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A One-Year Capture-Mark-Recapture study on Northern Pike (*Esox lucius*) in the lake Borrevannet, Southeastern Norway: Estimates of Key Demographic- and Population Dynamic Rates

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En ett-års merke-gjenfangst studie av gjedde (*Esox lucius*) i Borrevannet, i sørøst Norge: estimater av vitale demografiske og populasjonsdynamiske rater.

Preface

This thesis is part of my master's degree in Natural Resource Management at the Department of Ecology and Natural Resource Management (INA) and Norwegian University of Life Sciences.

The thesis was proposed by the landowners association of Borrevannet.

First of all a big thank you to my supervisor Thrond O. Haugen for everything I learned during this study of pike in Borrevannet. A big thank you goes to fellow student Silje E. Sikveland who did most of the field work together with Thrond in May of 2013. To Sondre Ski and Ronny Steen who helped me with field work in November 2013 and May of 2014.

I also want to thank Bjørn-Tore Freberg, head of the landowners association for lending us his cabin and boat.

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Abstract

Northern pike (*Esox lucius*) is distributed through Europe, Asia and North-America and is an important species in both commercial and recreational fisheries. It is a top predator that has an important role in regulation fish communities through predation and cannibalism.

Borrevannet is a shallow and eutrophic lake located in Vestfold County, SE Norway. Cyprinids (mainly roach (*Rutilus rutilus*) and bleach (*Alburnus alburnus*)) dominate the fish community and pike along with large individuals of perch (*Perca fluviatilis*) constitute top predators. There is a latent conflict related to the way pike is supposed to be managed in the system. Anglers want to favor a large proportion of large pike individuals in the population, whereas regional water management authorities would rather favor a large proportion of medium-sized pike as this will improve the water quality due to medium-sized pike being the more effective roach predators. In order to arrive at a sustainable and justifiable pike management policy of the lake, detailed information about the pike population is a prerequisite. How the pike would be managed in Borrevannet could be a conflict of interest for the landowners whether deciding to focus on sports fishing or to improve the water quality. It is on that basis that I have done my study on the pike population in Borrevannet.

The objective of this study was to estimate the population size, survival and migration rate of Borrevannet pike through capture-mark-recapture (CMR) analysis over 5 mark-recapture occasions covering a year. From scale samples individual back-calculated growth trajectories could be read and size-at age data was used for analysis of ambient temperature on growth. The population size of Borrevannet pike (larger than 40 cm) was estimated to be around 500 individuals. First-year individual growth in male pike responded positively to increasing ambient temperature, whereas females showed the opposite effect. Second- and third-year growths were either negatively or insignificantly affected by monthly growth-season temperatures. Cormack-Jolly-Seber (CJS) models were fitted the CMR-data used and the most supported model (AIC based) predicted that recapture probability for pike 40-65 cm was positively size-dependent during spring and negatively during fall. This finding can be related to differential activity levels between small and larger individuals during the two seasons. Borrevannet pike had an estimated monthly survival of 0.97, corresponding to an annual survival rate of 0.61. Most of the pike did not disperse far from the original marking point when recaptured (50 % dispersed less than 163 m), but there were a few individuals who dispersed up to more than 2000 m.

Borrevannet landowners association want to utilize the fishing resource for recreational- and sports fishing, but also improve the water quality in the lake. This may come in conflict with keeping a portion of large pike in the population for sports fishing. Estimated density of pike was low compared to other lakes. This may be because large pike, through cannibalism, forage on smaller individuals. Since the mark-recapture analysis did not show any size dependent survival, predation on smaller pike is uncertain. The mark-recapture study needs to continue to determine the relationship between harvest mortality and natural mortality via cannibalism.

Sammendrag

Gjedde finnes hele veien gjennom Europa, Asia og Nord-Amerika og er en viktig fiskeart i både nærings- og rekreasjonsfiske. Den er på toppen av næringskjeden og har en viktig rolle i å regulere fiskesamfunn gjennom predasjon og kannibalisme..

Borrevannet er en grunn og eutrof innsjø som ligger i Horten kommune i Vestfold fylke, sørøst i Norge. Karpefisk (hovedsakelig mort (*Rutilus rutilus*) og laue (*Alburnus alburnus*)) dominerer fiskesamfunnet og gjedde sammen med store individer av abbor (*Perca fluviatilis*) er topp-predatorene. Det er en latent konflikt knyttet til hvordan gjedda skal bli forvaltet i innsjøen. Sports fiskere ønsker en stor del av store individer av gjedde i populasjonen, mens regionale vannforvaltningen ønsker en stor proporsjon av mellomstore gjedder siden dette vil forbedre vannkvaliteten, da mellomstore gjedder er mer effektiv predator på morte. For å kunne komme til en bærekraftig og forsvarlig forvaltning av gjedde i innsjøen, trengs det informasjon om gjedde populasjonen. Hvordan gjedden blir forvaltet i Borrevannet kan gi en interessekonflikt for grunneierne, siden det må bestemmes om det skal fokuseres på sportsfiske eller å kunne forbedre vannkvaliteten. På bakgrunn av dette har jeg gjort min studie gjedde populasjonen i Borrevannet.

