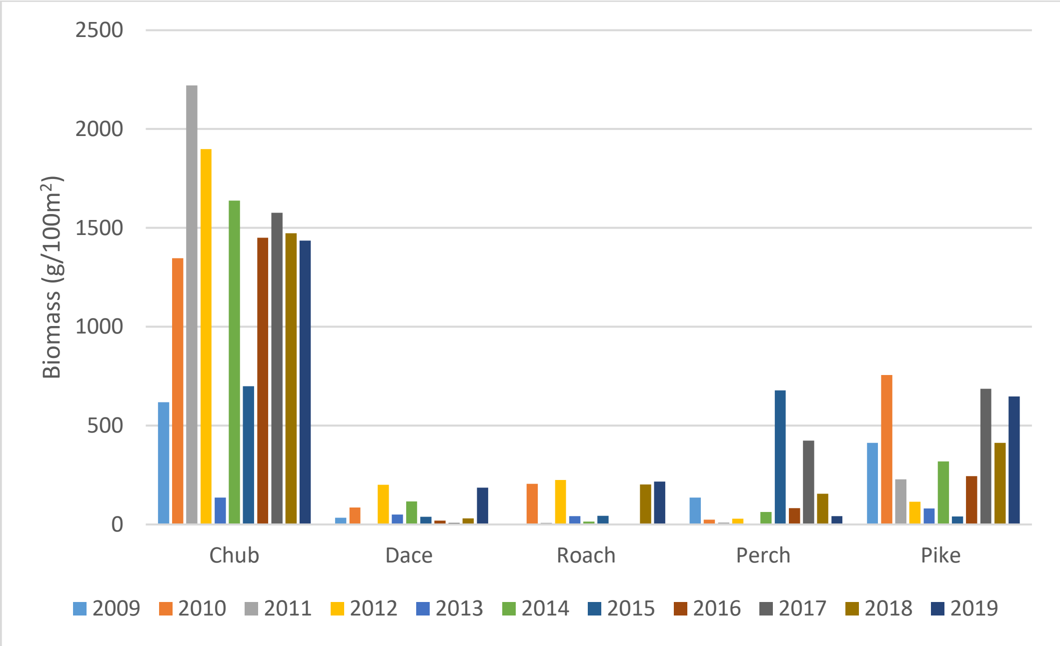


Figure 5-85. Estimated biomass of the 5 most abundant coarse fish species present within the restoration reach (>99mm), 2009 – 2019

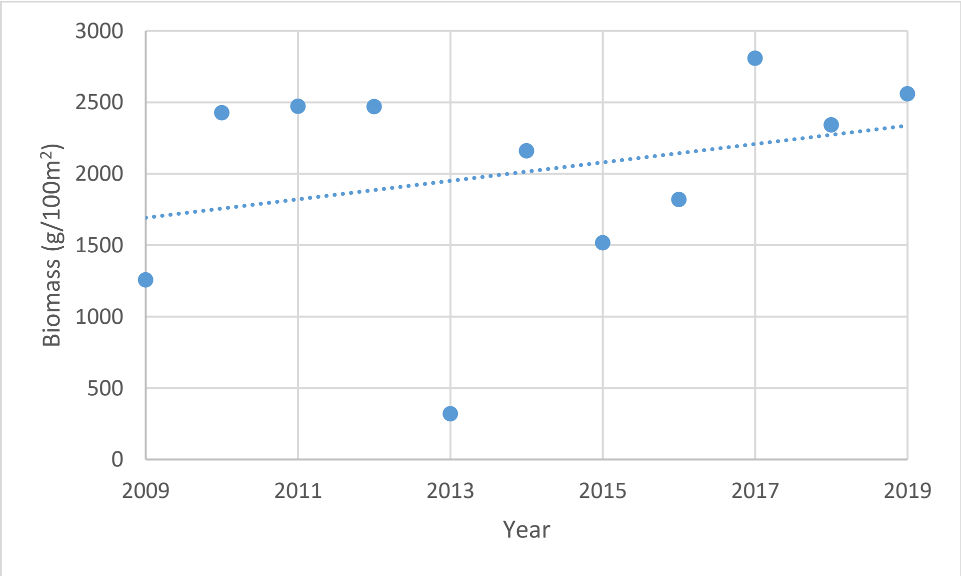


Figure 5-86. Estimated standing crop of all fish species present within the restoration reach (>99mm), 2009 – 2019

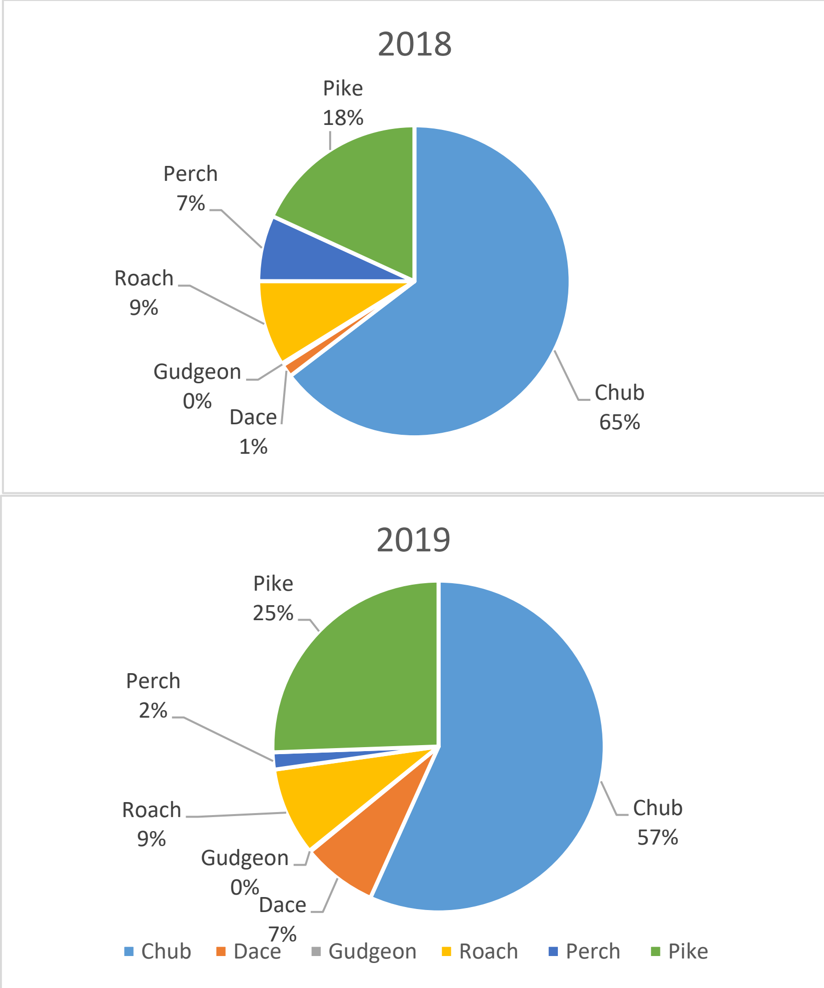


Figure 5-87. Community composition in terms of biomass (fish >99mm), 2018 and 2019.

Additional pie charts for previous years are available in the Appendix IV.

Table 5-9. General overview of changes in fish community (>99mm) within the Costessey restoration reach, observed following restoration work. "+" indicates clear increase, "-" indicates a clear decline, = indicates no clear changes

Species		Abundance change post -restoration	Biomass change post-restoration
Barbel	*Barbus barbus*	=	=
Chub	*Leuciscus cephalus*	=	=
Dace	*Leuciscus leuciscus*	+	+
Common bream	*Abramis brama*	=	=
Gudgeon	*Gobio gobio*	=	=
Roach	*Rutilus rutilus*	=	+
Perch	*Perca fluviatilis*	-	-
Pike	*Esox lucius*	+	=
European eels > elvers	*Anguilla anguilla*	=	=
Brook lamprey ammocoetes	*Lampetra planeri*	-	n/a
Tench	*Tinca tinca*	=	=

5.9.3. *Summary of results*

As the scheme was only completed in 2018, it only represents one year of post restoration data and will not have allowed much recruitment to take place. As such, limited conclusions can be drawn in relation to the impact of the scheme. It is likely that more time is needed for the fish community to respond to the changing habitat, which will also take time to establish fully.

As shown in Table 5-9, the community composition remains similar, with chub still the dominant species.

Perch numbers and biomass declined; however, this trend was already visible prior to the restoration work being completed so may not be as a direct result of the habitat changes.

One notable increase was in the dace population, which has returned to a level not seen since 2012.

In future, it is likely that more changes will occur once the habitat has adjusted.

6. FISH HABITAT REQIREMENTS

Many variables control fish populations, which can lead to large, natural, interannual variations. Physical habitat parameters can influence the suitability of a stretch of river for certain species and are some of the main factors controlling the fish community composition in a given area. The river restoration techniques used across the Wensum sites tend to result in changes to physical parameters, such as water velocity, depth, and substrate.

Changes to these parameters will alter the suitability of the habitat for certain species. Some species will find the resulting condition more favourable, whereas others will find the changes detrimental. As such, it is important to consider the habitat requirements (in particular, spawning habitat) when assessing the success of a restoration schemes impact on the local fish populations.

Adult fish are more robust and adaptable to their environment than younger fish. Most coarse fish are opportunistic in their habitat selection and are tolerant to a broad range of conditions (Table 6-1). However, it should be recognised that under certain conditions, a certain species may only survive, and not thrive (e.g. barbel are able to survive in still waters but are unable to breed (Taylor *et al*., 2004) As a result, restoration works leading to habitat changes are less likely to impact adult fish presence and it is more important to consider the suitability of the habitat for spawning, larval development, and juveniles.

Table 6-1. Broad habitat characteristics of freshwater fish species found in the River Wensum. Adapted from: 'Flow and Level Criteria for Coarse Fish and Conservation Species' (Cowx et al., 2004)

Species	Preferred habitat characteristics
Brown trout	Juveniles found mainly upper, clear fast flowing rivers with gravelly substratum
Bullheads	Stony stream and rivers, and some lakes
Stone loach	Stony stream and rivers, and some lakes
River lamprey	Moderately-flowing streams with areas of silt substratum
Brook lamprey	Moderately-flowing streams with areas of silt substratum
Eel	Middle and lower river reaches and small lowland tributaries
Roach	Lowland rivers; bankside vegetation or open water
Dace	Middle and lower river reaches and small lowland tributaries, sand/gravel/cobble substratum, moderate to high productivity
Chub	Middle and lower river reaches, sand/gravel/cobble substratum, strongly associated with tree and macrophyte cover, large woody debris, rocks, moderate to high productivity
Common bream	Lowland reaches; slow flow, deep backwaters, vegetated areas, mud/silt substrate
Rudd	Mainly still waters; slow flowing lowland rivers associated with littoral macrophyte stands
Barbel	Middle reaches; Moderate to fast flow, moderate productivity, high oxygenation, gravel substratum, vegetation and obstructions
Tench	Lowland reaches, backwaters; mud/silt substrate

Species	Preferred habitat characteristics
Gudgeon	Middle and lower reaches, slow to moderate flow, silt/sand/gravel substrata, moderate to high productivity rivers
Pike	Middle and lower reaches; slow-flowing to moderately flowing, emergent vegetation
Perch	Lowland reaches; slow-flowing, occasionally moderate flow, shallow water with emergent and submerged vegetation, moderately productive water bodies

The species recorded in the Wensum include a range of phytophilic and rheophilic fish, requiring different habitats for spawning (Table 6-2).

Table 6-2. Spawning habitat requirements of several British coarse fish. Adapted from: 'Flow and Level Criteria for Coarse Fish and Conservation Species' (Cowx et al., 2004)

Species	Depth (cm)	Water Velocity (cm s^{-1})	Substrate (diameter, mm)	Vegetation	Optimum temperature (°C)
Abramis brama	Variable	<20	>5	*Glyceria, Sagittaria, Nuphar*	12 - 20
Barbus barbus	R_{50} = 14 - 22	R_{50} = 35 – 49	R_{50} = 20 - 50	Absent	>14
Blicca bjoerkna	Variable	<20	Indifferent	Hydrophytes, Helophytes	16 - 25
Cyprinus carpio	Variable	<5	Indifferent	Submerged riparian or floodplain veg., *Carex, Glyceria, Phragmites*	>18
Gobio gobio		10 – 80	3 -- 30	Hydrophytes (occasional)	>17
Leuciscus cephalus	10 - 30	20 – 50 (R_{50} = 15 – 750	>5	Hydrophytes (occasional)	14 - 20
Leuciscus leuciscus	25 - 40	20 – 50	30 - 250	Hydrophytes, rootwad (occasional)	6 - 9
Phoxinus phoxinus	10 -- 25	>20, R_{50} = 25 – 45	20 - 100	Absent	
Rhodeus sericeus			Unionids		
Rutilus rutilus	15 - 45	>20 R_{50} = 35 – 60	50 - 150	*Fontinalis* moss, *Elodea, Salix, Scirpus*	14 - 18
Tinca tinca	Variable	<20	Indifferent	*Myriophyllum*, submerged riparian or floodplain veg	20 - 24

Rheophilic coarse fish species typically require areas of shallow depth, rapid flow and clean gravel substrate (Mann, 1996). For example, the common minnow (*Phoxinus phoxinus*) requires depths greater than 0.1 m, substrate 20-30 mm in diameter and velocities of between 0.2-0.3 m/s (Bless, 1992). Larger rheophilic coarse fish such as barbel (*Barbus barbus*) typically spawn over fine-coarse gravels in depths of up to 0.5 m and velocities of approximately 0.5m/s (Britton & Pegg, 2011; Mann, 1996).

Brown trout (*Salmo trutta*) have similar spawning preferences to rheophilic coarse fish; requiring depths of 0.15-0.45m, velocities of 0.2-0.55 m/s, and medium-large gravel (16-32 mm) (Louhi & Mäki-Petäys., 2008).

Phytophilic fish species, including pike *(Esox Lucius*), carp (*Cyprinus carpio*) and roach *(Rutilus rutilus*) adhere their eggs to submerged macrophytes. Although spawning would usually occur in shallow depths, species preferences vary, with some choosing to lay their eggs on permanently submerged macrophytes and others preferring flooded terrestrial grasses (Mann, 1996; Lelek, 1987).

As such, changes to depths/flows/substrates will impact the spawning success of certain species and lead to changes in community composition over time.

7. SUMMARY OF SCHEME IMPACTS

Table 7-1 and Table 7-2 aim to provide a high-level indication to help identify which species benefited most from the rehabilitation schemes on the River Wensum in terms of both abundance and biomass. Note that the changes documented may not be as a result of the restoration works, as there are many variables which affect freshwater fish populations.

Table 7-1. High level evaluation of which fish species benefited most from the Wensum/Tat restoration project. Green highlighting indicate species which generally increased in abundance following restoration work. Yellow highlighting indicates species which neither benefited nor declined following restoration. Red highlighting indicates which species were generally less abundant following restoration.

