# Northern pike VI tag retention and population dynamics in Sportsmans Broad

Broadland pike tagging project Phase 1 technical report

V3 November 2015

Fishtrack Ltd

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# Foreword

We are working closely with the pike angling community following concern about a perceived decline in the quality of the pike fishery in the Norfolk Broads. Working in partnership with the Pike Anglers Club (PAC) and the Broads Angling Strategy Group (BASG) Pike SubGroup, this study is an important step towards improving our understanding of Broadland pike stocks and the factors affecting them. The project also forms an important contribution to the objectives of the Broads Angling Strategy.

Thanks to all the anglers that have helped us, we have been able to learn a great deal about the pike population in a major Norfolk Broad, alongside delivering the primary aim of the study to evaluate a promising and novel technique for tagging pike.

We are now in the exciting position of being able to apply the findings of this study and work with the pike angling community to roll out the project to the wider Broads system. The knowledge we gain by working in partnership with pike anglers will help inform our fisheries management decisions and in turn protect and improve pike fishing for the future.

On behalf of the Environment Agency I would like to thank everyone who has helped with the project so far.

Steve Lane

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Project supported by:

# Executive summary

- This study forms the first phase of a wider project to evaluate pike populations and factors affecting pike fishery performance within the Broads area
- This is the first known study to investigate the suitability and retention rates of Visual Implant (VI) Alpha tags in northern pike and the first study to undertake estimates of pike populations within the Norfolk Broads
- Additionally we assessed fish capture, tagging, processing and data collection methodologies that would enable trained angling volunteers to undertake similar pike study work in the future. The second phase of this project is designed around using a 'citizen science' approach to enable pike stock assessment to be undertaken around the wider Broads system
- The Norwich and District Pike Club (affiliated to the Pike Anglers Club of Great Britain) and the Martham Angling Club were the principal partners to the EA on the project. Volunteer anglers contributed substantially to the study, catching all pike in 12 organised tagging events that were undertaken over the course of 2012 and 2013 (6 events per year)
- This is one of the largest recapture studies using VI Alpha tags in the UK or Europe. A total of 522 pike were caught during the study period, comprising 12 tagging events over 2 years. 424 captures represented fish that were only caught once during the study ('virgin caught fish') and 98 pike were recaptured. 504 fish could be positively identified by gender
- Overall, of all pike captured 19% were recaptured. Within the Recapture group, females made up 60%, males 37%, and 3% were attributed to gender uncertainty. Within the gender groupings females were recaptured more than males, 19% and 17% respectively. From the Capture group 99.6% of pike were identified by gender (0.4% not identified by gender). The Recapture group 96.9% were identified by gender (3.1% not identified). 58.9% of all pike caught were female, 41.1% male
- The average time between initial capture and recapture was 265 days. Average growth from recaptured fish over the study period was 39mm (maximum 204mm). Recaptured fish grew on average 0.18mm /day-1 (maximum 1.47mm /day-1)
- This study had one of the highest tag retention rates of all studies using VI tags. More than 95% of pike retained both their tags. Dorsal fin ray tags were retained more than anal fin tags
- Strongest age classes (numerical representation) were fish born 2006 and 2007. Year Class Strength (YCS) growth performance was strongest in 1993, pre-biomanipulation, and 2010, 15 years post-biomanipulation. The poorest growth performance was from fish born in 1996, the year post-biomanipulation suggesting the biomanipulation temporarily impacted on the pike population through depletion of prey
- Growth of pike from this study would suggest that their weight for body length is satisfactory, an improvement of the 2006 study (Bielby), where fish were lighter for their given body length
- The largest pike caught during the study were 960mm, 10.15kg, March 2012 and 956mm, 9.78kg, January 2013. The largest fish caught in Sportman's Broad was 946mm, 10.29kg, March 2015, 2 years after the study completed. This was a previously caught and tagged fish, verified on recapture
- The majority of pike caught were within the size range 550-650mm
- Female pike grew larger than male fish from 6 years of age
- The pike population in Sportsman's Broad is estimated at either 756 or 846 fish, depending on which population method is used
- Pike population appears recovered from the post-biomanipulation decline. Data indicate adequate weight for size of fish and food sources are not limiting

- The knowledge gained and subsequent understanding of pike population behaviour post biomanipulation event, will prove valuable in decision making and in anticipation of expected outcomes following other lake restoration consultations. It is expected that the knowledge gained from this study will provide a clear idea of response of the pike community on other broads that may be subject to restoration. The short term decline of pike populations within such lakes appears to be reversed once the lake has begun to re-establish
- This study confirms VI tags are suitable for identifying pike over a 2 year time span. Best results are using 2 tags per fish. Tag readability declines over time suggesting 3 years is probably the maximum life span for reading tags. The methods and approaches developed are transferable to larger studies at other localities and crucially should enable the roll out of Phase 2 of the Broadland pike Project as originally planned

# Contents

# Introduction

Northern pike (Esox lucius), (henceforth known as pike) a Holarctic, circumpolar freshwater predatory fish widely distributed across the northern hemisphere, is one of the largest predatory fishes in the United Kingdom. It's widely distributed throughout the UK with the exception of areas of northern Scotland and Cornwall (Harding & Carter, in Davies et al., 2004). Specimen fish can attain sizes >20kg, though more typically circa 10-14kg. Growth is fast, with young of the year fish typically attaining 120-150mm in the first year (Hindes, unpublished). Maturity is usually between 2-3 years of age, with spawning occurring in shallow water, over emergent or submergent vegetation (Casselman & Lewis, 1996), usually with a sunny, quiet aspect to allow warmth and shelter for hatching young. Dietary requirements are broad, varying from invertebrates (Mann & Beaumont 1990; Paradis et al. 2008; Beaudoin et al. 1999; Kobler et al. 2009; Skov et al. 2003; Armstrong & Hawkins 2008; Venturelli & Tonn 2005) to wildfowl (Lagler et al. 1956; Dessborn et al. 2011), and from fish (Nilsson & Brönmark 2000; Mittelbach & Persson 1998; Lathrop et al. 2002; Skov & Nilsson 2007; Jolley et al. 2008; Craig 2008; Eklöv & Jonsson 2007) to crayfish (Elvira et al. 1996; Craig 2008; Roinn & Agus 1973; Pierce et al. 2003). They have commercial value (Koz'min 1980; Mehner et al. 2004) as a table fish in some parts of Europe, but within the UK they are regarded as the premier freshwater predatory fish and targeted as such by dedicated specialist anglers and curious novices alike.  Despite their fearsome appearance, pike are a delicate fish, which require careful handling in order to ensure post capture survival. Correct angling equipment is also an integral part of ensuring the fish is returned in optimum condition and so maximizing survival.

There has been widespread concern that pike stocks are declining, both in Europe (Lorenzoni et al., 2002; Nilsson et al., 2008; Lucentini et al., 2009;Baetens et al. 2013; Ouellet-Cauchon et al. 2014) and North America (Farrell et al., 2008), some of which is attributed to eutrophication such as within the western Gulf of Finland (Lehtonen et al. 2009), and also in Denmark (Jacobsen et al. 2004). Others suggest interspecific interactions, such as stickleback predation of pike eggs ((J. Nilsson 2006), or elevated temperatures in southern countries of Europe (Lucentini 2010). Pike appear on the IUNC Red List of Threatened Species (2015) as least concern. Low genetic variability (Jacobsen et al. 2005) may well leave the species vulnerable to changing external environmental and anthropogenic pressures. Whatever the reasons for decline, multiple or singular, this concern is also echoed by pike anglers who observe declines in catch rates and sizes (J. Currie pers. comm.).

The need for a better understanding of factors affecting pike populations was identified at a local within the original Broads Fishery Action Plan (BFAP 2003), a strategic partnership between the Environment Agency (EA), Broads Authority (BA) and the local angling community represented though the Broads Angling Strategy Group (BASG). The area of BASG/BFAP influence extends to 303km2, encompassing 83 sites of Special Scientific Interest (SSSI), 7 National Nature Reserves (NNR), 9 Local nature Reserves (LNR), 7 RAMSAR sites, 3 Special Protected areas (SPAs) and 4 Special Areas of Conservation (SACs). The document makes specific reference to the status of pike within the Broads area (p15&16. Sect. 2.4.4, BFAP 2003) and the need for research into pike populations (p17. Sect. 2.5, BFAP 2003).

The BFAP was reviewed by all partners and a new Broads Angling Strategy (BAS 2013) document was published in June 2013 in conjunction with the Angling Trust. This document sets out the key issues and objectives for the management of fisheries and angling in the Broads area, with understanding fish stocks in the Broads (E1 Environments for fish, BAS 2013) a key objective underpinning future management action.

Recent consultations by Natural England (NE) regarding lake restoration acknowledged the concerns of the angling community for pike populations within the area. This resulted in species-specific studies to investigate population levels, distribution and spawning habitat availability (Hindes, 2014).

In recent years local anglers have been voicing specific concerns about pike stocks in the Broads. This lead to consultation with Environment Agency Fisheries Officers and in 2010 BASG formed a Pike Sub Group under the chairmanship of John Currie (BASG member, General Secretary PAC GB) to focus on reviewing issues and recommending options for future management of the Broads pike fishery. The BASG Pike Sub Group organized 2 Broadland Pike Conference events (September 2010, September 2011) to gauge opinions from pike anglers from around the country. The outcomes reflected ongoing concern for pike stocks and more specifically the potential range of pressures on pike stocks. Of particular concern was the perceived level of angling pressure on the Broads pike fishery, including the potential negative impacts of large numbers of inexperienced anglers (newcomers to angling generally or anglers that have not fished for pike before) on pike welfare and survival. In conjunction with the Norwich & District Pike Club (NDPC) and with support from the Pike Anglers Club of Great Britain (PACGB), BASG approached the EA to explore the potential for research into pike welfare and populations in the Norfolk Broads.

A review of past routine EA fisheries monitoring data confirmed that specific pike monitoring would be required to assess factors affecting pike stocks and inform pike fishery management. The first stage was to devise a collaborative project to identify individual pike. This would permit population estimates to be generated, the first steps to identifying issues adversely affecting fish populations. In-kind contributions from the pike angling community (NDPC and Martham Angling Club (MAC)) were supported with science and technical input from EA Fisheries staff and latterly Fishtrack Ltd, a specialised fisheries consultancy).

The project was a pilot study to identify methods of capture and tagging fish, which would not require Animals Scientific Procedures Act (ASPA) (a Home Office administered regulatory act to afford protection to vertebrate animals within scientific enquiry and laboratory fields) regulated procedures and would have minimal impact upon the pike, yet provide data that could be collected in future by non-specialist staff with suitable training. It was anticipated that this approach would facilitate wider reaching projects in the future by enabling a supervised ‘citizen science’ model for data collection. This model would also empower the pike angling community, by enabling anglers who had the most interest and knowledge to help conserve pike stocks through contributing valuable data.

This work aims to determine the effectiveness of VI alpha tags in Northern pike for purposes of identification and overall stock assessment. It will evaluate suitability of tag site selection and retention rates in order to inform future pike population studies. Due, in part, to the significant assistance received from angling volunteers, we also aim to estimate the pike population size and structure of an important lowland shallow lake and renowned pike fishery in the Norfolk Broads in the East of England. Additional objectives included determining gender ratios, Catch Per Unit Effort (CPUE) based upon angler days, as well as growth rates and performance of individuals.