Målet med denne oppgaven var å estimere populasjonsstørrelse, overlevelse- og migrasjonsrater av gjedde i Borrevannet gjennom merke-gjenfangst analyser over 5 merke-gjenfangstrunder som dekker et år. Fra skjellprøver kunne individuell tilbake-kalkulert vekst forløp bli bestemt og størrelse ved alder ble brukt for å analysere temperatur effekt på vekst. I Borrevannet ble populasjonen av gjedde (større enn 40 cm) estimert til å være rundt 500 individer. Første-års individuell vekst for hanngjedder reagerte positivt på økende temperatur, men hunnene reagerte motsatt. For andre og tredje års vekts ble enten negativt eller ikke signifikant påvirket av månedlig sesongvekst temperaturer. Cormack-Jolly-Seber (CJS) modellen ble tilpasset gjenfangstdataene og best tilpasset modell (AIC basert) forutsa at gjenfangstsannsynligheten på gjedde mellom 40-60 cm var positivt størrelsesavhengig på våren og negativt på høsten. Dette funnet kan relateres til forskjellig aktivitetsnivå mellom store og små individer gjennom to sesonger. Gjedde i Borrevannet hadde en estimert månedlig overlevelse på 0.97 og tilsvarende årlig overlevelses rate på 0.61. De fleste av gjeddene forflyttet seg ikke langt fra det originale merke punktet når den ble gjenfanget (50 % spredde seg mindre enn 163 m), men det var et par individer som forflyttet seg opp til 2000 m.

Grunneierforeningen i Borrevannet vil utnytte fiske ressursene for rekreasjon- og sportsfiske, men også forbedre vannkvaliteten i innsjøen. Dette kan komme i konflikt med å beholde en del store individer i populasjonen for sportsfiskere. Estimert tetthet av gjeddepopulasjonen var lav i forhold til andre innsjøen. Dette kan være fordi gjeddene gjennom kannibalisme spiser på mindre individer. Siden merke-gjenfangst analysen ikke viste tegn til størrelsesavhengig overlevelse, er forutsigelsen om predasjon på mindre gjedder usikker. For å kunne fastsette forholde mellom høstningsdødelighet og naturlig dødelighet via kannibalisme, trenger merke-gjenfangststudien å fortsette videre.

Contents

1. Introduction

Knowledge about population size and variation in abundance over time, and relationship between fishing effort and population size is a premise of all fish management (Borgstrøm & Qvenild 2000a). Our fish resources provide important ecosystem services such as recreation, tourism- and fishing industry. Salmon- and other freshwater fish in Norway are protected by law (Lakse- og innlandsfiskloven), which states that all fish populations and their habitat are to be managed in a sustainable fashion so as to secure larger yield, to accommodate those with fishing rights and recreational fishermen (Lakse- og innlandsfiskloven 1992). In most freshwater systems, one has to buy a fishing license or have permission from those who have fishing rights in that area, to be able to legally fish (Miljødirektoratet 2009).

Recreational fishing is, and most probably will be in the future, an important part of the tourism industry. In 2013, a survey on fishing tourist attendance, both national and international, in Hedmark County was carried out. The survey revealed that anglers purchased goods and services for over 100 million NOK (Dervo 2013). Nature-based tourism is important socioeconomically and people are willing to pay for great adventures in nature. Outdoor activities, like angling, are also important for the public's health. The Norwegian Government has made a strategy plan for the Norwegian people to use the nature for recreational purposes. More activity can help people appreciate and learn more about nature (Miljøverndepartementet 2013).

All harvest is size-selective and can thus affect life history traits, morphological, behavioral and physiological traits (Arlinghaus et al. 2009). For regulating abundance and recruitment in fish populations, physical factors are important. Piscivorous fish may consume a large portion of young age classes through cannibalism or forage on other small fish, and thus change the community structure (Sharma & Borgstrøm 2008a). Some piscivorous like pike regulates its own population through cannibalism (Craig 1996). By reducing the biomass of a predator through fishing, it can create cascades from the top trophic level down to the lowest in the food web. With lesser predation risk for zooplanktivorous fish (e.g. cyprinids) increase in abundance and inedible phytoplankton can develop (Benndorf et al. 2002). At a specific location, harvest can be regulated by permitted tools, appointed time for fishing, minimum length for catch and lower or maximum mesh width regulations on gillnets (Borgstrøm & Qvenild 2000b). If the fishing rate imposed to a population is larger than the population's recruitment rate over a period of time, the population equilibrium state changes and such overharvesting will inevitably decrease the population viability with extinction as an ultimate outcome (Allan et al. 2005).