Species		no. sites recorded as present	% of schemes where this species is present and increased in abundance
Bullhead	*Cottus gobio*	7	86%
Minnow	*Phoxinus phoxinus*	5	80%
Brook lamprey > ammocoete	*Lampetra planeri*	4	75%
Stone loach	*Barbatula barbatula*	8	63%
Brown / sea trout	*Salmo trutta*	8	63%
Dace	*Leuciscus leuciscus*	6	50%
Rudd	*Scardinius erythrophthalmus*	2	50%
3-spined stickleback	*Gasterosteus aculeatus*	8	25%
Chub	*Leuciscus cephalus*	4	25%
Lamprey sp. ammocoete	*Petromyzontidae*	8	25%
10-spined stickleback	*Pungitius pungitius*	5	20%
Gudgeon	*Gobio gobio*	6	17%
Tench	*Tinca tinca*	2	0%
Common Bream	*Abramis brama*	1	0%
Roach chub hybrid	*Leuciscus cephalus x Rutilus rutilus*	1	0%
Barbel	*Barbus barbus*	1	0%
European eels > elvers	*Anguilla anguilla*	6	-17%
Pike	*Esox lucius*	4	-25%
Roach	*Rutilus rutilus*	5	-40%
Perch	*Perca fluviatilis*	4	-50%

Table 7-2. High level evaluation of which fish species benefited most from the Wensum/Tat restoration project. Green highlighting indicate species which generally increased in biomass following restoration work. Yellow highlighting indicates species which neither benefited nor declined following restoration. Red highlighting indicates which species were generally less abundant following restoration

Species		no. sites recorded as present	Percentage of sites where this species is present and increased in biomass
Bullhead	*Cottus gobio*	7	86%
Minnow	*Phoxinus phoxinus*	5	80%
Dace	*Leuciscus leuciscus*	6	67%
Stone loach	*Barbatula barbatula*	8	63%
Brown / sea trout	*Salmo trutta*	8	63%
3-spined stickleback	*Gasterosteus aculeatus*	8	25%
Roach	*Rutilus rutilus*	5	0%
Brook lamprey > ammocoete	*Lampetra planeri*	4	0%
Gudgeon	*Gobio gobio*	6	0%
European eels > elvers	*Anguilla anguilla*	6	0%
Lamprey sp. ammocoete	*Petromyzontidae*	8	0%
10-spined stickleback	*Pungitius pungitius*	5	0%
Tench	*Tinca tinca*	2	0%
Rudd	*Scardinius erythrophthalmus*	2	0%
Common Bream	*Abramis brama*	1	0%
Roach chub hybrid	*Leuciscus cephalus x Rutilus rutilus*	1	0%
Barbel	*Barbus barbus*	1	0%
Chub	*Leuciscus cephalus*	4	-25%
Pike	*Esox lucius*	4	-50%
Perch	*Perca fluviatilis*	4	-50%

Table 7-3. Standing crop changes

Scheme	Increase in standing crop	Decline in standing crop
1		1
2	1	
3	1	
4		1
5	1	1
6		1
9		1
10	1	
11		1
Total	40%	60%

8. DISCUSSION

Although the driving force behind the restoration project was to improve the WFD score and SSSI classification for reasons aside from fish populations (inappropriate water levels, water pollution – agriculture/run-off, water abstraction, inappropriate weirs, dams and other structures, invasive freshwater species, and physical modifications to the channel), the rehabilitation works to tackle some of the historic physical modifications to the natural river were expected to have a significant positive impact on the fish populations.

Restoration works across the various sites tended to follow a similar trend, with the aim to increase flow and habitat heterogeneity through channel narrowing and bed raising, accomplished by introducing gravels, woody debris and creating lateral berms. Several of the schemes included reinstating the historic river channel or reconnecting previously bypassed meander loops to the river. Reconnection to the floodplain was also achieved where possible, through the lowering of embankments and re-connecting drainage ditches to the main channel.

As seen in tables Table 7-1 & Table 7-2, it appears that most species of fish were generally more abundant post restoration. Trout, dace, bullhead, stone loach, and minnows appear to have benefited the most from the restoration schemes, with bullhead increasing in abundance and biomass at 86% of the sites. This represents a significant gain for bullhead, a European designated species, which is also a qualifying species of the Wensum SAC (JNCC 2019). Lamprey ammocetes also tended to increase in abundance following restoration works, which is also promising as brook and river lamprey are also species of conservation importance. It is likely the works have improved the area of suitable habitat for the above species, by providing more cover from predators, food, juvenile and spawning habitat that has in turn improved their populations, especially as the results were fairly consistent, despite being conducted over a 9-year period. Although likely as a result of the restoration, these results should be interpreted cautiously; it is not possible to fully isolate the impact of restoration works from wider, catchment scale changes or other variables.

We have also tended to observe an increase in fish species diversity within the study reaches post-restoration. For example, at site 10, prior to rehabilitation works, trout accounted for 98% of biomass, with the remainder comprised of bullhead. Following restoration, minnows, stone loach, and 3-spined stickleback were also recorded. This increase in diversity is likely the product of the restoration works, which have created a more complex habitat that provides more niches and therefore supports a greater number of species.

The gains were however not ubiquitous; eel, pike, roach and perch tended to decrease in abundance following restoration works, and chub, pike and perch tended to decrease in biomass. Looking at the changes in standing crop (biomass) (Table 7-3) following restoration in isolation may come as a surprise as at 60% of the sites standing crop biomass was lower than before restoration took place. This however should not be taken as the restoration works having a negative impact on fish as there are many variables which help determine fish populations.

Unfortunately, the suggested control sites proved to be of little use in assessing the impacts of the restoration schemes. A good control site is one which is similar in physical (discharge, depth, width, velocity, and substrate) and biotic (fish / macrophyte community) characteristics, elsewhere on the same river system. The physical separation of a site by an impassable barrier does not constitute a control site, as the impounded habitat upstream will be fundamentally different to the likely more natural one downstream, especially on a low gradient system. Although in theory the lack of movement between sites could make the site a 'control' for restoration works, by being different in physical characteristics means the two sites may respond differently to independent catchment wide variables. For example, warmer air temperatures may have less of an impact on fish and invertebrates residing within a deep, shaded reach, than fish living in shallow, open water. Additionally, some of the control sites did not have comparable data (3 run vs single run) collected from the same period as the study sites, which makes it even more difficult to draw robust conclusions. Nevertheless, they may provide some insight into whether or not there was no change compared to sites that had been restored.

How did the results observed on the Wensum compare to similar rehabilitation schemes?

Similarly to the Wensum schemes, increasing habitat heterogeneity is a common objective of river restoration work. A common outcome of this form of intervention is a positive response by trout, as was seen at 63% of sites on the Wensum. For example, in a study of in-stream rehabilitation in Liechtenstein, which aimed to improve salmonid habitat in channelized streams, woody debris was introduced to increase mean water depth (Zika & Peter, 2002). Following this work, increases in both the abundance and biomass of both brown and rainbow trout (*Oncorhynchus mykiss*) were documented. A similar increase in brown trout abundance was observed on the River Piddle and Devil's Brook (Dorset, England) following similar restoration work (Summers, Giles, & Stubbing, 2008).

Why did some species decline in biomass but increase in abundance (and vice-versa) following restoration work?

Although in most instances where an increase in abundance was recorded following restoration works, the biomass of the same species also increased. However, in some cases this was not observed (e.g., Scheme 5- trout abundance did not change, however biomass increased. This was also the case for pike in Scheme 3).

This may be explained either by an immigration of larger individuals from outside the altered reach, or the enhanced growth of pre-existing individuals due to an improved, more favourable environment. It may also be the case that smaller individuals emigrated out of the restored reach or were preyed upon. A similar increase in mean brown trout size was achieved in a rehabilitation initiative of the White River, Arkansas, USA (Quinn & Kwak, 2000). Larger individuals of brown trout and pike are well known to prefer deeper pools within streams that comprise a diversity of meso-habitats (Armstrong et al., 2003; Stakėnas, Vilizzi, & Copp, 2013, Jalbert et al., 2021). It has been proposed that deeper pools provide better refuge and overwintering habitat for larger fishes (Maki-Petäys, et al., 1997). On the contrary, this may also help explain why trout biomass declined following restoration work in Scheme 10 (U/S Dunton Bridge), as large-scale bed raising may have created a shortage of deeper pool habitat, imposing a recruitment bottleneck as suitable adult habitat for large individuals was lacking. Similar reasoning may also help explain why chub also tended to increase in abundance but decrease in biomass across the restoration reaches. As chub are strongly associated with tree and macrophyte cover, they may be resident within nearby unrestored reaches with these features but are migrating to restoration reaches for spawning purposes. The newly restored reaches offer ideal chub spawning habitat, which is typically fast flowing water over a coarse gravel substrate. Once more time has passed, the restored reaches are likely to become more suitable for adult chub as trees mature and macrophytes become more established.

Why did the standing crop biomass not increase at some restoration sites?

As has been seen on several sites on the Wensum (e.g. Scheme 11, Costessey), changes in fish abundance are not always achieved in restored river reaches. Numerous studies have shown that stream rehabilitation does not necessarily translate into significant improvements in biotic communities, (e.g. Pretty et al., 2003; Palmer et al., 2010; Hasse et al., 2013). Little change was observed in fish species composition following the channel narrowing on Lowthorpe Beck, East Yorkshire, UK and the creation of gravel riffles on the River Stiffkey, North Norfolk, UK (Smith, 2013). Similarly, a study of thirteen rehabilitation schemes on lowland rivers found little change in fish abundances (Pretty et al., 2003).

One factor that is not addressed by reach-scale restoration work is catchment-scale pressures on rivers, such as declines in water quality through eutrophication, chemical pollution events and enhanced fine sediment inputs (Champkin et al., 2018). However, it is believed that other schemes are taking place to tackle these issues, so we may well see further changes to fish populations on the Wensum within the restored reaches in future. Plans have been put in place to reduce the impacts of water abstraction on the river. The issue of agricultural run-off is being tackled by a Catchment Sensitive Farming project (Natural England) and a Demonstration Test Catchment project lead by the University of East Anglia. The Norfolk non-native Species Initiative is taking steps to control invasive freshwater species.

Why did some species tend to decline in abundance post restoration?

River rehabilitation work can also fail to address broader-scale species-specific pressures, which may be the cause of some declines observed for some species at various Wensum sites (eel, pike, roach, perch). For example, the recruitment of European Eel (*A. anguilla)* has declined throughout its range in recent decades, due to a variety of factors (ICES, 2016). In addition to the recruitment decline at sea, water retention structures and unscreened abstraction intakes represent an issue to returning elvers. Unless these barriers are removed or their effect mitigated (e.g., through fish passes/appropriate screening), reach-scale restorations are unlikely to improve eel populations in affected water courses.

Declines may also be due to the changes of the physical habitat within the reaches. River restoration does not necessarily result in an improvement in habitat for all species, as some are well adapted to impounded, slow flowing water and silty substrates. For example, although eels can inhabit most waterbodies, they prefer dark and heavily coloured waters, or waters with plenty of silt and mud at the bottom. Evidence from the literature suggests that physical structures in water bodies are an important habitat component. Aquatic plants, submerged root systems, woody debris, undercut banks and channel substrates all provide physical structures that eels could use as refuges or ambush points. Where such structures are lacking, eels will be more susceptible to predation. Evidence also suggests that structural heterogeneity within water bodies influences the abundance of macroinvertebrates, which are an important component of many eels' diets (Walker et al., 2013). As such, it is likely that the habitats prior to restoration were potentially more suitable for eel than they are currently.

Similarly, pike may have also found the unrestored habitat preferable. As the body of the pike is adapted for rapid acceleration to facilitate ambush predation, the pike is regarded as being a poor swimmer, occurring in slower flowing stretches of rivers (Webb, 1984, Jones *et al*., 1974, Lamouroux *et al*., 1999). This is not only true for adult pike; juveniles have been found to prefer still, vegetated water, which has become scarcer within the restoration reaches (Copp, 1993). Pike also require dense weed for spawning, especially Elodea sp., which tends to favour slow flowing or still water where silt accumulates (Grimm & Klinge 1996). As the restoration works sought to reduce siltation and increase water velocities, it is likely that suitable pike and perch habitat for all life stages has become rare.

Perch are also likely to have declined as a result of the restoration works, as they have similar habitat requirements to pike. Perch are highly dependent on complex habitats, with a strong preference for vegetated areas (Westrelin et al., 2018). In autumn and winter, perch migrate to deeper waters, which have been made scarcer within the restored reaches through bed raising and changes to river planform.

On the other hand, bullhead, the species which benefited most from the restoration work utilises various habitats (according to different life stages), all of which have been improved or created through the Wensum restoration project. Coarse substrates with large stones appear essential for breeding although in the absence of a stony substrate other breeding sites may also be used such as woody debris or tree roots (Smyly 1957, Crisp 1963). Shallow, stony riffles are utilised by young-of-the-year fish (Gubbels 1997; Prenda et al. 1997; Perrow et al. 1997; Punchard et al. 2000), whereas sheltered sections created by woody debris, tree roots, leaf litter, macrophyte cover or large stones, are preferred by adult fish, at least during daylight (Perrow et al. 1997). In times of high flows, all age classes are likely to require slack-water refuges (Perrow et al. 1997). As these habitat requirements have been addressed by the restoration works (shift from silty, slow flowing to riffles and clean gravel with plenty of cover from woody debris), it is not surprising that bullhead populations have responded well.

Dace also responded well to the restoration works, and it is likely that this is linked to the creation of suitable spawning habitat. Dace spawn in spring time, where they release sticky eggs that adhere to gravels (EA, 1996). A good flow of water is required to keep them silt free and supplied with oxygen. All restoration reaches of the Wensum restoration project succeeded in providing more or better gravel beds with increased flow and reduced sediment, which will likely have been the main driving force behind the observed increase in dace abundance and biomass. Dace also mature in only 3-4 years, in contrast to chub which may take up to 7 (Mann, 1974). As they are relatively fast maturing, increases in population can be observed faster than for other species, whose increases may not yet be visible, especially for the sites that have only recently been restored.

8.1. CONCLUSION

It is expected that some species will flourish whilst others will decline as a result of restoration works and we would expect a shift in the population rather than an uplift across all species.

The main restoration works implemented within the strategy included narrowing the channel, restoring gravel beds (through gravel introductions and mobilising fine sediments to clean historic gravel beds by increasing velocities), reductions in impoundment, reconnecting the floodplain, improving channel sinuosity, and increasing the amount of large woody material in the channel.

Roach, perch and eel and to some extent pike (the species which tended to decline across the restoration sites), thrive in slow flowing, well vegetated, silty, turbid channels, whereas the species that have increased in abundance/biomass (bullhead, trout, dace, stone loach) typically prefer faster flowing reaches with gravel substates. These changes reflect the alterations to the physical habitat which occurred as a result of the above restoration works.

Although it might be regarded that declines are a negative outcome of the restoration, it is not necessarily the case. Although some species became less abundant following the completion of the works, the resulting fish communities are likely more similar to those which existed prior to the engineering work which altered the channel and degraded the river in the first instance.

Assessing the changes in the fish communities across the restoration reaches, it appears that the recent restoration works have indeed improved the natural functioning of the river and restored habitat and in turn fish communities more characteristic of a Norfolk chalk river. Whilst the initial results are encouraging, it will take time for the restored reaches to become fully established and population changes to occur. As such, surveys should be continued to allow for any interannual variation in fish populations to be captured, thus allowing for more robust conclusions to be drawn. Efforts should be made to undertake surveys at roughly the same time each year and with similar flow conditions.

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FISHTEK CONSULTING

APPENDIX I – Location of EA survey reaches

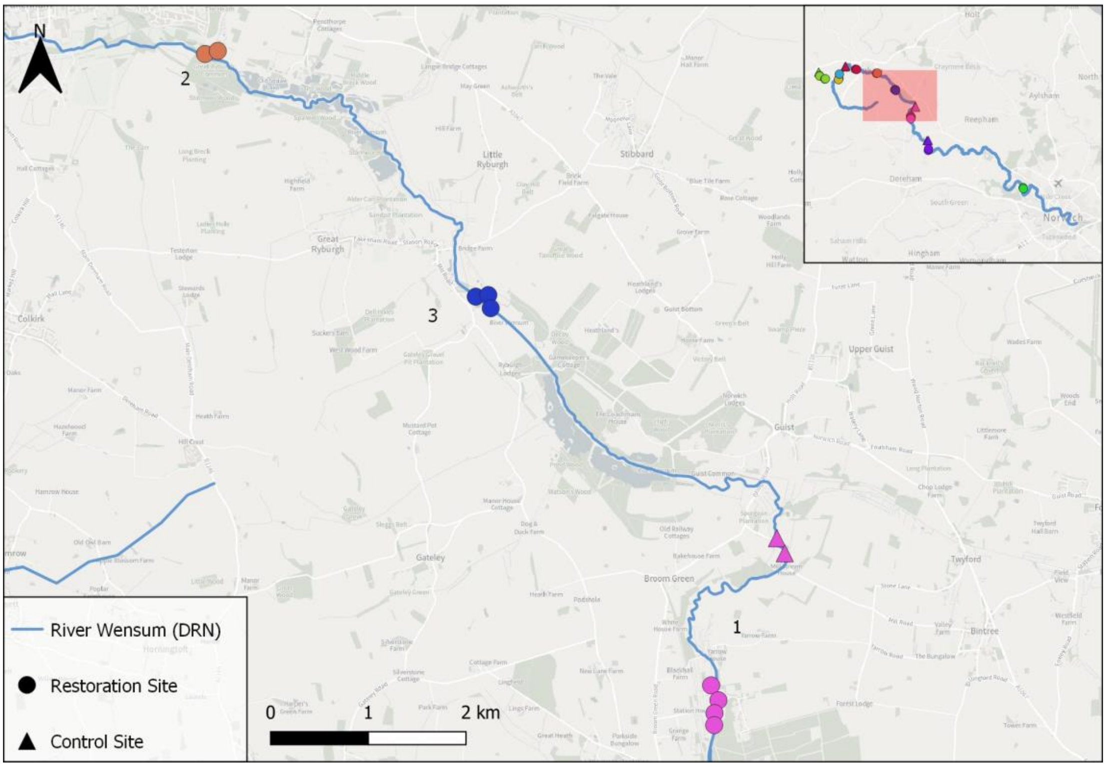


Figure 0-1. Location of survey reaches for sites 1, 2, 3.

