FISHERIES SURVEY & REVIEW TO INFORM A FISH MANAGEMENT PLAN FOR LOE POOL SSSI, CORNWALL

A view of Loe Pool © Andrew Harwood

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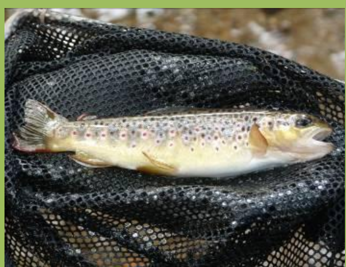


Fisheries Survey & Review to inform a Fish Management Plan for Loe Pool SSSI

Final Report
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1 Introduction

1.1 Scope & objectives of the project

This report details the findings of a project commissioned by the National Trust (NT hereafter) to develop a fish management plan to assist in conserving Loe Pool, a Site of Special Scientific Interest (SSSI hereafter), and move it towards favourable condition. The goal of the work was '*to assess the role of the fish community in Loe Pool's current condition and to propose any further action required with respect to the fish community*'. The project was divided into two main stages:

- **Stage 1.** Review existing data and survey of the fish community of Loe Pool, SSSI. The aim of fisheries survey is to provide a cost effective method of gathering suitable information on the fish community and to form a baseline dataset for future conservation management; and
- **Stage 2.** Develop a costed Fish Management Plan for Loe Pool, SSSI. Using the findings of Stage 1, this aims to identify and detail key actions required to manage the fish community to aid Loe Pool's recovery to a more macrophyte-dominated state.

It is also suggested that the findings of this project should feed into a third stage:

- **Stage 3.** Produce a revised Loe Pool Catchment Management Plan to incorporate the findings and identify any further steps that could aid in the restoration/ rehabilitation of Loe Pool based on a full appraisal of the lake ecosystem and wider catchment. This would ultimately identify a practicable combination of steps, and methods for implementation, to achieve the management objectives.

1.2 Report structure

Following an introduction to Loe Pool and the study area, the existing fisheries data and literature is reviewed. The current (September/October 2014) fisheries survey is then detailed and a discussion of the results is provided in relation to the ecological role of the fish community and implications for the condition of Loe Pool SSSI. Finally, recommendations of how the fisheries interest of the lake should be managed and estimated costs are provided.

1.3 Background information

1.3.1 Loe Pool and catchment

Loe Pool is the largest freshwater lake in Cornwall with an area of 56 hectares (ha) approximately 1.5 km to the southwest of Helston within the Penrose Estate which is owned and managed by the National Trust (Figure 1). The lake was once the estuary for the River Cober that flows into the lake from the north, before the river mouth was blocked from the sea by a dynamic shingle bar (Loe Bar) (Figure 1). Historically, the bar would have been periodically breached by the sea, but has also been deliberately broken to alleviate flooding along the River Cober in Helston. Loe Pool has remained relatively isolated since the bar was last breached in 1979 and 1984. Improvements were made to the Loe Pool outflow structure at the northern end of the bar in 1986 to aid drainage and better control of lake water levels (Wilson & Dinsdale 1998).

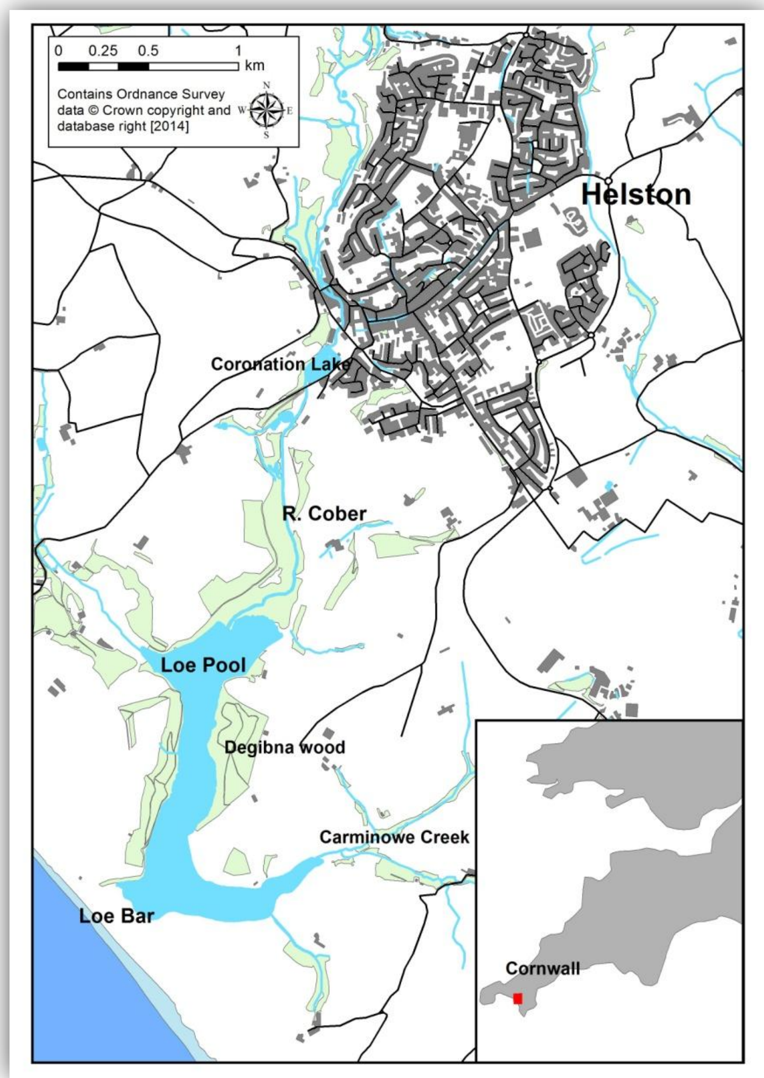

Figure 1. Location of Loe Pool and features of interest.

The lake has six tributaries: the Cober, Penrose, Chyvarloe, Degibna, Carminowe, Nansloe (Dinsdale 2009). Of these, although still relatively small, the River Cober is the largest, which after rising in Nine Maidens Down, flows southwest and drains a catchment of some 53.75 square kilometres (km^2) north of Porkellis Moor including the town of Helston before reaching Loe Pool (Cornwall Rivers Project - http://www.cornwallriversproject.org.uk/

geography/cober.htm). Stithians Reservoir to the east of the River Cober, can discharge untreated water into a tributary stream, the Medlyn. As part of flood alleviation schemes, sections of the upstream of Loe Pool have been channelised and re-profiled. The Carminowe, flows through the Carminowe valley and enters the lake at the tip of the eastern arm of the lake, known as Carminowe Creek.

The bathymetry of Loe Pool is varied, with relatively shallow areas in the top reaches of the two arms that drop off rapidly to the deepest areas close to the bar (Figure 2). A current bathymetric survey indicates that depths reach > 6 m (Jan Dinsdale – *pers*. *comm*.). The banks of the lake vary dramatically in gradient with very steep sides along the western edge and parts of the eastern edge that is again reflected in the bathymetry. Areas of the immediate catchment are wooded with a variety of trees, whilst other areas are farmed. NT has opened up the lake to the public by managing footpaths that circumnavigate the entire waterbody, which has proved popular and these are now well used.

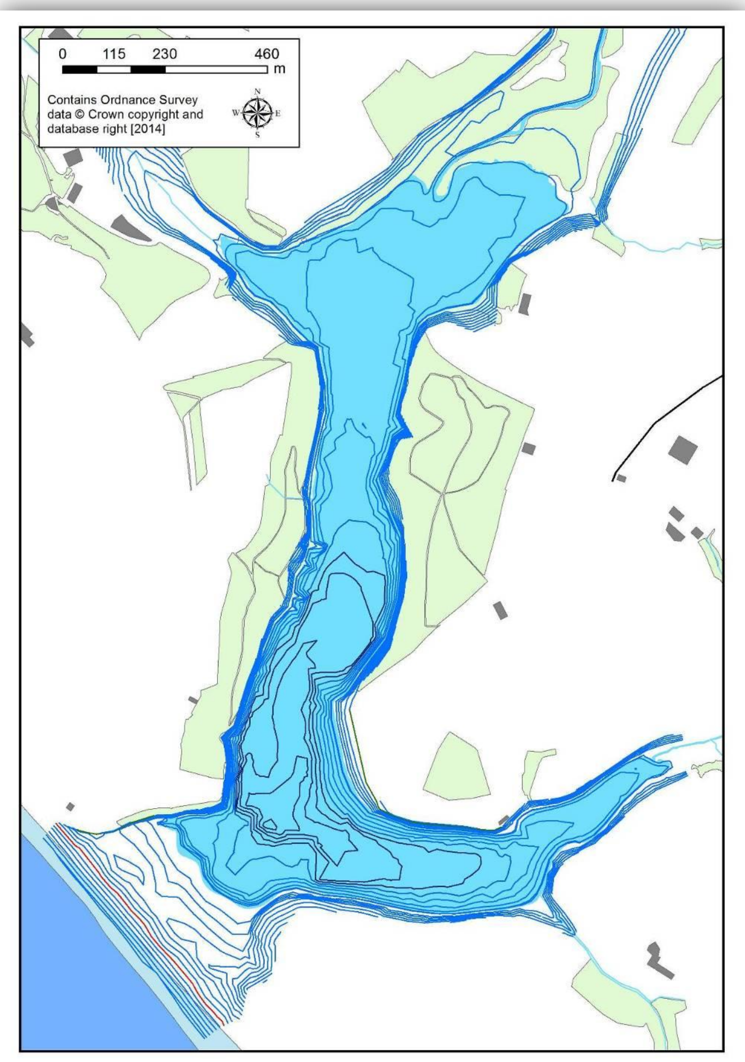

Figure 2. Bathymetric contours of Loe Pool (data supplied by National Trust).

1.3.2 Designations and current status

Loe Pool was designated as a SSSI, for its lake habitat which supported the following characteristic aquatic macrophytes six-stamened waterwort *Elatine hexandra*, perfoliate pondweed *Potamogeton perfoliatus*, shoreweed *Littorella uniflora*, horned pondweed *Zannichellia palustris* and amphibious bistort *Polygonum amphibium*. The area of carr woodland, containing grey willow *Salix cinerea* and common reed *Phragmites australis* was also part of the notification. Loe pools citation also refers to the Keeled Skimmer *Orthetrum coerulescens* dragonfly and numerous wintering birds (including almost 80 species of wildfowl) The latter are also a notified feature of the SSSI.

In addition to its designation as a SSSI, Loe Pool is within the South Coast Western section of the Cornwall Area of Outstanding Beauty (AONB) and a County Wildlife Site (CWS) (Dinsdale 2009). The bar is also part of the SSSI and is notified for its geomorphology, flora and fauna.

There was once an abundance of many of the macrophytes listed in the citation, however the occurrence of many of these species or any submerged vegetation is now rare (Dinsdale 2009). Advanced eutrophication is considered to affect Loe Pool (Geatches 1997, Wilson & Dinsdale 1998, Dinsdale 2003, Dinsdale 2009), a state resulting from increased nutrient inputs from the catchment. Historically, the lake suffered pollution by the many tin mines within the catchment, but since the cessation of mining in 1938, the sewered and non-sewered population of Helston has become the notable source of pollutants as nutrient input (Coard 1987, Wilson & Dinsdale 1998, Dinsdale 2009). The Royal Navy Air Squadron at Culdrose also discharges to Loe Pool via a Waste Water Treatment Works (WWTW) on the Carminowe and recent work has suggested that this accounted for over 20% of the nutrients entering the lake (http://www.keldawater.co.uk/our-operations/kws-defence/environmental-compliance. aspx). Farming practices around the lake also account for a proportion of the nutrient inputs through fertilizers (nitrogen, phosphorous and potassium) or slurry handling practices (Dinsdale 2009).

The process of eutrophication impacts on water quality and clarity, which has consequences on the biodiversity of the ecosystem. There is also evidence that associated toxic algal blooms have been common since 1968 and these have been circumstantially linked with fish kills (see Wilson & Dinsdale 1998), dog deaths and human illness (Geatches 1997). The latest Natural England' (NE hereafter) condition assessment conducted in 2011 classified the standing open water unit as 'unfavourable, no change'. This was due to the following reasons for failure:

- An impoverished characteristic flora with poor depth distribution;
- A loss (or significant decline) of characteristic species sine the 1986 SSSI citation;
- Total phosphate levels significantly exceeding the mesotrophic target, and
- Cyanobacterial blooms and past infestations of water net (*Hydrodiction*), *Elodea nuttallii* and 'cushion algae'.

The Water Framework Directive (WFD) assessment results presented in 2011 also suggested that the ecological and chemical status of Loe Pool was 'poor' and that of the River Cober was 'moderate' (Environment Agency 2011).

1.3.3 Current management strategy

In response to concerns of poor water quality and its effect on the ecological and recreational value, the Loe Pool Forum (LPF hereafter), originally the Loe Pool Management Forum was created in 1996. The LPF stakeholders include the NE, NT, Environment Agency (EA hereafter), Royal Navy, Kelda Water Services, Cornwall Council, andlocal universities.

In 1998, the Loe Pool Catchment Management Project (LPCMP hereafter) was produced (Wilson & Dinsdale 1998). The original plan identified the most important catchment level problem to be the eutrophication of Loe Pool, including the potential for toxic algal blooms and almost complete lack of submerged macrophytes. Major effluent inputs from Helston Sewage Treatment Works (STW) and Culdrose WWTW and agricultural runoff were identified as key causes of eutrophication.

This first management plan presented a catchment-based approach to the rehabilitation of Loe Pool SSSI. The management plan aimed for the rehabilitation of Loe Pool to a state that is ecologically stable, and one that the local community finds attractive. This was felt to incorporate clear water with a dense rooted-macrophyte community, supporting a good brown trout *Salmo trutta* population.

The management plan presented four key catchment objectives:

- ***Water Quality*.** To bring about a change from an algae-dominated turbid water state to a macrophyte-dominated clear water state, characteristic of mesotrophy;
- ***Water Levels.*** *To instate more natural seasonal fluctuations, in order to create conditions for a more diverse shoreline and submerged flora;*
- ***Nature Conservation*.** To maximise the nature conservation value of Loe Pool and its catchment; and
- ***Community Involvement.*** *To interest and involve the community in the management of Loe Pool and its catchment.*

The plan also described eight end targets for Loe Pool:

- Clear water, with a mean Secchi disc transparency (SDT) of 6 m to 3 m, and a minimum SDT of 3 m to 1.5 m;
- Mean annual total phosphorus concentration of 10 to 35 µg l^{-1};
- Mean annual chlorophyll *a* concentration of 2.5 µg l^{-1}, and max of 8 to 25 µg l^{-1};
- Eradication of Water Net (filamentous macro-algae);

- Macrophyte, rather than algae, dominated community, composed of a diverse range of species such as *Potamogeton natans*, *Ranunculus peltatus*, *Elatine hexandra* and charophytes, and a Trophic Ranking Score (TRS) of 5.5 to 7;
- Diverse assemblage of benthic macrophytes indicative of mesotrophic waters, such as Oligochaete species *Peloscolex ferox*, *Potamothrix moldaviensis* and *Nais elinguis*;
- Diverse community of shoreline plants, and;
- Healthy population of trout.

The lake rehabilitation programme was also divided into 3 steps: reduction of nutrient loading; biomanipulation and recovery of water plants. Dinsdale (2009) suggested that ongoing management should remain primarily focused on reducing sources of nutrient input within the catchment.

The objectives and targets have remained largely unchanged as the LPCMP has progressed. Sustainable flood management incorporated into the water level objective, and the target for a macrophyte-dominated status essentially incorporated the removal of Water Net, so thus was removed (Dinsdale 2009).

In relation to the existing strategy for fisheries management the National Trust has looked to maintain the wild brown trout fishery in Loe Pool, supported by natural spawning (Dinsdale 2009). In the most recent review of the Loe Pool Catchment Management Project, it was acknowledged that the emphasis of rehabilitation has gradually shifted from a sole focus on the reduction in point sources inputs of phosphorus to a more holistic approach and the potential benefits of biomanipulation of the lake's biotic structure was discussed. The conclusion of the report was that changes in the fish community structure due to reductions in water quality may have contributed to an imbalance between zooplankton and phytoplankton enhancing the potential for algal blooms (Dinsdale 2009). However, the need for further data to inform the decision making process was clear and previous management plans also identified the requirement for further surveys using both quantitative hydroacoustic and seine net surveys (to provide data on the species present). In addition, a fish gut content analysis study was proposed to inform potential biomanipulation strategies. Investigation of the quality of spawning habitat for brown trout in the Cober was also suggested as a potential research project. Both of these studies remain as outstanding objectives.

The NT has also considered the native brown trout population to be under pressure from angling and water pollution. Although it remains unclear how far the suggestions have been implemented, the NT suggested the following conservation measures for the species (see Wilson & Dinsdale 1998):

- Preventing angling in the spawning grounds of the Cober;
- Investigating ways of enhancing spawning grounds;

- Monitoring all catch records by liaising with current licence holders and restricting if necessary, and
- Preventing rainbow trout escaping into the Pool.

2 Review of fisheries information

This section provides a review of the existing fisheries information available to this project. NT records, EA records, peer reviewed literature, grey literature and local sources of information, including local experts and the anglers who fish Loe Pool, were consulted. Fish surveys of Loe Pool were conducted by the EA in 1998, 2006 and 2007 generally using seine nets but with the addition of acoustic surveys in 2007. The River Cober has been surveyed by the EA at 15 sites upstream of Helston, although only four sites have been surveyed since 2000, three of which were sampled in 2012. These river surveys only provide specific information on the status of the brown trout population rather than the entire fish community. Fish removals from sections of the Cober around Helston in relation to flood defence engineering works in 1998 and more recently in 2014 also provide some information on the fish community. The following section presents this EA data with permission (© Environment Agency and database right).

NT also provided catch return data collected as part of the ongoing management plan. Internet searches yielded little in the way of novel information that has not already been discussed within the existing management plans.

2.1 Historic fish community

Loe Pool is home to a native brown trout (see Appendix 1) population that has been well documented throughout history, although its taxonomy was once disputed. Some locals referred to the fish as land-locked sea trout (sea trout are the same species as brown trout, but migrate to sea principally for the increased resources). Others believed the population was a separate sub-species. In reality the fish in the Loe Pool catchment are brown trout. A decline in the brown trout population was noted during the twentieth and twenty-first centuries, with the population considered healthy until the 1970’s (see Wilson & Dinsdale 1998 for review). Anecdotal evidence presented by Wilson & Dinsdale (1998), suggests that in the 1970’s the fishery was healthy and brown trout were readily captured in the open water (three to five fish captured per hour effort) with fish averaging approximately one pound (lb) in weight. By the 1990’s, fish had increased in size to 1.5 to 2 lb in weight, however four or five hours were required to catch a single fish. This decline was attributed to the influxes of mine sediment and the practice of breaking the Loe Bar. However, the eutrophication of Loe Pool appears to be the main culprit and anglers have reported mortalities of up to 2,000 fish (mainly brown trout), during peak algal blooms since the late 1970’s. The NT has also suggested that heavy fishing of the River Cober during the spawning season may also have contributed to the decline (See Wilson & Dinsdale, 1998).

Rudd *Scardinius erythrophthalmus* have been present in Loe Pool and the Cober since the 1940's, having been introduced from Coronation Lake (the boating lake) in 1943. Perch *Perca fluviatilis* have been recorded in Loe Pool since 1994 and are thought to have colonised the lake after escaping from a coarse fishery upstream of Helston (Environment Agency 1998, Wilson & Dinsdale 1998). More recently, in 2006, roach *Rutilus rutilus* have been recorded in Loe Pool suggesting they have either been introduced deliberately or escaped from another water body. There have been no records of northern pike *Esox lucius*.

Along with the species found in Loe Pool, European eel *Anguilla anguilla* (eel hereafter), minnow *Phoxinus phoxinus* and three-spined stickleback *Gasterosteus aculeatus* have been recorded in the River Cober (Cornwall River Project http://www.cornwallriversproject.org.uk /education/ed_cd/background/cornish_rivers/b04j.htm) and therefore are also likely to occur in Loe Pool.

A summary of the ecology of the principal fish species of Loe Pool is provided in Appendix 1.

2.2 Fish surveys of Loe Pool

2.2.1 1998 survey

The first documented fish survey of Loe Pool was carried out on 29th and 30th October 1998. This survey was designed to provide a basis for an ongoing monitoring programme.

The survey of the lake used a 40 m seine net deployed from six shore sites around Loe Pool:

- Site 1 - Loe Bar
- Site 2 - Carminowe mouth
- Site 3 - Southern end of Degibna woods
- Site 4 - Pontoons (fishing groynes)
- Site 5 - Cober mouth
- Site 6 - Boat house

Fish were identified and measured with a representative set of scale samples being collected to produce age-length distributions. The survey captured perch (>372 individuals [ind.]), brown trout (70 ind.) and rudd (1 ind.) (Table 1). Assuming a sampling area of 300 m^2 per haul, the density of fish in the hauls ranged from 0 to 1.3 ind. m^{-2} (site 4), with the mean density for the whole lake calculated to be 0.25 ind. m^{-2}.

Table 1. Species and numbers of fish caught in the 1998 survey of Loe Pool. Reproduced from the report by the Environment Agency (1998).

Species	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Rudd	-	-	-	-	-	1
Brown trout	-	15	11	36	-	8
Perch	-	15	-	>350	-	7
Total	**-**	**30**	**11**	**>386**	**-**	**16**

2.2.2 2006 survey

In 2006, three hauls of a seine net were conducted at three locations on the 3rd October. All three hauls appeared to be taken in the area of the fishing groynes along the western margin, with site 1, Banjoree Beach, the furthest south. The survey recorded three species: brown trout, perch and roach , with the number of each species and the size range (fork length in mm) presented in Table 2. The area of water sampled by the seine net was not provided and therefore densities of each haul and a mean density from the lake as a whole cannot be calculated.

Table 2. Species and numbers of fish caught in the 2006 survey of Loe Pool. Length ranges in mm are shown in parentheses.

Species	Landing site 1	Landing site 2	Landing site 3	Total
Roach	-	1 (141)	-	1
Brown trout	-	-	1 (162)	1
Perch	6 (120-149)	-	133 (100-174)	139
Total	**6**	**1**	**134**	**141**

2.2.3 2007 surveys

In 2007, an acoustic survey was carried out by the EA, followed by a seine net survey to provide additional information on the relative abundance of the species present. Acoustic surveys are generally conducted at night, when most fish utilise the open water habitats, and in Loe Pool the acoustic survey was carried on the evening of 5th June along eleven transects (Figure 3). The results of this survey provided an estimate of the overall abundance and biomass of fish in the open water.

Figure 4 illustrates the results of the survey, which suggested that the highest densities of fish were to be found in the north of the lake and in the Carminowe Creek area of the lake. These areas correspond with the shallowest water depth, which likely represent the preferred habitat for more abundant smaller fish. A breakdown of the results from each transect adjusted to provide density and biomass estimates (ind. m^{-2} and g m^{-2}) is shown in Table 3. Densities varied between 0.036 and 0.001 ind. m^{-2} for abundance and biomass between 0.321 and 0.011 g m^{-2}. Interestingly, deeper areas supported the highest biomass estimates suggesting deeper waters supported the larger fish.