The evolutionary effects of size-selective harvest are often ignored by fisheries management. The traditional view is that evolution is a slow process, but in fisheries this can happen over a short period of time. With changes that can be detected in just a few generation or decades (Swain et al. 2007). The mortality that fisheries impose is high, often two or three times as high as the natural mortality in the populations. After over-exploitation, many fish populations have not been able to recover and get back to previous abundance (Swain et al. 2007). Implementing maximum and minimum length limits can mitigate the evolutionary effects of size-selectivity (Matsumura et al. 2011). Catch and release is an increasingly common practice among recreational anglers and is at least in theory, non-lethal fishing method. Even though it is intentionally non-lethal, catch and release can disturb short-term behavior and is energetically costly to the fish. The disturbance can lead to reduced forage ability and avoidance of predators. Other physically effects are reduction in the immune system, success of reproduction and thus fitness (Johnston et al. 2013). Bag limit is often used in anadromous recreational fisheries in Norway, but in other countries it can be bag limits also in lakes (Bartholomew & Bohnsack 2005).

Utmarksavdelingen i Akershus og Østfold conducted a project in 2006-2007 to develop products related to tourism of sports angling (Utmarksavdelingen Akerhus og Østfold) – where fishing for pike played a key role. The result of the project *fiskeland.no* is now a part of a boarder regional collaboration with Sweden and establish a popular destination for fishing tourism (Fiskeland). Borrevannet is a reputed lake for recreational angling both among local anglers, but also beyond Norway's borders Bjørn-Tore Freberg, the head of the local landowner association, has a rental cabin and boat to loan if one want to go out on the lake and fishing (Borrevannshytta).

The purpose of the management plan for Borrevannet is first to make sure that implemented activities and measures are in line with management regulations (Fylkesmannen i Vestfold 2011). Fishing experts have put Borrevannet as one of the three best pike-fishing lakes in Norway (Broms 2013). The landowners want to utilize the fish resources for recreational- and sport fishing purpose (Fylkesmannen i Vestfold 2011). That means keeping a portion of the population large in size. By allowing a portion of the pike to grow large, it can intervene with the water quality, which has been quite eutrophic since decades (Brettum et al. 1976). Large pike forage on smaller pike, which again eat perch and roach. Perch and roach eat zooplankton that in turn eats phytoplankton. By leaving a large portion of the pike-population as small/medium, the predation pressure on phytoplankton increases and thus improves the water quality (Berg et al. 1997). Hence, there is a latent conflict situation between anglers request for large pike individuals and water quality in Borrevannet. The management of pike plays a key role in this potential conflict and in order to arrive at a sustainable and justifiable management policy in the lake, detailed information about the pike population is a prerequisite.

The main objective of this study is to 1) estimate the pike population size in Borrevannet, 2) estimate key population rates like survival, growth and migration. I also aim at 3) exploring temperature effects on individual growth. Finally, 4) I will discuss my finding in light of different management goals for Borrevannet.

2. Materials and methods

2.1.Study area

Borrevannet is located in Borrevannet nature reserve not far from Horten city in Vestfold County, Norway. Borrevannet is surrounded by dense forest in the north and in the east, and intensive agriculture in the south and southwest of the lake. The lake is eutrophic and the overfertilisation comes agriculture and households, but also natural addition from the fertile marine deposition. Flourishing of algae can occur in the lake during the summer season. Mean temperature of the lake is 6.6 °C and is normally covered with ice from November to April (Fylkesmannen i Vestfold 2011).

Figure 1: View of Borrevannet (Photo: Monica B. Aasrum).

Borrevannet has a rich plant life and many fish species. The shallow area in the south, Vassbånd, is almost completely overgrown with vegetation. Common reed (*Phragmites australis*) dominates here and around the rest of the lake, but willow thicket (*Salicaceae*) is also present around the lake shore. In the shallow sections of the lake, closest to shore, one can find helophytes, such as sedge (*Carex*), common duckweed (*Lemna minor*). Further out one can find common reed, great bulrush (*Schoenoplectus tabernaemontani*), water horsetail (*Equisetum fluviatile*), water plantain (*Alisma plantago-aquatica* L.), white water lily (*Nymphaea alba*), yellow water lily (*Nuphar lutea*), pondweed (*Potamogeton*) and water knotweed (*Persicaria amphibia*). Under the water plant life consist of species of pondweed (*Potamogeton*) and water milfoil (*Myriophyllum*), hornwort (*Ceratophyllum demersum*) and water lobelia (*Lobelia dortmanna*) (Fylkesmannen i Vestfold 2011).