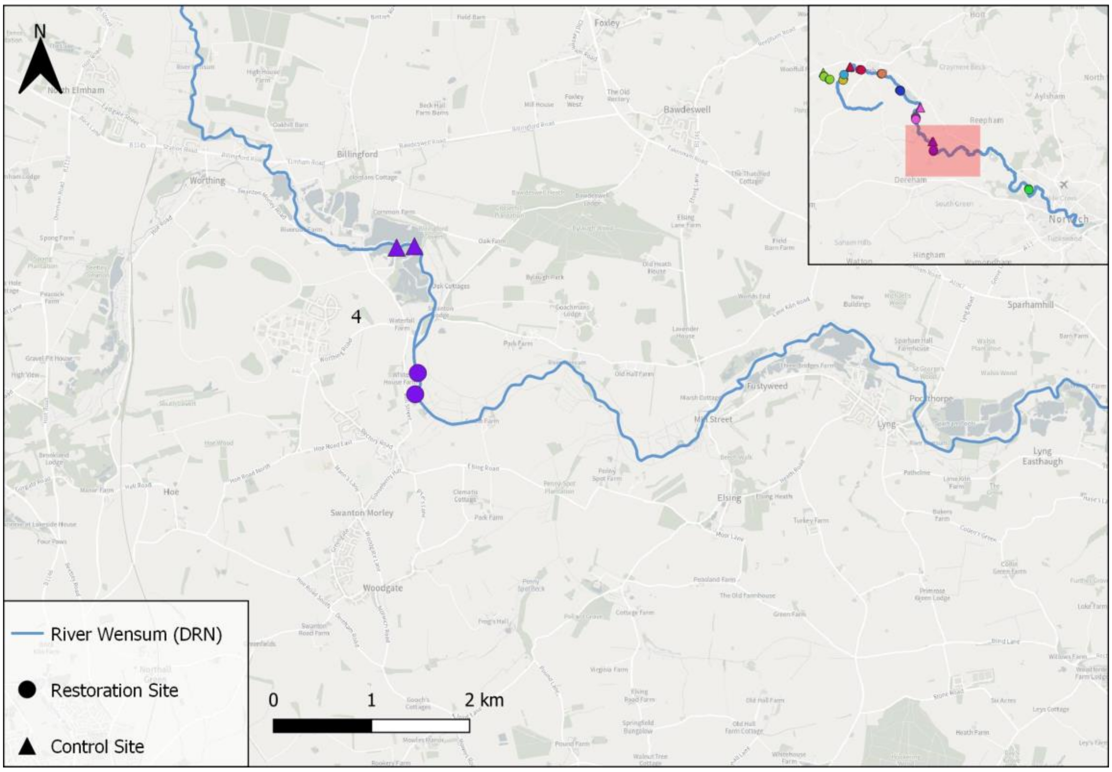


Figure 0-2. Location of survey reaches for site 4.

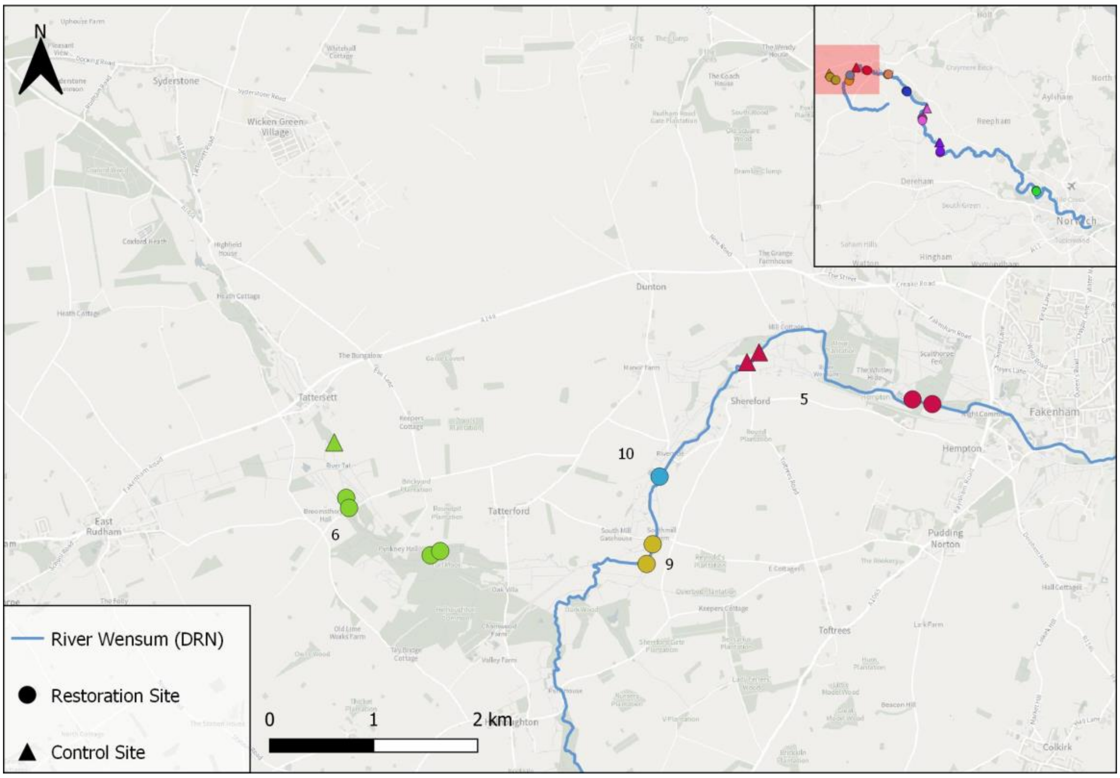
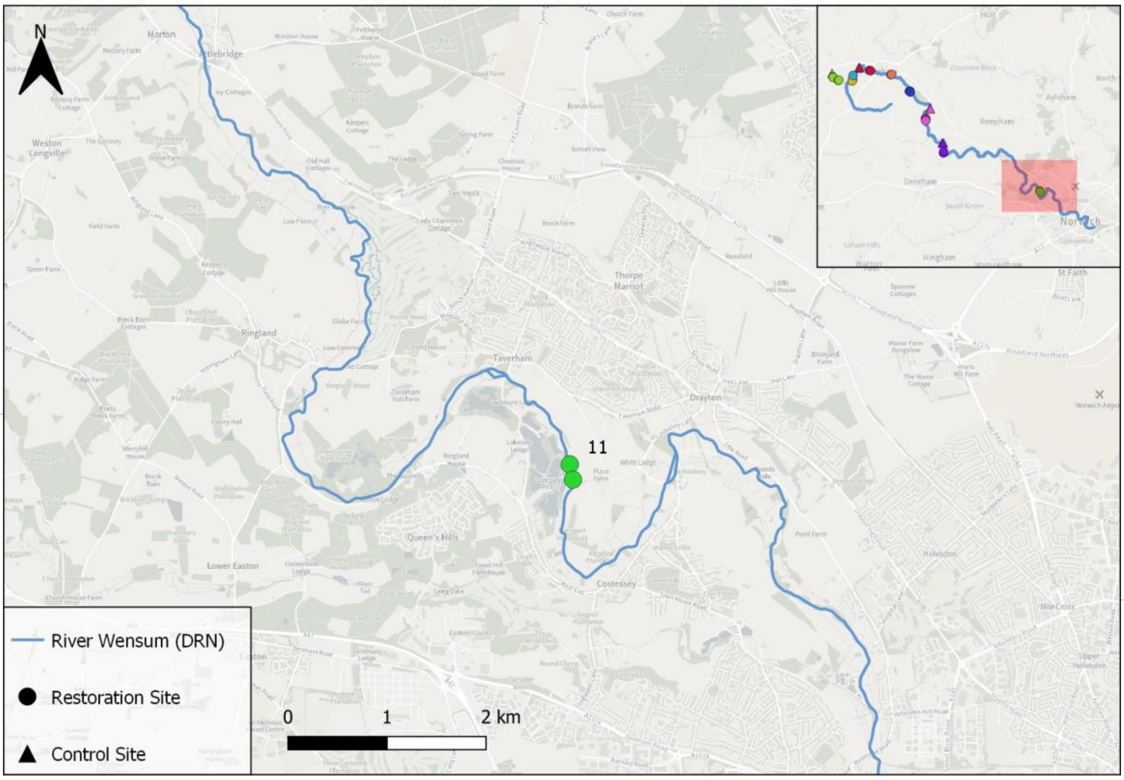


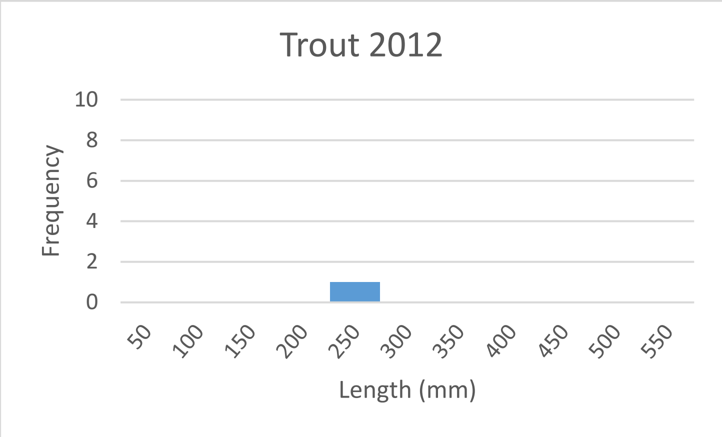
Figure 0-3. Location of survey reaches for sites 5,6,9,10.

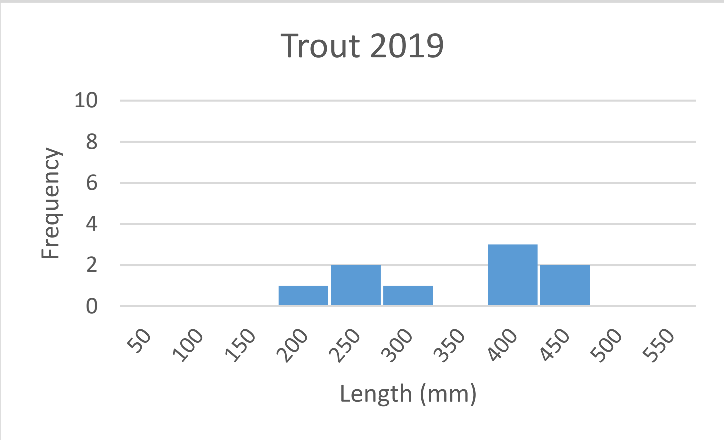
Figure 0-4. Location of survey reaches for site 11

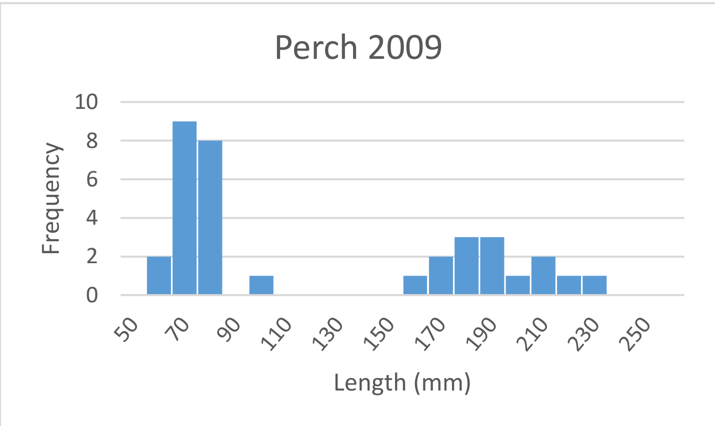
APPENDIX II – Length-frequency charts for the various fish species at each site.

U/S County School- Length-Frequency graphs of key species

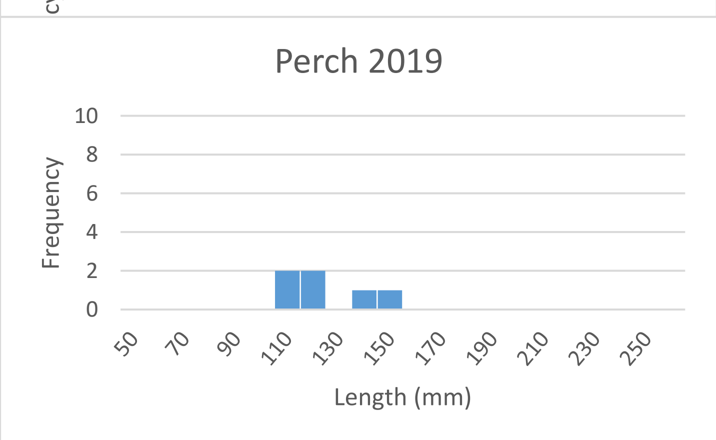


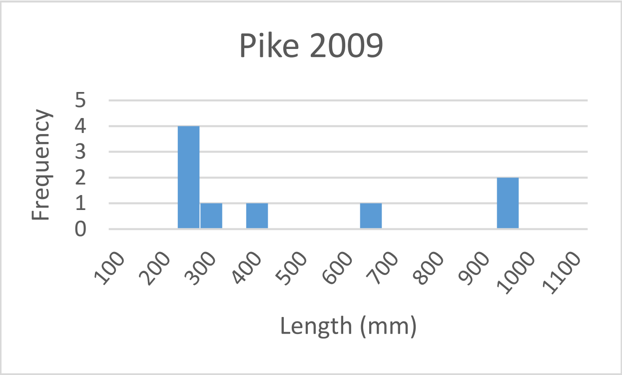

Trout 2012
Frequency
10
8
6
4
2
0
50 100 150 200 250 300 350 400 450 500 550
Length (mm)

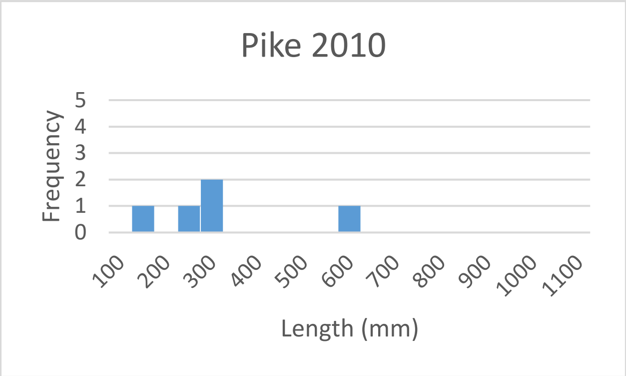

Trout 2019
Frequency
10
8
6
4
2
0
50 100 150 200 250 300 350 400 450 500 550
Length (mm)

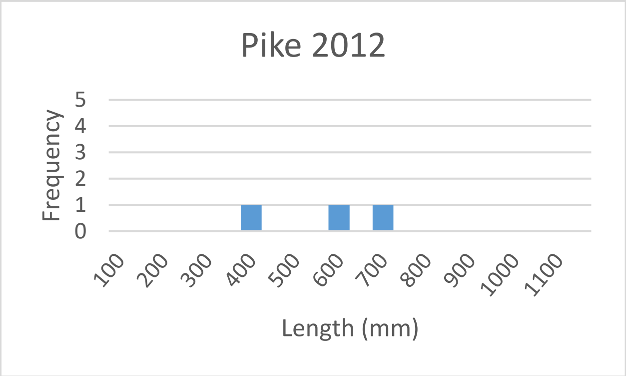

Perch 2009
Frequency
10
8
6
4
2
0
50 70 90 110 130 150 170 190 210 230 250
Length (mm)