In addition to the acoustic survey, seine nets were hauled from three locations on 22nd June 2007, with Banjoree Beach being the only replicate from 2006. Carminowe Creek was sampled from the northern bank whereas Snaggy Bay corresponds to the area to the north of Loe Pool sampled from the western bank. The species present and the number of fish captured are presented in Table 4. As with information provided for 2006, no densities can be derived as the details of the seine net are not recorded. In contrast to the previous survey roach was the dominant species overall in numerical terms, with approximately twice the number of roach compared to perch and about twice the number of perch to brown trout (Table 4). The presence of rudd was confirmed by the capture of a single large individual in Snaggy Bay.

The length frequency data derived from the acoustic surveys suggested numerous length classes of fish were present, with the derived lengths ranging between 3 and 33 cm but centered on fish around 12 to 15 cm in length (Figure 5). The seine net data provided a more limited range of length classes constrained to smaller fish of 15 to 18 cm in length. Angler catch return length estimates from the same period provide similar lengths, although also suggests that larger fish are also present in the water.

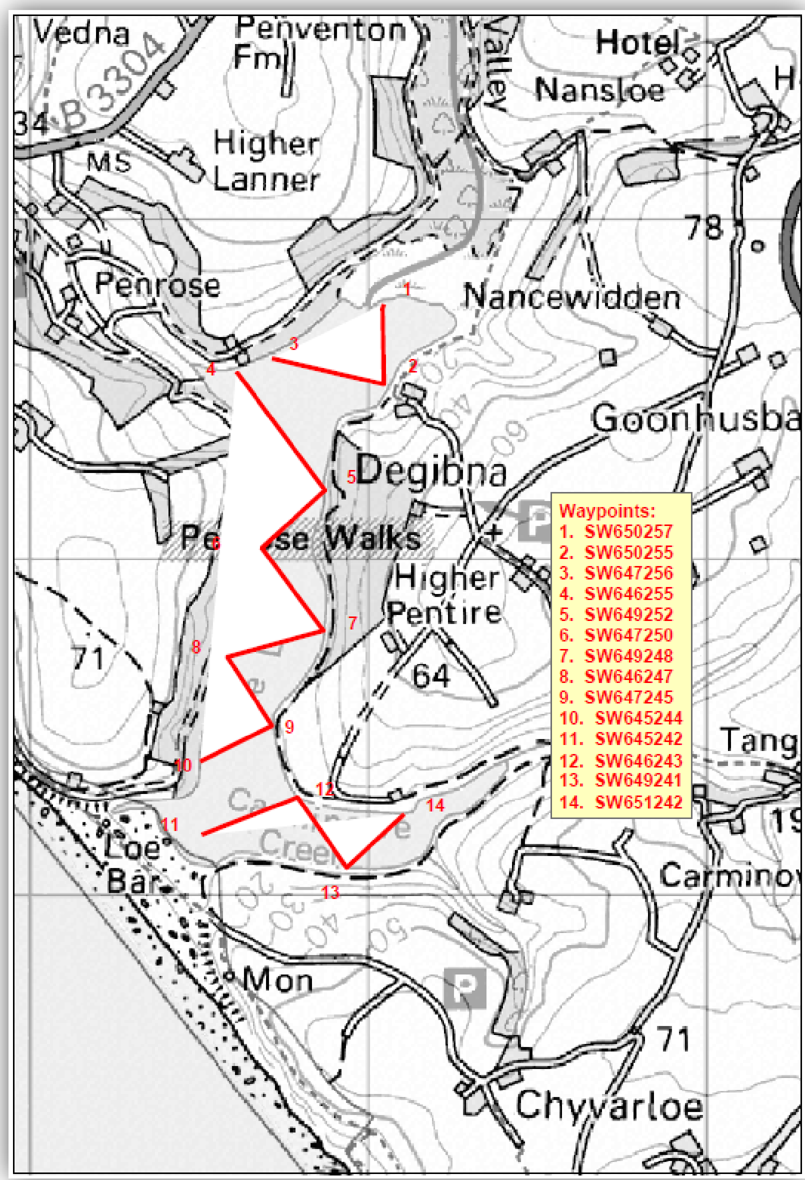

Figure 3. The locations of the transects surveyed by the Environment Agency using acoustic equipment. Note that densities are presented as per volume of water here.

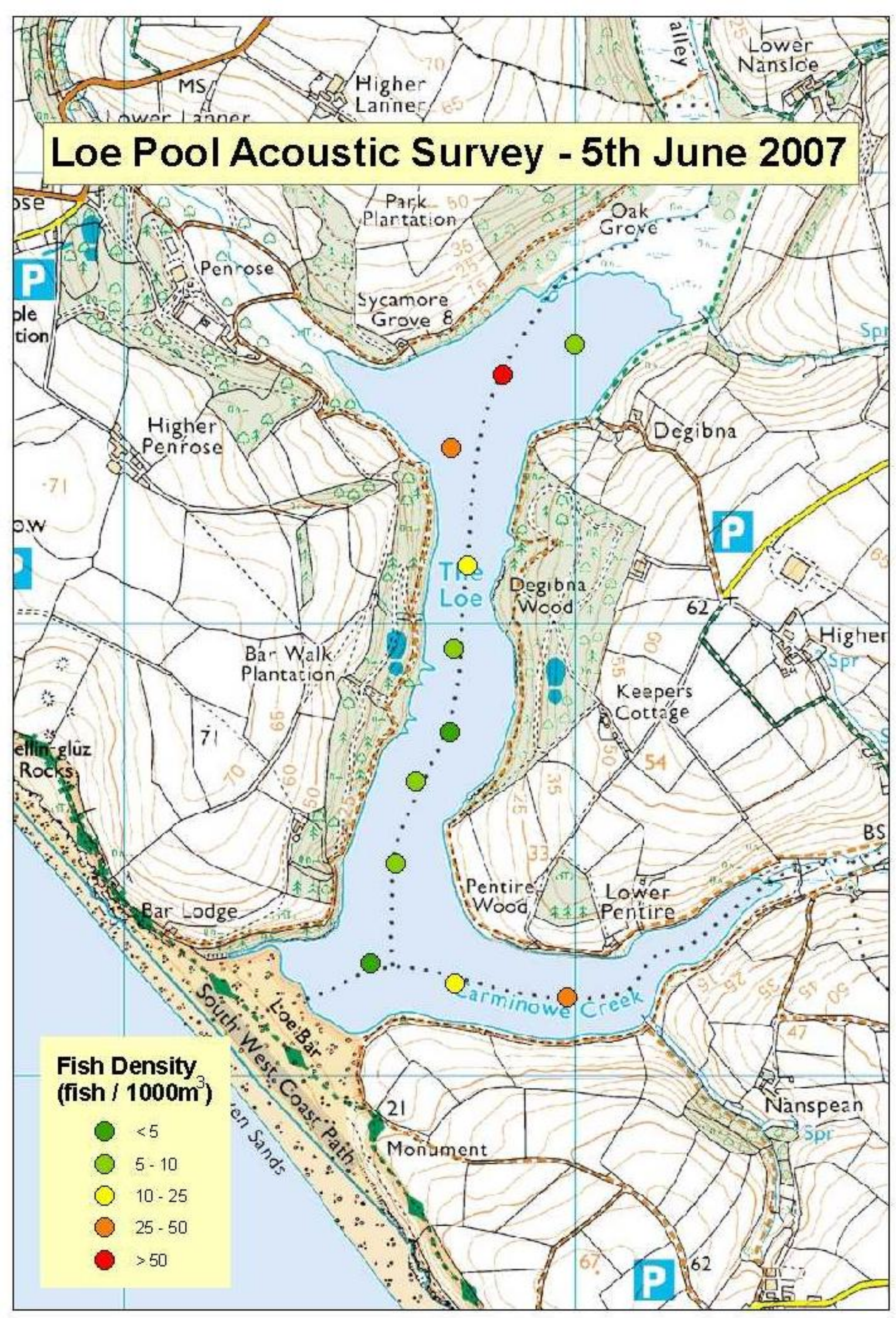

Figure 4. **An indication of the fish densities obtained from the surveys. Note that densities are presented as per volume of water (m^3).**

Table 3. **Density (ind. m^{-2}) and biomass (g m^{-2}) as derived from the 2007 acoustic survey of Loe Pool.**

Transect	Density (ind. m^{-2})	Biomass (g m^{-2})
1-2	0.006	0.011
2-3	**0.036**	0.150
3-4	0.020	0.162
4-5	0.008	0.024
5-6	0.006	0.030
6-7	0.002	0.051
7-8	0.003	0.014
8-9	0.003	0.134
9-10	0.001	0.217
11-12	0.012	0.088
12-13	0.017	0.321
13-14	0.006	0.011
Mean	**0.010**	**0.109**
Standard error	***0.003***	***0.030***

Table 4. **Numbers of fish caught in seine nets in surveys on 22nd June 2007. Length ranges are shown as fork lengths (mm) in parentheses.**

Species	Banjoree Beach (SW6459724716)	Carminowe Creek (SW 6518024294)	Snaggy Bay (SW6471525240)	Total
Roach	-	42 (125-189)	7 (158-172)	49
Rudd	-	-	1 (178)	1
Brown trout	2 (114-160)	7 (142-172)	-	9
Perch	-	16 (35-182)	7 (149-174)	23
Total	**2**	**65**	**15**	**82**

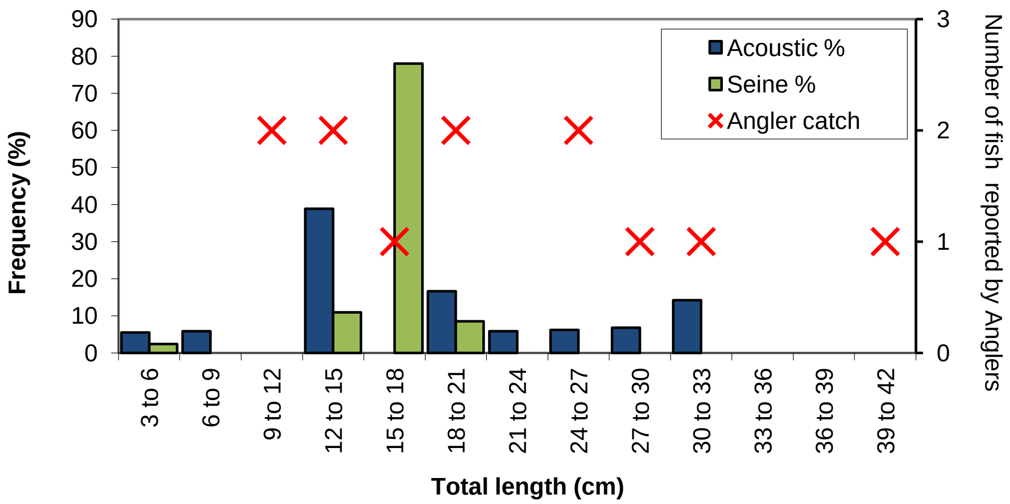

Figure 5. **Size frequency distribution of fish obtained from acoustic surveys, seine net surveys and angler catch returns in 2007.**

2.3 River Cober brown trout surveys

Between 1986 and 2012 (current extent of dataset) the EA conducted brown trout surveys at a total of 15 sites within the River Cober and its tributaries. Tables 5 and 6 provide the results of these surveys in relation to fry (0+) and parr (>0+) respectively. The National Rivers Authority (NRA – succeeded by the EA) National Fisheries Classification Scheme (NFCS) (NRA 1994) was used to classify the results of these surveys using the following categories:

➢ **A = Excellent:**	fry > 38 ind. 100 m^{-2}	parr > 21 ind. 100 m^{-2}
➢ **B = Good:**	fry = 17 - 37.9 ind. 100 m^{-2}	parr =12 - 20.9 ind. 100 m^{-2}
➢ **C = Fair:**	fry = 8 - 16.9 ind. 100 m^{-2}	parr = 5 - 11.9 ind. 100 m^{-2}
➢ **D = Poor:**	fry = 3 - 7.9 ind. 100 m^{-2}	parr = 2 - 4.9 ind. 100 m^{-2}
➢ **E = Very poor:**	fry < 3 ind. 100 m^{-2}	parr < 2 ind 100 m^{-2}
➢ **F = No fish present**		

The results of these surveys indicate that when records began both brown trout fry and parr were present in good or excellent (classes A and B) densities throughout the system (Tables 5 and 6). In 1986 only three sites of the 13 sampled were classed as poor or worse for fry, dropping to two sites out of 13 in 1992 (Table 5). In 1995, 11 sites were sampled, with two sites, albeit different ones, again being classed as poor or worse for fry (Table 5). The highest value of 174 brown trout fry per 100 m^2, was recorded in 1986 in a tributary of the Cober (Sithney Stream also known as the Mellangoose Stream) that joins the main river to the west of Helston (Table 5). This stream clearly acted as a nursery, with the two sites sampled consistently classified as 'A' with estimates of >50 per 100 m^2 recorded on every occasion. None of the sites received worse than a fair classification for parr between 1986 and 1995 (Table 6).

Sampling intensity then dropped significantly, with surveys seemingly only conducted at between one and three sites during the five monitoring years between 2004 and 2012. Only one site, the newly surveyed Boscadjack (SW 673 306) several kilometers north of Helston, has achieved 'A' classification for fry since 2004. Notably, in 2012 all three of the sites surveyed obtained 'E' or 'very poor' classifications for fry. However, the classifications for parr have generally remained reasonable, despite clear reductions in densities at some sites (e.g. St John's, on the western edge of Helston).

Table 5. Brown trout fry abundance estimates (ind. 100 m^{-2}) and NFCS classification (dark green= excellent, green = good, cream = fair, yellow = poor, orange = very poor and red = no fish present) derived from EA surveys at sites in the River Cober and associated tributaries.

Site	Grid reference	1986	1992	1995	2004	2005	2006	2008	2012
Burras	SW6802034730	94.6	19.3	158.5	-	-			
Porkellis Bridge	SW6881033300	10.3	14.4	-	-	-			
Poldark Mine	SW6841131577								1.0
Trenear	SW6827331474	22.8	54.0	6.2	16.5	-	10.1		
Boscodjack	SW6731630612	-	-	-	21.8	-	40.4		1.7
Coverack Bridges	SW6687030130	3.3	33.7	7.8	-	-			
Lower Town	SW6600029140	11.7	43.5	27.5	-	-			
St Johns	SW6548027980	17.8	66.4	37.4	-	27.1		23.3	1.8
Lower Nancelloe	SW6523026710	0.0	23.5	-	-	-			
Tolcarne	SW6887034750	23.4	22.4	39.5	-	-			
Lower Porkellis	SW6932032580	61.9	67.3	91.4	-	-			
Vellanewson	SW6659032680	78.3	9.5	8.3	-	-			
Lower Boscadjack	SW6718031560	52.9	58.1	19.6	-	-			
Sithney Green	SW6447029570	91.3	56.3	51.0	-	-			
Mellangoose	SW6472028980	173.7	93.8	157.6	-	-			

Table 6. Brown trout parr abundance estimates (ind. 100 m^{-2}) and NFCS classification (dark green= excellent, green = good, cream = fair, yellow = poor, orange = very poor and red = no fish present) derived from EA surveys at sites in the River Cober and associated tributaries.

Site	Grid reference	1986	1992	1995	2004	2005	2006	2008	2012
Burras	SW6802034730	84.2	96.4	46.5	-	-	-		
Porkellis Bridge	SW6881033300	59.4	58.4	-	-	-	-		
Poldark Mine	SW6841131577								11.4
Trenear	SW6827331474	56.3	51.8	19.2	28.3	-	22.0		
Boscodjack	SW6731630612				30.8	-	17.5		16.8
Coverack Bridges	SW6687030130	27.6	33.7	19.4	-	-	-		
Lower Town	SW6600029140	13.6	14.7	11.2	-	-	-		
St Johns	SW6548027980	16.5	15.0	24.5	-	11.6	-	4.3	13.7
Lower Nancelloe	SW6523026710	6.4	6.7	-	-	-	-		
Tolcarne	SW6887034750	60.7	83.6	65.9	-	-	-		
Lower Porkellis	SW6932032580	54.7	45.3	29.3	-	-	-		
Vellanewson	SW6659032680	110.7	45.2	82.8	-	-	-		
Lower Boscadjack	SW6718031560	27.1	24.4	41.1	-	-	-		
Sithney Green	SW6447029570	16.2	32.7	22.6	-	-	-		
Mellangoose	SW6472028980	6.5	16.5	6.5	-	-	-		

2.4 River Cober fish removals

2.4.1 1998 removal

A fish rescue was carried out on a stretch (1.3 km in length) of the River Cober on 30th June, prior to its dredging. The dredging was undertaken as part of essential flood defence works. This involved a single electric fishing run of the entire stretch, using two anodes and removing all fish captured. The report does not make clear whether fish were returned up or down stream of the section to be dredged. Brown trout, perch, eel and three-spined stickleback were the only species recorded and removed (Table 7). Brown trout were by far the most dominant species present, followed by perch, present in roughly half the numbers and eel, which were around half as abundant again.

Table 7. Species and numbers of fish caught and removed during the fish removal from the Cober in 1998 (Environment Agency 1998).

Species	Number
Brown trout	193
Perch	95
Eel	46
Stickleback	2
Total	**336**

2.4.2 2014 removal

The EA also conducted a fish rescue in the town section of the River Cober (adjacent to Coronation lake) on the 26th September 2014 due to scheduled dredging activity. A silt barrier (bund) was installed downstream of Coronation Lake and the A3304. Approximately 30 m of the river (and half the width of the river) was fished. In total, 19 brown trout fry, 15 brown trout parr and three eels were relocated downstream of the silt bund (EA, unpubl. data). Subsequent to the removals, but during the dredging works, it was noted that the silt bund had been compromised by the flow, allowing fish free passage upstream.

2.5 Anglers' catch returns

As part of the LPCMP, the NT became responsible for the management of the Loe Pool fishery in 1999. Amongst the new regulations introduced, the requirement of permit holders to submit annual catch records was reinstated (see Dinsdale 2003; Dinsdale 2009). Permits are also theoretically limited to residents of the old borough of Helston or Porthleven. Fishing of Loe Pool is only allowed from specific places on the bank using fly fishing tackle and wading is not permitted. The open season for fishing runs from 1st April to 30th September and a size limit of ten inches is stipulated for fish taken (Wilson & Dinsdale 1998).

Historic information from the 1970s suggested that between three and five brown trout were being caught per hour, whilst in the 1990s between four and five hours fishing effort was required to catch one trout (Wilson & Dinsdale 1998). The data from 2003-2008 implied that the decrease in abundance had continued, with one brown trout being caught only every 8.8 hours (Table 8). However, the data from 2009-2013 appears to show that the abundance may have increased since, with a brown trout being caught around every 2.6 hours of fishing.

The size range of the brown trout also appears to have decreased between the two periods, from between 100-400 mm in 2003-2008 to between 60-310 mm in 2009-2013. Notably, the presence of fish at 100 mm or 60 mm, likely first or second year fish, is perhaps surprising in the lake. The majority of fish caught by the licensed anglers using Loe Pool are returned, suggesting that angling has minimal effects on the trout population. The potential impacts of poaching are also likely to be relatively small but cannot be ruled out, although there is little information on the intensity of such activity at Loe Pool.

Catch returns suggest that the other fish species in Loe Pool have potentially increased in abundance, especially given that the anglers are specifically fishing for brown trout using targeted methods. Perch numbers particularly appear to have increased over the decade spanning 2003 and 2013, with the time taken to catch a fish dropping from 3.4 hours to 1.6 hours (Table 8). Roach have also appeared in the catch returns since 2009, although they became a feature of the seine net surveys in 2007 (see 2.1.3 above). The fact that roach are beginning to be caught by anglers using fly tackle is suggestive of high numbers of fish as, whilst perch might be expected to take a fly (especially a small fish imitation) more readily than a rudd or roach, rudd may be more likely to take a fly than roach, due to their surface feeding nature.

Table 8. Summary of catch return data for two periods (2003-2008 and 2009-2013). Numbers of fish (including number of hours to catch one fish in parentheses) and estimated length ranges of fish (mm) are shown.

Species	2003-2008		2009-2013	
	Number	Size range (mm)	Number	Size range (mm)
Brown trout	19 (8.8)	100-400	31 (2.6)	60-310
Roach	-	-	11 (7.3)	130-200
Rudd	26 (3.1)	170-260	37 (2.2)	100-280
Perch	49 (3.4)	130-470	103 (0.8)	60-380
Total	94 (1.8)	100-470	172 (0.4)	60-380
Fishing hours	**167.5**		**80.75**	

Interestingly, the total numbers of fish reported by anglers almost doubled between the two periods despite a halving of the numbers of reported fishing hours. If correct, this marks a substantial increase in the overall abundance of fish in Loe Pool over this time or changes in the tactics or fortunes of the anglers. However, further examination and scrutiny of raw catch return data for individual years may yield a better understanding of any trends and the quality of these data.

3 Fisheries survey

3.1 Aim

The aim of the fisheries survey was to gather information on the fish community of Loe Pool SSSI, including species composition, density and age structure, to provide a suitable baseline for future conservation management and to make recommendations for the conservation management of the fish community Sampling strategy

The original survey proposal incorporated the use of two sampling techniques, a survey of the Loe Pool littoral margin and open water using point abundance sampling by electric fishing (PASE) and a seine net survey conducted from shore focusing primarily on sampling the open water.

The use of two sampling techniques was felt to be necessary due to the size and nature of Loe Pool, i.e. up to 6 m in depth, in order to sample the lake sufficiently to meet the stated aims of the survey. The two techniques would provide two separate density estimates of Loe Pool, but would provide an overall species richness of the fish community of Loe Pool.

Budgetary restrictions, coupled with the hypothesis that early age class perch (and to a lesser extent cyprinid fish) were impacting on the condition of the SSSI lake, reduced the sampling strategy to just the single technique of PASE. Whilst the efficiency of the technique in sampling the open water is not considered to be as good as seine netting, particularly in deeper lakes, the information on the fish community, particularly the recruitment success of the key species (perch and rudd) derived from the littoral margin was considered sufficient for the success of the project. Due to the focus on the sampling of the littoral margin, the use of large Dutch style fyke nets fitted with otter guards, was added to the sampling strategy, with the aim of sampling larger specimens in the open water, providing additional qualitative information on the fish community.

Following discussions with Alastair Cameron (NT Loe Pool General Manager), Dr Jan Dinsdale (Independent Ecologist) and Dr Ruth Hall (NE Standing water Specialist), the survey was extended to the Loe Pool catchment, particularly the River Cober and potentially the Carminowe Stream. The discussions during the inception meeting revealed that the brown trout population spawned in the catchment rivers rather than in the lake itself and that there was good evidence that cyprinids, potentially from Loe Pool, formed large aggregations in the River Cober, during the late autumn period, corresponding to migration patterns to over-wintering habitats.