# Methods

Identification of pike by characteristic markings has been previously undertaken with some success (Fickling 1982; Hawkins et al. 2005). However, Hawkins et al., (2005) work was laboratory based and made use of 45 individual pike, whereas this study was field based and anticipated capture of many more pike. Fickling's (1982) work made use of photographs of pike for identification purposes. Although the sample size was large (n=187) it bore no resemblance to field based work and it had little application as a method of identification in field based studies with multiple contributors. Furthermore, Hawkins' (2005) study made use of large fish (838-1118mm) concluding that the method was more effective on fish larger than 500mm. The quantification of overall effectiveness was unclear and the author acknowledged its unsuitability on fast growing fish as well as time limited applicability (~2 years). The current study anticipated capture of fish at various sizes in an attempt to represent the population, anticipated a study of 2+ years and relied upon reporting from specialist anglers in the field. Therefore, photographic recognition was rejected as a suitable method. Furthermore, this method was not deemed suitable for scaling up to encompass and area as large as the Norfolk Broads due to its limitations in coping with and analyzing potentially large numbers of fish.

Previous work on pike in the Norfolk Broads (1999-2002) (Sportman's Broad) relied upon specialist pike angler contributions where fish were identified via a unique pattern of panjet dye markings (Hindes, unpublished). As the sample size increases the variance of marking options decreases. Recording such markings and ensuring all parties are aware of latest marks becomes increasingly more difficult. Furthermore, the reliability of panjet dye markings is subject to conjecture. For example, panjet dye markings on cyprinid fish are questionable over the longer term, with a fall off in reliability past 5 months (Bolland et al. 2010). Panjet marking of common bream Abramis brama in Sportsman's broad has been successful up to 2 years (Hindes, unpublished), but without double marking it is difficult to quantify the reliability of the method. However, experience of marking pike in this way has previously been largely unsuccessful (Hindes, unpublished).

Consultation with the BASG Pike Sub Group identified some key concerns that would need to be factored into the criteria for an applicable tagging methodology. These ranged from pike welfare to the perceived 'discreteness' of tags, which may otherwise detract from the angler's sense of achievement in catching a specimen fish (similar to the system of 'ethics' and 'etiquete' within the sport of climbing). A literature review and web trawl was conducted to investigate the variety of tagging methods that might be applicable to the tagging requirements for the project. Various methods of tagging fish (see Babaluk & Craig, 1990; Buckley et al., 1994; Basvaraju et al., 1998) were discounted due to unsuitability, poor tag retention (Moffett et al. 1997), poor mark retention (Hindes, unpublished), fish welfare (Rickardsen et al., 2000; Zerrenner et al., 1997; Mourning et al., 1994), potential impact upon fish movement or behavior (Halls & Azim, 1998), ASPA requirements and/or costs. It was decided to trial VI Alpha tags, a visual implant tag developed by North West Marine Technologies (NMT), not previously known to be used on pike (Table 1.). The tags comprise an alphanumeric code printed on a florescent background. The tag is inserted under the skin surface and is readable either with naked eye or augmented with a magnifying glass and/or a UV light.

A series of laboratory-based experiments were undertaken to determine potential tagging sites for pike. Previous studies employed VI Alpha tags for salmonids, where the tags are inserted into the postorbitol adipose tissue. In larger fish, retention rates can be as high as 75% (Davis et al., 2014). However, postorbital tissue is not present in pike, leading to other site selection possibilities. The lower mandible was considered, where the tissue is soft and white for a potential tagging site. However, following trials it was subsequently rejected. Meerbeek et al., (2013) tagging walleye, also found this location unsuitable.

It was eventually determined that tagging between fin rays in the soft, relatively clear tissue, would provide the optimum site, despite varied retention rates for anal fin tagging of some species, and being reported as low on small salmonids (Davis et al., 2014).

The dorsal and anal fin rays were selected as the target areas for tagging. In order to evaluate site effectiveness, tags were implanted into both sites, whist selecting specific fin rays on their transparency and lack of mottling. Furthermore, a dye was injected subcutaneously at the root of the dorsal fin and/or along the edge of the fin ray. This permitted identification of fish that had lost all tags.

Two study sites were selected for the pilot project.

- Burnt Fen, comprised a small privately owned broad with limited public access and a reputation as a pike fishery, located off the River Bure and adjacent to Horning. It was considered that this broad would probably produce the most fish per unit effort and would increase the probability of recaptures and hence developing population estimates.

- Sportsman's (Ormesby) Broad, is a large (55ha) broad, part of the Trinity Broads (a complex of 5 interlinking broads) located in a side valley off the main River Bure, Norfolk. Sportsman's Broad was selected due to past reputation as a pike fishery, because it was under the management of the NDPC which enabled participation events to be organised, and the large size better reflected the challenges of an intended wider roll out in the Broadland rivers, should the pilot study prove successful. Both broads have no access for holiday boat traffic.

The study was to run for 2 years with the potential for this to be extended formally or informally. There were 6 events scheduled per year at either broad, depending upon each sites performance in the initial trials. Due to mixed success on Burnt Fen, and high success on Sportsman's Broad, the later was used exclusively for the remainder of the study (Fig. 1).

Following an assessment of pike capture recapture methods employed in 4 small (2.1-13.8ha) lakes in southern Finland (Kuparinen et al. 2012) (Table 2), and the presence of mammalian and avian predators at both sites, it was decided catch methods from angling effort would be deployed. Each event comprised of pike anglers, EA and Fishtrack staff catching pike by rod and line using a variety of methods except live baits. Participants would meet at dawn for a briefing and fish throughout the day, returning at dusk. Each boat, composed of up to two anglers, and was provided with fish keep cages enabling captured pike to be retained and recover prior to any post processing by specialist staff. Large individuals were processed immediately to reduce retention times and ensure stress was reduced to a minimum. Furthermore, each boat had all necessary unhooking and fish landing equipment. All boats were in communication with specialist staff and each other to ensure any difficulties were quickly identified and rectified. Anglers made judgment as to numbers of pike per keep cage, which was also dependent upon size of individual, season and water temperature.

Post processing comprised tagging, marking and collecting biometric data. The post processing team was composed of 4 personnel, each assigned specific duties. This reduced processing time and ensured each fish was handled as little as possible and returned to the water promptly and efficiently. Scales were taken to estimate age of fish and growth rates and also to enable stable isotope analysis (in prep). Fish were assessed for gender using vent recognition as the indicator, and all personnel were trained in this method to ensure consensus. Each fish was weighed and measured to the nearest mm fork length (Fl) to provide size class information and growth performance. The fish did not require sedation during any stage of the post processing and tagging.

Tagging was carried out on the left hand side of the fish in both dorsal and anal fin rays, with a dye mark added to the dorsal fin. The alphanumeric tag codes were recorded along with all other data for each individual. Tagging comprised subcutaneous insertion of the VI tag via a long tunnel created by the needle insertion at the outer end of the fin ray towards the fin ray root. Care was exercised to avoid areas of dark pigmentation and also to ensure the tag was inserted shallow within the subcutaneous material to reduce opacity inhibited readability of the tag. Scale packets were identified to the individual with their respective tag codes also on the packet. Recaptures were recorded, and the weights and lengths re-taken as well as gender checks. Individuals with missing tags were noted along with which location the tag was absent from. Fish with no tags but a visible mark were also recorded. General body condition and any outstanding features or injuries were also recorded. During post processing no fish required sedation and this was not considered part of the protocols. However, fully recovered pike require careful and expert handling requiring a dedicated team to process the fish. Database construction included looking at CPUE (Table 3) based upon angler effort, which was recorded at each event.

All catches at each event were recorded. Further to this, a catch reporting system was designed and incorporated into the project that allowed anglers outside the events to also contribute. A system of report cards, text, mailbox and email was provided along with instructions for specialist anglers to process and report their catches. Tagging of fish was not permitted on such occasions, but taking biometric data and recording tag presence and identification was.

The study was to incorporate two capture-mark-recapture methods in order to provide an estimation of the pike population. The ‘first catch’ was year 1 and the ‘second catch’ being year 2. Both Petersen (Fig. 12) and Schnabel (Fig. 13) mark recapture methods were incorporated into the population estimate protocol.

Petersen mark recapture method (PMR) is a basic method for estimating population based on single sessions of marking and recapturing. In this study the first year is the single first session, the second session is the second year. The PMR is estimated thus:

$n1$ = number pike captured and marked and released on the first occasion

$n2$= total number pike caught in second occasion

$m2$= number of marked individual pike found on the second occasion

Total population size ($N$) is estimated thus:

$N = (n1 + 1) (n2 + 1)/(m2 + 1)-1$

95% confidence intervals (CI) were also calculated.

The Schnabel method is based upon quite similar assumptions as the PMR, but more appropriate to several capture and recapture events. As in this study, all unmarked pike caught are marked prior to release. The Schnabel method is thus:

$S$ = number of fishing events

$ni$ = number of pike in the ith fishing/sampling event

$mi$ = number of pike in the ith fishing/sampling event that are already marked/tagged

$ui = ni - mi$ = number of unmarked pike prior to the ith fishing/sampling event

$Mi = i\text{-}1/\sum/j\text{=}1uj$ = number of pike tagged prior to ith fishing/sampling event

95% CI were also calculated.

# Results

Preliminary work on both sites in 2012 demonstrated that pike captures, both male and female, were more prolific on Sportsman's Broad when compared to Burnt Fen and would provide a considerably larger data set (Fig. 1).

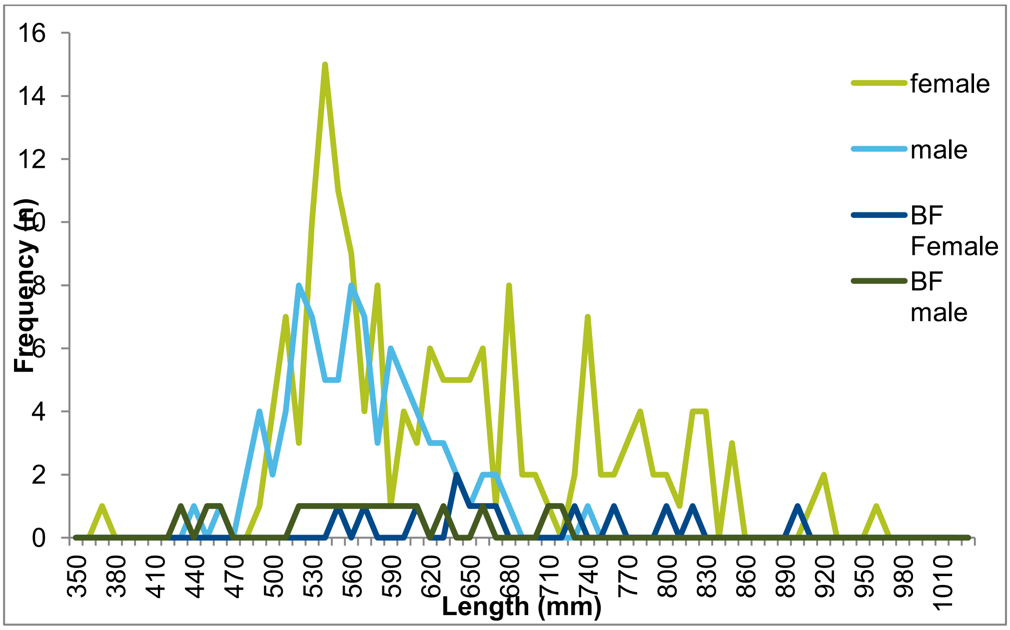


**Figure 1 Length frequency of pike in Burnt Fen (BF) and Sportsman's Broads, differentiated by gender 2012-2013.**

Evaluation of visual implant tags was undertaken prior to tag selection. The majority of the studies concentrated on the effectiveness of VI alpha tags in salmonids (circa 30 papers overall, 12 presented here). No reviews of VI alpha tag retention in northern pike could be found within the literature, with just a single esocid related review (Table 1). Duration of the review of tag retention in that study was short (28 days). Only two studies monitored retention rates > 1 year with few studies trialing on large fish (typically 150-300mm) and no fish >534mm Tl (Table 1.). The current study has tagged and monitored fish of > 960mm Fl. Of the 13 studies within 12 papers, which recorded 17 different monitoring durations, only 1 study exceeded the current studies tag duration of 730+ days and that was on walleye Sander vitreus, a North American percid (Meerbeek et al., 2013). There was a singe study using the anal fin tag site (Davis et al., 2014), in two sizes of rainbow trout and no incidences of dorsal fin tagging within the range of studies (Table 1.). Overall average retention rate was 65.5% (+5.0) where mid-point figures for a range were added to the baseline retention rate have been included. Overall average duration of study was 256.1 days (+101.4).