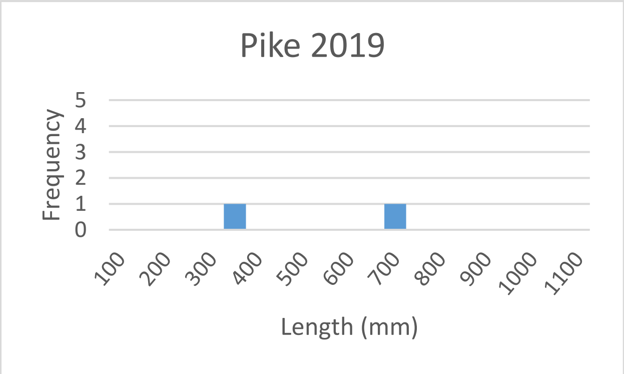

Perch 2010
10
8


Perch 2019
Frequency
10
8
6
4
2
0
50 70 90 110 130 150 170 190 210 230 250
Length (mm)

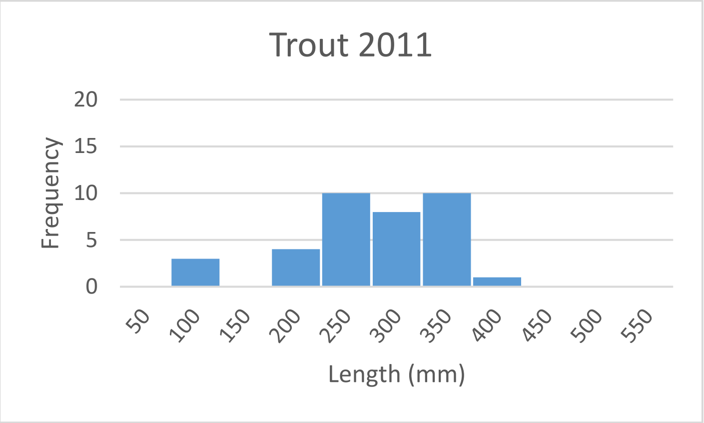

Pike 2009
Frequency
0 1 2 3 4 5
100 200 300 400 500 600 700 800 900 1000 1100
Length (mm)

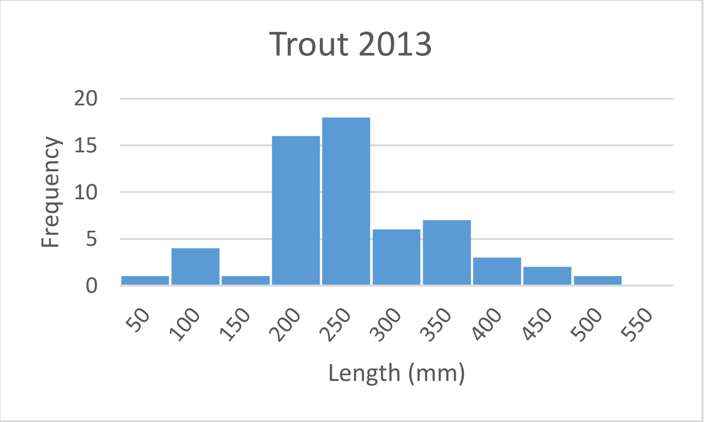

Pike 2010
Frequency
0 1 2 3 4 5
100 200 300 400 500 600 700 800 900 1000 1100
Length (mm)

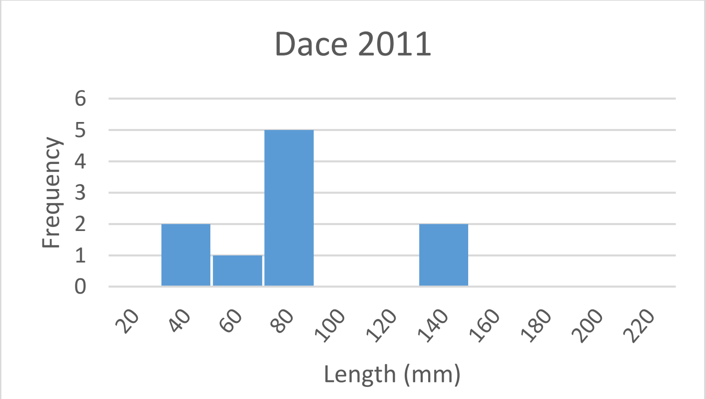

Pike 2012
Frequency
0 1 2 3 4 5
100 200 300 400 500 600 700 800 900 1000 1100
Length (mm)

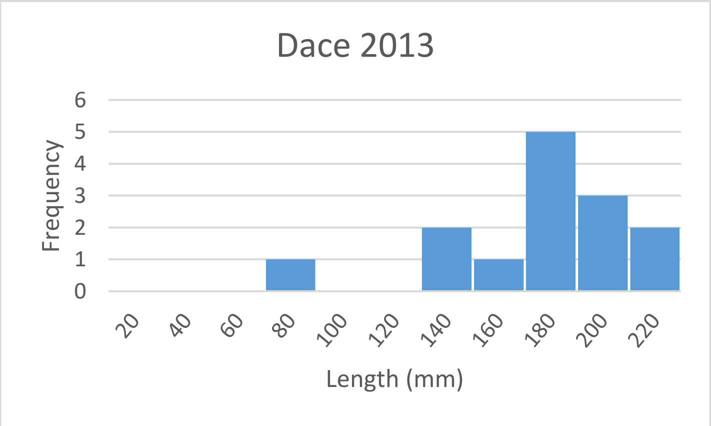

Pike 2019
Frequency
0 1 2 3 4 5
100 200 300 400 500 600 700 800 900 1000 1100
Length (mm)

Great Ryburgh – New loop, Length-frequency graphs of key species

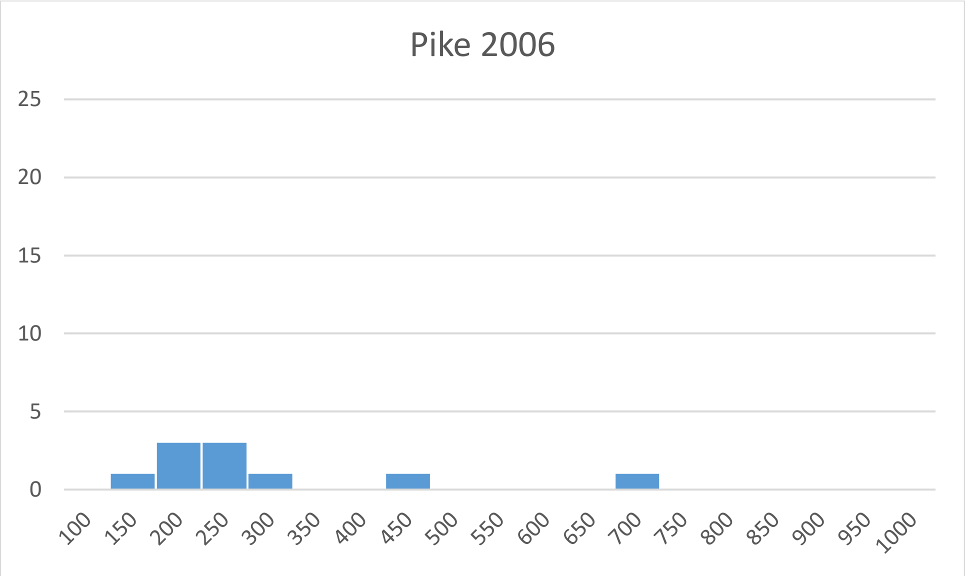


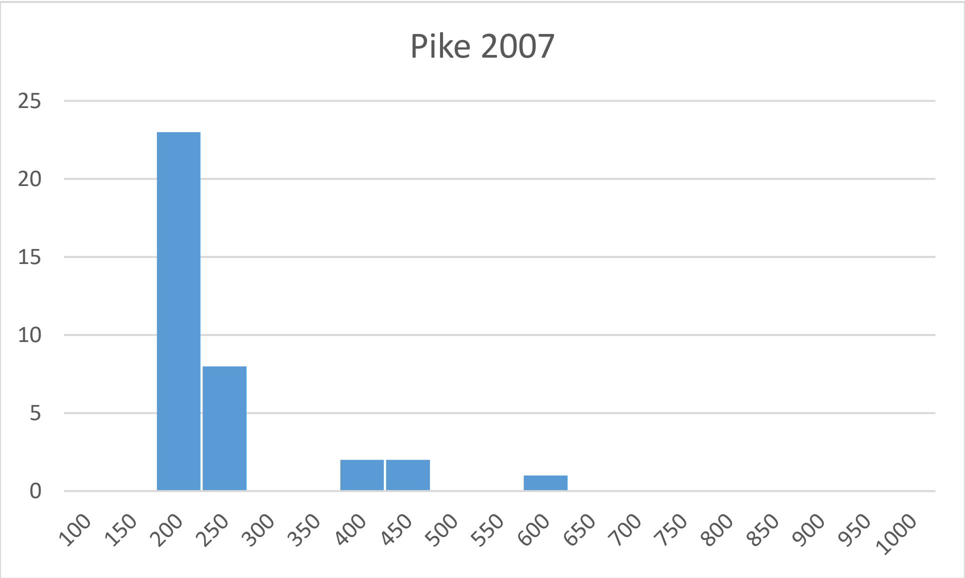


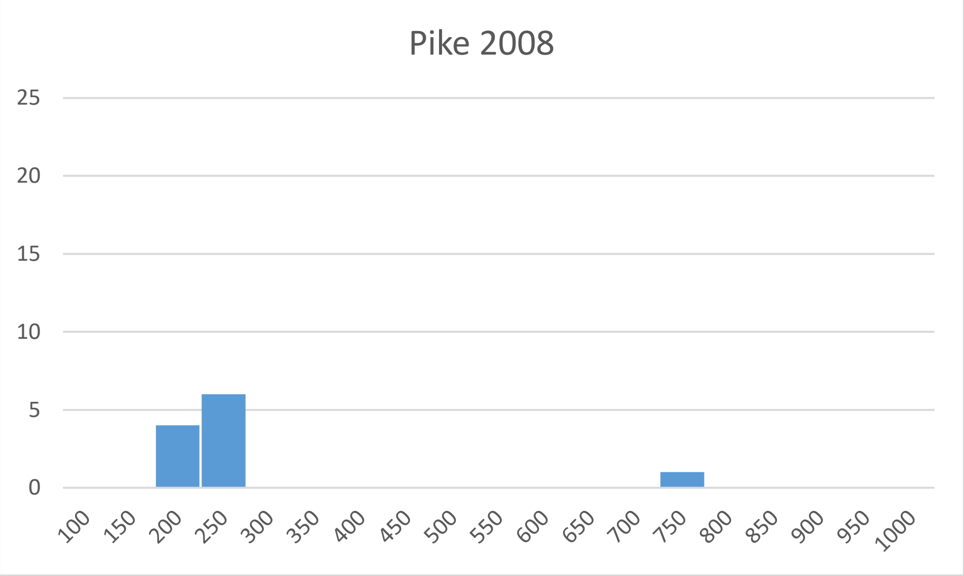




Scheme 3- Length frequency of key species






Pike 2008
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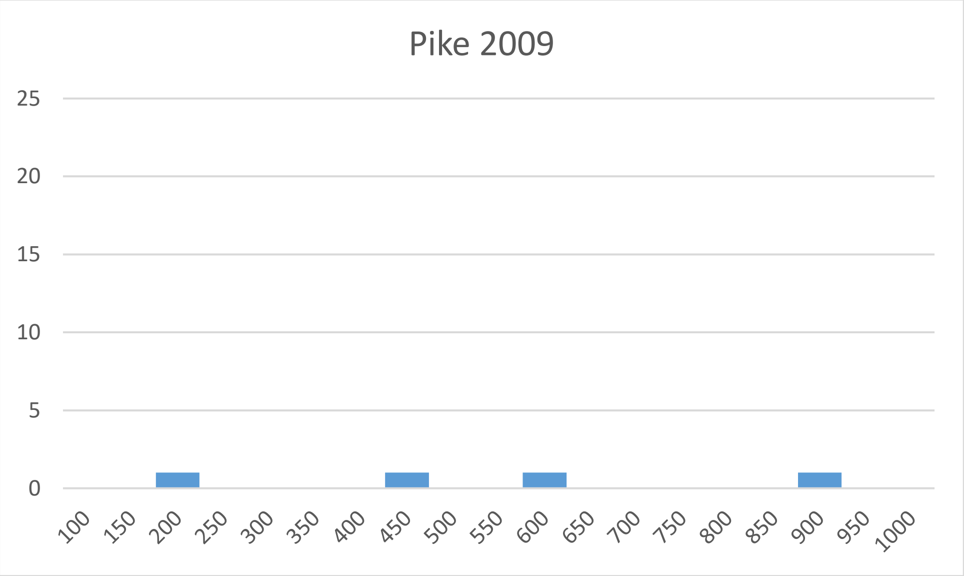
100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850 900 950 1000