Surveying the wider catchment was therefore felt to be a key component of the project to give an indication of the recruitment of the brown trout population and potential migration of both salmonid and cyprinid fishes. The stretch of the Cober from Loe Pool to the area around Coronation Lake in Helston catchment was also to be sampled by PASE. The precise location(s) of the river to be sampled was to be determined in the field once access and the nature of the river could be assessed. Depth and the suitability of the river substrate would dictate whether the survey would be conducted from a boat or by wading, or both. The EA stipulated that all riverine sampling, as opposed to sampling within the lake itself had to be completed by 30th September.

On arrival at the River Cober, flood alleviation engineering works were being conducted in the Coronation Lake stretch of the river, which had also been subject to a fish removal by the EA (see 2.3.2 above). Therefore a stretch of the River Cober upstream of the engineering works was added to the sampling strategy (see 3.3.3 below).

3.2 Methods

3.2.1 Survey details and equipment

The survey of Loe Pool and the River Cober was conducted between 30th September and 2nd October 2014 by Mark Tomlinson and Dr Andrew Harwood of ECON. The electric fishing equipment used as detailed in Table 9, produces pulsed direct current (DC) and is powered by a 1 KVa generator. The anode used was equipped with a relatively large (380 mm) ring, which aims to reduce the danger zone close to the anode and thus potential fish mortality (Novotny 1990). The equipment induces effective galvanotaxis of fish towards the anode within its associated sphere of influence. Fish may react slightly differently to the anode, depending on size and species, but will generally move toward the anode with momentary incapacitation allowing them to be caught in a long-handled net. The area of the sphere of influence, and thus the sample area, was determined by the distance from the anode at which the voltage gradient decreases to 0.12 V, the minimum effective voltage at which inhibited swimming occurs (Copp & Peňáz 1988). This was determined to be at a distance of around 55 cm, equating to an area of influence of 1.72 m^2 in Loe Pool, and an area of 1.33 m^2 in the River Cober. Using this value simple density and biomass estimates may be calculated (see below).

Table 9. Details of the electric fishing equipment used for the PASE surveys of the Loe Pool catchment.

Unit	Input amps (A)	Frequency (Hz)	Output volts (V)	Area of influence (m^2)
Electracatch WFC3i	<1	50	c. 25	1.72 / 1.33

All fish caught were identified to species level, measured to the nearest mm (fork length) and any particular characteristics of individual fish noted including any ailments or obvious parasites. Weight estimates are calculated from length-weight regression relationships for each species compiled and held by ECON. The exception to this process is the capture of eels, where individuals are weighed and only an estimate of length is often possible.

3.2.2 Loe Pool surveys

The PASE survey of Loe Pool was conducted on the 1st and 2nd October 2014 from a 3 m fiberglass dinghy (Figure 6) with two operators, one controlling the boat by 'push-rowing' from the bow, keeping the electric fishing operator in sight at all times.

Figure 6. Dinghy used to conduct the PASE survey of Loe Pool.

Open water points were sampled systematically, approximately 15 m apart, along eight transects distributed to provide good coverage of most of Loe Pool, although no transects were carried out across the deepest area of the lake to the southwest (see Figure 7). Open water transects ran from one bank across to the opposite bank. The littoral margin was then sampled separately, with points taken approximately every 20 m, covering the entire margin. The number of points taken in each zone of the lake is presented in Table 10.

Table 10. Details of the habitats sampled by PASE within Loe Pool.

Habitat	Number of points sampled	Area (m^2)	Date sampled
Open water	63	534,510	1 - 2 October 2014
Littoral margin	182	28,490	1 - 2 October 2014

At each open water and littoral margin point the 2.5 m long anode was rapidly immersed and a lightweight, long handled net was swept through the point, thereby collecting stunned fish even if none were seen. All fish captured were processed as described in 3.3 above. The location of each point sampled was also logged using a hand-held global position system

(GPS) unit for later geographical analysis. In addition, macrophyte presence and a measure of turbidity by recording the depth to which the anode ring could be seen (i.e. an approximation of Secchi depth), were recorded during open water transects. At each littoral margin point, the width (available to fish) was estimated and emergent and /or overhanging vegetation within a 'visualised transect' was noted. All submerged and emergent vegetation was identified to species level where possible.

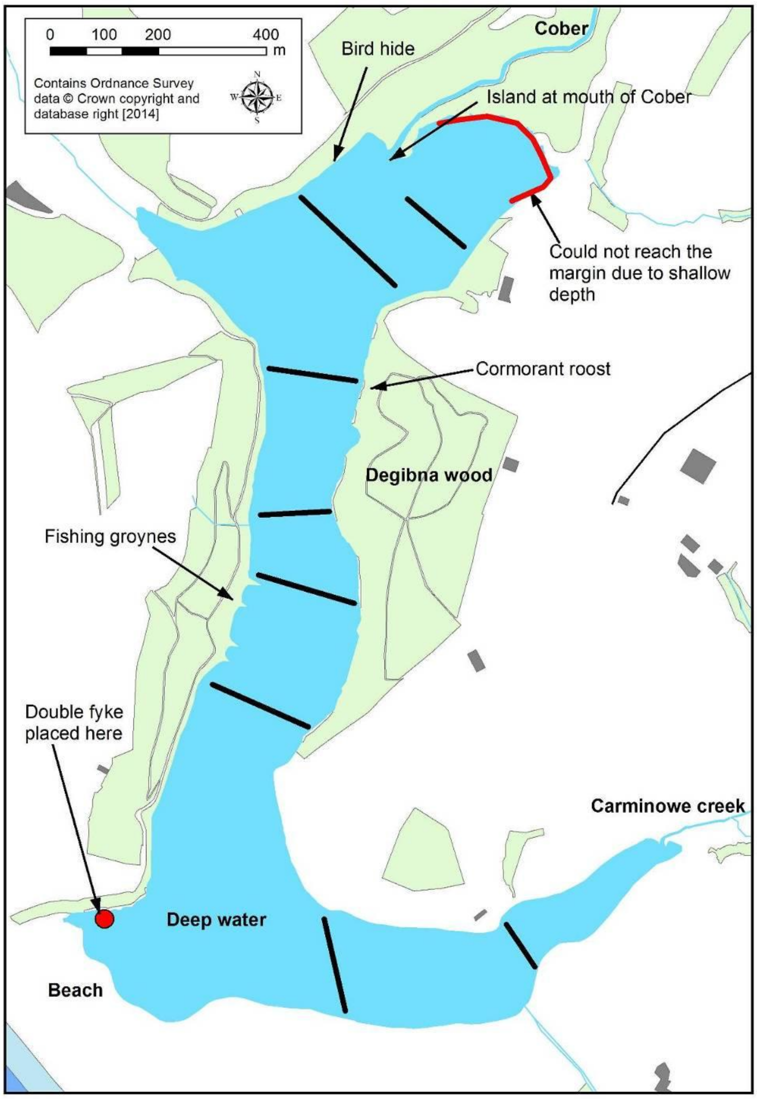

Figure 7. Location of the open water transect for the PASE survey of Loe Pool and position of fyke net.

Separate fish density estimates were calculated for both the open water and the littoral margin (total number or biomass of fish / the number of points / effective area). These were combined to provide an overall estimate for the whole lake by determining the relative size of each area (Table 10) and adjusting the figures accordingly. The overall estimate for thelake, by nature of the calculation, does not have a measure of variance associated with it. However, an indication of variance and thus confidence in the estimate is provided for each of the areas surveyed. The advantage of theoretically providing a better overall estimate was deemed to outweigh the disadvantage of the lack of an overall measure of error.

Whilst surveying the littoral margin and open water, all fish encountered outside of points (i.e. directly observed or through evidence of movement), were captured to increase the sample size used for length frequency distributions and provide a greater understanding of age class structure.

In addition to the PASE survey, a double fyke net was set on the evening of 1st October and checked and processed the following morning. The fyke net was set adjacent to the littoral margin, approximately 2 m into the open water. The location is shown in Figure 7.

3.2.3 River Cober surveys

Three sections of the River Cober were sampled by PASE on the 31st September 2014. Two sections were located downstream of Coronation Lake (Sites 2 and 3) with a section upstream of the boating lake (Site 1) running parallel to the northwest of Helston (Figure 8). The number of points sampled in each section is presented in Table 11.

Table 11. Location and physical details of the locations surveyed with associated timing and scale of sampling effort.

Site	Number of points sampled	Length (m)	Mean width (m)	Area (m^2)	Date sampled
1: Upstream of Coronation Lake	31	125	5	625	30 September
2: Downstream of Coronation Lake	44	850	6	5100	30 September
3: Immediately upstream of Loe Pool	5	60	4	240	30 September

Site 1 did not have sufficient water depth to be surveyed by boat. Therefore, the survey was conducted by wading with an anode with a long cable (100 m) attached to the equipment (Table 9) mounted on the bankside. The points were systematically selected (approximately 5 m apart), again moving diagonally from bank to bank upstream, with the points selected in the same manner as for the boat survey.

Sites 2 and 3 were surveyed from a 3 m fibreglass dinghy (see 3.3.1 above), with points systematically selected approximately 10 m apart. The survey was conducted in an upstream direction, zigzagging from bank to bank, with the number of points sampled in the margin determined by the average relative of the margin to that of the channel. In Site 2, the margin was estimated to equate to 1 m of the 6 m channel, therefore 1 in 6 points were sampled in the margin. Few points could be sampled in Site 3 as a result of the blockage of the channel by a fallen tree. Thereafter a number of fallen trees and debris dams were present.

At each point, the 2.5 m long anode was rapidly immersed and the lightweight, long handled net was swept downstream of the anode, thereby collecting stunned fish even if none were seen. At all sites all fish captured were processed as described in 3.3 above. Densities were calculated in the same way described for the habitats within Loe Pool (i.e. number of fish divided by number of points, divided by the effective area).

In addition to the fish, the composition of the river bed at each point was noted in terms of percentage of different components (e.g. cobble, stones, gravel, sand, silt and clay). The presence of leaf litter, woody debris, overhanging canopy or other habitat components were also recorded at each point.

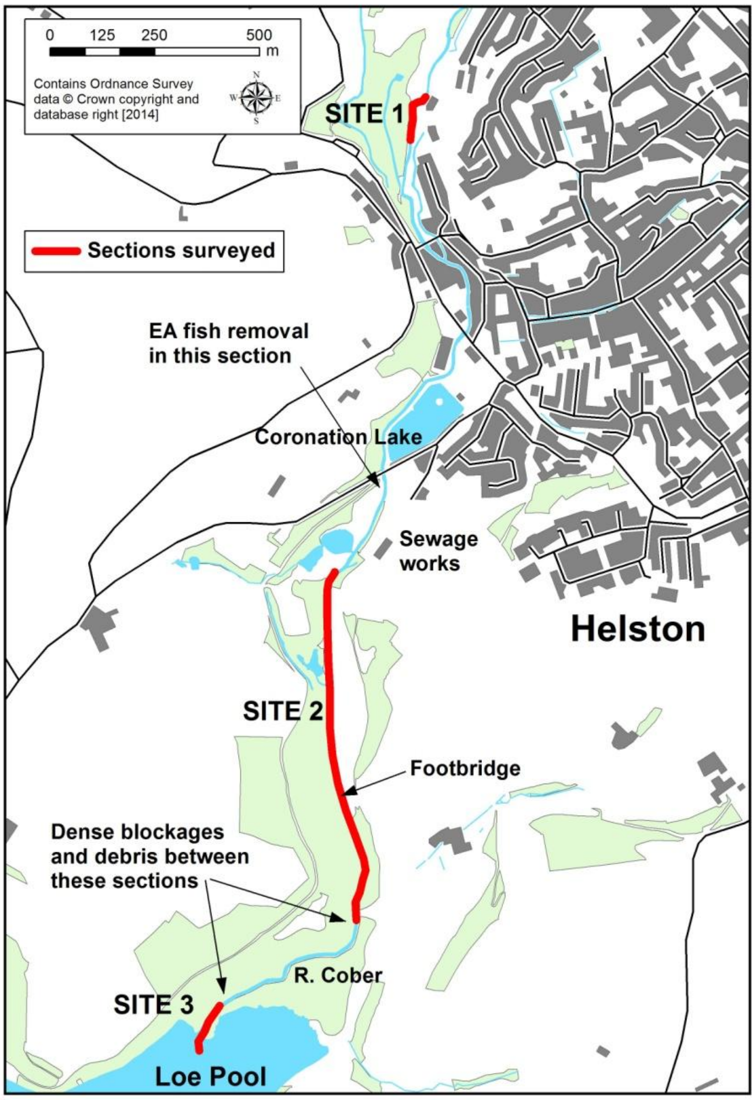

Figure 8. Location of the sections sampled by PASE for fish survey of the River Cober.

3.2.4 Data analysis

Survey effort was briefly assessed using species accumulation curves and examination of variations in mean density estimates (with associated standard errors) based on increasing numbers of points for each area surveyed (i.e. Loe Pool littoral and limnetic regions and sections of the River Cober above and below Helston). The results of these analyses are presented in Appendix 2.

In addition to the calculation of fish densities (abundance and biomass), spatial variation in the abundance and biomass of fish in Loe Pool derived from the PASE surveys are mapped in ESRI ArcGIS v10.1 (GIS) to identify any clear trends in distribution.

Habitat characteristics for the River Cober and Loe Pool and the spatial variation in the type and depth of margin around Loe Pool were also mapped in GIS.

Length frequency histograms, for Loe Pool and the River Cober (and combined) were produced to identify likely age class structures for key fish species.

In regard to fish condition, a non parametric two-sample Kolmogorov-Smirnov test was used to assess whether there was a potential significant difference in length distributions (and therefore growth) of roach (1+ or older which were larger than 100 mm) pooled from both the Cober and Loe Pool with and without obvious infections (characterised by an over-distended abdomen).

3.3 Results

3.3.1 Loe Pool

3.3.1.1 Habitat characteristics

The PASE survey of Loe Pool estimated a range in the width of the littoral margin available to fish of between 0-20 m (a fallen tree), with a mean width of 4.4 m. The littoral margin was categorised into six main habitats: reed bed, lily bed, tree, beach, rocky shore and bedrock. The extensive reed beds were primarily comprised of common reed, although a small section of great bulrush *Schoenoplectus tabernaemontani* and sedges *Carex* spp. and rushes *Juncus* spp. were also recorded (Figures 9 & 10). Whilst not recorded at a point, greater reedmace *Typha latifolia* was observed at the mouth of the River Cober.

After common reed, trees formed the next most abundant habitat (Figures 9 & 10), through cover being provided by either branches immediately overhanging the water or branches and more commonly fallen trees providing habitat in the water column. Large areas of lilies, believed to be white water lily *Nymphaea alba*, were recorded between the fishing groynes on the western edge of the main lake (Figure 9). The fishing groynes were similar to the bare bedrock that was present on both sides of the ‘valley’. Bare sand, or beach was recorded along the Loe Bar (Figure 9).

No submerged macrophytes were recorded in open points sampled during the PASE survey of Loe Pool. Turbidity varied throughout the lake, with estimates of the Secchi depth (using the anode ring) ranging from 50 to 80 cm, best described as indicating moderate water clarity.

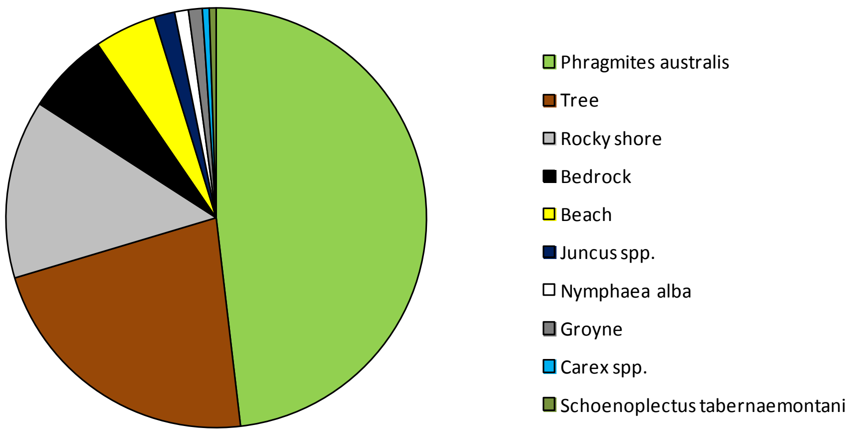

Figure 9. Composition of the littoral margin as derived from the PASE survey of Loe Pool.

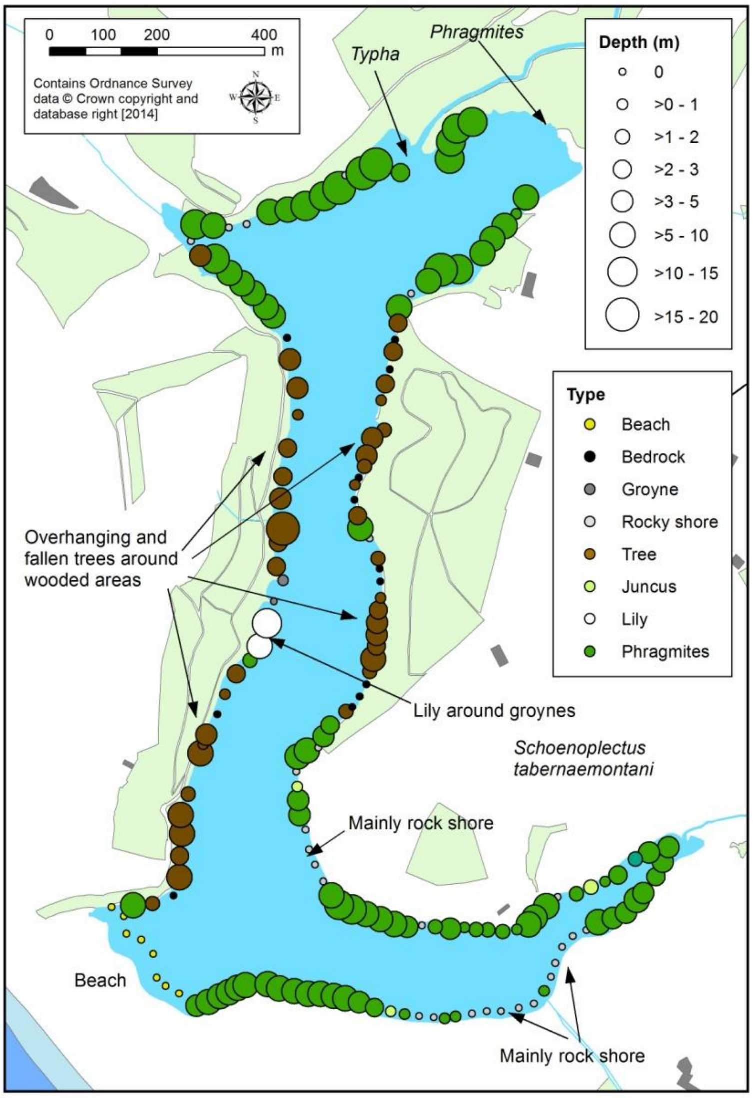

Figure 10. Variation in the type and width of margin present around Loe Pool.

3.3.1.2 Fish

Five species of fish were captured in the PASE survey of Loe Pool. In order of abundance these were, roach (372 ind.), perch (30 ind.), rudd (12 ind.), eel (3 ind.) and a single three-spined stickleback (Table 12). This resulted in overall abundance and biomass estimates for Loe Pool of 0.15 ind. m^{-2} and 3.98 g m^{-2} (Table 13). This is equivalent to 1,500 ind. ha^{-1} and 39.8 kg ha^{-1}, which suggests a minimum whole lake population (based in 56.3 ha) of around 84,000 fish and biomass of 2,241 kg.

Table 12. Total numbers of fish captured by the various techniques used in Loe Pool. Minimum and maximum fork lengths (mm) of fish are shown in parentheses.

Species	PASE - littoral margin	PASE - open water	Fyke	Free electric fishing	Total
Roach	364 (53-176)	8 (109-140)	1 (126)	56 (104-155)	429
Perch	29 (86-153)	1 (142)	3 (86-154)	12 (119-142)	45
Rudd	12 (27-71)	-	-	1 (42)	13
Eel	3 (550-700)	-	-	3 (350-500)	6
Three-spined stickleback	1 (27)	-	-	-	1
Total	439	9	4	72	494

Table 13. Mean (± 1 standard error [SE]) abundance (ind. m^{-2}) and biomass (g m^{-2}) estimates for all fish species captured in the PASE survey of Loe Pool. Standard errors associated with the estimates are shown in italics.

Species	Open water		Littoral margin		Overall	
	ind. m^{-2}	g m^{-2}	ind. m^{-2}	g m^{-2}	ind. m^{-2}	g m^{-2}
Eel	-	-	0.010	6.196	0.000	0.314
	-	-	*0.006*	*3.820*		
Roach	0.074	2.167	1.258	20.311	0.134	3.085
	0.057	*1.608*	*0.225*	*2.859*		
Rudd	-	-	0.038	0.070	0.002	0.004
	-	-	*0.024*	*0.046*		
Three-spined stickleback	-	-	0.003	0.001	0.000	0.000
	-	-	*0.003*	*0.001*		
Perch	0.009	0.368	0.093	2.721	0.013	0.487
	0.009	*0.368*	*0.020*	*0.642*		
Overall	0.083	2.535	1.402	31.050	0.150	3.978
	0.066	*1.964*	*0.228*	*4.862*		

The majority of the fish captured were present within the littoral margin (Figures 11 & 12), with fish present at 56% of the points sampled. The habitat was estimated to support a density of 1.5 ind. m^{-2} (Table 13) equivalent to c. 40,000 fish. The spatial variation in fish abundance shown in Figure 11 is mainly reflective of the roach distribution and it is clear that the species was more abundant in the reed beds (Figure 10). The spatial variation in fish biomass also reflected this trend although the mismatch between biomass and density illustrates variations in the age classes present and in some cases, the presence of large eels (Figure 12).