**Table 1. Review of VI tag retention literature in various fish species**

| Common name | Binomial nomenclature | Retention rate (%) | Fish size range (mm) | Duration (days) | Reference |
|---|---|---|---|---|---|
| **Arctic charr** | Salvelinus alpinus | 68<br>96 | 100-150 Fl<br>150-200 Fl | 30-365 | Rikardsen (2000) |
| | | 46<br>91 | 100-150 Fl<br>150-229 Fl | 25-70 | Rikardsen (2000) |
| **Arctic grayling** | Thaymallus arcticus | 98 | 137-236 Tl | 30 | McMahon et al, (1996) |
| **Brook trout** | Salvelinus fontinalis | 63-100<br>89-100<br>97-100<br>75<br>50<br>100 | 211-470 Tl<br>211-470 Tl<br>260-355 Tl<br>197-265 Tl<br>130-160 Tl<br>200+ Tl | 29-100<br>29-100<br>354-454<br>7-251 | Hughes et al. (2000)<br>Zerrenner et al. (1997)<br>Bryan et al. (1994) |
| **Brown trout** | Salmo trutta | 72 | 235-273 Tl µ | 183 | Summers et al. (2006) |
| **Rainbow trout** | Oncorhyncus mykiss | 15<br>25<br>28<br>63<br>30<br>75 | <200 Tl ^<br><200 Tl `<br>200-300 Tl ^<br>200-300 Tl `<br>>300 Tl ^<br>>300 Tl ` | 182 | Davis et al. (2014) |
| **Walleyes** | Sander vitreus | 58<br>36 | 534 Tl µ | 1825 | Meerbeek et al. (2013) |
| **Tiger muskellunge** | Esox masquinongy x Esox lucius | 92 | 91 Tl µ | 28 | Turek et al. (2014) |
| **Patagonian catfish** | Hatcheria macraei | 90<br>80<br>66 | -<br>-<br>- | 45<br>200<br>254 | Barriga et al. (2014) |
| **Orange barbel** | Barbus haasi | <20 | <110 Tl | 84-310 | Aparicio & de Sostoa. (1999) |
| | | 46 | >150 Tl | | |
| | | 56 | >200 Tl | | |
| **Ling cod** | Ophiodon elongatus | 100 | 152-190 Tl | 160 | Buckley et al. (1994) |

| **Puget Sound rock fish** | Sebastes caurinus | 85 | 152-190 Lt | 330 | Buckley et al. (1994) |
|---|---|---|---|---|---|

Fl fork length Tl total length

µ mean length

^ anal tag site

` adipose tag site

- information not available

Angling is an effective method of harvesting fish and the reason it was deployed in this study. It was also selected to ensure that future data collection could be undertaken in partnership with the angling community. In the analysis of Kuparinen et al., (2012) angling was the second most effective method in 3 of the 4 lakes studied (Table 2) across all years. Only in Lake Hokajärvi did the method fall to third place in overall mean catches (n) by method overall all years.

**Table 2. Assessment of capture recapture methods of pike in four small Finnish lakes, 2006-2009. (Adapted from Kuparinen et al., 2012).**

| **Lake** | **Method** | **2006 (%)** | **2007 (%)** | **2008 (%)** | **2009 (%)** | **Lake Mean n (+ 1 S.E.)** |
|---|---|---|---|---|---|---|
| **Hokajärvi** | Angling Lure | 27.1 | 20.8 | 34.7 | 29.1 | 17.3 (4.52) |
| | Fyke | 42.4 | 33.3 | 22.2 | 32.9 | 18.8 (4.23) |
| | Trap | 27.1 | 37.5 | 38.9 | 34.2 | 20 (4.56) |
| | Gill net | 3.4 | 8.3 | 4.2 | 3.8 | 2.2 (0.29) |
| **Haarajärvi** | Angling Lure | 29.1 | 17.1 | 33 | 35.8 | 43.3 (13.19) |
| | Fyke | 10.5 | 29.7 | 15.2 | 21.6 | 27.3 (6.12) |
| | Trap | 60.5 | 51.4 | 50 | 41.2 | 71.3 (14.7) |
| | Gill net | 0.0 | 1.8 | 1.7 | 1.4 | 2.0 (0.82) |
| **Majajärvi** | Angling Lure | 42.7 | 35 | 17.9 | 37.1 | 21.5 (5.98) |
| | Fyke | 18.3 | 43.8 | 12.5 | 5.7 | 14.8 (7.26) |
| | Trap | 36.6 | 18.8 | 64.3 | 51.4 | 24.8 (4.96) |
| | Gill net | 2.4 | 2.5 | 5.4 | 5.7 | 2.3 (0.25) |
| **Haukijärvi** | Angling Lure | 51.5 | 17.9 | 21.4 | 46.7 | 9.3 (2.95) |
| | Fyke | 27.3 | 57.1 | 28.6 | 20 | 12 (6.79) |
| | Trap | 12.1 | 23.2 | 28.6 | 20 | 6.0 (2.35) |
| | Gill net | 9.1 | 1.8 | 21.4 | 13.3 | 2.3 (0.48) |
| **Angling annual mean n (+ 1 S.E.)** | | 23.25 (4.4) | 15.5 (5.07) | 28.5 (16.48) | 24 (10.21) | |

A total of 522 fish were captured during 12 events over 2 years. Of these, gender was ascertained in 507 individuals, which was reduced to 504 positive gender identifications by consensus, the others being indeterminate or conflicting assessments. Within this period there were 424 individual fish captured, ‘virgin fish’. Recapture data shows 98 pike were recaptured during the course of the study. However, after data cleaning (due to typographical, instrumental and field data errors) some data has been omitted from analysis. Therefore, the actual comparisons are with a data set of 96 recaptured fish (Table 3.).

**Table 3. Angler based specific and mean effort (+ 1 S.E.), capture and recapture & Catch Per Unit Effort, Sportsman’s Broad 2012-2013**

| Fishing Date | Angler effort | Pike virgin caught & total caught ( ) | CPUE |
|---|---|---|---|
| **18/2/12** | 3 | 17 (17) | 5.667 |
| **10/3/12** | 10 | 18 (20) | 2.0 |
| **5/5/12** | 15 | 100 (103) | 6.867 |
| **10/6/12** | 15 | 68 (76) | 5.067 |
| **18/11/12** | 11 | 22 (28) | 2.545 |
| **2/12/12** | 19 | 45 (50) | 2.632 |
| **17/2/13** | 17 | 22 (29) | 1.706 |
| **2/3/13** | 8 | 18 (20) | 2.5 |
| **5/5/13** | 7 | 34 (65) | 9.286 |
| **9/6/13** | 14 | 39 (54) | 3.857 |
| **17/11/13** | 14 | 14 (21) | 1.5 |
| **1/12/13** | 16 | 27 (39) | 2.438 |
| **Mean** | 12.42/trip | 35.33(8.91) | 3.84 |
| **S.E.** | 1.35 | 1.24 (0.84) | 0.70 |

Recaptured fish were subsequently re-measured and re-weighed on recapture. This enabled differences in growth to be determined from original capture. Since length is assumed to be correlated with growth, (and so weight), fish length at recapture was the principle focus. Individual pike that lost length between first and subsequent capture comprised 14.6% of the total recaptured fish. This is attributed to miss-measurements and these fish were subsequently excluded from the study. Of the remaining recaptured fish, 23.2% saw no change in growth, and 76.8% increased growth between these events. Average growth was 38.62mm (+ 4.799) and maximum growth 204mm. Comparison of pike growth between capture and recapture shows that significant growth occurs between the two events (T-test P= 0.035).

Recaptured pike data was obtained from project events as well as via the reporting scheme, therefore more than 12 events are reported on (Fig. 2). The highest capture per event was 103 fish, May 2012 (Fig. 2). May 2012 and 2013 also provided the highest number of pike captured during the study (Fig. 2).

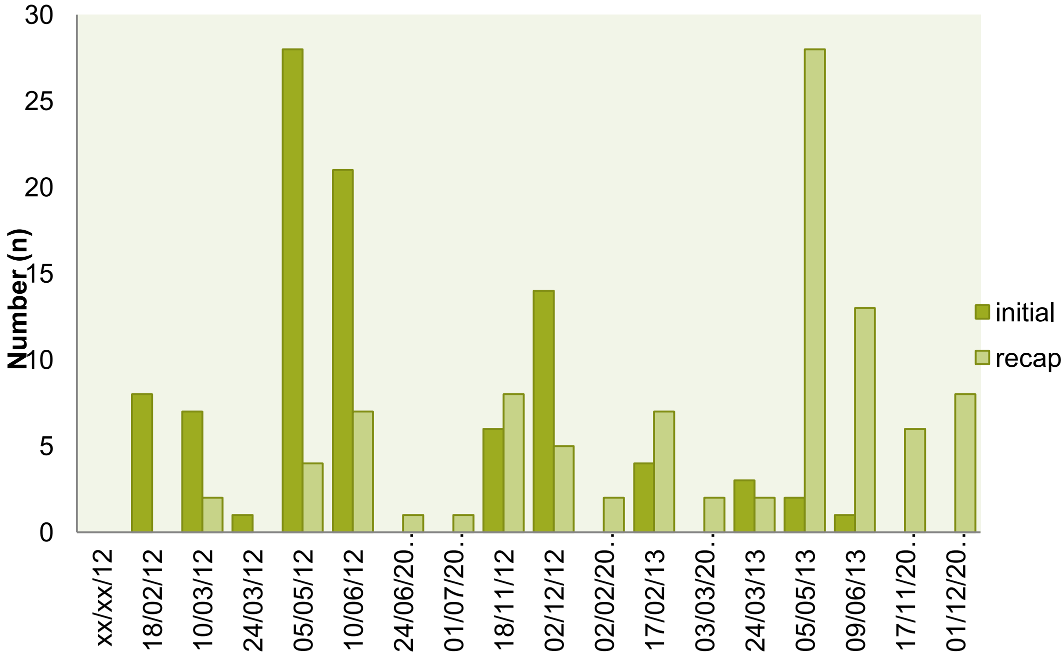


**Figure 2. Initial pike capture and recapture by event, Sportmans Broad, 2012-2013.**

A total of 9 different alpha prefixes were used to identify individual fish and also an overlap where two tags changed between tag sheets (Fig. 3). The highest number of fish tagged with a prefix were D prefix tags (Fig. 3.).