Pike 2009
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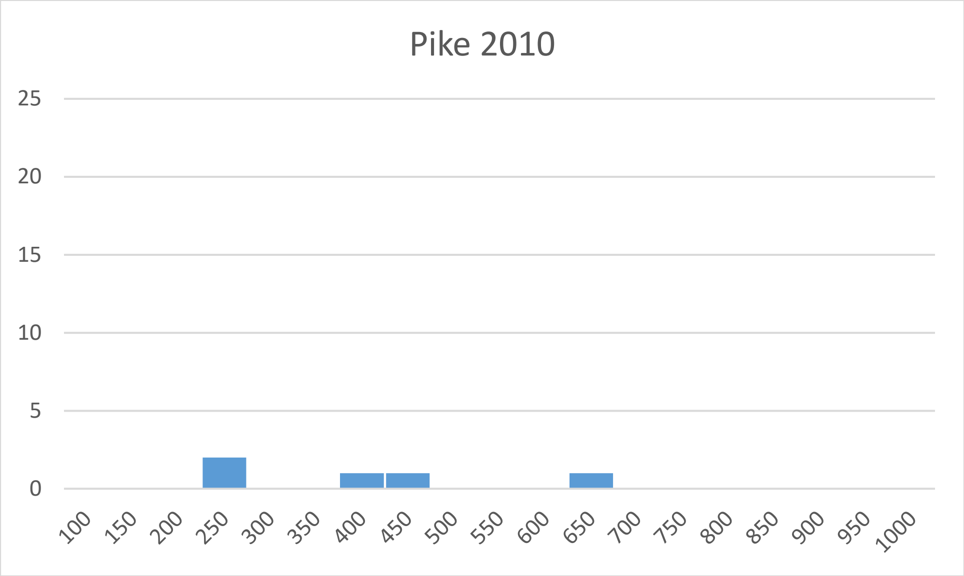
Pike 2010
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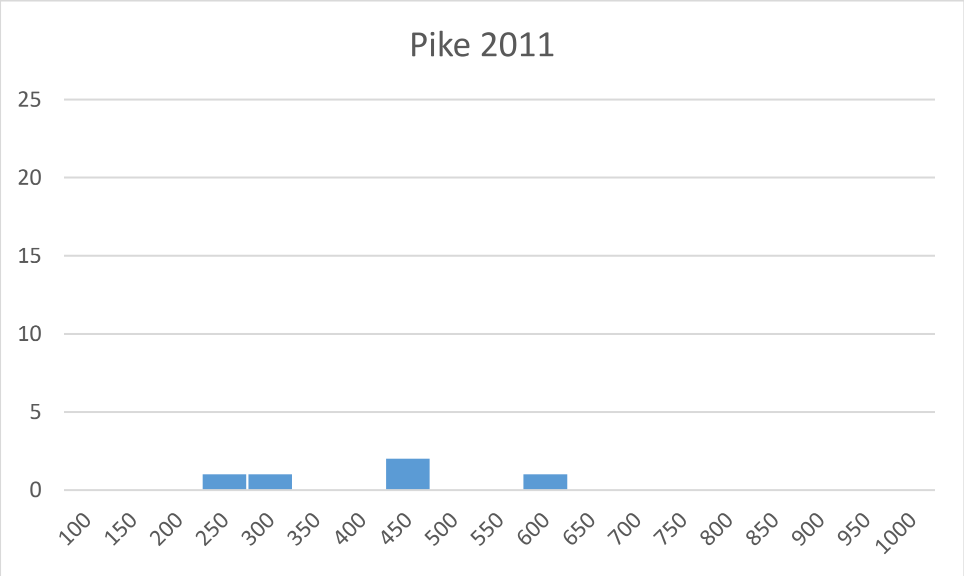
Pike 2011
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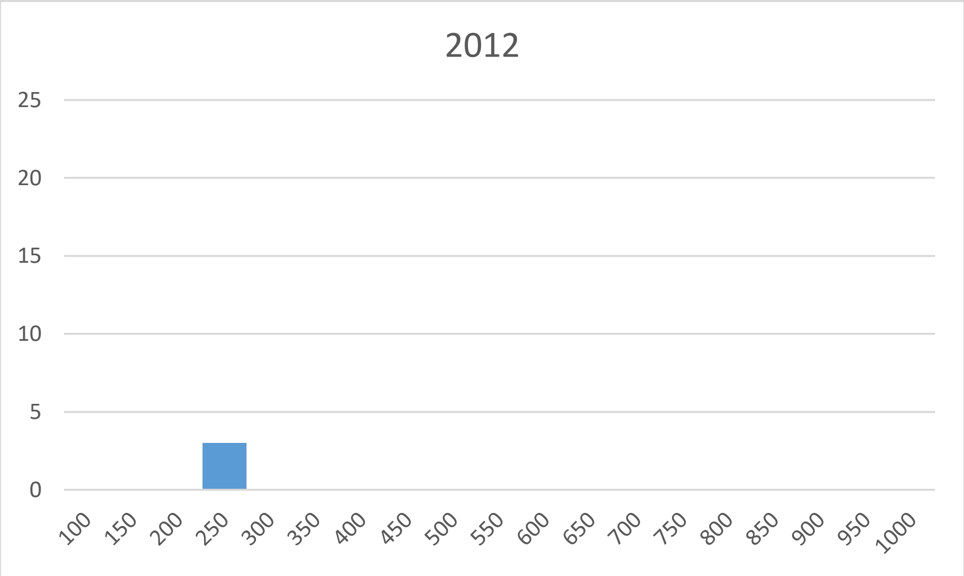
100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850 900 950 1000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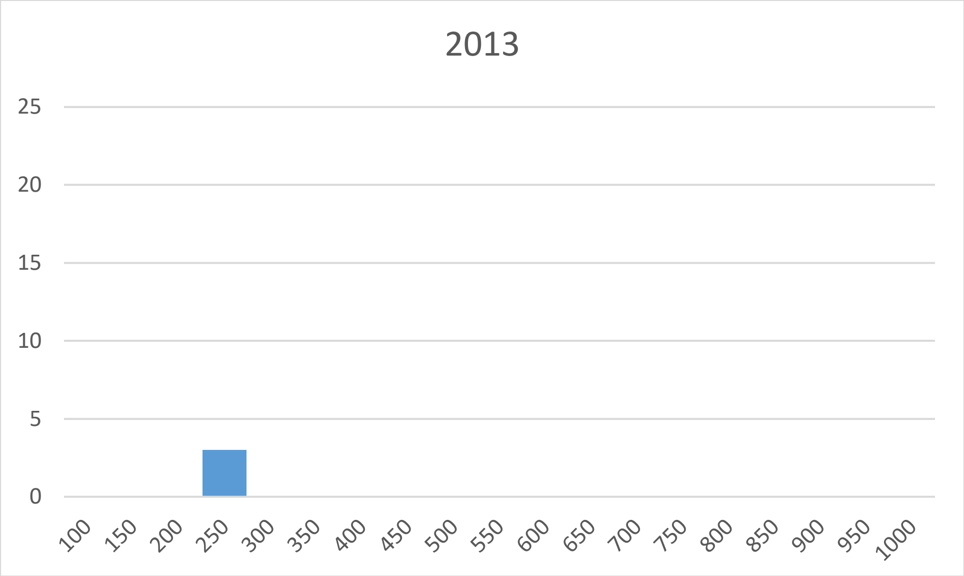
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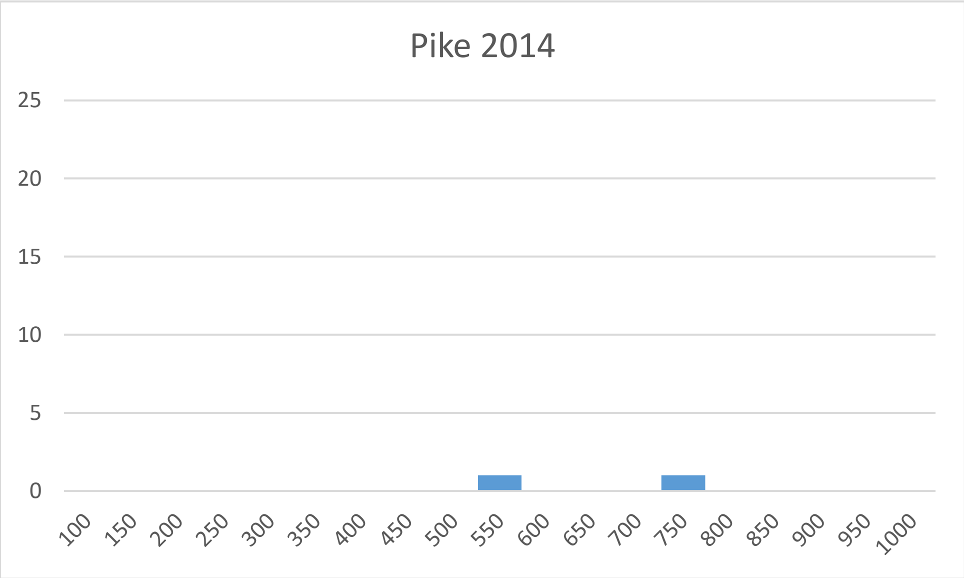
Pike 2014
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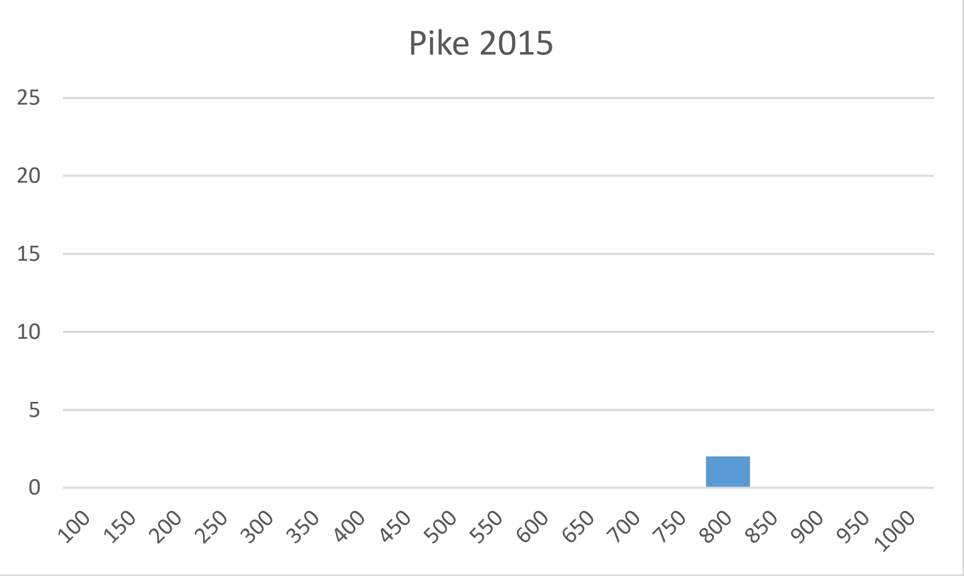
Pike 2015
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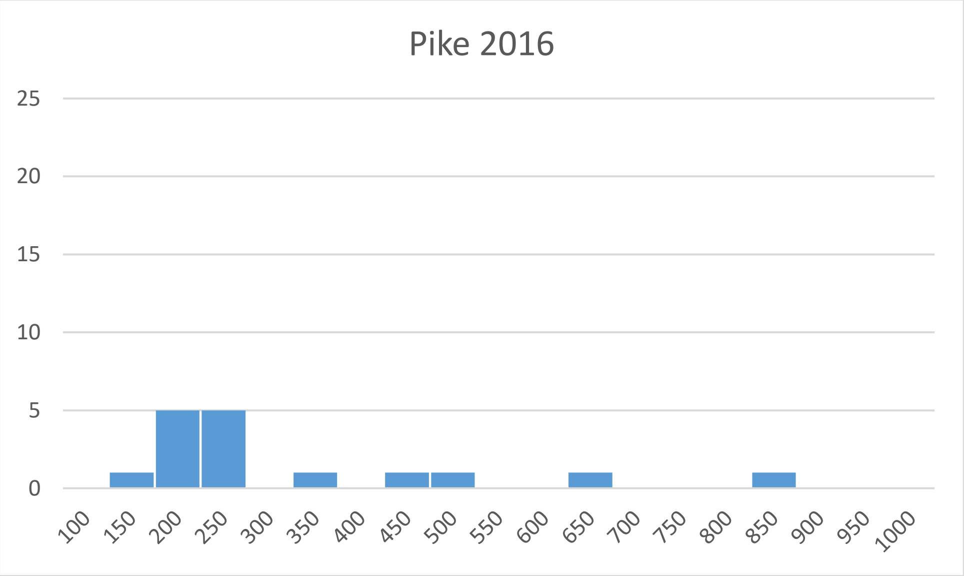
Pike 2016
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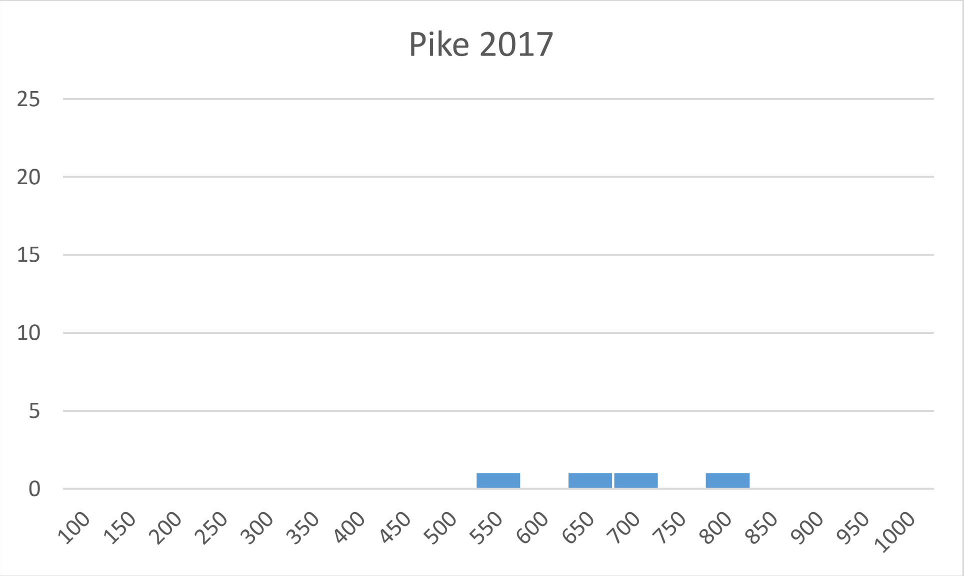
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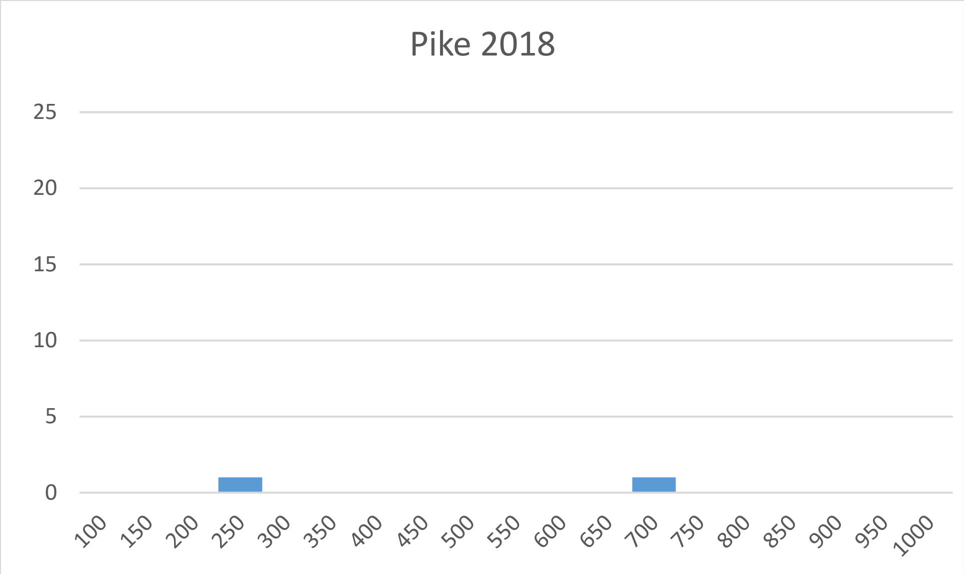
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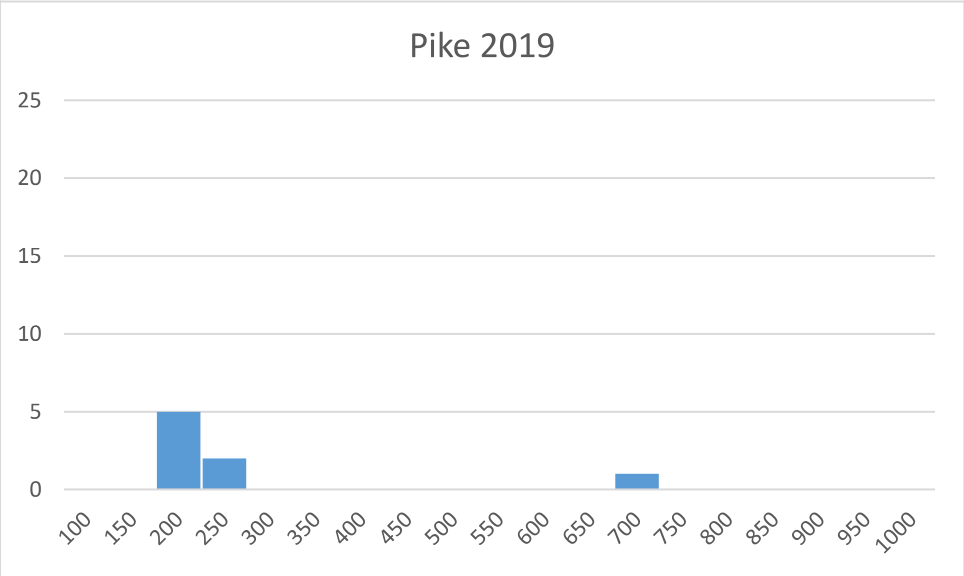
Pike 2019