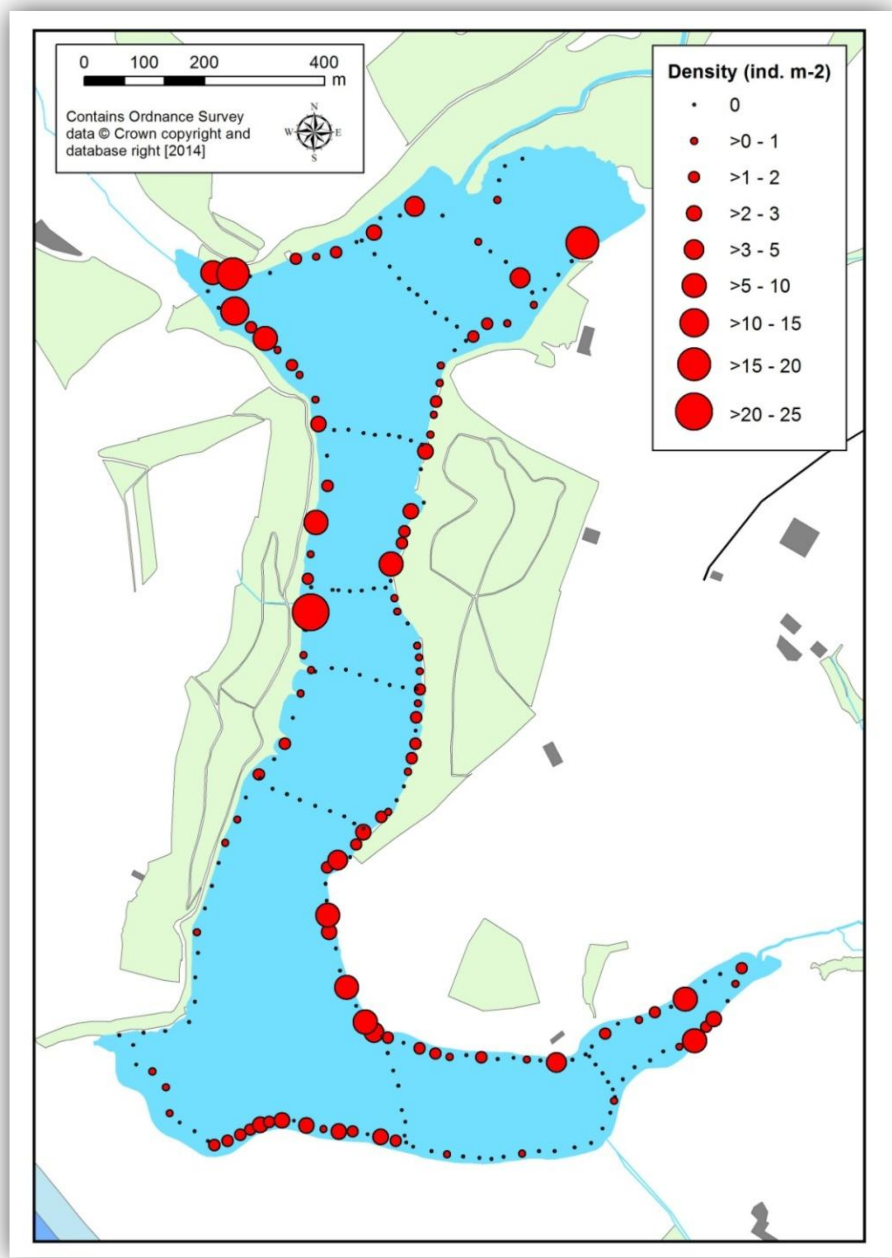

Figure 11. Spatial variation in overall density (ind. m^{-2}) estimates derived from points surveyed in Loe Pool.

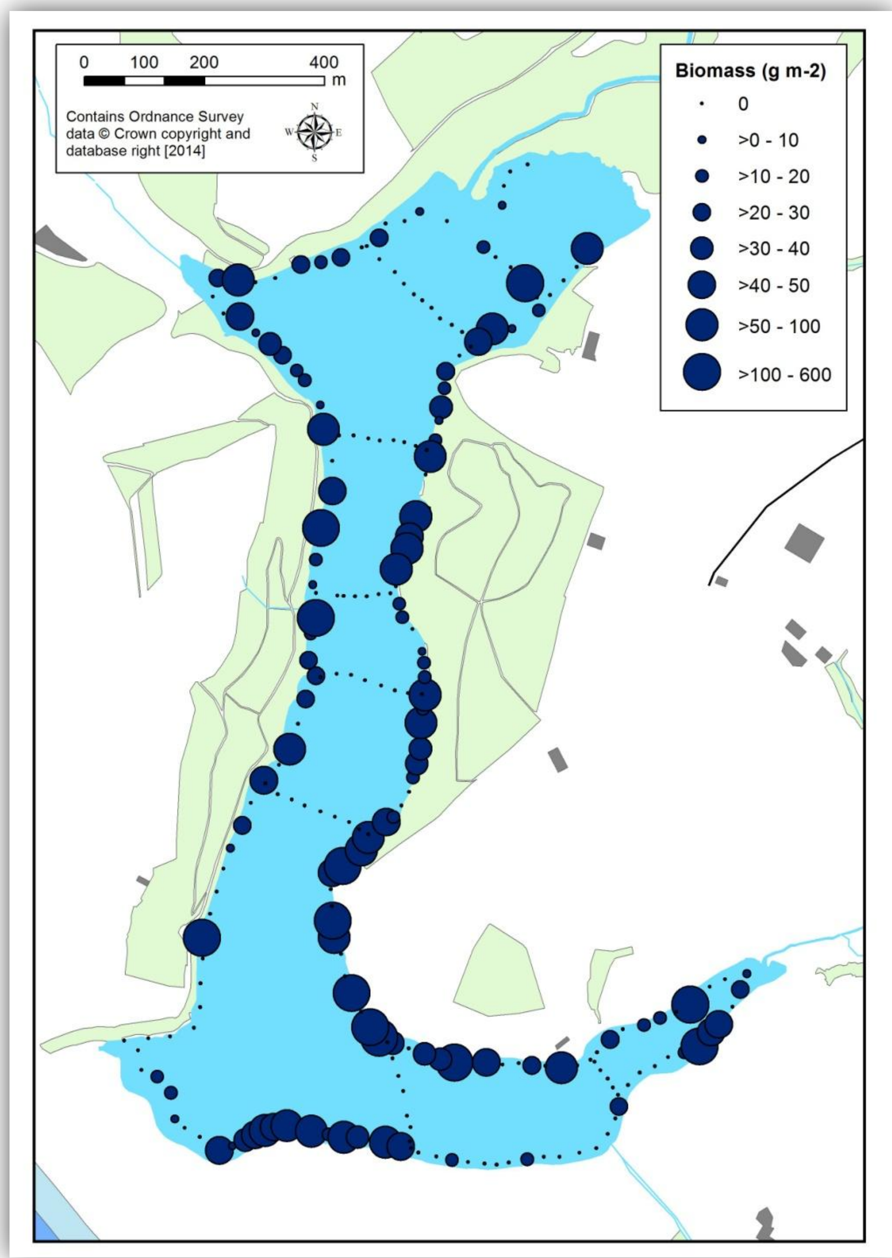

Figure 12. Spatial variation in overall biomass (g m^{-2}) estimates derived from points surveyed in Loe Pool.

Roach were the dominant species overall by both number (0.13 ind. m^{-2}) and biomass (3.1 g m^{-2}) (Table 12). The species was most abundant in the littoral margin (1.3 ind. m^{-2}) but was also captured in the open water in the shallow northern bay of the lake producing an abundance estimate of 0.07 ind. m^{-2} in open water (Table 12, Figure 11).

The roach captured within Loe Pool, incorporating all techniques employed, ranged from 53 to 176 mm in fork length (Figure 13). Likely young-of-the-year (YOY) fish ranged from 53 to

79 mm, representing 37% of the total roach catch. The dominant age class within the lake was the fish considered to be 1+ (hatched in 2013), which ranged from 100 to 145 mm in fork length. Larger fish (149 to 176 mm) were also captured and potentially could represent 2+ fish (hatched 2012).

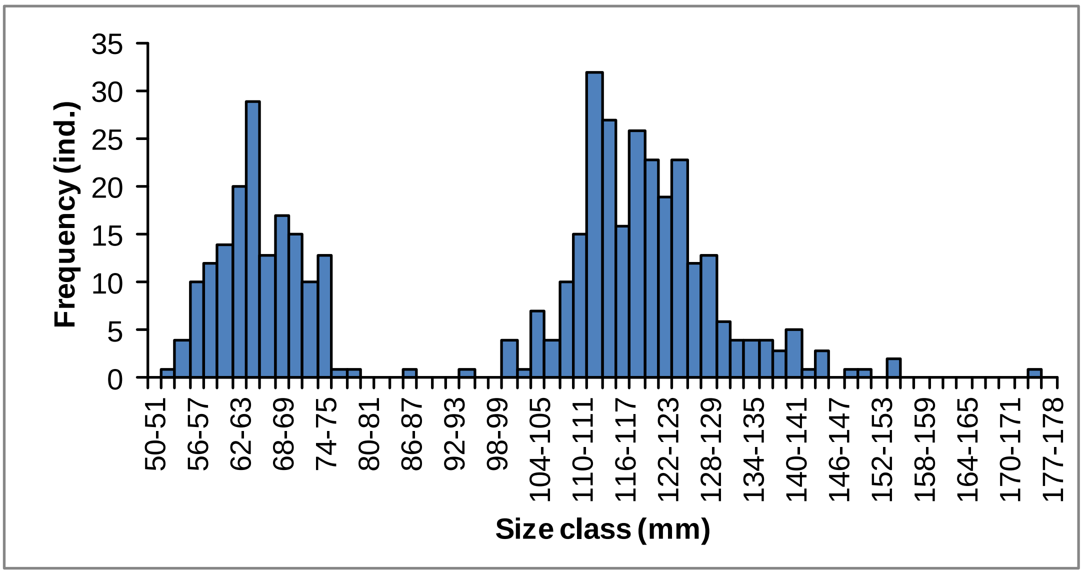

Figure 13. Length-frequency distribution for all roach captured in Loe Pool (*n*=429).

Some of the roach from the 1+ age class had markedly distended abdomens (Figure 14), which is often characteristic of a parasitic infection (likely to be *Ligula intestinalis*) although a health check would need to be performed to confirm this.

Figure 14. Roach with distended abdomen illustrating potential infection of the parasite *Ligula intestinalis*.

Within Loe Pool, perch were the next dominant species with estimated overall numerical and biomass densities of 0.01 ind. m^{-2} and 0.49 g m^{-2} respectively (Table 13). As with roach, perch were more abundant in the littoral margin (0.09 ind. m^{-2}) but were also encountered in the shallow open water in the northern area of the lake. The fish captured ranged from 86 to 154 mm in fork length. These fish most probably represent two age classes: YOY from 86 to 93 mm and 1+ fish from 115 to 154 mm in fork length (Figure 15).

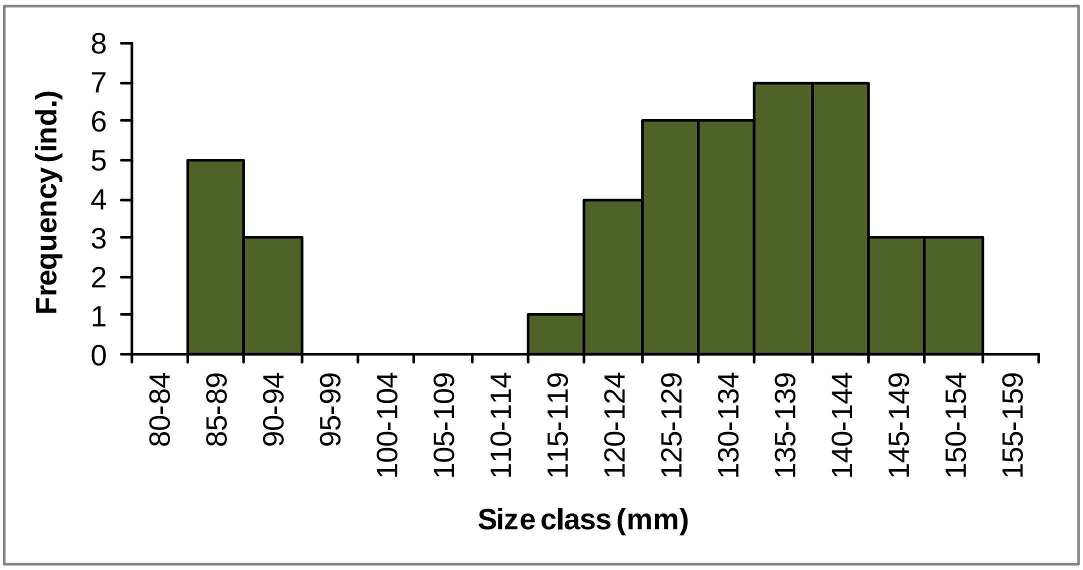

Figure 15. Length-frequency distribution for all perch captured in Loe Pool (*n*=45).

Due to the size of the individuals captured in the PASE survey, eel contributed a similar proportion to the fish community of Loe Pool by biomass. The estimated biomass for eel was calculated to be 0.31 g m^{-2} (Table 13), with individual fish ranging from 120 g to 1 kg (derived from all methods). Based on the size range of these eels, all fish are considered to be mature pre-spawners, with females comprising the largest fish captured.

Rudd was only encountered in the littoral margin, resulting in an overall abundance estimate of 0.002 ind. m^{-2} (Tables 12 & 13). Two age classes were captured: YOY fish ranging from 27 to 44 mm and most probably two 1+ fish at 70 and 71 mm in fork length (Table 12).

The single three-spined stickleback (27 mm) captured in the PASE survey resulted in an abundance estimate of just 0.0002 ind. m^{-2} (Table 12 & 13).

3.3.2 River Cober

3.3.2.1 Habitat characteristics

Five substrate categories were recorded at site 1: cobble (15.6%), stone (31.5%), gravel (34.8%), sand (9.0%) and silt (9.0%) (Figure 16). No macrophytes were recorded in the channel, although moss was recorded at four points (5.9% cover). Due to the wooded riparian zone, leaf litter (4.7% cover), coarse woody debris (3.3% cover) and tree root (1.9% cover) provided instream habitat. Whilst the river level was also obviously low at the time of the survey (mean depth of approximately 15 cm) the steeply cut banks, often over 0.5 m above the current river level, hinted at the volume of water that can pass down the channel under certain conditions.

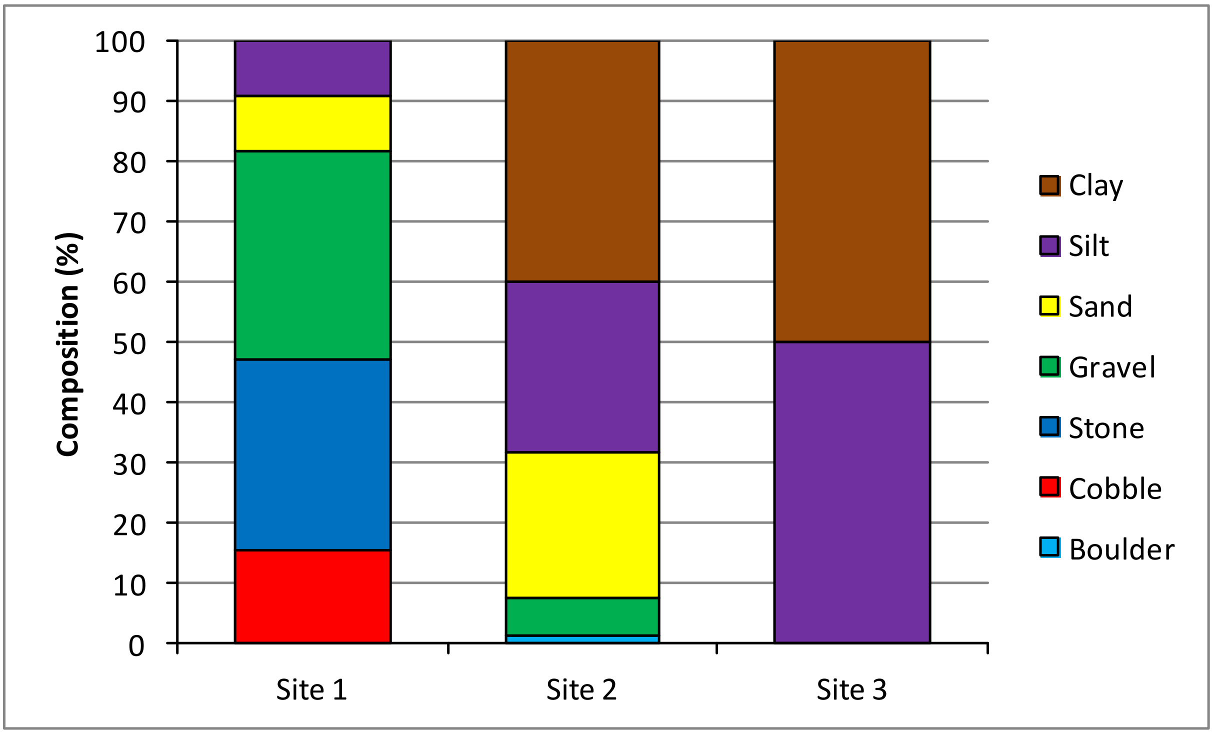

Figure 16. Mean composition of substrate variables at the three sites sampled by PASE on the River Cober.

Five substrate categories were also recorded at Site 2 of the River Cober, which covered a large section downstream of Helston. The substrates were boulder (1.4%), gravel (6.3%), sand (24.0%), silt (28.5%) and clay (39.8%) (Figure 16). The prominence of silt and clay are a result of the impounded nature of the lower reaches of the sampled stretch (below the footbridge – see Figure 8). Fallen trees or overhanging branches prevented the section being sampled in entirety. Most of the instream habitat was leaf litter and coarse woody due to the high cover by riparian trees (canopy cover was 30% in this section). Above the footbridge, moving towards Helston, the river bed changed as the channel narrowed and flows increased becoming more uniform with more sand/gravel substrate. Macrophytes were recorded in the channel above the footbridge with emergent vegetation (possibly reed sweetgrass *Glyceria* spp.) acting as a submerged macrophyte, with greater duckweed *Lemna major*, present in some points recorded in the edge of the channel.

Only silt (50%) and clay (50%) were recorded in site 3 in the final section of the Cober before the river discharges into Loe Pool (Figure 16). The substrate recorded was characteristic of the lower flows and deep pools were present near the mouth (>1 m deep) of the river.

3.3.2.2 Fish

Two species were captured in the PASE survey of site 1: brown trout and eel (Table 14). A perch was also captured whilst free electric fishing a pool (Table 14). With fish present at 19.4% of the points sampled, a mean (±1SE) abundance of 0.27 ± 0.13 ind. m^{-2} was estimated (Table 15).

Table 14. Total numbers of fish caught during the PASE surveys. Minimum and maximum fork lengths (mm) of fish are shown in parentheses.

Species	Site 1	Site 2	Site 3	Free electric fishing	Total
Eel	1 (~200)	-			**1**
Roach	-	43 (95-154)			**43**
Brown trout	10 (119-261)	5 (75-250)	1 (200)	3 (131-210)	**19**
Three-spined stickleback	-	2 (35-40)			**2**
Perch	-	3 (133-145)		1 (115)	**4**
Total	**11**	**53**	**1**	**4**	**69**

Table 15. Mean (±1SE) abundance (ind. m^{-2}) and biomass (g m^{-2}) estimates for all fish species captured in the PASE survey of the River Cober. Standard errors associated with the estimates are shown in italics.

Species	Site 1		Site 2		Site 3		Overall	
	ind. m^{-2}	g m^{-2}	ind. m^{-2}	g m^{-2}	ind. m^{-2}	g m^{-2}	ind. m^{-2}	g m^{-2}
Eel	0.024	0.728					0.009	0.282
	0.024	*0.728*					*0.009*	*0.282*
Roach			0.735	21.338			0.404	11.736
			0.187	*5.736*			*0.110*	*3.358*
Brown trout	0.243	14.255	0.085	5.912	0.116	11.420	0.150	9.698
	0.132	*10.310*	*0.036*	*3.669*	*0.116*	*11.420*	*0.063*	*5.119*
Three-spined stickleback			0.034	0.030			0.019	0.016
			0.024	*0.021*			*0.013*	*0.012*
Perch			0.051	1.910			0.028	1.051
			0.029	*1.084*			*0.016*	*0.603*
Overall	0.267	14.983	0.906	29.190	0.116	11.420	0.611	22.783
	0.133	*10.302*	*0.199*	*7.958*	*0.116*	*11.420*	*0.140*	*6.803*

At site 2, fish were present at 47.7% of points sampled. Four species were represented in the following order of abundance: roach, brown trout, perch and three-spined stickleback (Table

14). The overall abundance and biomass estimates for the site was calculated to be 0.91 ± 0.20 ind.m^{-2} and 29.20 ± 7.96 g m^{-2} respectively (Table 15).

A single brown trout was captured in the mouth of the River Cober (site 3), resulting in an abundance estimate of 0.12 ± 0.12 ind. m^{-2} (Table 15).

For the length of the River Cober sampled by PASE, the overall density estimates were calculated to be 0.61 ± 0.14) ind. m^{-2} and 22.78 ± 6.80 g m^{-2} (Table 15).

Roach was the dominant species by both number and biomass in the surveyed stretches of the River Cober, although all fish were captured in the mid section of the sites sampled (Tables 14 & 15). The fish ranged from 95 to 154 mm in fork length (Table 14, Figure 17). These fish could represent two age classes, with 1+ fish reaching 144 mm and the 154 mm fish potentially a 2+ specimen. No YOY fish were captured in the PASE survey, nor were any observed or captured gratuitously. It is also worthy of note that a proportion of the roach captured had swollen abdomens as was the case for those in Loe Pool.

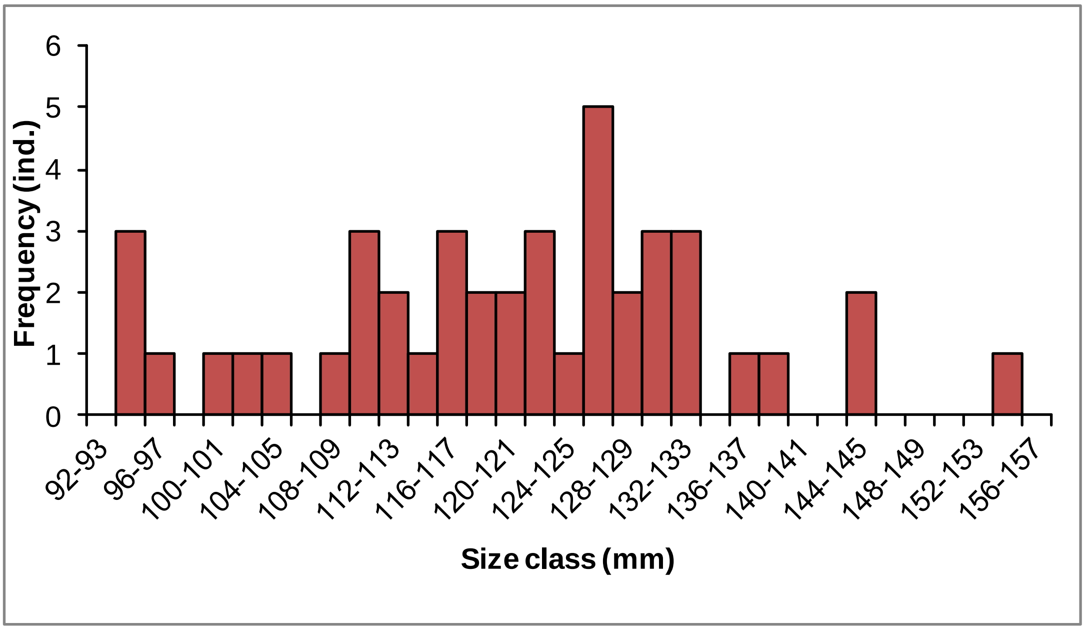

Figure 17. Length-frequency distribution for all roach captured in the River Cober (*n*=43).