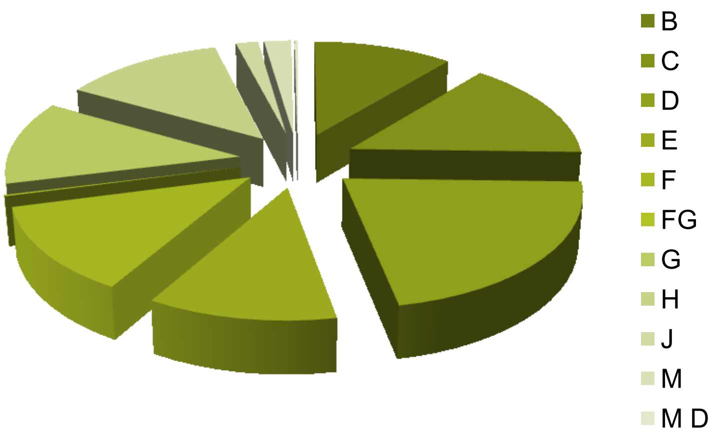


**Figure 3. Relative proportion of pike tagged with different prefix tags**

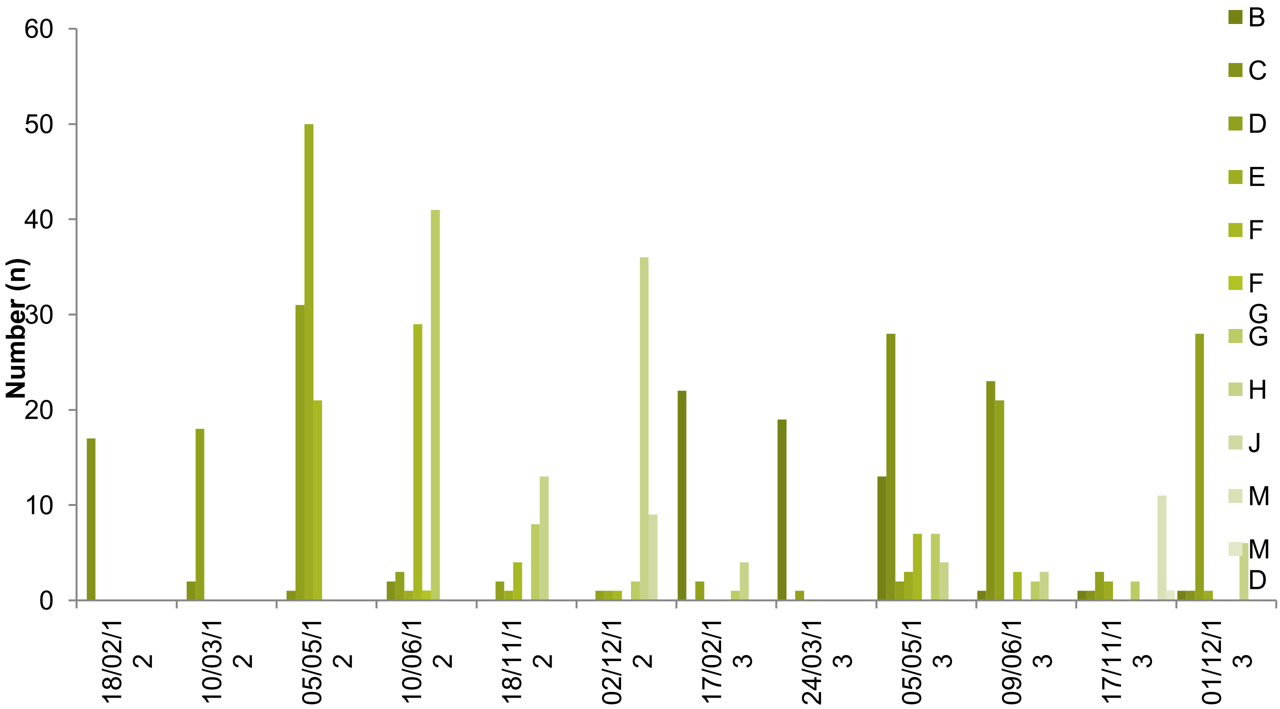


**Figure 4. Numbers of tags and prefixes issued per event, Sportsman's Broad, 2012-2013.**

Gender distributions were slightly skewed towards females, 58.9% to 41.1% male (Fig. 5, Table 4).

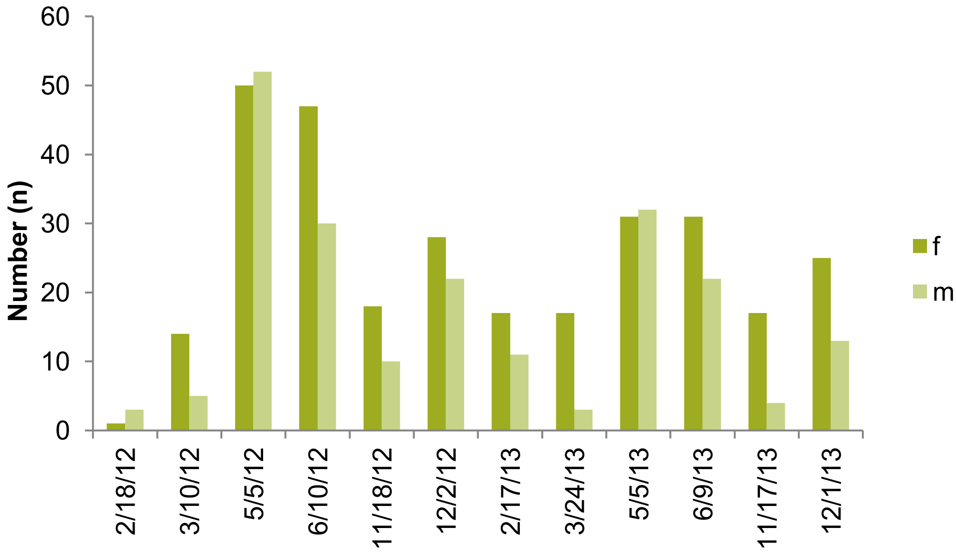


**Figure 5. Male and female pike captures by event, Sportsman's Broad, 2012-2013.**

Overall, of all pike captured 19% were subsequently recaptured (Table 4). Within the recapture group, females made up 60%, males 37% and 3% were attributed to gender uncertainty. Within the gender groupings females were recaptured more than males, 19% and 17% respectively. 0.4% of pike were not identified by gender from the Capture group. Indeterminate gender assessment from the Recapture group was 3%. More females were captured than males 58.9 & 41.1% respectively.

**Table 4. Gender Based Capture and Recapture, Sportsman's Broad 2012-2013.**

| | Female | Male | F/M? | ? | M? | Total |
|---|---|---|---|---|---|---|
| **Captures** | 297 | 207 | | 1 | 1 | 506 |
| **Recaptures** | 57 | 36 | 2 | | 1 | 96 |

Overall mean length of captured pike was 612.9mm (+ 4.1) (Fig. 6). The length frequency of pike peaked between 530-650mm (Fig. 6). The overall distribution was skewed towards the mid sized fish upwards. Few small fish were captured. The largest fish was a 960mm female, though the heaviest fish was a 946mm female which was caught in 2015 (Table 5.). This fish was a previously caught fish tagged in March 2013 at 840mm, weighing >6kg. There were several fish >800mm also captured (Table 5.). Growth rates of recaptured pike averaged 0.18mm (+ 0.03) /day-1, maximum 1.47mm /day-1.

**Table 5. Date of capture and size of the larger component of the pike stock, Sportsman's Broad 2012-2013.**

| Event | Fish length (mm) Fl | Fish Weight (gms) |
|---|---|---|
| **10/03/12** | 960 | 10149.1 |
| **05/05/12** | 850 | 4195.7 |
| **05/05/12** | 911 | 6940.5 |
| **10/06/12** | 904 | 6577.1 |
| **17/02/13** | 910 | 6151.8 |
| **17/02/13** | 956 | 9780.6 |
| **05/05/13** | 864 | 5783.3 |
| **05/05/13** | 910 | 6945.6 |
| **17/11/13** | 854 | 5896.7 |
| **17/11/13** | 884 | 5896.7 |
| **01/12/13** | 900 | 7030.7 |
| **07/03/15*** | 946 | 10290.9 |

* recapture, captured outside the 2 year study during training event.

The largest individual pike by length were captured during March and May of 2012 and January and May 2013 (Table 6.). Overall average size pike by length was highest during November 2012 and January 2013. Pike were heaviest (collectively) during May 2012, taking into account the larger variance surrounding the March 2012 estimate. During 2013 January produced the highest average weight 3075.43 (+ 338.69).

**Table 6. Angler caught pike overall mean length and weight (+ 1 SE) and minimum and maximum size per event 2012-2013.**

| **Ln (mm) Fl** | | | | | | |
|---|---|---|---|---|---|---|
| **2012** | 18/02/12 | 10/03/12 | 05/05/12 | 10/06/12 | 18/11/12 | 02/12/12 |
| **mean** | N/A | 585.30 | 603.12 | 588.26 | 608.21 | 607.44 |
| **S.E.** | N/A | 27.72 | 9.94 | 8.77 | 12.25 | 11.95 |
| **min** | N/A | 493.00 | 440.00 | 366.00 | 463.00 | 465.00 |
| **max** | N/A | 960.00 | 911.00 | 904.00 | 733.00 | 836.00 |
| **2013** | 17/02/13 | 24/03/13 | 05/05/13 | 09/06/13 | 17/11/13 | 01/12/13 |
| **mean** | 663.97 | 636.35 | 631.47 | 605.04 | 653.48 | 625.21 |
| **S.E.** | 22.41 | 16.80 | 10.81 | 10.47 | 21.51 | 12.73 |
| **min** | 464.00 | 487.00 | 437.00 | 440.00 | 461.00 | 443.00 |
| **max** | 956.00 | 840.00 | 910.00 | 786.00 | 884.00 | 900.00 |
| **Wt (gms)** | | | | | | |
| **2012** | 18/02/12 | 10/03/12 | 05/05/12 | 10/06/12 | 18/11/12 | 02/12/12 |
| **mean** | N/A | 2297.25 | 2285.67 | 1881.01 | 1759.69 | 2269.66 |
| **S.E.** | N/A | 469.18 | 109.44 | 104.71 | 111.96 | 119.35 |
| **min** | N/A | 1077.28 | 907.18 | 396.89 | 907.18 | 963.88 |
| **max** | N/A | 10149.12 | 6940.51 | 6577.08 | 3061.75 | 4791.06 |
| **2013** | 17/02/13 | 24/03/13 | 05/05/13 | 09/06/13 | 17/11/13 | 01/12/13 |
| **mean** | 3075.43 | 2625.16 | 2485.60 | 2007.04 | 2535.25 | 2270.14 |
| **S.E.** | 338.69 | 249.22 | 161.71 | 100.17 | 285.11 | 166.80 |
| **min** | 793.79 | 992.23 | 0.00 | 850.48 | 765.44 | 878.83 |
| **max** | 9780.57 | 6010.09 | 7370.87 | 4224.07 | 5896.69 | 7030.67 |

Overall peak length frequency was between 550mm to 650mm (Fig. 6), with an overall average length of 612.9mm (+4.06).