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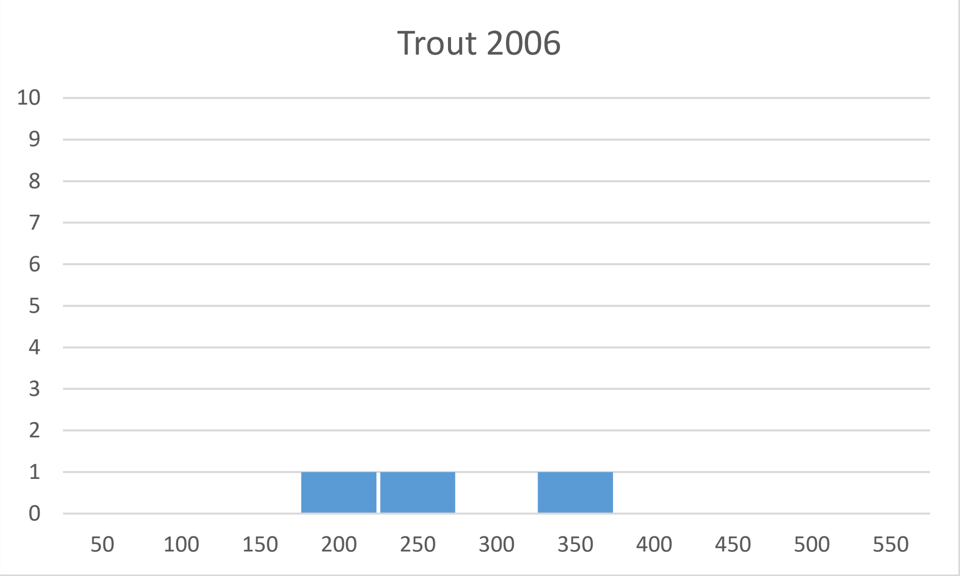
Trout 2006
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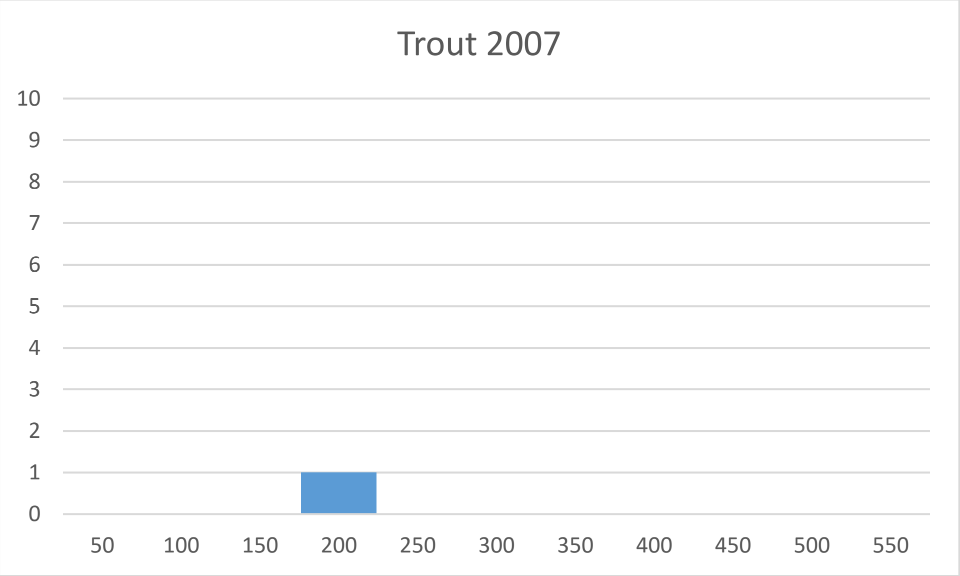
Trout 2007
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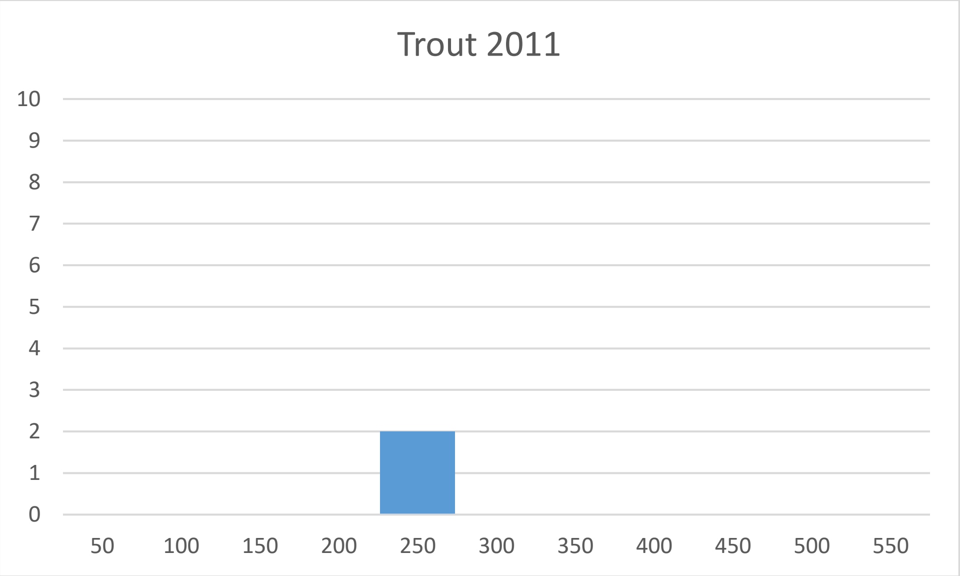
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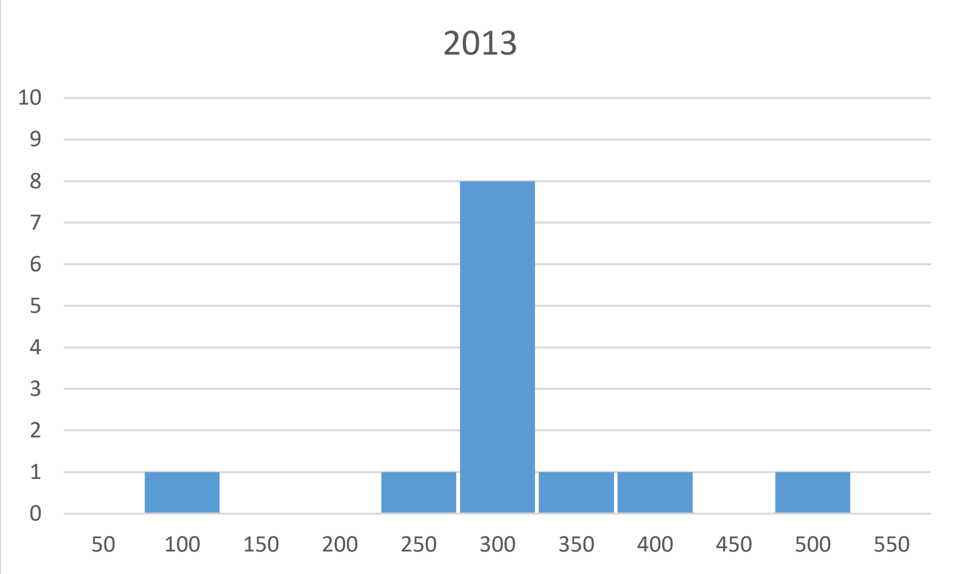
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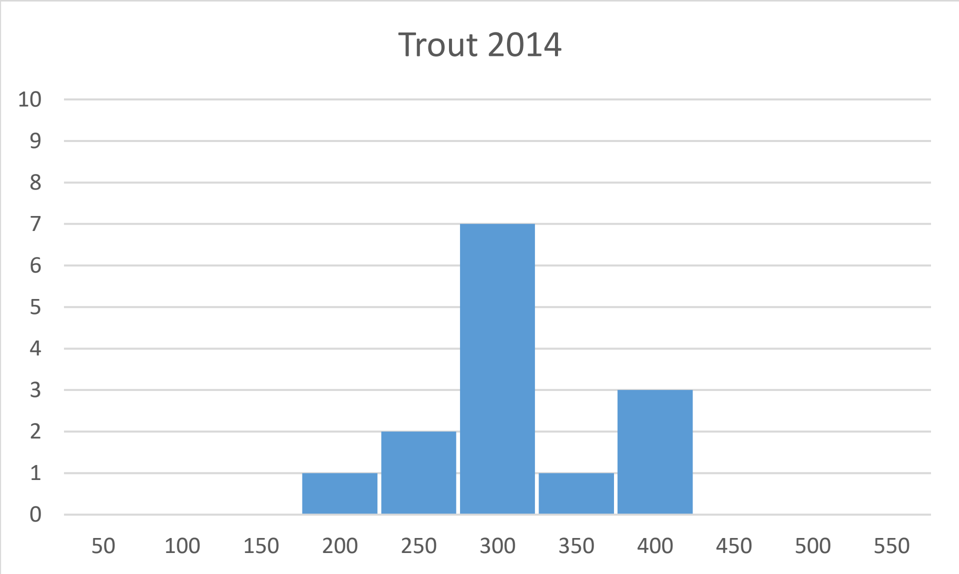
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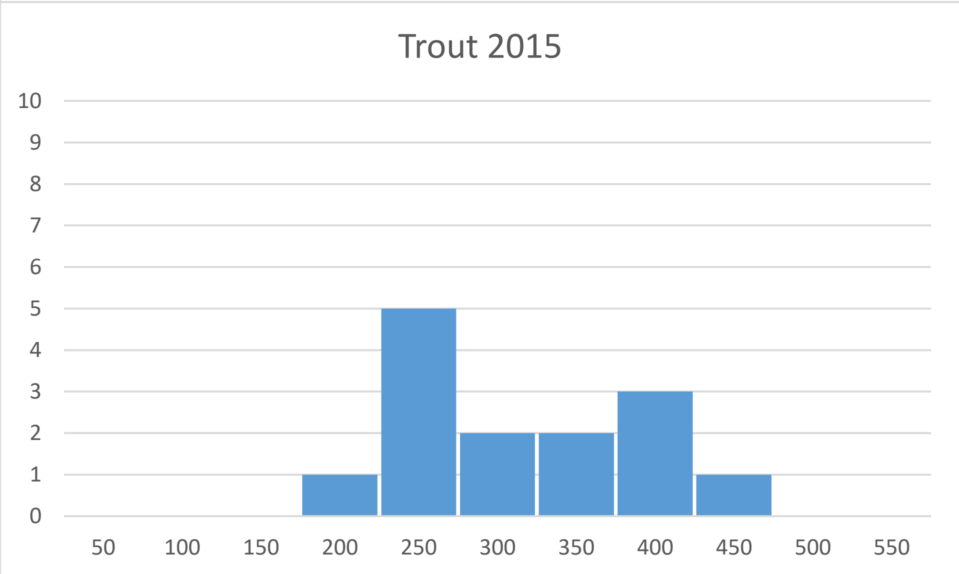
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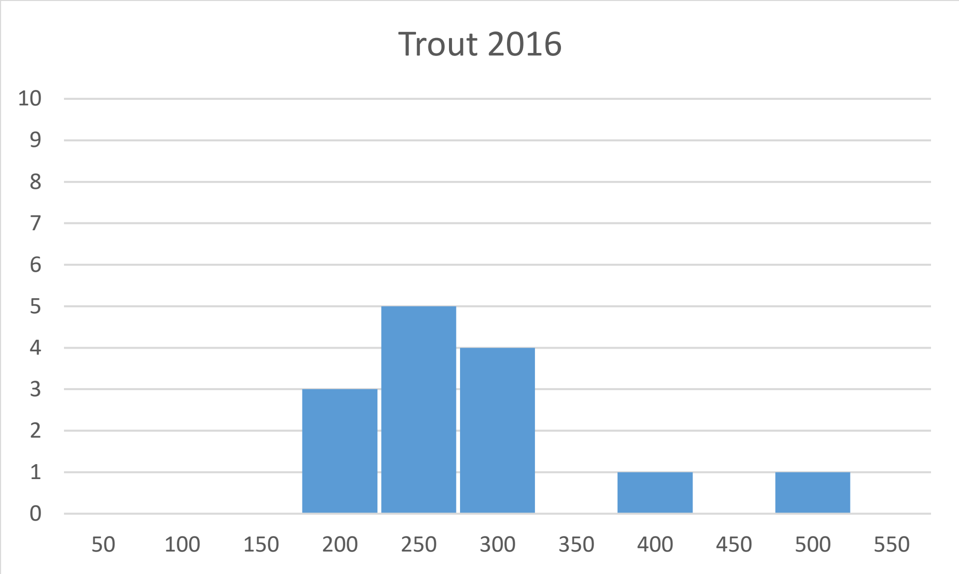
Trout 2016
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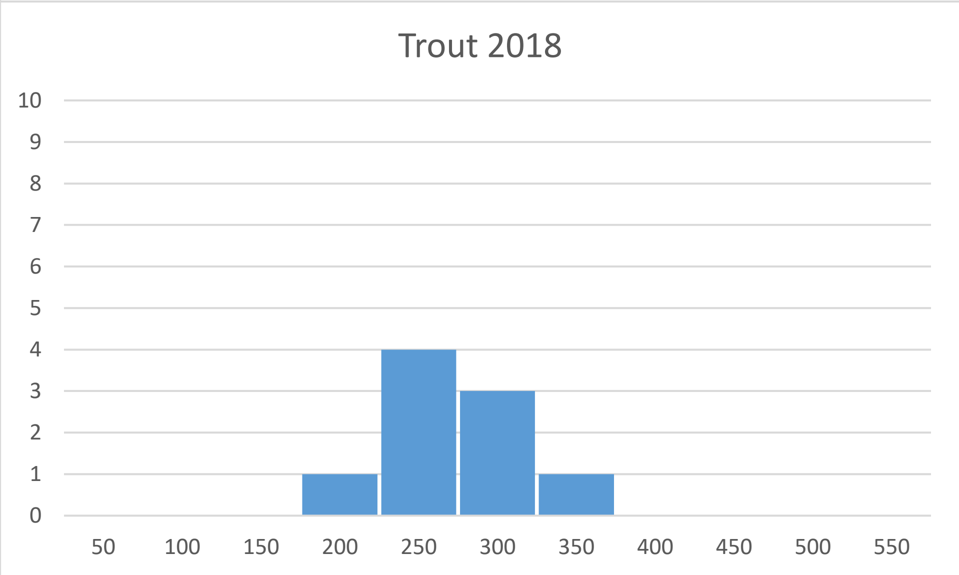
Trout 2018
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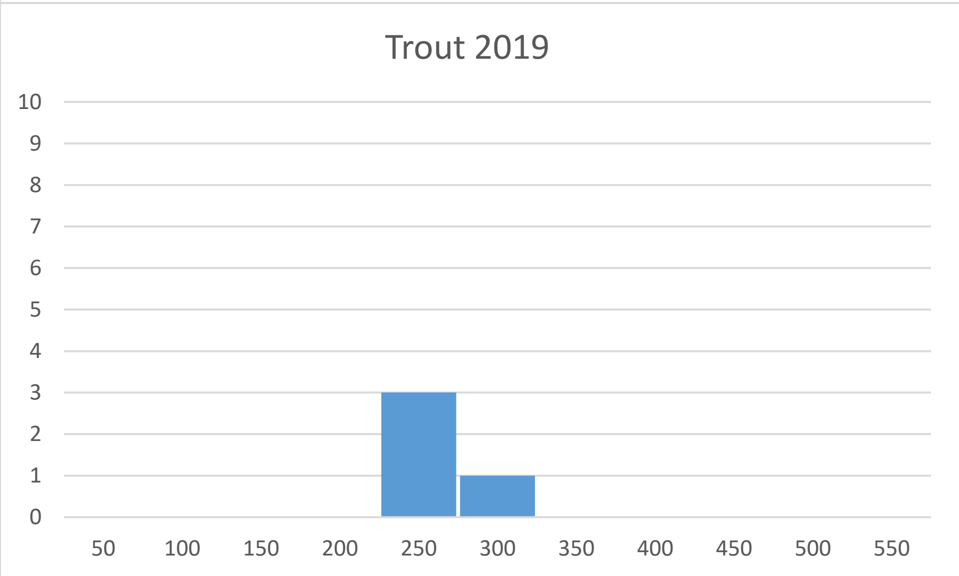
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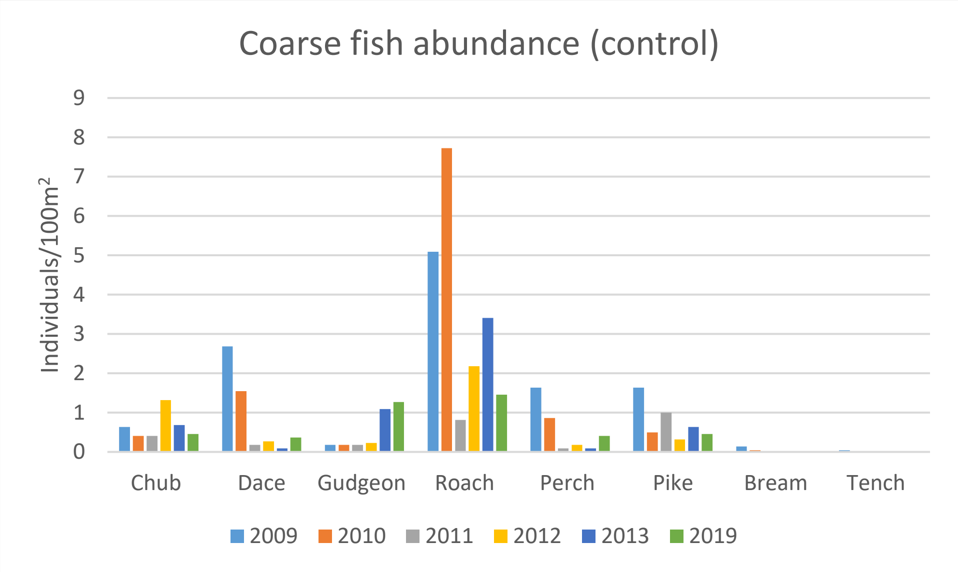
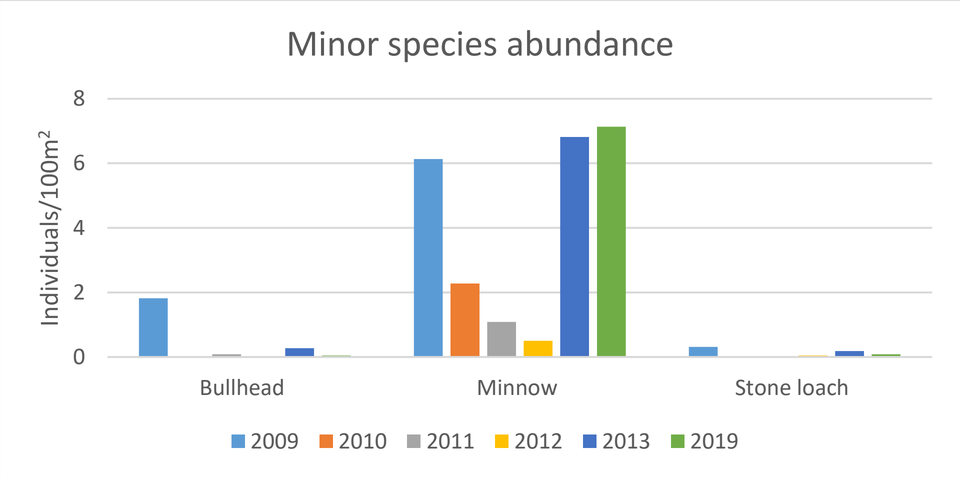
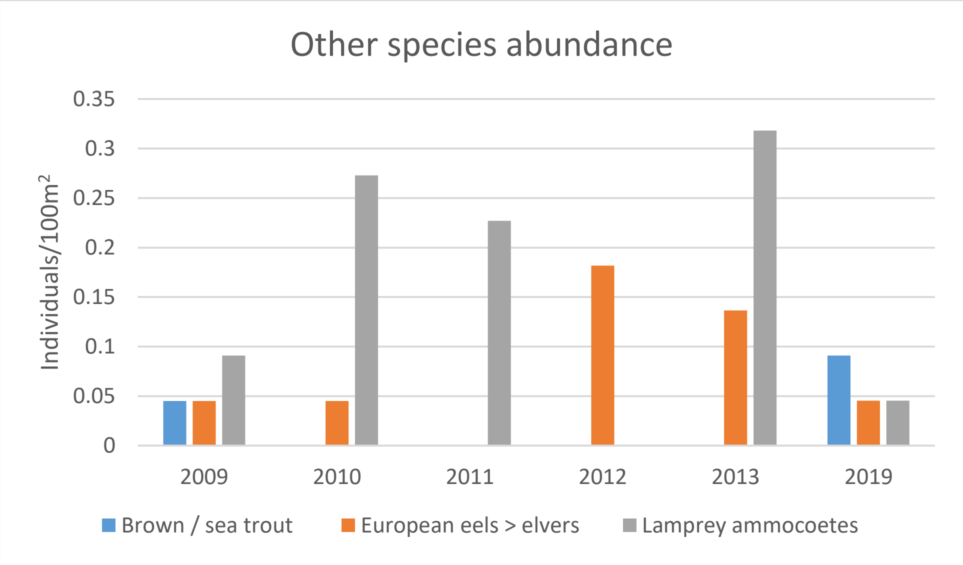
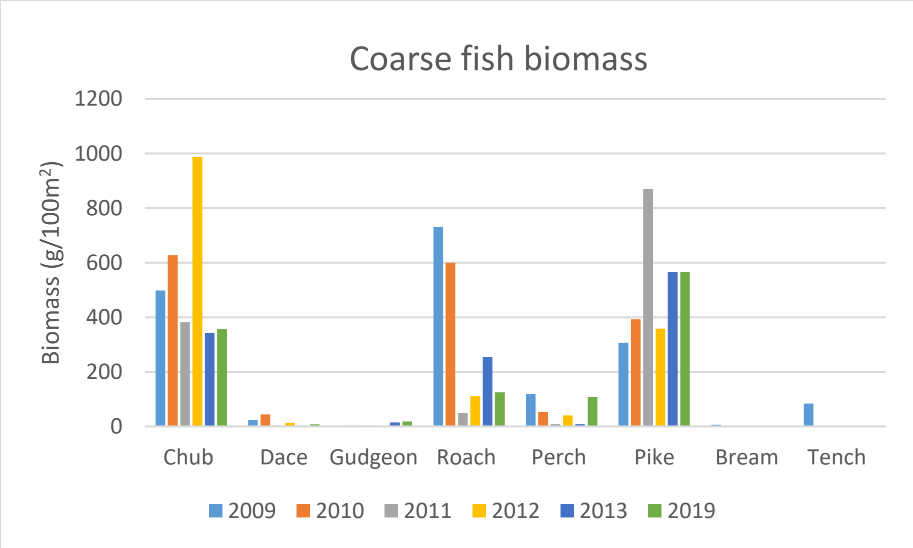
APPENDIX III – Control site fish data charts