Brown trout were the only species to be captured in the three sites sampled by the PASE surveys. Using all fish captured (including gratuitous catches), brown trout ranged from 75 to 261 mm in fork length (Table 14, Figure 18). Insufficient numbers were captured to confidently assign each fish to age categories although two fish at 75 and 93 mm were likely to be YOY specimens, with 1+ fish ranging from 119 to 143 mm in fork length. Fish between 172-218 mm and 250-261 mm respectively could represent two further age classes.

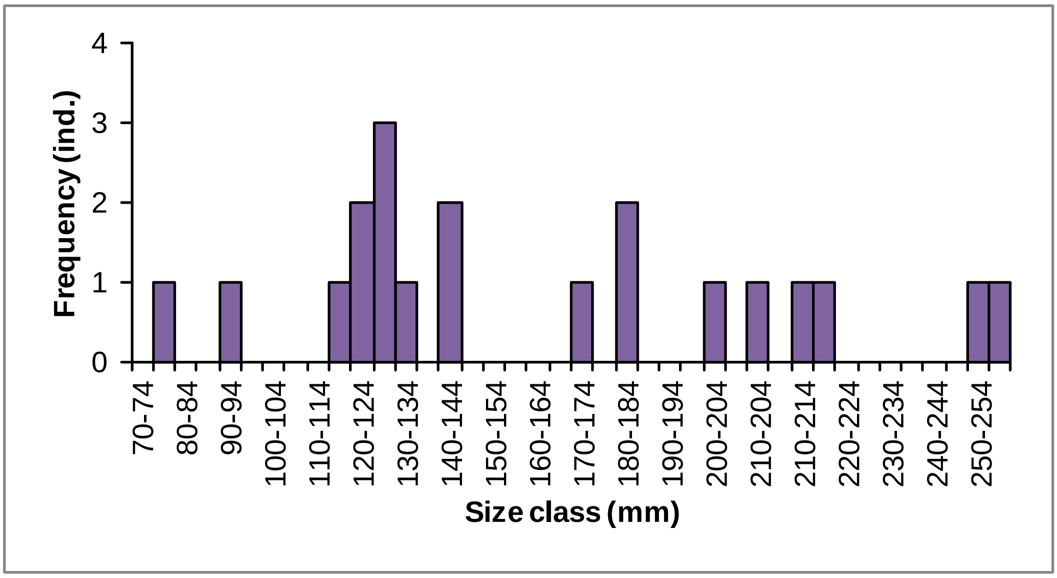

Figure 18. Length-frequency distribution for all brown trout captured in the River Cober (*n*=19).

The majority (75%) of the brown trout captured at site 1 were considered to be 1+ fish (119 - 143 mm), with the largest brown trout captured (261 mm) also captured at this site. In contrast, no 1+ fish were captured at site 2, with the YOY and potentially 2+ and 3+ (172 to 250 mm) fish present. Both the fish captured in the lowest section of the Cober were in excess of 200 mm fork length.

Using the NFCS (NRA 1994) to assess the quality of the sites for brown trout abundance, only site 2 could be classified for level one 0+ (or YOY) brown trout abundance as a 'D' or 'poor' (3 to 8 ind. 100 m^{-2}). In contrast, site 1 for level one >0+ brown trout abundance would achieve a classification of 'A' or 'excellent' (> 21 ind. 100 m^{-2}) with an estimate of 24 ind. 100 m^{-2}. Combining all three sites, the River Cober would be classified as 'B' (12 to 21 ind. 100 m^{-2}) for >0+ brown trout abundance, with an estimate of 13 ind. 100 m^{-2}.

The perch caught in the river ranged between 115 and 145 mm in fork length and probably represented 1+ fish. The single eel caught at site 1, was approximately 200 mm in length and weighed approximately 30 g. This represents a young fish, with its sex yet to be determined.

3.3.3 Fish condition

With respect to fish health, a proportion of the dominant species in the catchment, roach, had distended abdomens and it is thought that this is likely to be symptomatic of a gut parasite infection. It is worthy of note that only 1+ fish appeared to be affected. Around 8% of the roach caught in the Cober and open water points of Loe Pool appeared to be showing obvious symptoms of infection (Table 16). Over 16% of the fish from the littoral margin showed strong symptoms although further free electric fishing around the groynes and beach yielded a much higher proportion of roach with clear symptoms (36%). Overall, 19% of roach in Loe Pool appeared to show obvious symptoms. Interestingly the fish showing acute symptoms of infection were generally smaller (up to 10 mm) than those without obvious symptoms (Table 16). However, in the case of the Loe Pool margins, the difference was much less (3.8 mm), likely due to the presence of 0+ fish that did not show symptoms of infection although their size does not rule out infection.

Table 16. Numbers of roach sampled with symptoms of gut parasite infection and variations in the mean length of those with and without symptoms.

Location	Number			Mean length (mm)		
	Symptoms	No symptoms	% with symptoms	Symptoms	No symptoms	Difference
River Cober	3	36	7.7	113.3	123.9	10.6
LP Margin	35	180	16.3	116.9	120.7	3.8
LP open water	1	12	7.7	112.0	121.4	9.4
LP Other	14	25	35.9	116.5	126.0	9.5
LP total	50	217	18.7	116.3	120.9	4.6
Total	53	253	17.3	116.2	121.4	5.2

The results of the non-parametric two-sample Kolmogorov-Smirnov test was performed to assess whether the length data from fish with distended abdomens and those that did not were drawn from the same distribution (Figure 19). The data was limited to 1+ or older fish (>100 mm) as data was also drawn from the River Cober where no 0+ fish were present. The results suggested a significant difference (*D*=0.282, *P*=0.002) between the two samples. No fish >134 mm had the characteristic symptoms of an infection. This is suggestive of selective mortality of infected fish or some form of size selection in the infection pathway.

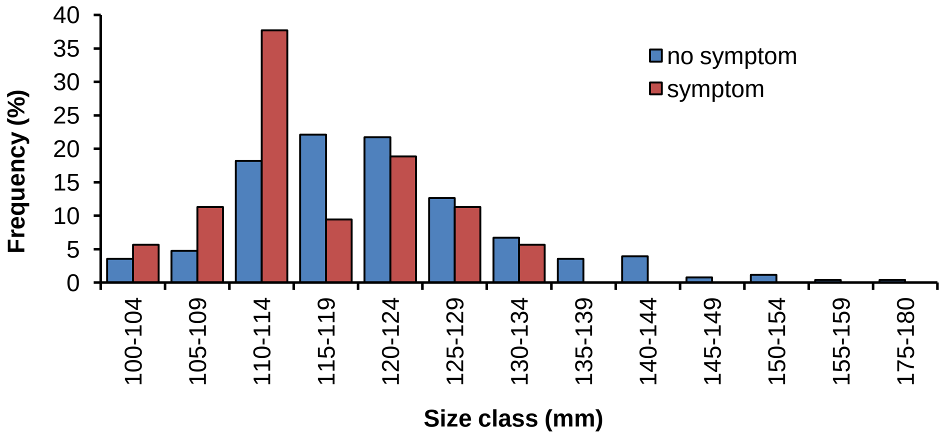

Figure 19. Frequency (%) of roach showing symptoms of a gut parasite infection and those without symptoms.

In addition to the parasitic infection affecting a proportion of the roach population, one roach had a tumour and one rudd had a deformed mouth.

3.3.4 Other observations

During the surveys a variety of birds species were observed including great cormorant *Phalacrocorax carbo*, of which a number appeared to roost in one specific tree near the edge of the water in the Degibna woods. Various gull species were also observed using the water as a roost, forming large rafts of >100 birds at times. Some gulls were observed fishing and presumably were taking smaller roach from near to the surface. Other bird observations included coot *Fulica atra*, moorhen *Gallinula chlororpus*, mute swan *Cygnus olor*, great crested grebe *Podiceps cristatus*, kingfisher *Alcedo atthis* and buzzard *Buteo buteo*.

Large stretches of the banks along the lower sections of the River Cober were found to be dominated the alien Himalayan balsam *Impatiens glandulifera*.

Non-sanctioned fishing activity was also observed during the surveys with two persons seen using spinning tackle along the open shoreline to the south of the Degibna woods.

4 Discussion

4.1 Loe Pool

4.1.1 Survey performance

Appendix 2 provides the results of analyses to assess whether the sample sizes achieved for the PASE surveys of the littoral margin and limnetic region of Loe Pool adequately represented the diversity and overall abundance of fish species present. Species accumulation curves suggested that the effort for the littoral margin of Loe Pool was likely to be sufficient to describe the species present. However, the effort for the limnetic region may not have identified all species present. This is supported by the failure to catch brown trout which are likely to inhabit the lake (particularly the open water) and some of the species recorded in the littoral margin which may also be found in the open water. Increasing the PASE survey effort in the open water may not yield improved results due to the limitation associated with the method and potential rarity of some of the fish species within this habitat given the size and the depth of the lake. In an attempt to account for this, fyke nets were included in the sampling strategy. Only four fish were caught in the fyke which suggests that greater effort would provide increased confidence in the results.

Despite the lack of brown trout, the fish community of roach, perch, rudd, eel and three-spined stickleback was consistent with existing assessments and information (see sections 2.2 and 2.3 above). Whilst the survey does not provide evidence that brown trout has been lost from the lake, the fact that only one individual was captured in the 2006 EA seine net survey (compared to 70 ind. in 1998), specifically aimed at sampling the open water, is evidence of the scarcity of the species as well as difficulty in capturing the species in large, deep waters. Anecdotal information supports this view, as licence holder John Head has failed to catch a brown trout on the fly for at least two years. This is at odds with the generic catch return data, which seems to suggest a better catch return in recent years, although this may be biased by chance captures in otherwise limited effort (see section 2.4 above). The use of other survey methods and repeated surveys at different times of year would provide further detail and confidence in relation to the status and dynamics of the fish community.

The achieved sample sizes also appeared adequate to determine overall densities for the littoral and limnetic areas, as the variation in mean densities with increasing sample size (and the associated standard errors) reached a relatively stable point in all cases (Appendix 2). The densities calculated from the PASE survey of Loe Pool are comparable, or greater than those suggested by previous EA surveys. For example, the 2007 hydro-acoustic survey recorded a peak fish abundance of 0.036 ind. m^{-2}, and an overall mean of just 0.01 ind. m^{-2} (Table 3). Taking these densities to represent the whole lake, as hydro-acoustic surveys are conducted during the night when fish are active in the open water rather than refuging in the littoral margin, the PASE survey produced an abundance estimate of 0.14 ind. m^{-2} representing a ten-fold increase (Table 13). Moreover, despite, the reduced sampling efficiency due to the depth of Loe Pool the abundance estimate of the open water by PASE at 0.08 ind. m^{-2} (Table 13) was directly comparable to the hydro-acoustic survey. The density derived from PASE for the open water was also comparable to densities from the individual seine net hauls conducted in 1998 (i.e. 0.04, 0.05 and 0.1 ind. m^{-2} – see 2.2.1 above). The peak haul, which captured >350 perch (density estimate of 1.3 ind. m^{-2}), incorporated the area of waterlilies, essentially part of the littoral margin, which is therefore comparable to the 1.4 ind. m^{-2} derived from PASE for the margin (Table 13).

4.1.2 Fish community

4.1.2.1 Shifts in species composition

Key to this report is the understanding that Loe Pool was a former estuary or ria (drowned river valley), open to the sea with saline waters. The little information available on the historic fish community of Loe Pool, suggests the dominance of a potamodromous brown trout population tied to the catchment. Otherwise, only eel and possibly sticklebacks (maybe three-spined and/or ten-spined *Pungitius pungitius*) would have been present within a species-poor community prior to 1943 (see Wilson & Dinsdale 1998). These are all species which can tolerate or thrive in the marine conditions, which were then present, at some stage in their lives.

Following the isolation of Loe Pool from the sea, freshwater conditions will have generally prevailed (except during natural or induced saline incursions) and the brown trout will not have been able to run to the sea. Moreover, saline intolerant fish species could potentially colonise Loe Pool if introduced somewhere within the system. Indeed, rudd were introduced into the Cober from Coronation Lake in 1943, and it was subsequently reported to have become prominent within both Loe Pool and the River Cober.

The brown trout decline throughout the 1970's was thought to coincide with the influx of sediment from the many decommissioned tin mines within the catchment, the aforementioned saline incursions and, most importantly, the general eutrophication of Loe Pool leading to associated algal blooms. A prominent algal bloom in 1976 resulted in the mortality of 2,000 fish, the majority of which were brown trout (Wilson & Dinsdale 1998).

By the 1998 EA survey, the fish community appears to be dominated by perch, the source of which was believed to be a local fishery upstream of Helston, from a flood event or illegal introduction. The first record of the species in the Cober was in 1994/1995, although whether perch colonised Loe Pool at the same time is unknown. The dominance of the perch population was attributed to the decline in the rudd population and that the population would continue to grow and exacerbate the problem of eutrophication. As a recent introduction, it was recommended that the population should be controlled through a variety of measures, including lowering the water levels during the breeding season to limit access to spawning grounds and biological control through the introduction of perch ulcer disease (EA 1998).

Despite the concerns, a further survey was not undertaken until 2006, with this showing that, whilst perch continued to be the dominant species, there was little evidence of a rapid increase in the population. The capture of only one brown trout indicated a further decline in the abundance of the species within Loe Pool. Whilst brown trout would have suffered, increasing competition with the introduced fish species, particularly perch within Loe Pool, it could have maintained a stronghold in the wider catchment irrespective of the problems in the lake. With sufficient recruitment in the catchment, larger adults may even have benefitted from the presence of small individuals of other species as prey. An increase in average growth could then have maintained population fecundity and should adult fish still have been able to access good spawning grounds in the upper parts of the catchment, good fry populations could also have been maintained. Simply put, the decline in brown trout may owe as much to issues in the wider catchment as to the decline in the quality of the lake.

The 2006 survey also revealed the presence of roach in Loe Pool for the first time, albeit through the capture of a single specimen. However, the following year, the seine net survey conducted in conjunction with the hydro-acoustic survey indicated that roach were the dominant species in numerical terms. The presence of roach in anglers' catches was not noted until the 2008-2013 period, although this is likely to be a function of the fishing method employed (see 2.4 above). Though it remains unclear exactly when, or how, they entered the system, it is plausible that a similar source to that for perch is responsible.

4.1.2.2 The current status of the fish community

The current survey confirms that roach is still the dominant species in Loe Pool. Perch remain prominent within the fish community, and although a rudd population still persists, it appears to be diminutive. The survey did not provide evidence of brown trout within Loe Pool, although a fish thought to be a trout was observed close to Loe Bar. Whilst some larger mature fish seem likely to ultilise the deeper open waters, it seems unlikely that parr are present and the bulk of the population of the catchment will be in the Cober and other streams draining the catchment. The few eels captured in Loe Pool were all thought to be mature pre-spawners ultimately preparing to go to sea. Thus, three of the fish species revealed by the current survey are all due to introductions over the past 70 years, effectively replacing the original simple fish community of brown trout, eel and possibly sticklebacks present in the lake prior to 1943.

The current prominence of roach within the fish community, despite its relatively recent introduction to Loe Pool, is likely to be a result of its competitive superiority when young (especially 0+), over both rudd and perch in open structureless systems (Winfield *et a*l. 1986). Notably, the process of a roach population increasing at the expense of rudd and perch has previously been observed and monitored at Slapton Ley, a SSSI lake with similar characteristics to Loe Pool (see Box 1).

Akin to Slapton, there are signs that the roach population might be experiencing natural regulation. For example, whilst some recruitment occurred in 2014, this year's cohort was clearly not as strong as in 2013. Of the total roach captured by all techniques within Loe Pool, 37% were considered to be YOY fish, with 67% thought to be 1+ fish. Typically these proportions would be reversed, with the most recent age class dominating. Overall abundance estimates from the PASE survey for the 2014 and 2013 cohorts were 0.03 and 0.10 ind. m^{-2} respectively. Recent poor recruitment could have been caused by a range of factors ranging from climatic conditions to access of suitable spawning substrate, although could also link to intraspecific competition. In some cases this can lead to population cycling, whereby the fecundity of slow-growing adults limits the number of eggs laid and thus the number of recruits (Townsend & Perrow 1989).

The current growth rates of the roach do not indicate that particularly high densities have recently been recorded in Loe Pool. The mean growth rates of the two age classes, 65.1 mm for YOY and 112.3 mm for 1+ fish, are considerably greater than the national averages of 50.0 and 91.9 mm respectively (Hickley & Dexter 1979) and would fall into the fast growing category for southern rivers (Fisheries Technical Services – *unpubl*. *data*).

A more tenable explanation for apparent lower recruitment in 2014 and perhaps relatively low recruitment in general is a potential parasite infection (described in Section 3.4.3 above), which seems most likely to be *Ligula intestinalis*, as in Slapton Ley (Box 1). *Ligula* uses planktonic copepods as a first intermediate host, with roach and other fish species as a second intermediate host and can be introduced to new waterbodies by its final host, birds (Kennedy & Burrough 1981). The parasite can sterilize its fish host and make it more susceptible to avian predation and is thus highly pathogenic to roach (Loot *et al*. 2002). Within two years of the arrival of *Ligula* in Slapton Ley, almost 30% of the roach were infected and this was sufficient to halt the expansion of the roach population and then cause a decline (Bregazzi *et al.* 1982, Kennedy 1996). Although the natures of the pathogen and rates of infection were not fully quantified in this study, the numbers of roach with obviously distended abdomens in Loe Pool was around 19%. There would therefore seem to be potential for the roach population to begin to decline and allow perch and / or rudd to increase in the near future.

BOX 1 The case of Slapton Ley

Comparisons can be drawn between the shifts in the fish community at Loe Pool and the changes documented at Slapton Ley SSSI (south Devon), which is also a form of coastal lagoon separated from the sea by a shingle ridge. The main difference between the two lakes is that Slapton Ley was always a coarse fishery with pike, perch, roach, rudd and eel being the dominant and most important species, whilst a few brown trout were thought to move into the lake from the River Gara during the summer months but were not permanent residents (Kennedy 1996).

Historically, Slapton Ley was regarded as an important coarse fishery highly valued for its pike fishing in an area dominated by salmonid species. Following declines in the quality of the fishery it became the subject of research (Bregazzi *et al*. 1982). Prior to 1967 perch and rudd had been numerically dominant in Slapton Ley, but after this the roach population began to expand concomitant with the decline of the rudd population, which had almost disappeared by 1974 (Bregazzi *et al*. 1982). The expansion of the roach population coincided with increasing eutrophication resulting from changes in land-use in the catchment.

Extensive mortality of roach then occurred in 1975 that was attributed to severe infections of the tapeworm *Ligula intestinalis*, which thinned the population and allowed a partial recovery of rudd (Bregazzi *et al*. 1982). This illustrates the well-documented competition between 0+ fish of the two species which feed on planktonic invertebrates.

The decline in the perch population was also attributed to the increase in roach, although not necessarily through competition at the 0+ stage, which may have been exacerbated by the increasingly eutrophic conditions (Bregazzi *et al*. 1982). The pike population increased but individuals were generally smaller with this thought to reflect the prey base being mainly smaller fish (Kennedy 1996). The perch, pike and roach populations generally had a very young age structure with a high mortality rate resulting in a population with very few large specimens. The current status of the fish population at Slapton Ley and response to management initiatives is not readily available, although a fishing moratorium was introduced in 2005 and continues to protect breeding wildfowl from disturbance by boats.

Thus, despite the lack of pike and focus on brown trout, Loe Pool appears to have undergone similar changes to Slapton Ley and ultimately it is possible that *Ligula* infestation of roach may reduce current population size, with benefit for other species such as rudd and perch. However, it seems unlikely that any mortality of roach will be sufficient to benefit the brown trout population through reduced competition or trophic effects promoting better water quality (reduced phytoplankton populations). The background levels of nutrients may simply be too high, coupled with factors limiting the recruitment of brown trout within the catchment such as poor habitat quality and competition with other fish species.

Perch remain in the fish community at low density (0.01 ind. m^{-2} – Table 13) seemingly suppressed by competition with roach for zooplankton when young and generally disfavoured by the lack of structured habitats providing further invertebrate prey and lower than desirable water quality. The growth rates of the two age classes captured can be considered as reasonable, with the YOY fish exhibiting nationally fast growth rates, with a mean length of 88.1 mm and 1+ fish in the average / fast growth rates (mean of 135.3 mm) (Fisheries Technical Services – *unpubl. data*). That the YOY fish exhibited good growth rates could indicate an early switch to piscivory, as even young perch of 30 mm are capable of predating on smaller cyprinids of <20 mm (Borcherding *et al*. 2000). Like roach, perch did not recruit particularly well in 2014 compared to 2013, again perhaps indicating an effect of climate influence although perch do spawn considerably earlier than roach and may be affected by different conditions.

The rudd population is small and although sizeable (>200 mm) adults are known to be present as these are still captured by anglers, recruitment appears to be poor with YOY and 1+ fish possibly mainly restricted to the littoral margin and the reed beds in particular. Thus, of the two species, it would seem that perch are more likely to respond to any decline in the roach population than rudd. However, should the general conditions remain more or less as they are in Loe Pool, it seems most likely that the roach population would quickly recover.

4.1.3 Potential impacts of the fish community

The well-documented eutrophication of Loe Pool resulted in the formation of the LPF and the production of management plans (Wilson & Dinsdale 1998, Dinsdale 2003, 2009). Nutrient input into the lake has reduced dramatically since the inception of the LPF and implementation of measures in the wider catchment, principally the removal of phosphorus at the Helston sewage treatment works. By 2005-2007, mean annual TP was ~80 µg l^{-1} having reduced from approximately 300 µg l^{-1} a decade earlier (Dinsdale 2009). The non-native Nutall's waterweed *Elodea nuttalli* increased in cover from 1999-2006 reaching a peak in 2006. Perfoliate pondweed *Potamogeton perfoliatus* was also recorded between 2003 and 2007. However, Nuttall's waterweed crashed in 2007 and perfoliate pondweed has not been recorded subsequently (Dinsdale 2013).

Fish can disfavor submerged macrophytes whilst reducing water quality and promoting a turbid algal-dominated state in shallow lakes. Benthivorous species, such as common bream *Abramis brama* and common carp *Cyprinus carpio*, feed amongst the lake sediments, re-suspending sediments, releasing nutrients into the water column and uprooting macrophytes (although these have not been found in Loe Pool). Herbivorous species, particularly rudd and roach to a lesser extent, may selectively graze on palatable species and on actively growing shoots (Prejs 1984, Lake *et al*. 2002). Young individuals of most species are zooplanktivorous and particularly efficient species such as roach selectively predate on large zooplankton, reducing the grazing potential of zooplankton on algae, whose populations increase as a result.