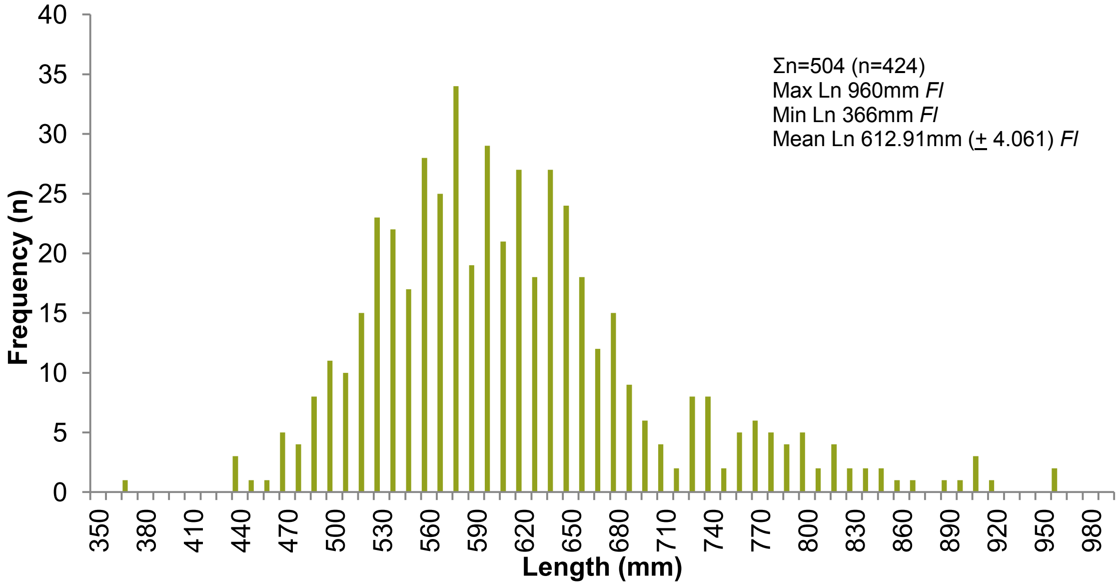


**Figure 6. Pike overall length distribution, total captured, length (mm) Fl; max, min & mean (+ 1 S.E.) are also shown. Sportsman's Broad 2012-2013.**

Within the duration of the study peak length frequency shifted upwards from approximately 530-580mm in 2012 to 580-650mm in 2013 (Fig. 7).

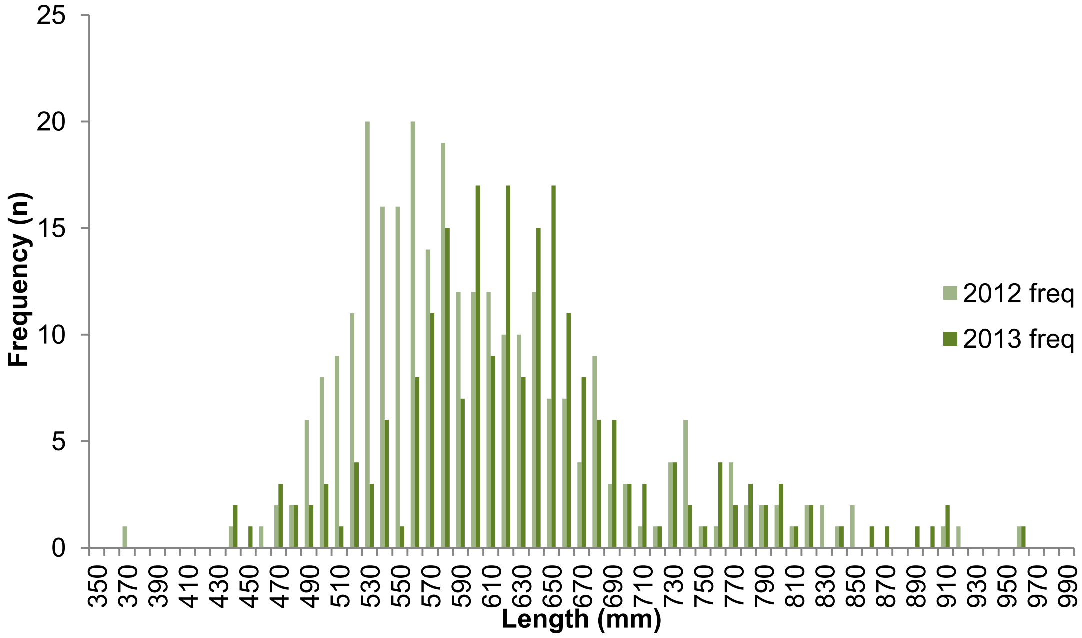


**Figure 7. Length frequency distribution for pike by year, Sportsman's Broad 2012-2013.**

Growth and size of pike appeared to be related to gender, with females exhibiting higher average and maximum growth at a given age (Fig. 8). Strongest differentiation of average size appears to be as pike age, from ~6 years of age upwards.

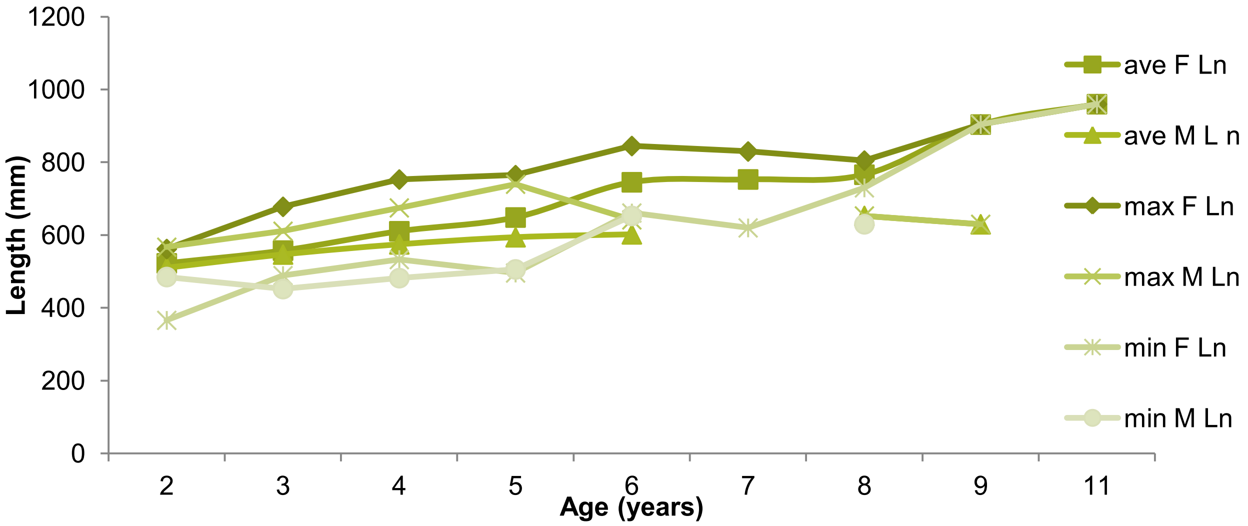


**Figure 8. Pike minimum, maximum and average length (mm) Fl at age (years) by gender, Sportsman's Broad, 2012-2013.**

Weight frequency distribution shifted upwards as the study progressed, indicative of growth of the population (Fig. 9).

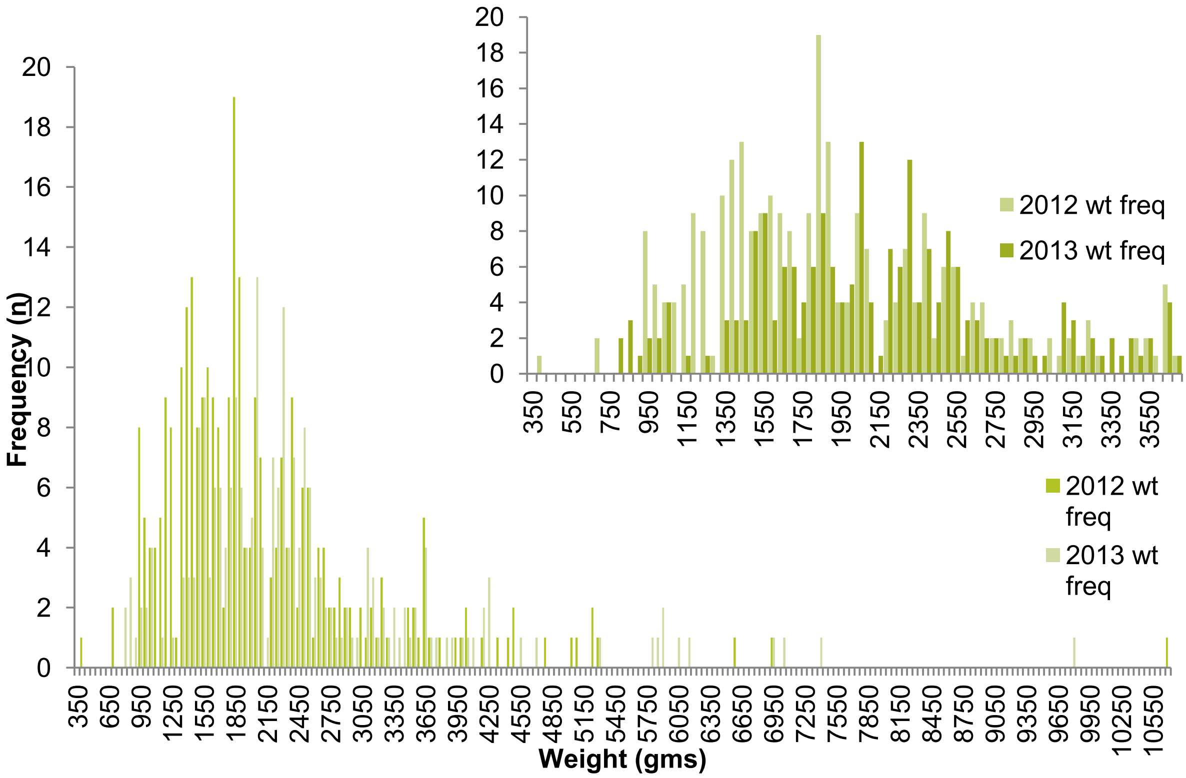


**Figure 9. Weight frequency distribution for pike by year, and key data (inset), Sportsman's Broad 2012-2013.**

Size differentiation between genders (indicated by lack of overlap of the standard error bars), starts from 6 years of age (Figs. 10 & 11).

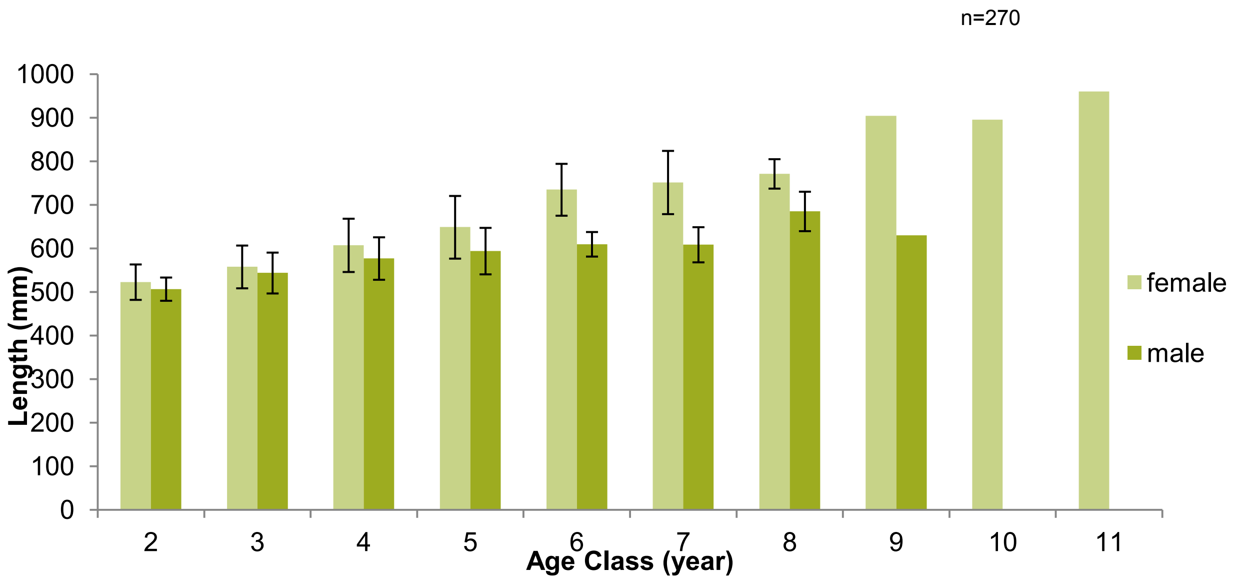


**Figure 10. Pike average length (mm) Fl (+1 St. Dev.) back calculated for age class, differentiated by gender, Sportsman's and Burnt Fen Broads Combined, 2012.**