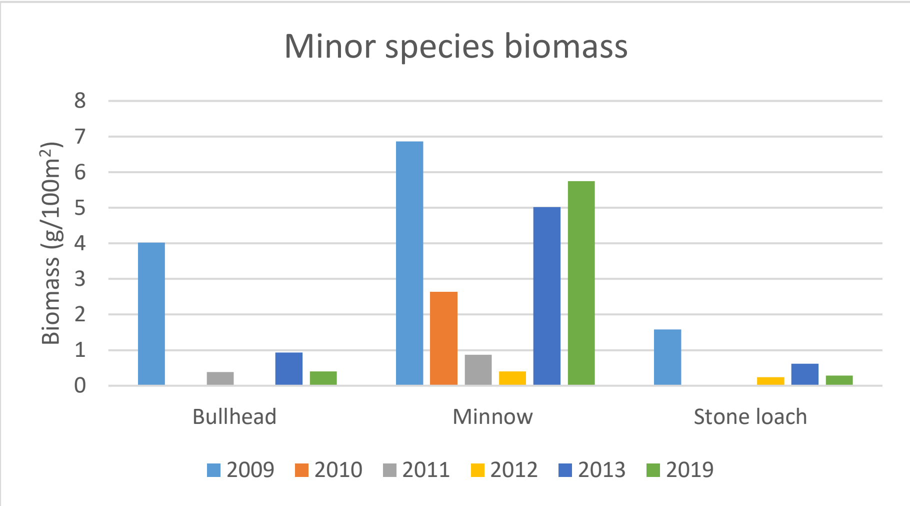
Scheme 4 – control site

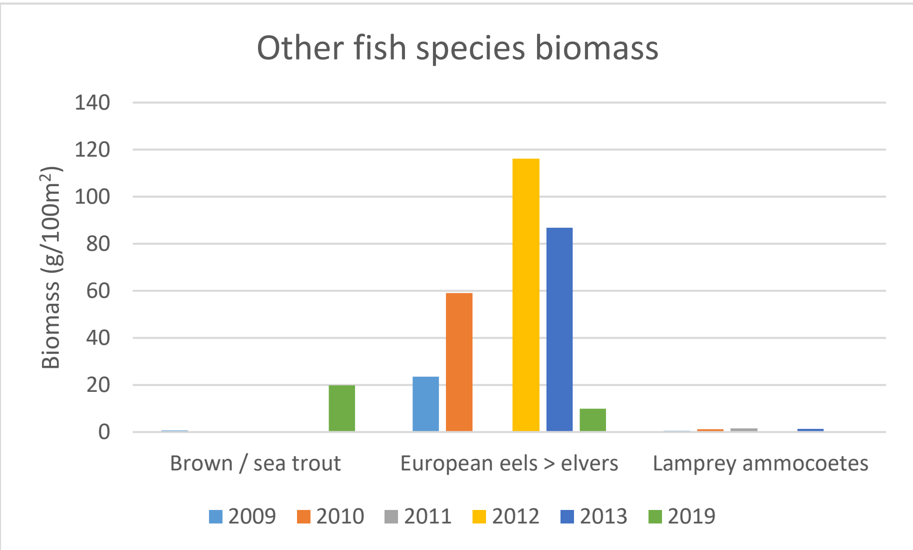




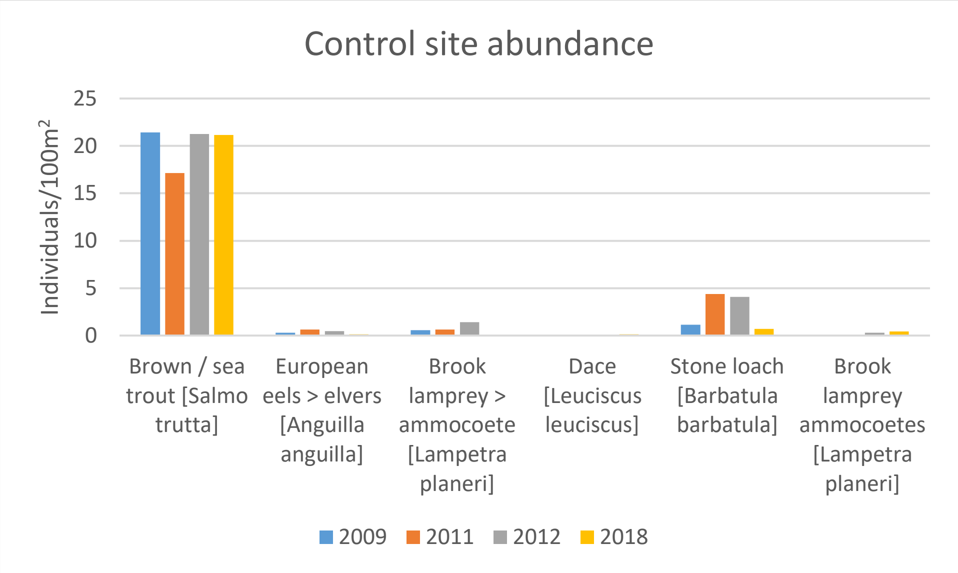


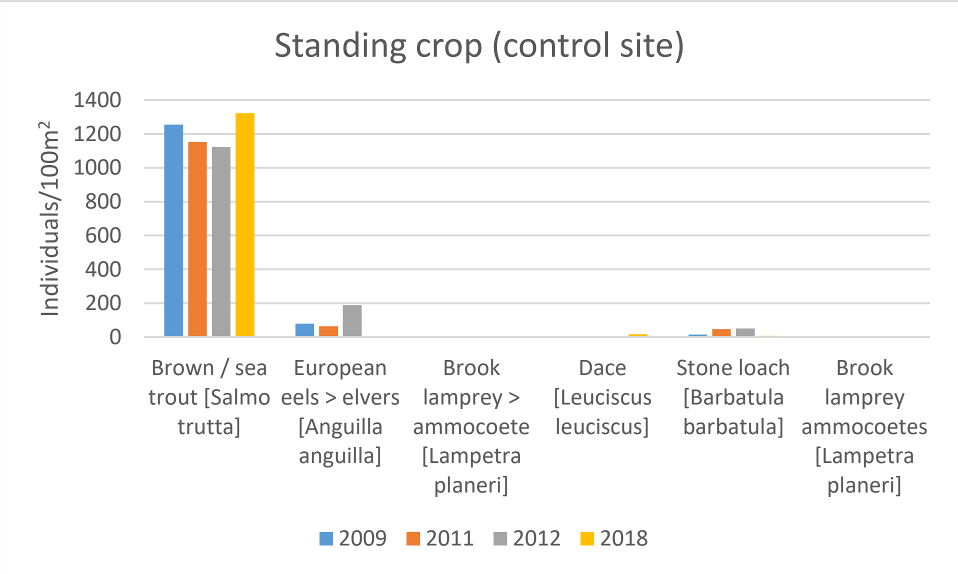

Coarse fish biomass
Biomass (g/100m²)
1200
1000
800
600
400
200
0
Chub
Dace
Gudgeon
Roach
Perch
Pike
Bream
Tench
2009 2010 2011 2012 2013 2019


Minor species biomass
Biomass (g/100m²)
8
7
6
5
4
3
2
1
0
Bullhead
Minnow
Stone loach
2009 2010 2011 2012 2013 2019


Other fish species biomass
Biomass (g/100m²)
140
120
100
80
60
40
20
0
Brown / sea trout
European eels > elvers
Lamprey ammocoetes
2009 2010 2011 2012 2013 2019

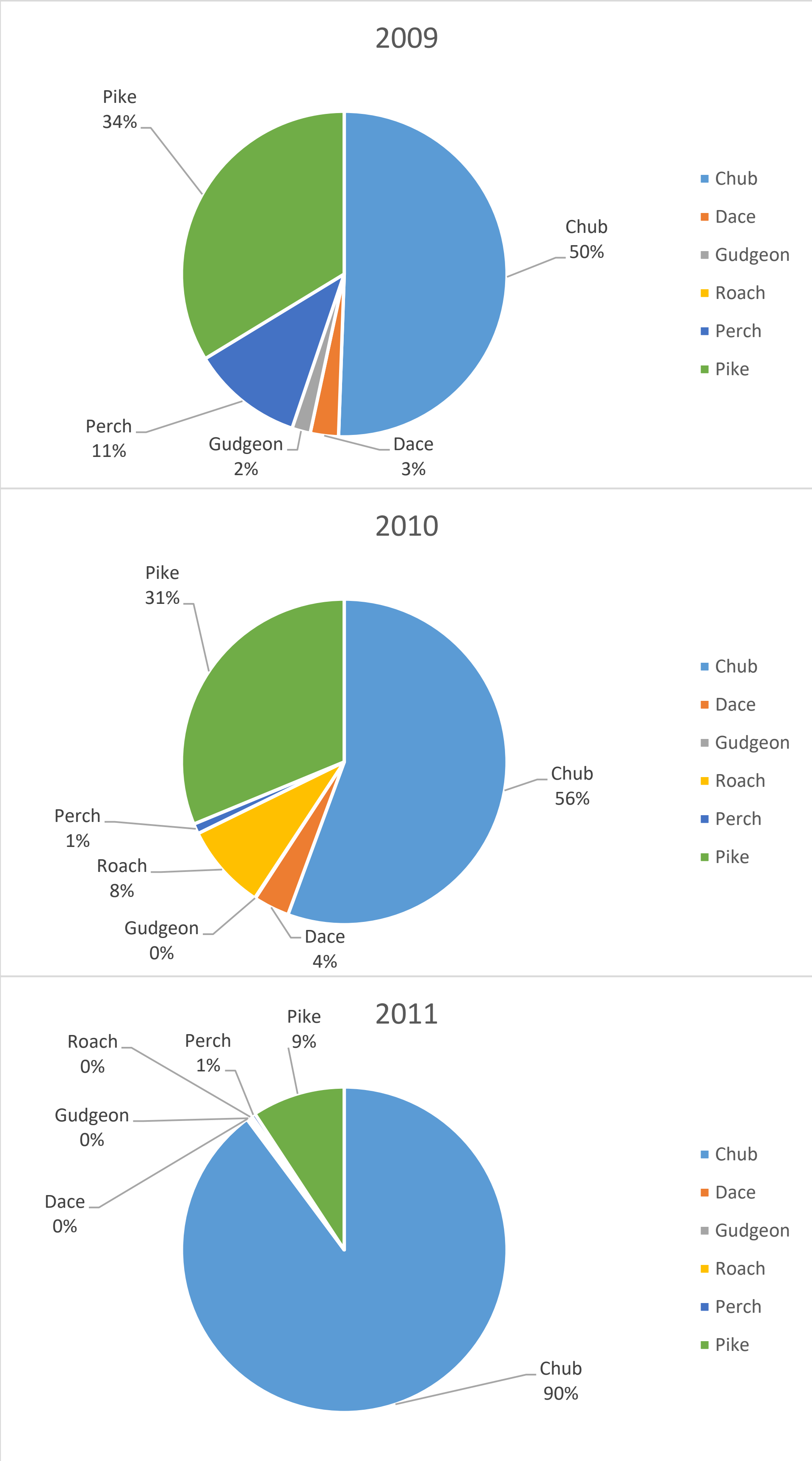
Scheme 5 - U/S Sculthorpe Mill (control site)