During the period of macrophyte cover, perch and to a lesser extent rudd, were the dominant fish species, along with some brown trout. Both perch and especially rudd are associated with submerged macrophytes and generally do not tend to threaten the macrophyte dominated state, even through herbivory by larger rudd introduced to a system may reduce vulnerable native species (Lake *et al*. 2002) or inhibit regeneration (Bakker *et al*. 2013). The loss of macrophytes also appears to be broadly coincident with the introduction of roach to the system.

Although roach and perch may feed on benthic prey, they are not truly benthivorous nor do they typically have the capacity to inhibit macrophytes through 'bottom-up' (via nutrients at the base of the trophic chain) processes. That is unless they occurred at very high biomass. The same argument may be adopted for herbivorous rudd grazing on plant material.

The EA survey in 2007 suggested that there was a biomass of fish equating to only ~1 kg ha^{-1} (Table 3), which is insufficient to precipitate a decline in macrophytes through bottom-up processes or grazing. For comparison, a study of 28 lakes in Norfolk, including estate lakes, fisheries and Norfolk Broads undergoing restoration (including biomanipulation), biomass estimates derived from PASE ranged between 0.3 and 64.8 g m^{-2} (equivalent to 3 and 648 kg ha^{-1}) (Zambrano *et al*. 2006). It is also worthy of note that the estimated biomass from the PASE survey of Loe Pool was considerably lower than the stocking limit of 200 kg ha^{-1} (20 g m^{-2}) of fish currently recommended by NE for Special Areas of Conservation (SAC) / SSSI lakes (Clarke 2008) and the 350 kg ha^{-1} suggested as typical for mature, lowland estate lakes by the EA (http://northerntrout.co.uk/docs/stocking_eng_ 172017.pdf). However, this is not to say that macrophytes could be sustained at such biomass. Although the relationship between fish biomass and macrophyte cover is poorly understood, the range of 150-250 kg ha^{-1} suggested by Smith (2001) which was based on data for just 11 lakes (several of which were not in the UK) appears to have precipitated the use of a standard threshold of 200 kg ha^{-1}.

The effect of fish upon zooplankton via a top-down trophic cascade is generally not a function of fish biomass but rather fish density. Roach are highly efficient zooplanktivores in structureless environments and may exert a measurable effect upon zooplankton at a relatively low density, shown by Perrow *et al*. (1999) to be at around 0.2 ind. m^{-2}. Again, the EA survey in 2007 suggested an extremely low density of fish at 0.01 ind. m^{-2} (Table 3). Even if this density was assumed to be comprised entirely of roach, the most efficient species in open water compared to rudd and perch (Winfield 1986), there seems to be no possibility of an effect on zooplankton.

It is possible of course that the hydroacoustic survey in 2007 significantly underestimated both fish density and biomass. However, it would have to have underestimated by over one order of magnitude for density and well over two orders of magnitude for biomass considering the mix of species present, in order for fish to have been having an effect. At the time, hydroacoustic survey techniques were still in a development phase compared to today and it is difficult to judge the quality of the methods of survey and analysis as these are not particularly well described. Nevertheless, researchers in the UK (e.g. Winfield *et al*. 2007) were producing reliable estimates using hydroacoustics, with this defining the methods used by other institutions such as agencies and consultancies. Thus it seems unlikely, although not impossible, that the true fish density and biomass were so dramatically underestimated at the time of macrophyte decline. As a result, there is no evidence to support the view that fish precipitated the collapse of macrophytes.

The spontaneous collapse of macrophytes may occur as a hysteresis event as a particular threshold of effect is exceeded (e.g. nutrients, light climate, fish biomass, bird grazing etc). However, monitoring of water quality parameters provides no evidence of any significant change in the trophic status of the lake immediately before the collapse of macrophytes (Figure 20). Indeed, TP and chlorophyll appeared to 'step down' after 2003, due to the introduction of tertiary treatment at the Helston STW. Furthermore, from 2004 to 2012, the mean of annual mean values for TP and chlorophyll were 78 µg l^{-1} and 28 µg l^{-1} respectively. From this perspective, there is no obvious limitation for macrophyte growth.

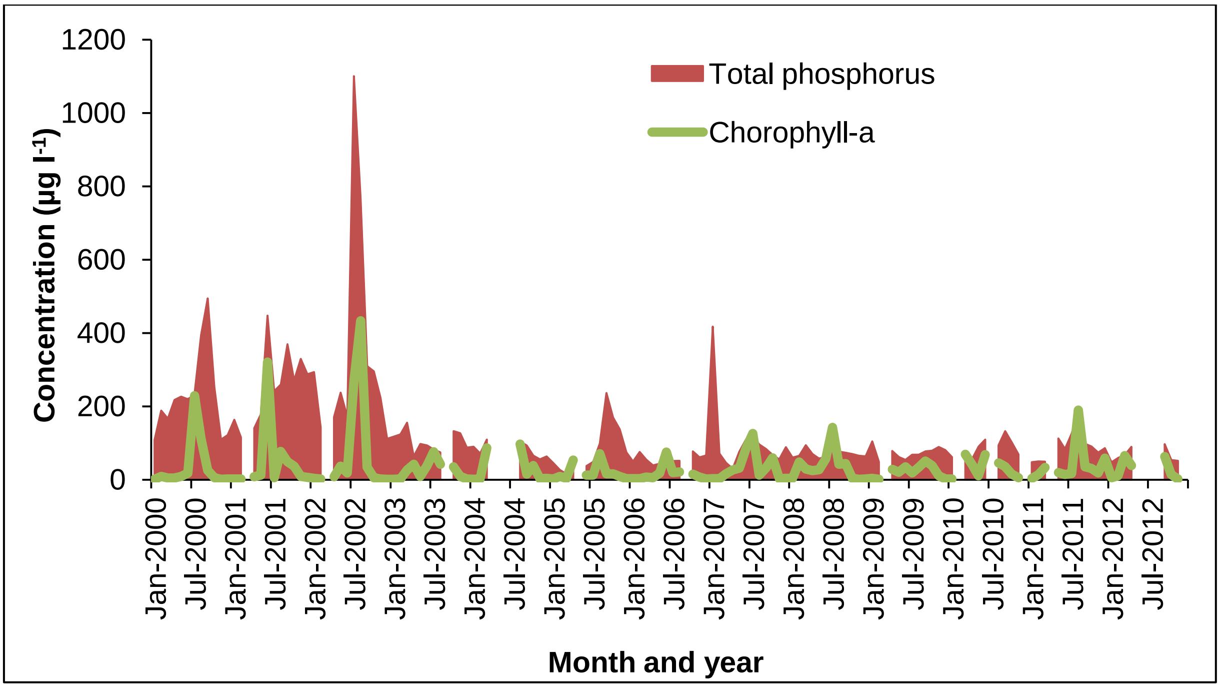

Figure 20. Concentrations of total phosphorus (TP) and chlorophyll *a* measured at the outfall of Loe Pool from 2000-2012.

It should also be noted that species-poor communities are not buffered against change in the fortune of the dominant species. Thus, if the dominant species declines for any reason, there is little prospect of substitution, as would occur in a species-rich community with competition between species. As a result all cover may be quickly lost. Collapse also seems more likely for asexually reproducing species that are non- or weakly-rooted, such as hornwort *Ceratophyllum demersum* and *Elodea* spp. Such species are adapted to relatively high nutrient concentrations and grow prolifically until the clone runs out of vigour or nutrients reduce. The dependence on overwintering vegetative parts such as turions also means that such species are vulnerable to sustained winter grazing by herbivorous birds such as coot *Fulica atra* or swans (Perrow *et al*. 1997, Mitchell & Perrow 1998).

The loss of the non-native *Elodea nuttallii* from Loe Pool may therefore have occurred for a number of reasons, combined or in isolation. Moreover, as an invasive non-native plant, its loss is something of a blessing in disguise and only undesirable from the perspective of a loss of macrophyte cover. The concomitant loss of perfoliate pondweed, a native species that was part of the lake description at designation is obviously less desirable, although it is not specifically clear how much was lost at this time. If this involved only a limited cover, this could be linked to the decline of the dominant *Elodea nuttallii*, which may have acted as a nursery species reducing the prospect of isolated grazing events for example.

Even if fish may not have been responsible for the recent loss of macrophytes, it is possible that they are linked to the lack of regeneration of plant cover if their biomass or density is currently high enough to mean either bottom-up or top-down mechanisms are in operation (see above). In the case of fish biomass, the current survey estimated this to be 3.98 g m^{-2} or 39.8 kg ha^{-1} of all fish (Table 13), which although far higher than the 2007 EA survey, is still low. Such a low biomass of non-facultative benthivorous fish means that there is little to no prospect of fish-induced bottom-up process being responsible for a lack of macrophytes.

In terms of the prospect of a fish-induced top-down cascade structuring the interactions within the lake, the density estimate for the entire fish population is low at 0.15 ind. m^{-2} (Table 13), although the majority of this is roach at 0.13 ind. m^{-2} (Table 13). Whilst this is below the threshold at which an effect on zooplankton may be expected, any uncertainty around this estimate could mean that the roach population is high enough to suppress zooplankton. For example, at the time of survey at least part of the roach population of Loe Pool may already have moved into the River Cober to spend the winter months. During the summer, most of the roach within the catchment may actually be concentrated within Loe Pool. Moreover, the patterns of recruitment suggested by the PASE survey, suggest the roach population has been higher in the recent past with evidence of greater recruitment in 2013 for example. The potential effects of a parasite infestation within the population may also have already reduced the population.

It is also important to note that Loe Pool is relatively deep, with much of the lake potentially beyond the depth at which *substantial* growth of rooted macrophytes would be expected, even if the target concentration of chlorophyll of 2.5 µg l^{-1} was achieved. As such, Loe Pool is not really a ‘shallow lake’ where the entire lake-bed falls easily within the photic zone, Nevertheless, some interesting species may exist in relatively deep, very clear water. But at present, even a relatively low standing crop of phytoplankton seems likely to limit the extent availability of lake-bed with a suitable light climate at the sediment surface for rooted macrophytes. Chlorophyll concentrations have been maintained at a reasonably low level over the last decade, but still reflect a relatively high current TP concentration, some 10-fold higher than the target condition. Additional phosphate stripping at the Culdrose WWTW has also recently gone online (October 2014) and further improvements in water quality are expected in response to this. Thus, TP could be further reduced with subsequent reductions in phytoplankton in the coming years.

Whilst submerged macrophytes could exist at the nutrient concentrations occurring in Loe Pool at present, this is only likely in truly shallow lakes. Even then, experiences in the Norfolk Broads show that macrophytes are not likely to spontaneously regenerate unless TP is <50 $\mu g\ l^{-1}$ and the light climate dramatically improves as a result of a total chlorophyll a concentration of <30 $\mu g\ l^{-1}$. In the deeper Loe Pool chlorophyll may need to be <10 $\mu g\ l^{-1}$ to generate the same effect. To achieve such low chlorophyll in the face of relatively high TP, biomanipulation of fish populations is often employed (see Perrow *et al*. 1997, Jeppesen & Sammalkorpi 2002, Søndergaard *et al*. 2007, 2009, Jeppesen *et al*. 2012).

4.2 River Cober

4.2.1 Survey performance

Species accumulation curves from the PASE surveys of the River Cober above and below Helston suggested the effort for the downstream section was likely enough to describe the fish community composition (Appendix 2). However, the effort for the upstream section was unlikely to have identified all species present and this was borne out by free electric fishing which further identified perch in the survey stretch. The fish community in the River Cober described by the current surveys (roach, brown trout, perch, eel and three-spined stickleback) was also consistent with existing survey data (see sections 2.2 and 2.3 above).

The overall densities derived from the PASE samples for these two areas were also likely to provide good estimates, as illustrated by the reduction in variation in mean densities (and associated standard errors) with increasing sample size. The brown trout density estimates and NFCS classifications achieved in the current study were also comparable to those derived from the EA surveys in 2012 for two similar sites. For example, the St John's site, immediately upstream of site 1 in this study, yielded a 'very poor' classification (< 2 ind. 100 m^{-2}) for fry in 2012 and the current study found no fry. In the same year, St John's achieved a 'good' classification (14 ind. 100 m^{-2}) for level one >0+ brown trout abundance whereas site 1 was classified as 'excellent' in 2014 (see Sections 2.3 and 3.4.2.2 above). Moreover, the number of brown trout (all ages) removed from the Coronation Lake section equates to 0.28 ind. m^{-2}, assuming a 4 m strip was electric fished. The section sampled upstream of the removal (site 1) was estimated to support a comparable density of brown trout, at 0.24 ind. m^{-2} (Table 15). The above is considered evidence of confidence in the PASE survey of the Cober.

The removal exercise undertaken by the EA prior to the survey of the River Cober is unlikely to have significantly affected the outputs, as few fish were introduced into the sampled section, but principally due to the corruption of the silt barrier would have allowed free passage to their preferred habitat.

A potential loss of information about the wider Loe Pool catchment may have arisen from not surveying the Carminowe, due to time and EA electric fishing constraints. In particular it is unclear as to whether the stream acts as a nursery or refuge for brown trout or other species. From observations made from the adjacent footpath, the stream did not have sufficient structure to support adult fish, as it appeared to be of uniform shallow depth, i.e. no pool structures. The substrate comprised of clean gravels, which could provide spawning substrate for adults and thus could support YOY specimens.

4.2.2 Fish community and status of brown trout

The PASE survey of the River Cober indicates that there are two distinct fish communities within the surveyed stretches of the river, the downstream section below Helston was dominated by roach and upstream of Coronation Lake was dominated by brown trout.

The downstream section supported a simple fish community, similar to that present in 1998 during removal exercises, with the exception of its domination by the recently introduced roach. Of the species removed from the section in 1998, only eel were not captured in the current survey. How the fish interact between habitats in Loe Pool and the River Cober is at present unclear. The project was extended to the River Cober, in part due to large aggregations of cyprinids (largely roach) documented in pools within the lower reaches of the river around Helston during the late autumn period. It was surmised that these fish were from Loe Pool and were migrating to preferred over-wintering habitat in the Cober. Whilst this migration may still occur, the density of fish present in site 2, considered typical of the section downstream of Coronation Lake, was high (particularly as no YOY roach were captured in the survey) at 0.7 ind. m^{-2} (Table 15), and sufficient to create these aggregations. The fish present in the Cober at the time of the survey are unlikely to represent fish migrating to preferred over-wintering sites, based on the timing of the survey and the weather conditions.

A further possible interaction between the two habitats could be that roach in the Cober use Loe Pool as spawning and nursery grounds. The lack of YOY fish captured in the survey of the lake and sections of the river where they were present could imply that recruitment was very poor within the population in 2014. It would seem more likely that roach spawn and potentially spend their first year in the lake before migrating up the river.

The density of brown trout encountered in the downstream section (sites 2 and 3 combined) was greater than that based on the fish removal exercise in1998. Using an area of 7,800 m^2 (a length of 1.3 km and a width of 6 m), the 193 brown trout removed equates to a density of 0.02 ind. m^{-2}, which is lower than the estimated 0.09 ind. m^{-2} derived for sites 1 and 2 combined. The density derived from the removal equates to brown trout surveys conducted by the EA between 1986 and 1992, with a peak density of brown trout parr of 0.02 ind. m^{-2} (unpubl. data).

However, in the period prior to the removals, good densities of brown trout, both fry and parr, were present in the upper reaches of the Cober or supported within its tributaries (see Section 2.3 above). There is the possibility that fish matured within these areas for a number of years before migrating down to Loe Pool as adult fish, whereas adult fish are currently not migrating down to Loe Pool in such numbers, but instead are remaining in the lower reaches of the River Cober.

The EA survey data suggests that the classification of the river in relation to brown trout fry had dropped from between 'fair' to 'excellent' in 1986, 1992 and 1995, to 'very poor' in 2012 (Section 2.3). This could reflect a reduction in nursery habitat for the fry or reductions in productivity. The current survey of the Helston section sampled in the present survey (site 1) indicated that the brown trout population is comparable to the twenty-two year period between 1986 and 2008 (St. John's) (see 4.2.1 above).

More information is clearly required on the brown trout population within the Loe Pool catchment, particularly as they are comprised of wild, native stock. Whilst not given the same status as Atlantic salmon *Salmo solar*, the conservation value can be considered as very high. Greenhalgh (2000) argues that wild trout populations, uncontaminated by artificial stockings ought to be given conservation priority.

As with the brown trout supported by the River Cober, more information on the eel population should be gathered on this species which is currently on the IUCN red list of threatened species (Jacoby & Gollock 2014). The 1998 Cober fish removal suggested that eels were present in good numbers below the town. The current surveys found eel in the section above Helston, whilst the EA removal prior to the survey found eels just downstream of Coronation Lake below the road bridge. Given the proximity of the water to the sea the presence of eels is perhaps unsurprising but encouraging.

As described above for Loe Pool, the perch found within the river are unlikely to be indigenous and were probably introduced in 1994/95 during a flood event. Only a single age class of perch was found in the river (1+), whilst at least two age classes were recorded in the lake (0+ and 1+). This may suggest that perch could be using the lake for spawning and as a nursery.

5 Management Options

5.1 Fish in Loe Pool

In this section three options for the management of the fish community in relation to the long-term objectives for the lake water quality and ecological condition are considered:

1. Do nothing;
2. Conduct a full-scale biomanipulation; or
3. Carry out an experimental demonstration of the effect of fish within fish exclosures.

Options 1 and 2 represent management extremes in terms of intensity and cost, with 3 providing an intermediate approach that will provide a clear direction for future fish management.

5.1.1 Do nothing

Simply doing nothing as an approach to the management of Loe Pool fish community may be justified on the grounds that the conditions for submerged macrophyte growth have been reached and the density of fish, particularly roach, is relatively low.

The LPCMP successfully reduced nutrient levels in Loe Pool to a level where the growth of submerged macrophytes rather than filamentous algae is likely to be favoured. A good coverage of Nutall's waterweed, albeit a non-desirable species, with some perfoliate pondweed, a submerged macrophyte specified on the SSSI designation, was supported over a number of years. The crash in the submerged macrophyte cover in 2007 may have been part of a natural cycle of the population, rather than due to the influence of external pressures, such as the shift in the fish community. It could be speculated that viable inocula in the form of seeds, roots or tubers of several macrophyte species remain within the lake's substrate, providing the potential for macrophytes to spontaneously return to Loe Pool should suitable conditions occur. This could be a suitable light climate at the sediment surface or perhaps a climate trigger such as a particularly warm spring leading to germination of any seeds.

The roach population revealed by the PASE survey does not appear to be at the density threshold at which water clarity, and thus submerged macrophytes would be detrimentally affected (Perrow *et al*. 1999). Insufficient information is available from the current and previous surveys to confidently describe recent trends in the roach population, although it does appear to be lower than in recent years. What is thought to be a *Ligula* infestation may be reducing the population viability and may continue to at least partly control the potential impact of roach on trophic processes in the lake.

The key advantage of doing nothing is that the cost is minimal, being limited to monitoring of the fish community in order to establish whether the *status quo* is maintained. However, the key disadvantage is that the target condition of the lake effectively relies on existing and future management of nutrient inputs including the recent introduction of phosphate stripping at the Culdrose WWTW. From the limited information available it seems likely that internal loading will maintain chlorophyll concentrations at too high a level to allow macrophytes to spontaneously generate. In simple terms, the target concentration of 2.5 $\mu g\ l^{-1}$ chlorophyll looks to be unattainable and there is some debate as to whether, even if this could be achieved in the long-term, it would lead to the re-establishment of the former macrophyte community. Other factors could be contributing to the suppression of macrophytes in the lake including the nature of the sediment itself and perturbations caused by flood events. It is also currently unclear what the true nature of the historic macrophyte community was and the natural evolution of the lake after being isolated from the sea will likely have led to associated changes in the plant community. However, given the depth of the lake it seems most likely that macrophytes were generally restricted to the shallower parts of the lake with more specialist low-growing species at low density in some of the deeper waters.

Crucially though, doing nothing would mean that the fish community would remain dominated by roach, perch and rudd: species that do not appear to be native to the catchment at any time. The key fish species, brown trout, would likely remain at very low levels, with this mainly governed by factors responsible for recruitment in the wider catchment. Siltation, sub-optimal water quality and competition with other fish species may all be ultimately limiting the part of the brown trout population that uses Loe Pool. As such, doing nothing is unlikely to be most effective management strategy.

5.1.2 Whole-lake biomanipulation

Biomanipulation may be defined as the *"re-structuring of the biological community to achieve a desirable response*". The latter is generally a reduction in populations of troublesome algae, attainment of clear water and promotion of a diverse biological community. In shallow lakes this often involves the promotion of a diverse submerged and emergent aquatic flora (water plants excluding all planktonic and filamentous algae) and its dependent faunal populations.

Biomanipulation originally encompassed a range of techniques as initially used in the US (Shapiro 1990), but is now typically applied to the removal of zooplanktivorous and benthivorous and/or the enhancement of populations of piscivorous species to control the other groups (see Perrow *et al*. 1997, Jeppesen & Sammalkorpi 2002, Søndergaard *et al*. 2007, 2008, Jeppesen *et al*. 2012). In the case of Loe Pool, the historic fish community would have had few zooplanktivores, perhaps mainly limited to sticklebacks and no facultative benthivorous fish. Native piscivores would include brown trout but also eel to a lesser extent. Large specimens of the introduced perch are probably the dominant piscivore in the lake currently.

It could be argued that at the current TP levels of ~80 µg l^{-1}, either algal-dominated turbid waters or macrophyte-dominated clear waters may exist as alternative stable states. Moreover, although submerged macrophytes could exist, they do not at present and could be considered to be unlikely to spontaneously regenerate unless TP is, say, <50 µg l^{-1} and the light climate dramatically improves as a result of a total chlorophyll-a concentration of, say, <15 µg l^{-1} in a relatively deep lake. To achieve such low chlorophyll in the face of relatively high TP, biomanipulation is likely to be the best, perhaps even the only feasible management option without further reduction of nutrients (Jeppesen & Sammalkorpi 2002).

In this instance, the biomanipulation of Loe Pool SSSI would involve the removal of roach, and potentially rudd and perch. However, as well as the biomanipulation of the whole lake and connected catchment, there is also the option of creating a fish exclusion zone within the lake in order to demonstrate the effects of fish and the viability of whole-lake biomanipulation (see 5.1.3 below).

Biomanipulation of lakes of the size of Loe Pool has been successfully undertaken in the UK (e.g. Ormesby Broad - Perrow *et al*. 1998, Tomlinson *et al*. 2002), although there is no example of the additional biomanipulation of a catchment system the size of the Cober and its tributaries. The entire catchment would have to be manipulated as Loe Pool could not be isolated from its catchment and the roach and perch within Loe Pool and the lower reaches of the River Cober very likely migrate through the catchment. There are however, many examples of the successful biomanipulation of far larger lakes including their catchments in continental Europe such as the 109 km^2 Lake Vesijärvi in Finland (Jeppesen & Sammalkorpi 2002). The costs of biomanipulation are low relative to other restoration techniques (e.g. suction dredging) with Jeppesen & Sammalkorpi (2002) suggesting costs of up to £541 ha^{-1} (after conversion to GBP and adjustment for inflation) in large lakes although costs are reduced through the use of commercial fishermen with a product to sell as well as community involvement. Small lakes have a higher cost per unit and in the UK, it has cost up to £4,000 ha^{-1} although this is typically based on repeated effort over several years. An equivalent cost for the 56 ha Loe Pool would be in the region of £220,000. It is anticipated that an initial removal of more than 80% of the stock in the lake and catchment would cost approximately £75,000, followed by further works to reduce stocks until they become functionally extinct. Other restoration techniques such as sediment removal are far more expensive, with suction dredging of the 74 ha Barton Broad costing in the region of £2.5 million (i.e. ~£34,000 ha^{-1}).