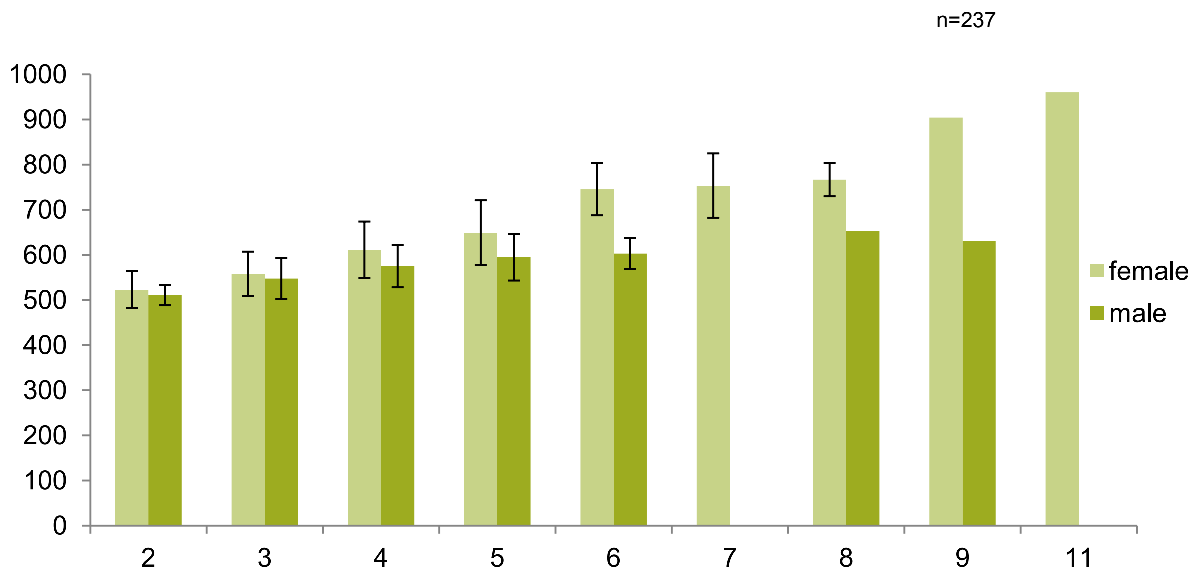


**Figure 11. Pike average length (mm) Fl (+1 St. Dev.) back calculated for age class, differentiated by gender, Sportsman's Broad 2012.**

Dorsal fin ray tags were retained more than anal fin ray tags, with a ratio of dorsal to anal 1.44:1 (Table 7). Retention rates for both tags being retained in an individual fish was >50%. Overall tag retention rates, combining all site retention rates (dorsal, anal and both), was high (>95%). Incidences of spun tags were few, though where they spun readability was not possible.

**Table 7. Tag site evaluation on pike, numerical assessment and retention rate (%) and overall combined retention rate (all variations), sportsman's Broad 2012-2013.**

| Tag Site Evaluation | Dorsal<br>Tag site only + retention rate (%) | Anal<br>Tag site only + retention rate (%) | Dorsal & Anal sites + retention rate (%) | Spun tag | Overall tagging retention rate all sites combined |
|---|---|---|---|---|---|
| | 24 (25) | 17 (17.8) | 51 (53.1) | 4 | 95.8% |

Average time (days) between capture and recapture was 265.37 (+17.85). The longest time between the 2 events was 638 days with tags still readable. Shortest time between capture and recapture was 35 days.

Pike growth between capture and recapture, where it was possible to determine, varied between 204mm & 1mm, the later potentially being a mis-measurement. Average growth between the two events was 38.61mm (+4.79). Overall, with mis-measured fish (approx. 14.6%) excluded from the analysis, 76.8% of all recaptured pike gained size between original date of capture and subsequent recapture. Difference in growth of individuals between the two events was significant P=0.01.

The two strongest featured year classes, derived from pike captured during 2012, were from fish born in 2006 and 2007, now 5+ to 6 years of age (Fig. 12). Poorest year class strength by proportional representation were 2008 and 2010.

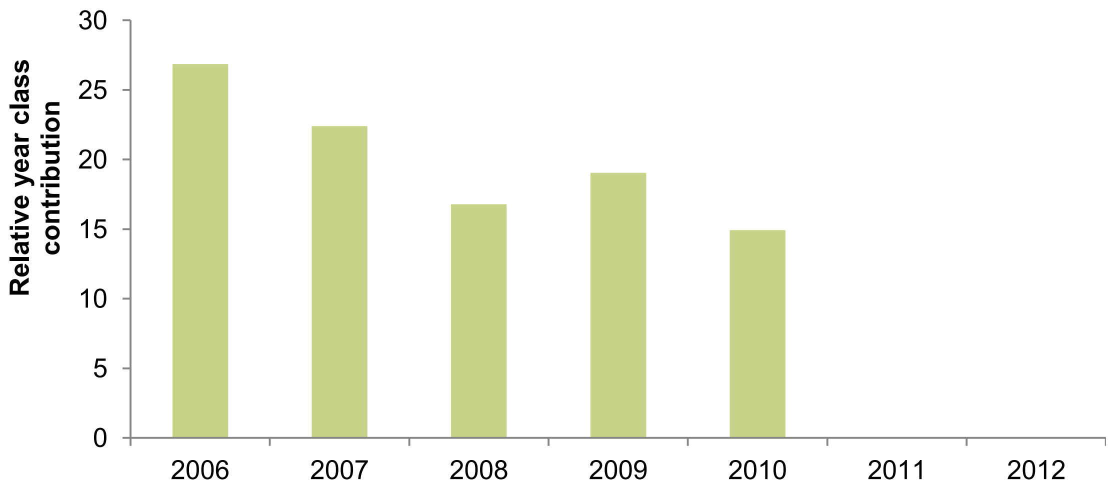


**Figure 12. Pike Year class strength by relative proportional representation, Sportman's Broad 2012**

Pike ranged between 2-11 years of age. >60% of pike captured during the first year (2012) comprised fish aged between 3 and 5 years old (Fig. 13).

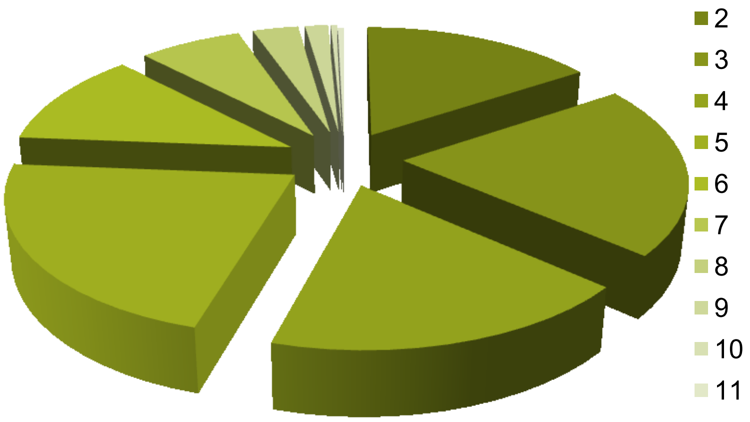


**Figure 13. Relative proportion of pike by Age Class  Sportman's Broad 2012**

Mean length at age was estimated from back-calculated scale circuli measurements for the 2012 data (Fig. 14).  Pre biomanipulation pike exhibited the fastest growth rates with young 2+ fish of the 2010 year class also showing strong growth to 2 years of age (Fig. 14). Only the 1997 year class showed superior growth over pike of the 2000's.

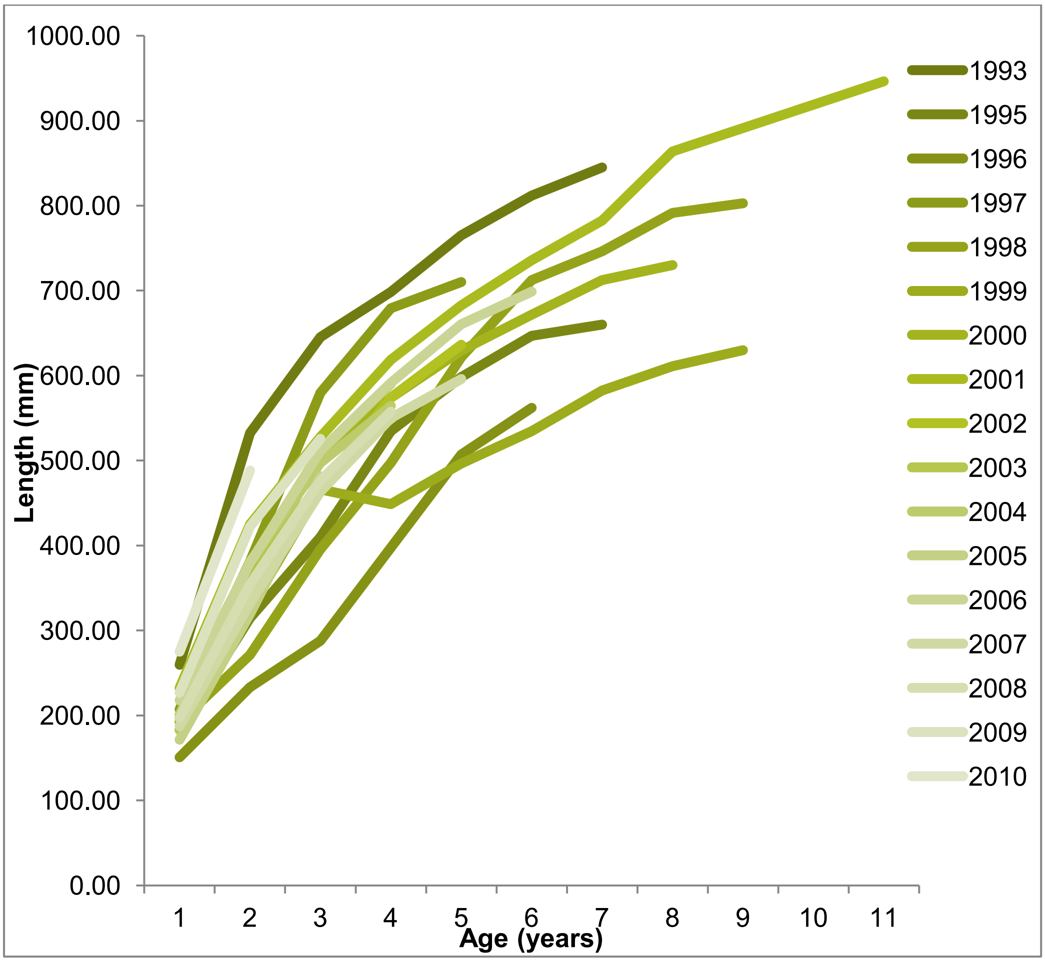


**Figure 14. Back calculated mean length at age determined by year class.**

Lowest growth performance was the 1996 year class (immediately post biomanipulation), with pike only attaining 233mm at 2 years of age compared to 488mm of 2010 year class. The average size of pike across all year classes at 2 years of age was 390mm. The low performance of this year class (1996) can be seen against the age class average (Fig. 15). However, small sample sizes of early data may affect the reliability of the estimates. Sample size increased from 2006. Mean percentage standard growth (mPSG) compared to standard growth curves for pike by Hickley and Sutton (1984) were 101% with strongest growth in the younger ages (1 and 2 years) ~109-110%. The 1996 year class showed poor PSG, ranging from 60-77% and overall mPSG of 70%.