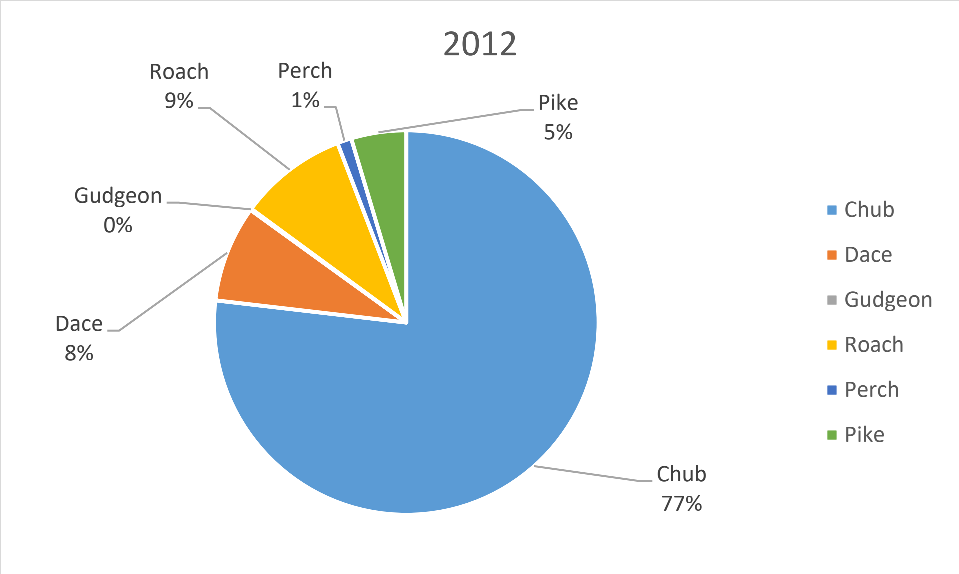


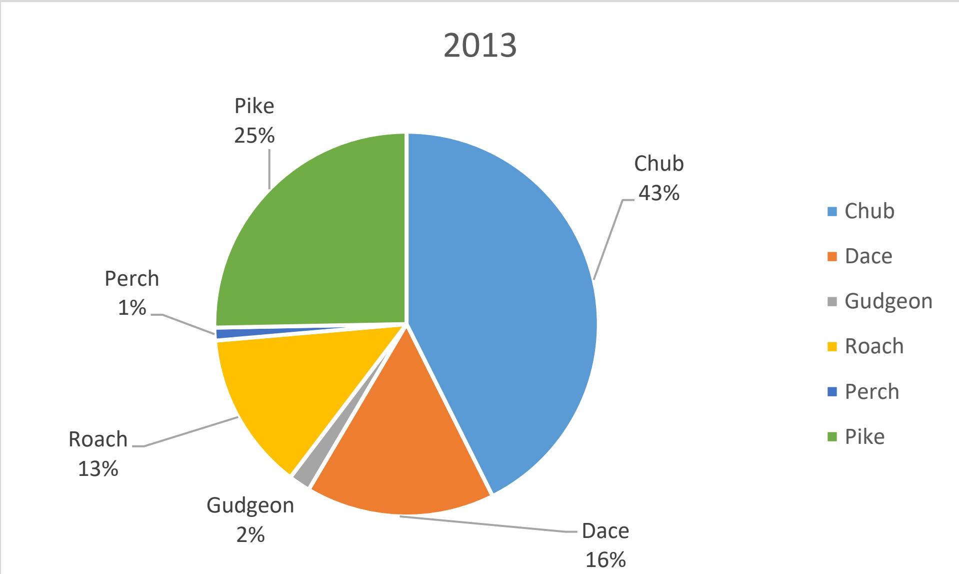


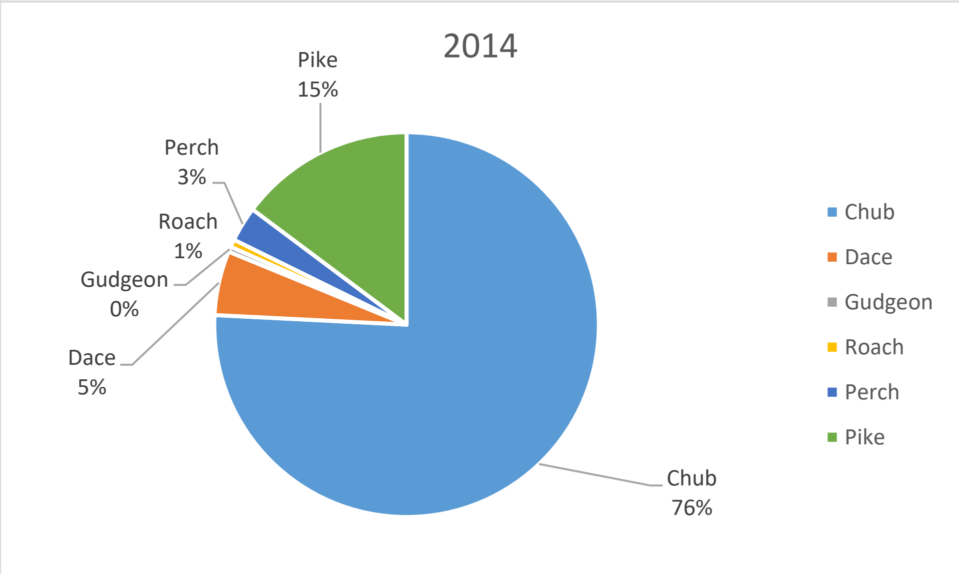
APPENDIX IV – Pre-restoration community composition of Scheme 11

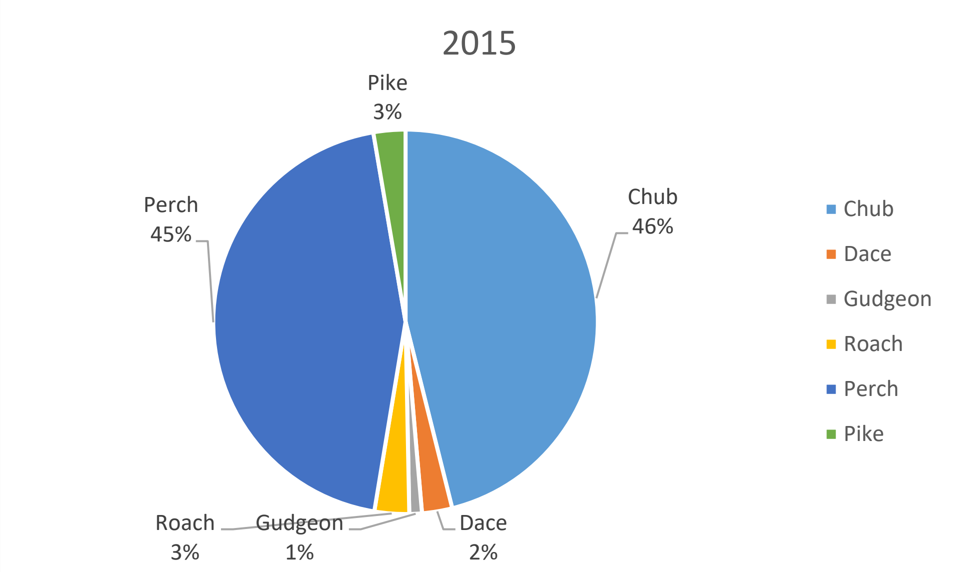
Scheme 11 – pre-restoration community composition

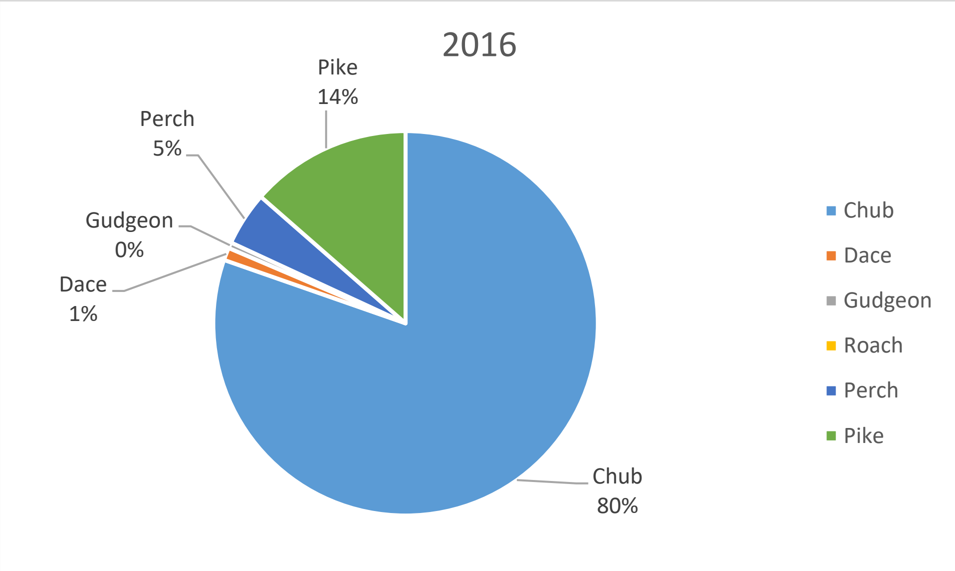


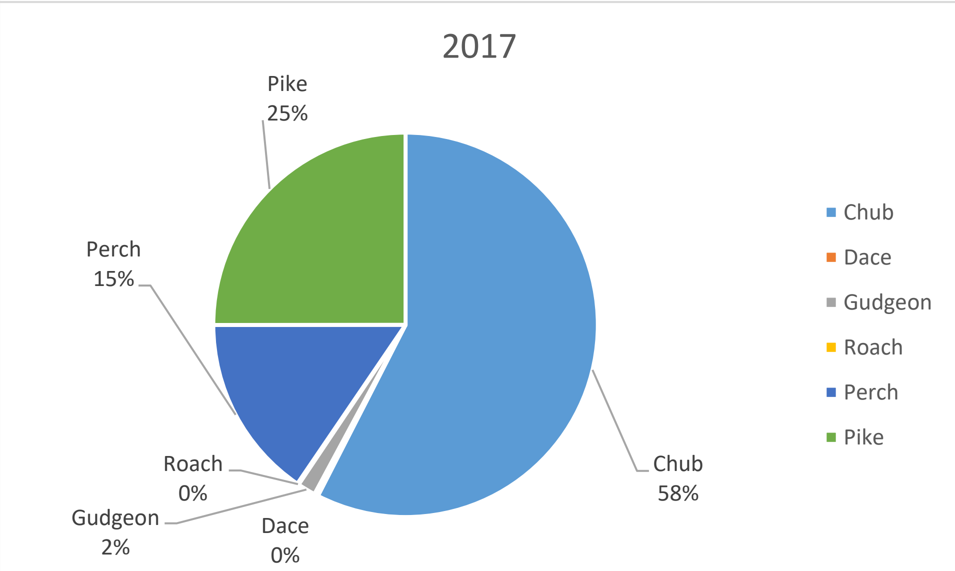

2012
Roach 9%
Perch 1%
Pike 5%
Gudgeon 0%
Dace 8%
Chub 77%
Chub
Dace
Gudgeon
Roach
Perch
Pike

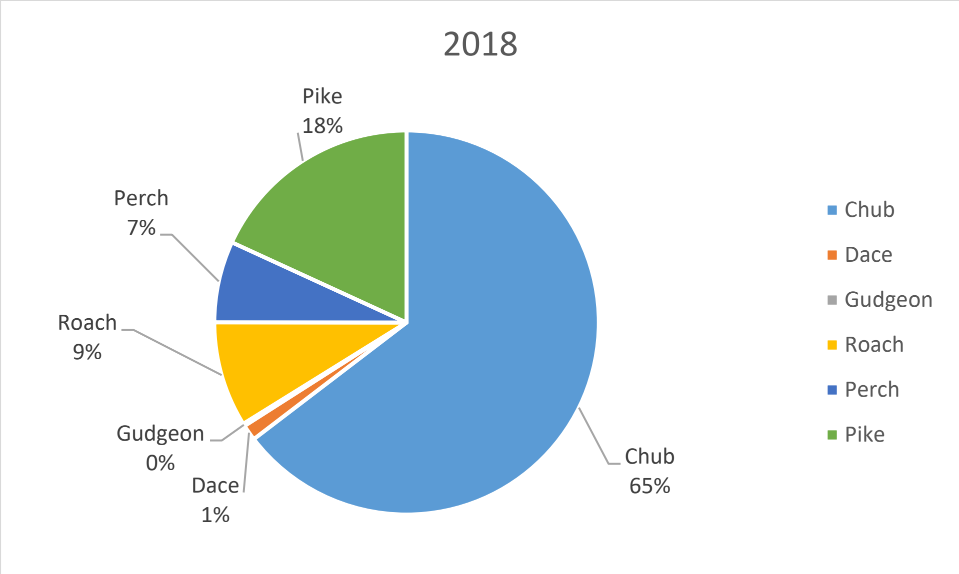

2013
Pike 25%
Chub 43%
Perch 1%
Roach 13%
Gudgeon 2%
Dace 16%
Chub
Dace
Gudgeon
Roach
Perch
Pike

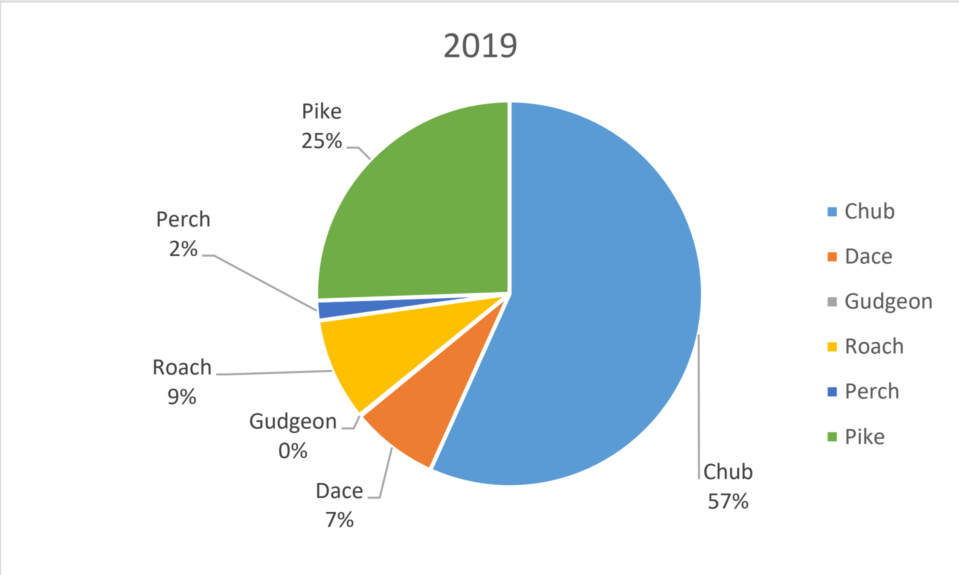

2014
Pike 15%
Perch 3%
Roach 1%
Gudgeon 0%
Dace 5%
Chub 76%
Chub
Dace
Gudgeon
Roach
Perch
Pike


2015
Pike 3%
Chub 46%
Perch 45%
Roach 3%
Gudgeon 1%
Dace 2%
Chub
Dace
Gudgeon
Roach
Perch
Pike


2016
Pike 14%
Perch 5%
Gudgeon 0%
Dace 1%
Chub 80%
Chub
Dace
Gudgeon
Roach
Perch
Pike


2017
Pike 25%
Perch 15%
Roach 0%
Gudgeon 2%
Dace 0%
Chub 58%
Chub
Dace
Gudgeon
Roach
Perch
Pike


2018
Pike
18%
Perch
7%
Roach
9%
Gudgeon
0%
Dace
1%
Chub
65%
Chub
Dace
Gudgeon
Roach
Perch
Pike


2019
Pike
25%
Perch
2%
Roach
9%
Gudgeon
0%
Dace
7%
Chub
57%
Chub
Dace
Gudgeon
Roach
Perch
Pike