A further technical issue is that the fish would have to be removed from the catchment, and especially since a proportion of the roach population is likely to be infected with parasites, these fish might not be able to be transferred to a donor site under fisheries legislation (Salmon and Freshwater Fisheries Act 1975). Whilst permission could be sought to destroy the fish in such a case, this could prove unpopular and provoke animosity towards the project, and as a result this would have to be handled sensitively with both stakeholders and public. However, the attempt to return the fish community of Loe Pool to its probable ancestral state could be a key ‘selling point’ of the project and in that context the ‘end may justify the means’ of it being achieved. Biomanipulation is generally approached in several phases or approaches to removal and suppression of fish populations:

- **Phase 1:** This typically involves a large-scale removal to eliminate >80% of the stock. This can be achieved through the targeting of fish aggregations or shoals, especially during winter, or involve systematic fishing of preferred habitats (e.g. the littoral margin or sections of river moving upstream). Fish are also often easier to capture in low water temperatures, which could also increase the survival of fish being transferred to other waters.
- **Phase 2:** The targeted removal of particular species in specific habitats undertaken in the most cost-effective manner, often using a range of techniques tailored to different situations (e.g. seine netting, electric fishing and passive traps).
- **Phase 3:** Additional measures to reduce the breeding success of the target species. Spawning medium such as nets, can be introduced in preferred spawning habitats and after fish have spawned on the nets, they can be removed from the water and the eggs dried. Adult fish may also be captured at the same time.

The aim of biomanipulation is to achieve a desirable state, which in the case of Loe Pool appears to be significant macrophyte cover comprised of a range of species that were part of a known historic community. Thus, manipulation of the fish stocks will need to be continued until this is achieved. Attainment of the desired state often takes many years, perhaps between 5-10, and if an alternative stable state is not achieved then initial success, seen in the form of reduced chlorophyll and TP (much TP may be removed with the fish, comprised of around 3% P), typically proves to be short-lived (Søndergaard *et al*. 2007, 2008).

For a full-scale biomanipulation to be a long-term success, a detailed plan would have to be developed, which in turn would require greater knowledge of the fisheries within the catchment than is currently available. A key element would be to understand the source(s) of the non-indigenous species within Loe Pool and to ensure that this (these) can no longer supply such fish. Knowledge of all fisheries and fish farms within the catchment and the prospect of flooding enhancing the connection with the Cober and any tributaries must be obtained as a prerequisite. At this stage, Coronation Lake seems to be a likely source of non-native and perhaps even future colonists. At the very least, a fisheries survey of Coronation Lake should be undertaken to determine if roach, rudd and perch are present and if there is further threat from other species such as bream, carp or even goldfish *Carassius auratus*. The consequences of the accidental introduction of an obligate benthivore into the Cober and thus Loe Pool would most likely be disastrous.

Furthermore, the means of stabilising the lake structure and function following biomanipulation is currently poorly understood, and recent analyses of multiple case studies in countries such as Denmark describe the fish community and the trophic status of the lake switching back to an undesirable condition) in <10 years, seemingly linked to maintenance of relatively high TP through external or internal loading (Søndergaard *et al*. 2008). For this reason, the sources, sinks and pathways of nutrients must be understood. Although credit is due for the significant reduction of TP already achieved, Dinsdale (2009) suggests considerable levels of nutrients are still entering Loe Pool via the Cober. The phosphate stripping introduced at Culdrose WWTW in 2014 is likely to provide further significant benefits for water quality. In relation to the internal cycling of phosphates, Olosundé (2002) predicted this would be low in loe Pool due to the high metal content of the sediments resulting from a legacy of metalliferous mining (Dinsdale 2009). This is supported by the dramatic fall in lake phosphorous following the tertiary treatment at Helston STW in 2003 (Figure 20). Thus further treatment of inputs appears to be the most appropriate course of action.

5.1.3 Experimental fish exclosures

Given the high level of uncertainty of the influence of fish on the water quality of the lake and specifically whether fish are currently preventing macrophytes from regenerating, a particularly appealing strategy is to undertake a sizeable demonstration of the effect of fish through the use of fish exclosures. These exclosures provide a controlled area to assess the impacts of manipulating the fish community. Barrier may also reduce the re-suspension of sediment, further aiding in producing clear water conditions, as they can reduce wave and wind effects within the exclosure. Such an experimental approach has been used on several occasions in the Norfolk Broads (e.g. four areas to 2.4 ha in size in Barton Broad, several exclosures to 1 ha in Hoveton Great Broad as well as a smaller exclosure in Ranworth Broad) and is also planned by NE in one of the West Midland Meres. In the Broads, exclosures have almost invariably been highly successful in the production of clear water and in Barton triggered the development of a historical macrophyte community comprised of several stonewort species (*Chara* spp.) and a spectacular growth of *Ranunculus circinatus* (Figures 21 & 22).

Figure 21. Submerged macrophytes, especially *Ranunculus circinatus*, recolonised and dominated one of the fish exclosure at Barton Broad within two years

The technology of fish barriers is well advanced, as is their installation, which typically involves including an area of littoral margin. Barriers are generally supplied as interlocking panels which cost ~£100 m^{-1} depending on depth. The cost of installation is generally relatively low, in the region of a few £1000s. The effective connection of barriers to the littoral margin is particularly critical. The removal of fish from within barriers is generally straightforward and cost-effective and typically involves flushing or driving of fish from an open end of the barrier before it is sealed. Barriers are usually installed in the winter months, as few fish may have to be removed and the maximum length of time is available for the barrier to be prepared and stabilise before the summer growing period.

A further advantage of fish exclusion zones is that fish would not need to be removed from the catchment and/or destroyed as all fish captured in the removal exercise would simply be released the other side of the barrier. Moreover, the local anglers could play a role in any removal exercise by fishing within the area and releasing their catch into the wider lake.

Monitoring of key parameters such as water clarity, chlorophyll, TP and macrophytes as well as PASE surveys of fish would be required in- and outside the exclosure following fish removals. If resources are limited, water transparency and macrophyte growth may even be assessed visually without formal sampling, although confidence in the assessment of the response would obviously be considerably improved through structured sampling of the lake and exclosure for comparative purposes.

Figure 22. One of the biomanipulated fish exclosures in Hoveton Great Broad in spring 2011 showing the development of lilies and other plants in the clear waters. Picture courtesy of Mike Page aerial photography

5.2 Brown trout in the catchment

One of the aims for Loe Pool is for it to have ‘a healthy trout population’, although clear targets of what this means in terms of numbers, biomass or age structure were not stipulated. It is also implicit that the population of trout in the lake is entirely dependent on the population of the catchment, where the species spawns and recruits, with perhaps only older fish undertaking downstream migration to spend time in the lake before migrating back upstream to spawn. Thus, as with the successful reduction in nutrient input into the lake, a catchment-scale approach is required.

Whilst the survey data and anecdotal evidence from anglers indicate that the brown trout numbers within Loe Pool continue to decline, a greater understanding of the size and health of the population within the catchment and its interaction with Loe Pool is needed. For example, a reduction in numbers in the lake could simply reflect a decline in the wider population, or alternatively the fish, especially larger individuals could be actively avoiding the lake. Three potential options are available to assess the brown trout population of the Loe Pool catchment:

- A full-scale fisheries survey;
- a walk-over habitat survey, and
- redd counts and monitoring.

The completion of at least one of these options would be required in order to create a targeted management plan for the brown trout population. A further option, ‘stocking’, is also provided to directly increase the numbers of brown trout in Loe Pool.

5.2.1 Full-scale fisheries survey

The data on the brown trout population catchment gathered by the EA, in seven years between 1987 and 2012, sampled a total of 15 sites, with between one and thirteen sites being surveyed in each year (see Section 2.3). There is clear value in repeating a full survey of all of the former sites using the same sampling techniques (catch depletion by electric fishing) for comparative purposes. The NFCS classification would allow direct comparison of population quality scores as well as patterns of growth. Visualisation of the data within a Geospatial Information System (GIS) would also aid in understanding of trends in the data. For example previous the surveys identified key sites, such as the tributary to the west of Helston, which likely acted as a spawning and nursery site. It would be extremely useful to know if the same patterns are replicated or important sites have been degraded, which may have impacted upon the catchment population as a whole, including Loe Pool.

The information gained from this survey would then underpin a catchment scale management plan and ‘restoration vision’ for native brown trout, particularly when combined with the results of the walk-over habitat survey (see below)

5.2.2 Walk-over habitat survey

The aim of a walk-over (part could be undertaken by boat or canoe) survey of the River Cober would be to identify the availability and quality of habitat available to trout in the system. The surveys would also identify any factors which might limit recruitment, including artificial barriers to migration and any point sources of pollution. During the walk-over the potential for sources of non-native fish should also be investigated. There has been some discussion of the existence of fish-farms in the catchment. However, no specific information has been obtained in relation to the species held, practices undertaken and current status of these facilities.

It is already clear from the current survey that the system is far from natural, even down to the fact that the alien Himalayan balsam dominates the bankside vegetation over large stretches. Part of the river downstream of the lower pedestrian footbridge was not surveyed for this project due to blockage of the channel by overhanging vegetation and fallen trees in combination with debris brought down the river during flood conditions. Coarse woody debris may be excellent habitat for brown trout although in extreme cases could conceivably deter up- or downstream migration in periods of low flows.

A River Habitat Survey (RHS) style methodology could be employed, with a focus on identifying all suitable habitats for the species, such as clean, stony substrate for spawning and suitable pools with good cover for larger parr and adult fish. A cost-effective approach to the work may be for the surveys to be undertaken through the link with Falmouth Marine School, provided suitable training and supervision could be arranged. The survey would be best undertaken during the summer as conditions, especially flow may become limiting at this time.

The ultimate aim would be to extend the survey methodology into the River Carminowe and other tributaries to allow a catchment-wide assessment of the habitat available to brown trout. It is important that the resulting report provides clear detail of the means of improving the habitat available to brown trout as a series of rehabilitation schemes, perhaps ten or so that in combination would provide the basis for the ‘restoration vision’ for brown trout in the catchment (see above).

5.2.3 Redd counts & monitoring

Trout and other salmonids such as Atlantic salmon *Salmo solar* bury their eggs in nests, known as redds, within stone and gravel substrate. An initial survey at spawning time (typically from mid-October to early November – although local knowledge may provide a more specific indication) would aim to identify key spawning areas for brown trout within the River Cober (and Carminowe). Potential areas of search could be identified during the walk-over survey during the summer. With annual redd count surveys any trends in spawning activity may be identified.

5.2.4 Stocking

Where habitat quality for larger fish is not limiting, then stocking may provide a ‘quick fix’ to overcome limitations of spawning or fry habitat. However, as the population in the Cober and Loe Pool appears to be isolated and potentially genetically distinct, any introducing of non-indigenous stock to the catchment to increase brown trout numbers should not be undertaken.

However, there is the option that all brown trout (and eels) captured during any removal exercises in the River Cober (see above) could be introduced to the lake rather than immediately downstream of the isolated section to be dredged for flood defence work. This may at least enhance the stock in the lake, which is currently very low for whatever reason.

5.2.5 General fisheries management

A number of management options should be considered for the benefit of the fish community of Loe Pool. These are:

- Greater communication with the license holders should be attempted. Catch return data provides an important source of information and, although the current quantity is relatively small and the quality of the data cannot be verified, anglers fishing the water should continue to be encouraged to supply this information. This would lead to more detailed information on angling activity and would provide a greater understanding of the fish community of Loe Pool;
- Maintenance of the fishing pontoons, introduction of new pontoons or allowing limited boat access could be considered for the licence holders;
- Fishing activity should be monitored and licensing practices enforced to identify and minimise any poaching activity;
- Whilst promoting angling, a moratorium on removing catches (i.e. a catch and return policy) from Loe Pool should be introduced, the impact of which is likely to be minimal; and
- A fish health check of all fish should be undertaken, particularly for the roach, to further establish the condition of the fish community.

6 Conclusions and recommendations

6.1 Summary of findings

This report has provided detailed information on key aspects of the fish communities present within Loe Pool and the lower reaches of the River Cober. Analyses showed the current surveys performed reasonably well in identifying the general nature of the fish communities and abundance of the species present. Despite a lack of routine fisheries monitoring in the past, the information gleaned from the available survey data and literature, combined with the recent surveys, has allowed a general understanding of how the fish community has changed over time. The following points provide a summary of the key findings of this work:

- Historically the fish community of Loe Pool and the River Cober was likely to be dominated by potomodrous brown trout with eel and three- or ten-spined stickleback also present.

- Introductions of rudd in 1943, perch in 1994/95 and roach in ca. 2006 have lead to the sequential dominance of each of these species within the fish community. Rudd is known to originate from Coronation Lake but the sources of perch and roach remains unclear.
- There were two distinct fish communities present in the surveyed sections of the River Cober. Downstream of Helston and the Coronation Lake, roach were the dominant species whereas brown trout were the dominant species upstream. The community of the downstream section reflects the introductions of fish species noted in Loe Pool.
- The brown trout population within Loe Pool declined throughout the 1970's, and was attributed to an influx of sediment from decommissioned tin mines in the catchment, saline incursions and the general eutrophication of Loe Pool with associated algal blooms.
- The population of brown trout appears to have continued to decline in the lake despite improvements in water quality. No brown trout were caught in Loe Pool during the current survey, although they could still be present in low numbers.
- During the last two decades the riverine population of brown trout also appears to have been showing signs of a decline according to abundance classification, particularly in relation to fry. This may potentially be linked to a reduction in key habitat within the river and associated tributaries or other unknown factors influencing recruitment.
- Roach are currently the dominant species within Loe Pool and probably have been since 2007, shortly after their appearance. Perch remain prominent in Loe Pool and rudd remain present in low densities.
- Given the densities of fish derived from the 2007 hydroacoustic surveys and the lack of a possible fish-induced response in chlorophyll-a levels there is little evidence to suggest fish precipitated the collapse in macrophytes at this time. There is also no evidence for concurrent changes in TP during or before the loss of macrophytes. The loss of macrophytes remains unexplained, but periodic boom-and-bust is known to be a feature of populations of asexually reproducing species such as *Elodea nuttallii*.
- The current survey suggests that whole-lake fish densities are low at 0.15 ind. m^{-2}, with the majority comprised of roach (0.13 ind. m^{-2}). This is below the threshold (0.2 ind. m^{-2}) at which an effect on zooplankton might be expected. However, uncertainty surrounding the density estimates or threshold could mean that fish, particularly roach, are having a significant top-down effect on zoopkankton and thus on chlorophyll-a. Even small increases may reduce the available light climate at the sediment surface in a relatively deep lake such as Loe Pool, with a subsequent effect on macrophyte growth/re-establishment.

- A proportion of the current roach population may have a parasite infection (though this needs to be confirmed), which could inhibit the expansion of the population to greater densities. Such an infection may have already reduced the roach population, again leading to uncertainties regarding the historic influence of the species within the lake ecology.
- Although greatly improved, TP levels still remain high within Loe Pool relative to the target conditions and although macrophytes can exist at these nutrient concentrations, spontaneous regeneration may not be achievable until further reductions are achieved and the light climate improves.

Some key questions remain unanswered by this study, namely:

- How do brown trout and other fish species use the lake and riverine environments respectively, and how much movement is there between the two?
- Where did two of the colonising fish species (perch and roach) originate from and, more importantly, do these or other potential sources present a further risk from other invasive species to the system?
- What other key factors (e.g. sediment quality, nutrient cycling or availability of seed stock) are preventing macrophytes regeneration within Loe Pool, and can these be addressed?
- Can water quality targets be achieved through the current management plan and will further changes result in regeneration of the macrophytes?
- Will future climate change affect the productivity and success of brown trout within the system and how can future management plans mitigate any impacts?

6.2 Management recommendations

The following management recommendations are considered to provide practicable, cost-effective options that are most likely to aid in the understanding and improvement of the condition of Loe Pool:

- **Introduce experimental fish exclosures:** this provides a cost effective approach to determining whether whole-lake biomanipulation would be successful in aiding the rehabilitation of the Loe Pool macrophyte community. This would reduce uncertainty of the impact of the fish community on the status of the lake and other factors contributing to the failure of macrophytes to establish, following the successful reduction in nutrient input. The size, or number, of barriers would be largely dependent on cost (~£100 m^{-1} and installation for a few £1000s), as there are several suitable areas for such projects within the lake.
- **Conduct a walk-over survey of the River Cober:** This should identify any barriers to salmonid migration and availability of suitable brown trout habitats, providing vital information on factors linked to the success of the brown trout population. The

survey could also further identify any potential sources of non-native fish along the river. This work could be carried out by Falmouth Marine College and should ideally be run as an annual survey and potentially extended to tributaries of the Cober and also the Carminowe.

- **Carry out brown trout surveys throughout the catchment**: This should aim to survey the 15 sites previously sampled and classified by the EA, and use catch depletion methods in line with the previous surveys. Spatio-temporal trends in the results should be examined to determine any clear problem areas within the catchment during the monitoring period (1987-present). In combination with the walk-over survey, the surveys would provide a much better understanding of the Loe Pool catchment population, factors limiting recruitment and ultimately allow a targeted management plan for what appears to be a unique brown trout population. Given the results of these and the walk-over surveys the future of the brown trout population could be more accurately assessed in relation to changing conditions and different management scenarios.
- **Conduct a survey of Coronation Lake:** This should assess the fish community present in the lake and would aid in identifying whether it constitutes a potential source of non-native fish either historically or in the future. In combination with the walk-over surveys and further research, this would contribute to the understanding of the sources and control of potential invasive fish species within the system.
- **Introduce a moratorium on the removal of brown trout from Loe Pool:** Although it is unlikely that many brown trout are currently removed from the lake by anglers, given the apparent declines in the brown trout populations a moratorium on removals is a fundamental conservation step.

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9 Appendix 1: Summary of key fish species ecology

Brown trout *Salmo trutta*

Ecology: There are two forms, the anadromous (sea trout) and the fully freshwater (brown trout) which can be potamodromous (migrating from lakes into rivers to spawn). Freshwater brown trout can vary in colour from mostly silver to dark brown along the back with variable numbers of spots. The two morphs can co-exist in the same water but tend to be genetically identical and the factors determining the transition to sea trout remain unknown. Cover and habitat structure is important and provides protection from extreme conditions and predators. Deeper pools provide protection from freezing in the winter and fast flowing water provides good oxygen levels in the summer. Brown trout are an important commercial species in some areas as a sport fish (particularly sea trout) and have been widely farmed, introduced and stocked for sport fishing. Few fully natural populations of brown trout are likely to exist in isolated places.

Distribution: Widespread in UK, mainly in running and standing waters.

Reproduction: Occurs between September and October in small rivers and streams where eggs are laid in a nest (redd) which the female excavates in gravel substrate. Eggs hatch within around 150 days and the fry stay in the nursery stream for a year or more before moving down into a larger river, lake or the sea (sea trout). Adults mature at 3-5 years and females produce around 5,400 eggs each (around 2,000 eggs per kg).

Age and growth: Length of fully grown wild trout can range from an average of 26-42 cm up to 1 m. In many rivers a mature weight of <1 kg is usual.

Diet: Active during day and night, brown trout are opportunistic feeders. Young fish feed on invertebrates and adults feed on invertebrates (including terrestrial), frogs and even small mammals. In small streams they can be important predators of macroinvertebrates and declines in the species may affect the entire food web.

Roach *Rutilus rutilus*

Ecology: A shoaling species often associated with productive waters (e.g. shallow eutrophic lakes and rivers). The species is a highly efficient zooplanktivore when young and considered competitively superior to bream, rudd and perch which can limit those species to the littoral margin in algal dominated lakes. Predation by roach on zooplankton is known to cause dramatic ecosystem effects leading to algal domination. Capable of feeding in virtual darkness and turbid waters through olfactory and lateral line senses.

Distribution: Widespread in UK but generally found in lowland areas within small ponds, large lakes, small streams, large rivers and upper estuaries.

Reproduction: Spawning temperatures >12oC and between April and June. Highly fecund with between 5,000 and 200,000 eggs produced per female. Males develop tubercles mainly on head. Mass spawner on tree roots, emergent vegetation such as sedge roots and macrophytes. Eggs hatch in 5-10 days. Improved development above 14^{o}C. Males mature at 2-3 years and females mature at 3-4 years.

Age and growth: Often around 4-6 cm at end of first growing season. Growth typically density dependent. Competition can occur between age classes, reducing the growth, fecundity and survival of older fish. In eutrophic water bodies can grow quickly, reaching 15 cm at the end of the second year, more usually 10-12 cm. In such waters the species rarely exceeds 5 years of age, otherwise may live to 15 years or more, reaching over 1 kg in weight.

Diet: Adaptable omnivore. Larvae eat rotifers, protozoans etc. with some diatoms, quickly switching to cladoceran zooplankton. Older fish eat larger invertebrates (worms, insect larvae and mollusks) if available, otherwise zooplankton and benthic invertebrates are the main prey. Consumption of macrophytes increases with age, 80% of metabolic demands may be satisfied by blue-green algae. Guts often filled with detritus in winter.

Perch *Perca fluviatilis*

Ecology: May be abundant in mesotrophic and eutrophic lakes, both shallow and deep. Declines in eutrophic systems relative to cyprinids. Competitively inferior to roach in eutrophic lakes, where it relies on structured habitats and is often associated with macrophytes or littoral margins. Interactions between 0+ perch and roach are complex and depend on the available habitats, resources and temperature. Clear ontognetic shift in diet from zooplankton to invertebrates and then to fish with age. Habitat shift from pelagic and then littoral and benthic in large lakes. However, may feed on smaller fish at all ages, even fry known to be cannibalistic. Large adults may be important piscivores in macrophyte dominated waters. May structure populations of tench *Tinca tinca* and crucian carp *Carassius carassius*. Active pursuit predator in open water, in groups and relies on vision. May suppress recruitment of small cyprinids and itself.

Distribution: Widespread in UK in lowland and upland lakes, in slow flowing rivers and canals.

Reproduction: Spawning temperature 10-15^{o}C from mid-March and peaking in April/May, prior to most cyprinids. Females highly fecund, producing ~45,000 eggs per kg of body weight. Eggs are laid in ribbons amongst vegetation, tree roots etc. Eggs hatch within 8-16 days. Males may be precocious, spawning in year after birth. Females typically take at least one year more.