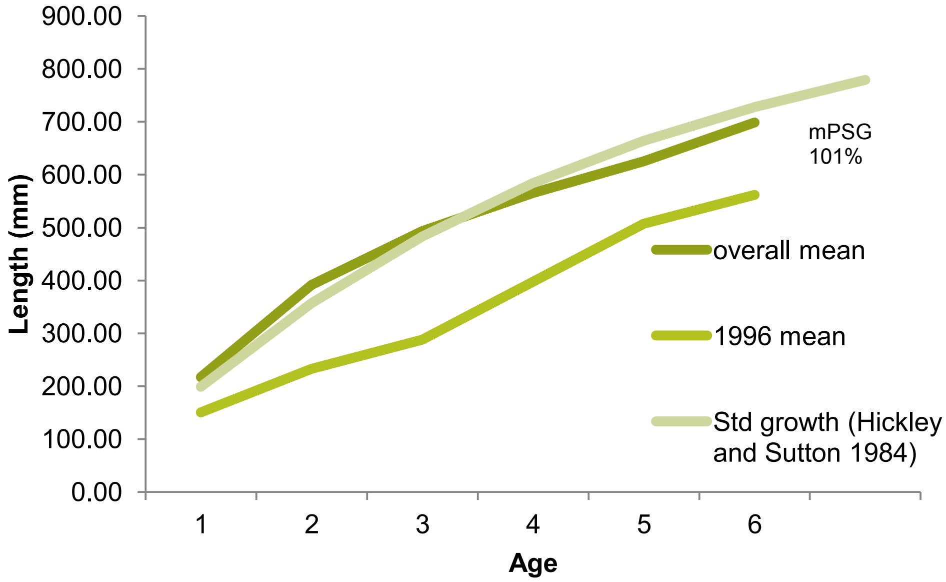


**Figure 15. Back calculated mean length at age 1996 year class vs overall mean length at age (all year classes) and standard growth, 2012**

Length weight regressions for female and male pike show the improved weight factor of females over males (Figs 16 & 17) indicated by the steeper slope. Female log10 weight = 2.8562, log10 length -4.645. N = 303, R2=0.882. Male log10 weight = 2.5017, log10 length -3.6518. Comparison with Bielby (2006) shows improvement in slope gradient, indicative of heavier weight to length relationship. Using the formula log10 a+b log10 L, b is invariably close to 3.0 (Schneider et al, 2000), where it has been determined that the closer to 3.0 the nearer to isometric growth (Schneider et al, 2000). Female pike attain 2.9 indicating good weight characteristics and an improvement over Bielby (2006) pike data; female 2.03, male 2.21. The Bielby (2006) pike data exhibits a shallow gradient, which in turn suggests (bearing in mind the above) that at the time pike were relatively under weight. Sample sizes of female and male pike in the 2006 study were modest (n=20 & 18 respectively) in comparison to this work (n >500 combined).

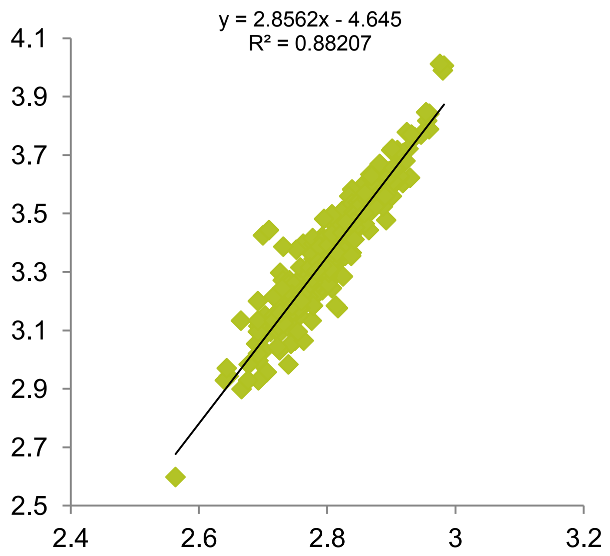


**Figure 16. Female pike length weight regression**

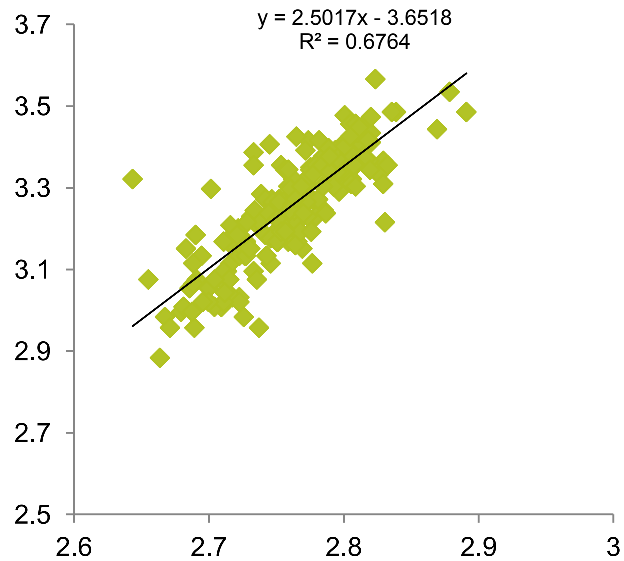


**Figure 17. Male pike length weight regression**

Pike population estimate for Sportsman's Broad.  Using PMR Population Estimate the pike population is represented below (Fig. 12). 95% Confidence Intervals (CI) are also calculated.


**Figure 18.  PMR Pike Population Estimate, (95% CI are shown) Sportsman's Broad, 2012-2013**

A second estimation was generated using Schnabel Estimation (Fig. 13).


**Figure 19.  Schnabel Pike Population Estimate, (95% CI are shown) Sportsman's Broad, 2012-2013**

# Discussion

There have been a number of mark recapture studies on pike for spawning site identification (Iller 2001), site fidelity (Cucherousset et al. 2009; Kobler, Klefoth & Arlinghaus 2008; Roach 1998; Iller 2001), fish movement (Rosell & Macoscar 2002; Koed et al. 2006; Kobler, Klefoth, Wolter, et al. 2008; Masters et al. 2005; Ovidio & Philippart 2003; Burkholder & Bernard 1994), but relatively few on pike population density and size estimation (Kuparinen et al. 2012; Haugen et al. 2007; Winfield et al. 2010).  Within the Norfolk Broads we are unaware of any studies relating to pike population size or structure.

The resultant work has determined the pike population of Sportsman's broad to be between 846 & 756 individuals, depending upon which metric is used to estimate the population. The Peterson mark recapture method (PMR) exhibits less spread of confidence intervals (CI) around the estimate (207 upper, 129 lower) than the Schnabel method (455 upper, 206 lower) and so is intuitively the estimate of choice. In both cases the higher degree of variance is between the estimate and the upper CI. A population of this size would suggest few limitations in terms of prey availability. Although conspecific predation occurs in pike (Nilsson, 2002: Nilsson et al. 2012) this would be unlikely to be high enough to support such a large population of mature fish.

Furthermore, cannibalism between larger individuals is assumed to be inversely proportional to body size, since gape size will determine prey size selection (Mittelbach & Persson 1998) and larger gape size of already large individuals would differentiate less between large conspecifics than between large and small individuals. The modal size (565mm) and the length frequency curve (Fig. 6) suggest that the population is skewed asymmetrically from young mature fish towards larger, older fish. The paucity of young fish, i.e. those fish <300mm, may be related to sampling bias. Although all sampling methods are subject to bias to a greater or lesser extent, angling for pike would tend to select those bolder fish that are of sufficient size to face reduced predation pressure and so permit a degree of freedom of movement within a range for hunting. Gape size can affect the distribution of pike within a water and constrain territory (P. A. Nilsson 2006; Nilsson et al. 2006; Magnhagen & Heibo 2001; Hart & Hamrin 1988). This in turn affects probability of encountering a fish. Furthermore, deployment of large dead baits or lures will also preclude those smaller fish by virtue of insufficient gape size (Arlinghaus et al. 2008). Despite poor estimates of young fish generated by this method, the length frequency curve would suggest a strong robust pike population with potentially adequate recruitment. Therefore, the paucity of young pike within the sample may not be indicative of absence within the broad.

Prey availability may have previously been a limiting factor for pike. Sportsman's Broad has previously undergone biomanipulation (from 1995) with subsequent limited removals and remedial action in the intervening years up to ~ 2006. It is perhaps not coincidental that the poorest year class in terms of growth performance was the 1996 year class, the year immediately following the biomanipulation. Pike captured during the intervening years (- 2003/4) were often reported as slim and emaciated and of low weight and poor condition. Rod caught pike data from monitoring by the Trinity Pike Conservation Group also revealed fish with poor weight for length characteristics. During this time pike were difficult to catch, suggesting few pike present within the broad and below detection levels. Surveys revealed few pike (Tomlinson & Perrow, 2004). Work by Bielby (2006) suggests that pike were light for their size and so relatively underweight. It was widely considered that since the biomanipulation had removed a substantial food source, this had resulted in the population decline and poor condition from limited or restricted feeding opportunities. However, it was also possible that lack of natural recruitment of young pike was a significant contributory factor. This was probably exacerbated by the substantial reduction in small cyprinids available to young maturing pike undergoing ontogenetic shift towards psicivory.

Recent PASE surveys indicate an overall low density fish community (overall 0.0925 ind./m-2 & 4.1983 g/m-2) (Tomlinson & Harwood, 2014), but rudd Scardinius erythropthalmus have shown a steady increase in density post biomanipulation to present day. It may be that they are released from competitive pressure by roach removal and the subsequent reduction in population density, enabling rudd to thrive. Works along the littoral margin reducing scrub encroachment and tree shading continue to encourage reedbed Phragmites australis growth and regeneration (E. Rothney pers. comm.). Since rudd prefer structured habitats, this work would suit them. Their relatively small size (26-49mm) and young age classes (0+ to 1+ years of age) (Tomlinson & Harwood, 2014) may mean as a prey fish they are mainly suitable for younger age classes of pike, though fish of ~500-600mm have been observed taking small 30-40mm lures during warmer months (Lane, pers. comm.) suggesting their food source function may well extend to supplementing larger fishes diet too. High resolution sonar work on other Bure broads has also revealed larger pike fry feeding extensively during summer months (Hindes & Lane, unpublished). Tench Tinca tinca have also increased in number since 2003 and there are a number of very large fish present within the broad (Clarke, pers. comm.). Bream recruitment appears to be generally low, despite large numbers of bream fry often seen early season (Hindes, pers. obs.). These young fish do not survive through to late summer (Tomlinson, pers. comm.). The young bream will serve to supplement the diet of piscivorous young of the year (YOY) pike, which will in turn support pike recruitment through nutrition and growth as well as increased survival. This study has concluded that growth of pike at this time has improved on prior past poor performance (immediately post biomanipulation mPSG=70%) and is average when compared to standard growth curves (Hickley and Sutton 1984), and that their weight, and so body condition, is also improved over the previous analysis on pike length to weight relationships (Bielby, 2006). Capture of adult fish with exclusion of juveniles suggests, perhaps unsurprisingly, that growth is isometric. Presence of juvenile fish within the catch would tend to skew the relationship towards allometric growth and hence a much steeper gradient to the regression line.

Earlier work (Hindes, unpublished) on pike recruitment, following concerns regarding the pike population post biomanipulation, focused on spawning habitat creation. Internationally, and to a lesser extent within the U.K., there has been a number of studies related to the spawning habitat requirements and habits of pike, and various workers have reported on them over five or six decades (Carbine, 1944; Clarke, 1950; Hunt and Carbine, 1951; Franklin and Smith, 1963; Frost & Kipling, 1967; Forney, 1968, 1977; Hassler, 1970; Howard and Thomas, 1970; Koz'min, 1981; Souchon, 1984; Derksen & Gillies, 1985; Giles et al., 1986; Wright & Giles, 1987; Wootton, 1990; Wright, 1990; Farrell, 1991; 2001; Gillet & Dubois, 1995; Bry, 1996; Farrell et al., 1996; Morrow et al., 1997) with others focusing on artificial spawning substrates (Gillet and Dubois, 1995) where egg density can be higher than natural substrates (Souchon, 1984). Within the Norfolk Broads, there has been some limited success in persuading pike to spawn on artificial spawning substrate comprising of 30cm squares of weldmesh with 'fronds' of greenhouse shading material tied to form dense stands of material (Hindes, unpublished.; Bielby, 2006) and 1m x 4m AstroTurf strips (Hindes, unpublished). Pike were observed using spawning mats (R. Lay, pers. comm.), but in only one location. Young pike were captured the following year (Hindes, unpublished) and deployment of artificial substrates were attributed to the increased capture during routine point abundance sampling by electrofishing surveys (PASE) (Tomlinson, pers. comm.). The numbers of young pike captured were relatively low and the study could not conclude recruitment via increased spawning habitat opportunity was successful. Therefore, the question relating to spawning habitat availability and quality remain unanswered. Ongoing improvements to the littoral margin have resulted in deeper margins with less over shading, which will benefit young pike. The question regarding habitat availability and quality still remains however.

mPSG rates are ~100% which are within the accepted zone of average growth. There is some variance between age classes and younger fish exhibiting slightly improved growth on the standard growth curves (109%). Putting this growth performance in perspective, the 1996 year class, (immediate post biomanipulation) had a mPSG of ~70%. Therefore, it appears that the population is recovering from the main biomanipulation event, presumably linked to increase in prey availability. The dominant 2006 year class contributed >26% of all pike to the 2012 surveys (Fig.15). Not only were this year class dominant numerically but growth rate performance was the 3rd highest from pike from the >2000's, only fish from 2009 and 2010 outperforming them (Fig. 14). Young age classes (2 years of age) of the 2010 year class has mPSG of ~138%.

Growth rates are important on both a stock and individual level. Faster growth rates enable individuals to reduce size specific predation that most affects them (Smith et al. 2007), i.e. when they are of small to intermediate sizes and vulnerable to conspecific predation, cannibalism and antagonistic behaviour of larger individuals, and also prey to avian piscivores. Growth rates and year class strength for Sportsman's Broad varies between years (Fig. 12). The 1993 year class shows elevated growth above all other years of growth data relating to year class 1993-2010 (Figs. 14). This would be indicative of a fishery with high cyprinid stocks and abundant available prey for pike. Biomanipulation of the cyprinid community was undertaken in 1995, (~9 tonne of cyprinids removed (Perrow, 2009)) and growth rates for the 1996 year class being low (following the biomanipulation and coarse fish removal) when compared to the overall average growth rates in all age classes, the only exception being fish 6 years of age (Fig. 14). The subsequent understanding of pike population behaviour post biomanipulation event, will prove valuable in decision making and anticipation of expected outcomes following other lake restoration works. The knowledge gained from this study will provide a clear idea of what response to expect in the pike community on other broads that may be subject to lake restoration. The short term decline of pike populations within such lakes appear to respond positively once the lake has begun to re-establish. Greatest growth divergence is in the 3-year-old fish (Fig. 15), which would suggest that these fish have been adversely affected by the paucity of prey fish at a time of key growth. The small sample size of pre 2005 fish may affect reliability of mean estimates and therefore is considered indicative as opposed to quantitative. Faster growth rates of specific year classes and the survival of numbers of individuals will provide greater opportunity for successful spawning and recruitment. Year class strength (YCS) is influenced by external variables such as temperature and water levels as well as habitat availability and quality. YCS may be associated with elevated water levels during late winter and early spring, when pike typically spawn (Avian et al., 1998; Bregazzi & Kennedy, 1980; Treasurer, 1990), though it is more usually March-May in the U.K. (Frost and Kipling, 1967), and typically March – April in the Norfolk Broads (Hindes, unpublished.). During this time, littoral vegetation may be partially or wholly submerged, providing ideal spawning substrate for pike spawning (Johnson 1956; Franklin and Smith 1963; Kipling and Frost 1970; Scott and Crossman 1973; Diana et al. 1977; Chapman and Mackay 1984; Margenau 1986; Cook and Bergersen 1988; Wootton, 1990; Casselman & Lewis, 1996; Farrell et al., 1996; Farrell, 2001) and egg development and survival (le Cren 1987; Houde 1997a,b; Casselman 2002). There is no reliable data regarding water levels within the broad during this period, precluding relational analysis.

Vegetation, whether for spawning site selection, or habitat association, is considered to be essential to the life cycle of pike (Bry, 1996). Pike are strongly associated with vegetation outside of spawning site selection. Work in this field has led to categorisation of habitat association, where guilds have been proposed based upon vegetative preferences of fish related to size (Hindes, 2014; Grimm and Klinge, 1996). Where versatility of site selection exists between pike, it appears to be confined to the larger individuals, where they have been found (in North American Lakes) to utilise both shallow, limnetic, vegetative areas as well as deeper limnetic sites with less vegetation (Bry 1996; Grimm and Klinge 1996; Chapman and Mackay 1984). This type of resource partitioning, between the small and the larger individuals, may enable fish with larger gape size to predate proportionally larger prey, such as bream or large perch, which do not associate so strongly with littoral margins and vegetation as do their smaller conspecifics (Margenau et al., 1998) and still opportunistically take advantage of food sources within the shallow areas when available. They may also use these areas, or the edges of these areas, to launch ambush attacks on larger prey in the deeper water.

Temperature plays a pivotal role in egg development and is a significant factor in determining YCS (le Cren 1987; Casselman 2002). Furthermore, since both growth, and concomitantly survival, are also influenced by temperature (le Cren 1987) and are essential factors in the early stages of life (Houde 1997a,b), waters which provide optimum temperatures and early season warmth will provide, in turn, enhanced survival opportunities. Sportsman's Broad is a large open broad subject to wind sweep and affected by northerly winds which sweep down the broad causing considerable fetch. The effects of such wind activity are reduced water temperatures and re suspension of surface sediments. Reduction in water temperature affects rate of egg development (Hokanson et al., 1973; Casselman 1978; Crossman, 1978; Fortin et al., 1982; Kipling 1983; le Cren 1987; Cooper, 2000) and undue fetch may dislodge eggs attached to littoral vegetation since pike eggs, initially sticky (Cooper et al., 2008), soon loose their adhesive properties as they water harden and are easily dislodged. Initial adhesion is essential if the eggs are to avoid being deposited on surfaces with low oxygen availability. Oxygen availability and uptake affects egg development (Raat, 1988). Pike eggs are also susceptible to mortality from sedimentation (R. Wright. pers. comm.; Hassler, 1970), emphasising the importance of the availability of suitable substrate for pike spawning (Howard and Thomas, 1970) and the impact of fetch on shallow lakes with readily suspended sediments. Since there are wide variations in reported egg survival (4-90%) (Monten, 1948; Franklin and Smith, 1963; Wright and Shoesmith, 1988; Gillet and Dubois, 1995) the importance on site selection and habitat quality cannot be underestimated.

Tag retention rates of VI tags in studies are highly variable (15% rainbow trout Oncorhyncus mykiss (Davis et al, 2014) – 97-100% large brook trout Salvelinus fontinalis (Hughes et al., 2000)) with a strong bias towards salmonids. During the literature review there were >30 such studies, with a few selected to represent the salmonid component of the literature. Few studies compare with, or exceed the duration of this study (except, Meerbeek et al. 2013), so direct comparison between studies and retention rates is problematic, not least because duration of implanted tags and readability or retention appear to be closely negatively linked. Increases in duration adversely affect readability due to increases in pigmentation and also subcutaneous thickening. Time may also affect the stability and sustainability of the tag in its location. Overall retention rates of 95.8%

for double tags compares well with the literature (Table 1) exceeding the overall average retention rate 65.5% as well as the overall average duration 730+ days – 256 days. Paucity of VI retention rate work on esocids further diminishes the opportunity for comparison. With a single study on tiger muskellunge Esox masquinongy x Esox Lucius (Turek et al., 2014) focusing on retention rates under laboratory conditions over a short time period (28 days). Their retention rates (92%) may not reflect likely scenarios in a field based environment. The short duration gives little indication as to longevity of such an approach to establishing methodology for mark recapture work, population studies or individual performance assessments. We consider the comparative success of our approach is related to site selection and tag insertion methods. Site selection was achieved by a combination of literature based reviews and laboratory trials. Methodology of insertion was determined by laboratory based trials. Our approach of a long syringe lead-in tunnel between the fin rays and nipping the tag upon removal of the syringe needle ensures the tag is situated at the end of the tunnel after tag insertion. Failure to nip the tag can lead to the tag being dragged partially back up the tunnel resulting in poor tunnel depth and increased opportunity for tag loss. Locating the tag at the end of the tunnel reduces the likelihood of the tag migrating through fin articulation up towards the syringe entry/exit and eventually exiting the tunnel, subsequently being lost to the fish. The disadvantage of such a method is skin pigmentation. Finding the least pigmented fin ray is important to ensure subsequent readability of the tag. Deep tunnels are often associated with increase in fin ray pigmentation close to the root of the fin in northern pike. Inserting too close to the fin root may impede readability through high pigmentation. Furthermore, subcutaneous depth of the tunnel, relative to the upper skin side of the fin ray web, impedes tag readability. With increases of depth a thicker skin covering increases opacity and decreasing tag readability. Therefore, long syringe tunnels are initiated near the top of the fin ray.

# Conclusion

Tagging pike for unique or stock identification and subsequent stock assessment, population dynamics and growth performance is possible using VI implant tags. The methods do not require sedation of the fish and the subcutaneous implant is located where there are no nerve endings or sensory pits on the fish, causing no pain. The method is fast, enabling a fish to be processed quickly with minimal time out of water. Pike can be studied in this way over a period of at least 2 years, with supplementary data suggesting that this might be extended to up to 3 years, however, this would require further work. Readability declines with tag duration due to pigmentation and skin thickening increasing opacity. Double tagging fish ensure readability of at least one tag is usually possible and provides back up should one tag be shed. The findings of this Phase 1 study confirm the planned approach to Phase 2 of the study is viable. Simple processing & data recording techniques can be imparted to selected angling volunteers by training and future supervised data collection Utilising skills of experienced pike anglers with such suitable training should empower and enable the specialist angling community to achieve larger wider projects with a key awareness for fish welfare and scientific approach to data collection and analysis.

Growth rates of pike in Sportsman's Broad are average or slightly above the standard growth curves. Weight length relationships demonstrate that pike are not undernourished and close to the ideal isometric growth (Schneider et al., 2000). The gradient of the slope in linear regressions are more favourable than those of previous work (Bielby 2006), which indicate an overall improvement in pike condition and infer better feeding opportunities than the mid 2000's. Population estimates are the first for this broad, or for any other broad within the Norfolk Broads. The CI surrounding estimates (both Schnabel and PMR) are tight, indicating the accuracy of the estimate. This suggests that the actual population size is likely to be close to the estimated population. Catch records exceed all others carried out on Sportsman's Broad suggesting that the pike population is indeed in a recovered position since the declines following biomanipulation. Growth performance data from age classes and YC would broadly to support this. The length frequency distributions show a paucity of young pike, specifically YOY and 1+ fish. This is partly explained by the sampling methods but cannot be discounted. Despite available habitat, there does appear to be a recruitment issue surrounding pike. This may just be reflective of high populations of adults reducing YOY recruitment, which in times of depressed adult numbers YOY recruitment may well increase. However, this is not currently known.

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