Age and growth: Grows quickly in good conditions, reaching larger sizes than cyprinids, often 9-10 cm at end of first year, 15 cm after second. Much individual variation dependent on diet. Competition between age classes on macroinvertebrates may act as 'bottleneck' determining growth, fecundity and survival. Lives to 10-13 years and reaches weights in excess of 2.5 kg.

Diet: Carnivorous. Zooplankton when small, switching to aquatic invertebrates and fish when older.

Rudd *Scardinius erythophthalmus*

Ecology: A shoaling species generally associated with macrophytes, which can be the dominant food item for mature fish. The species may have declined in the UK due to increasing eutrophication. Suffers from competition with roach, especially when young, although an upturned mouth provides an advantage when surface feeding. The species can hybridise with roach and bream.

Distribution: Widespread throughout the UK with a bias to the south. Mainly found in still or slowly flowing waters, particularly in lowland ponds and lakes.

Reproduction: Spawning temperature >15^{o}C and between April and June in southern UK (later further north). Males develop tubercles (nodules). Mass spawner, females producing 90,000-230,000 eggs which adhere to plants. Eggs hatch within 5-10 days. Mature at 3-4 years.

Age and growth: Typically smaller at end of first growing season than roach, only 3-4 cm. Variable growth thereafter. Can form stunted populations of small individuals in small lakes where they are dominant. Reaches at least 17 years of age and achieves larger size than roach.

Diet: Omnivorous. Young feed on diatoms, algae and zooplankton. Older fish feed on crustaceans and insect larvae, particularly weed-associated caddis and midge larvae. Some food is taken from the surface e.g. terrestrial insects. Macrophytes are important component of the diet of older fish.

European eel *Anguilla anguilla*

Ecology: Catadromous migrating to the Sargasso sea to spawn. Leptocephali larvae drift in the Gulf Stream, reaching the coasts as 'glass eel' the following year with a peak in the elver run in May. Elevers migrate against the salinity gradient into freshwaters, crossing some barriers and even travelling across damp ground. Often dominant by biomass in degraded rivers and alluvial systems in general. Nocturnal, remaining buried in cover during day. Uses olfaction to forage. Role in ecosystem function poorly understood, although likely to be important. May compete with bream for benthic invertebrates when small and may be an important piscivore when larger. Eels are an important food for a variety of piscivorous birds and otter. They are commercially valuable and often stocked as elvers for later harvest. Ongoing population declines have been associated with exploitation, increases in barriers to movements, parasites and water quality.

Distribution: Widespread throughout the UK. Present in brackish and freshwaters accessible from the sea.

Reproduction: Poorly understood. Spawning migration from freshwaters at varying sizes in late summer/autumn and spawn the following spring (Feb-May). Females may produce several million eggs and apparently die afterwards.

Age and growth: Little known. Generally migrate earlier at smaller sizes. Typically grow slowly, with virtual torpor in winter. Can reach over 1 m in length and >5 kg.

Diet: Carnivorous. Leptocephalus larvae apparently consume plankton. Elvers and older fish are largely benthic in habit, eating invertebrates of all types. Large eels take fish. All sizes of eels scavenge.

10 Appendix 2: Evaluation of sampling effort

Species accumulation curves were plotted in an attempt to determine whether the surveys were likely to have identified all fish species present in the littoral and limnetic habitats of Loe Pool (Figure 20) and the sections of the River Cober surveyed below and above the town (Figure 21). These figures suggest that the surveys of the Loe Pool littoral margin and the section of the River Cober below the town are likely to be broadly adequate in identifying the full diversity of fish species present as they approach an asymptote. However, the surveys of the limnetic region of Loe Pool and the section of the River Cober above the town suggest that an asymptote has not been reached and further species might be discovered. Note that although brown trout are probably present, they were not encountered in the surveys of Loe Pool and perch were also encountered outside of the PASE surveys (during free fishing) of the section of the River Cober above the town.

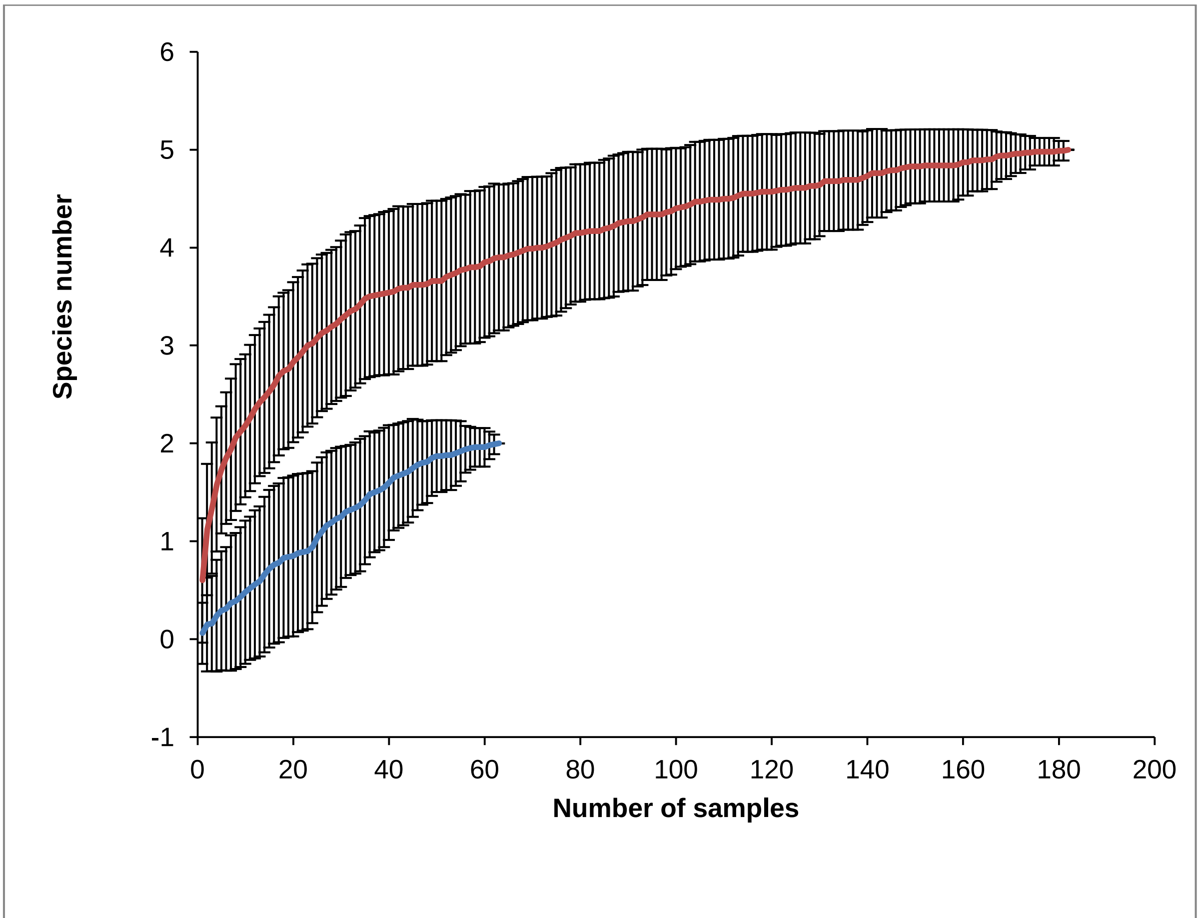

Figure 23. Species accumulation curves based on data from the PASE surveys of the littoral margin (red) and Limnetic zone (blue) of Loe Pool. Errors bars represent associated standard deviations.

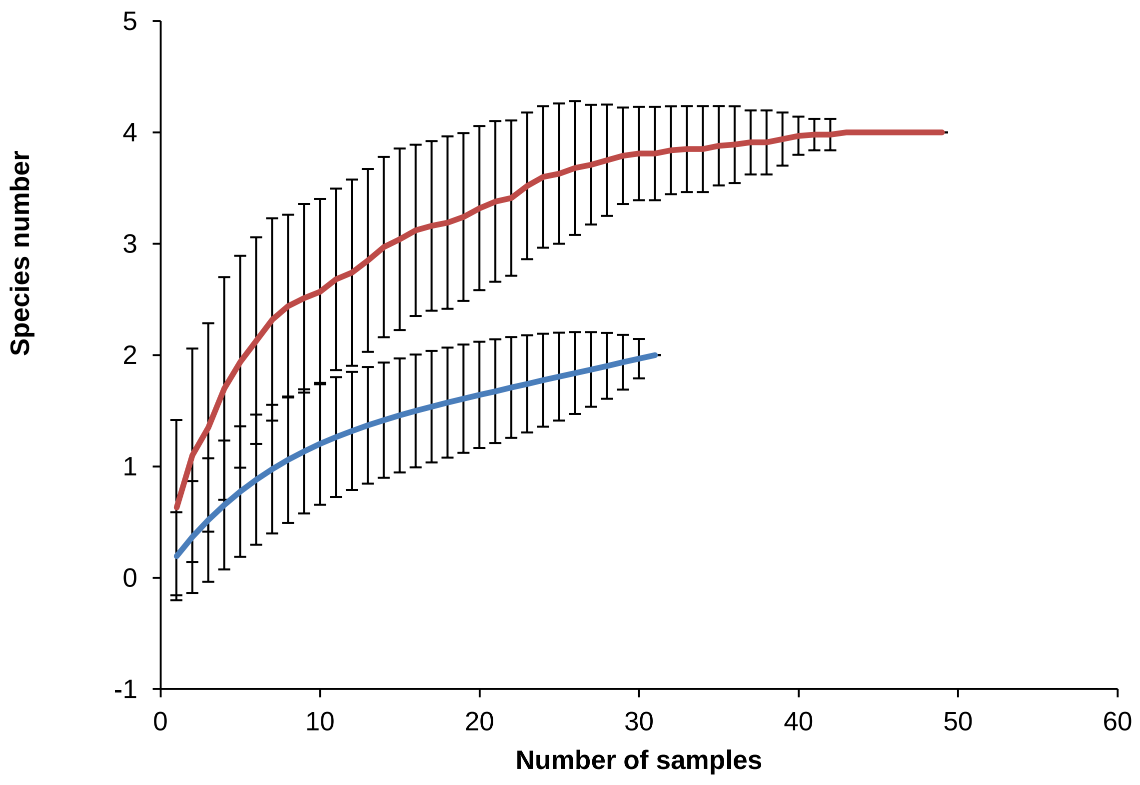

Figure 24. Species accumulation curves based on data from the PASE surveys of the downstream (red) and upstream (blue) sections of the River Cober. Errors bars represent associated standard deviations.

To examine the adequacy of the sample sizes to determine mean overall densities of fish, in the four areas discussed above, mean density estimates (and associated standard errors) were derived based on the use of increasing numbers of points (Figures 22 to 25). One would expect there to be high variability in the mean density estimates during initial survey points, with the estimates becoming more stable as a consensus is reached. This outcome is clearly shown in the plots for the littoral margin of Loe Pool (Figure 22) and section of the River Cober down-stream of the town (Figure 24). The results for the limnetic component of the Loe Pool surveys (Figure 23) suggest that the mean and standard errors are stabilising, although still decreasing slightly towards the limits of the sample effort achieved. In regard to the section of the River Cober above the town (Figure 25), the estimates appear to have stabilised with falling standard errors. These results again suggest that the sample sizes achieved are likely to provide a good approximation of the overall densities of fish in the different areas surveyed during this study.

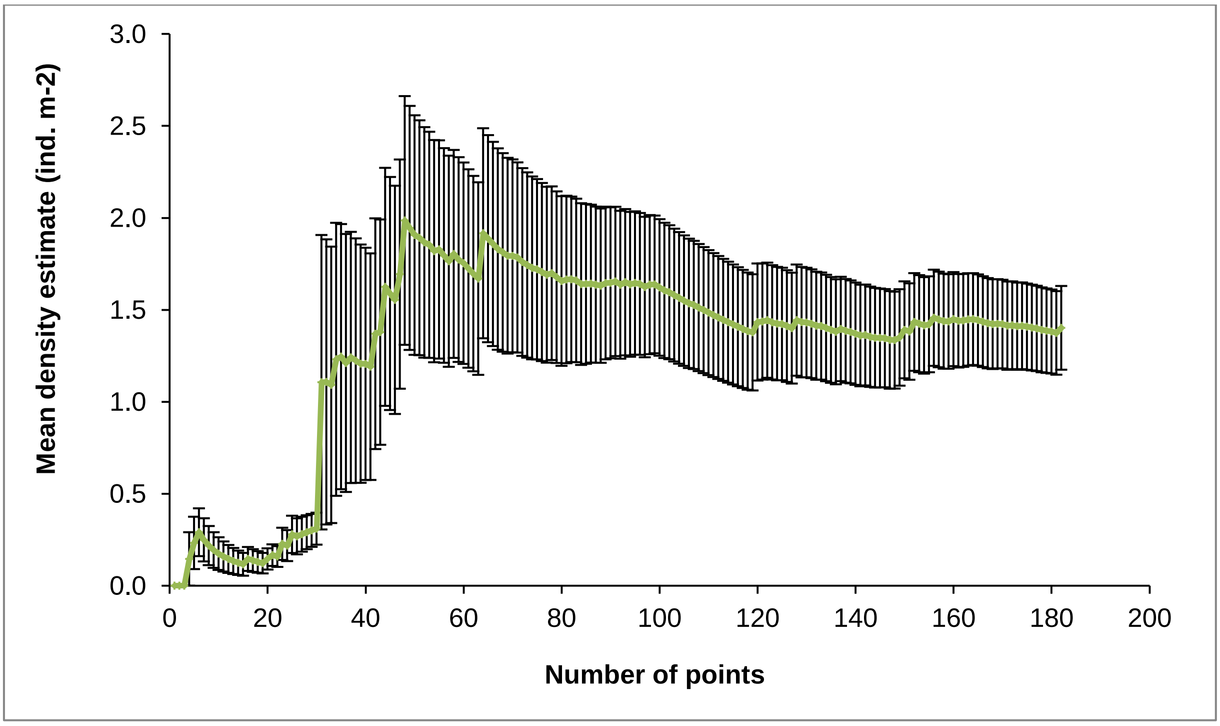

Figure 25. Mean density estimates for the littoral margin of Loe Pool derived from varying numbers of sample points added sequentially. Errors bars represent standard errors for each estimate.

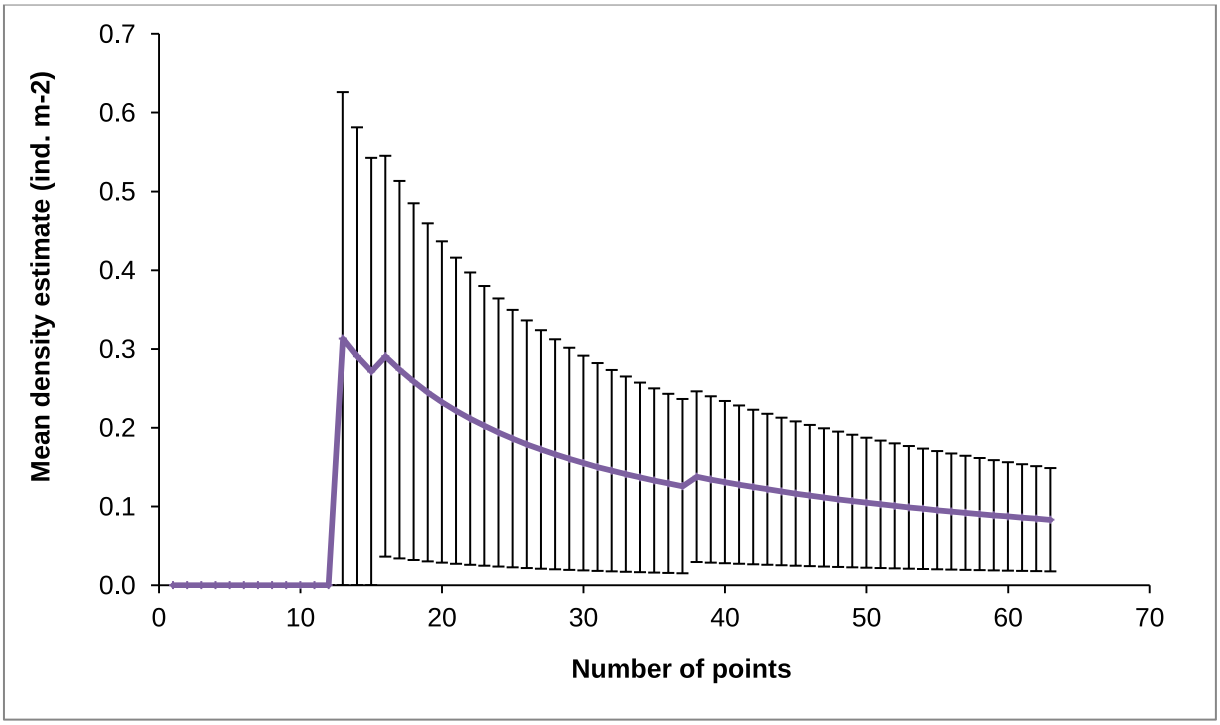

Figure 26. Mean density estimates for the limnetic region of Loe Pool derived from varying numbers of sample points added sequentially. Errors bars represent standard errors for each estimate.

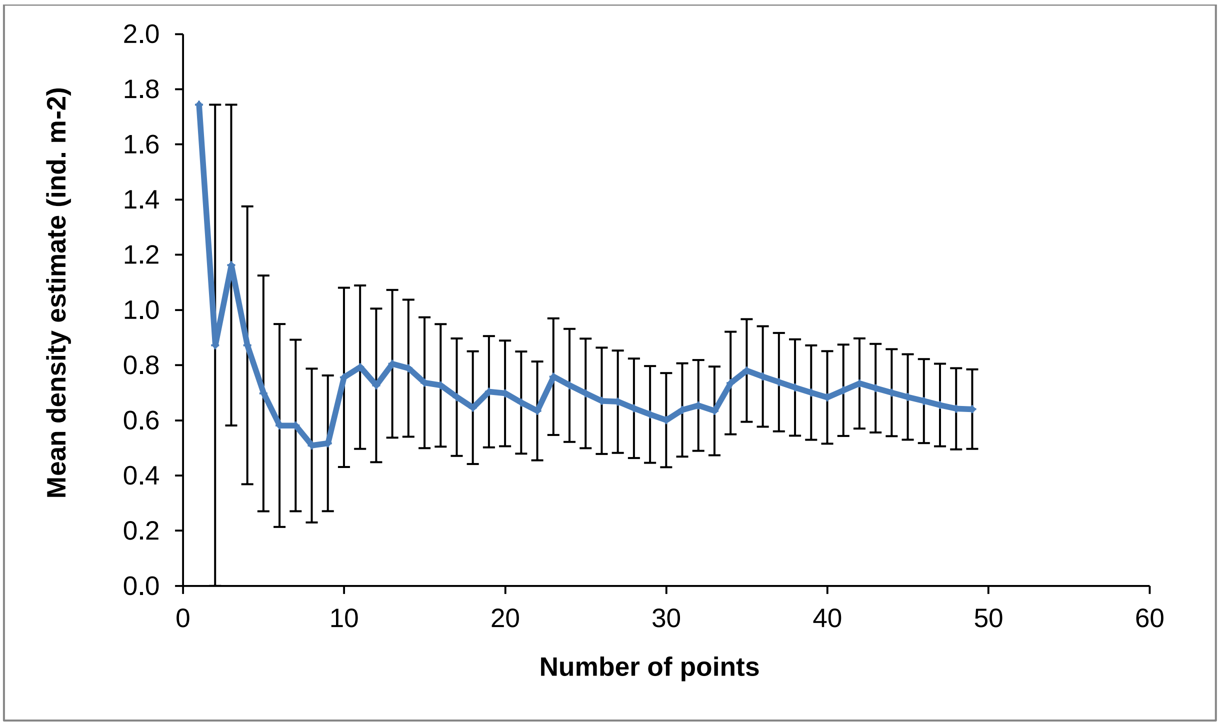

Figure 27. Mean density estimates for the downstream section (below the town) of the River Cober derived from varying numbers of sample points added sequentially. Errors bars represent standard errors for each estimate.

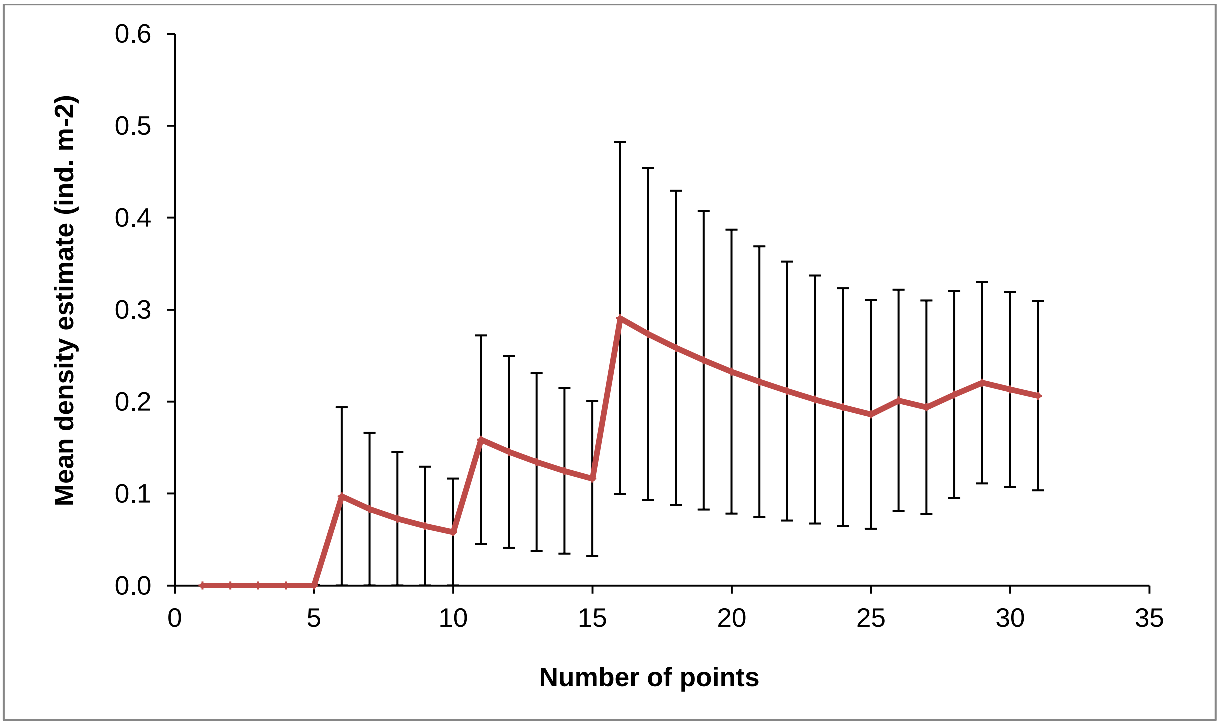

Figure 28. Mean density estimates for the upstream section (above the town) of the River Cober derived from varying numbers of sample points added sequentially. Errors bars represent standard errors for each estimate.