Fish species in Borrevannet is dominated by cyprinid such as roach (*Rutilus rutilus*), bleak (*Alburnus alburnus*), bream (*Abramis brama*) and rudd (*Scardinius erythropthalmus*). But one can also find perch (*Perca fluviatilis*), pike, pikeperch (*Sander lucioperca*), tench (*Tinka tinka*) and eel (*Anguilla anguilla*). The pikeperch was introduced to the lake in 1989 and is currently most likely extinct (Fylkesmannen i Vestfold 2011).

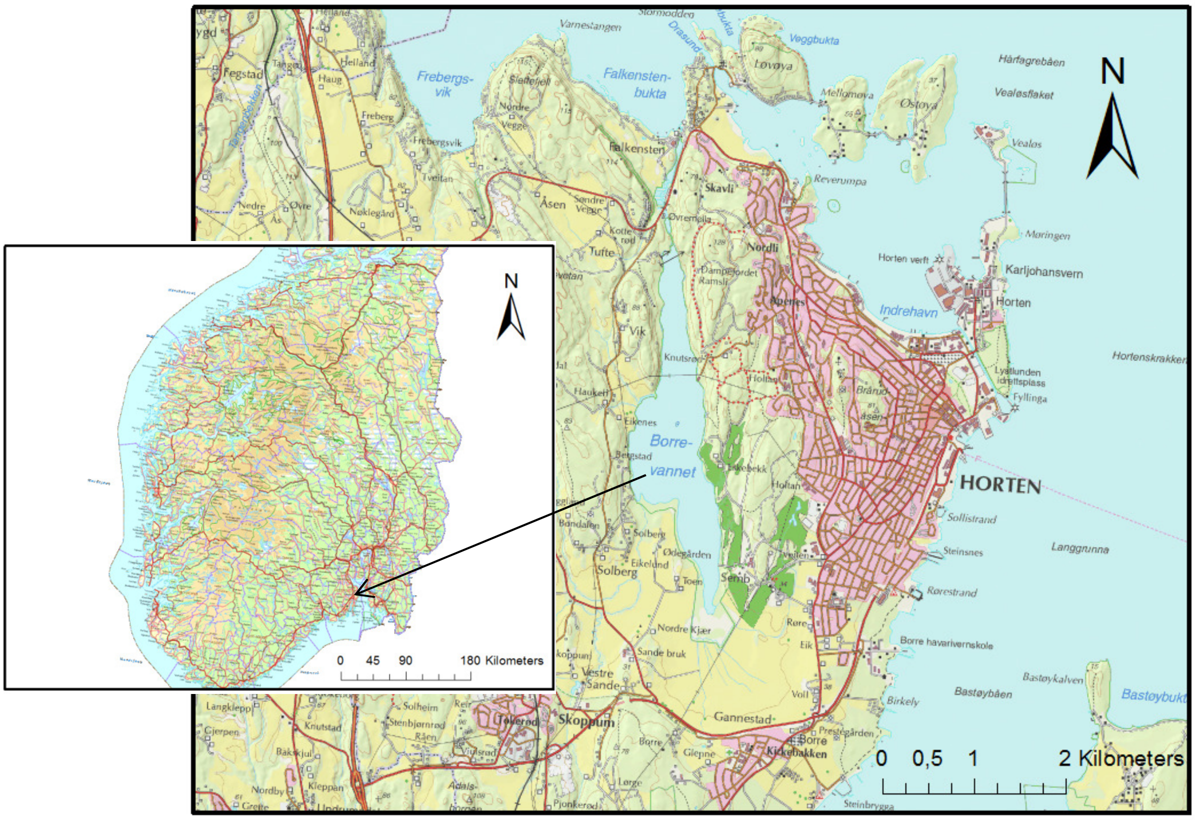

Figure 2: Map over Borrevannet and its location in Norway.

2.2.Study species

Northern pike (*Esox lucius*), pike from now on, can be found around the northern hemisphere in Eurasia and has been stocked into lakes in Northern America (Crossman 1996). Popular fish for angling that has been shown to have an important ecological function in eutrophic lakes (Berg et al. 1997).

It has a long body form with unpaired fins (dorsal, caudal and anal). The snout is long and flattened, with a large gape and an impressive set of teeth (Crossman 1996). When the pike reaches maturity it depends on size rather than age and is affected by factors such as temperature, availability of food and growth rate in the juvenile stages (Billard 1996). Females can grow too a much bigger size than male pike (Casselman 1996). Spawning occurs from February until June, depending on the pikes geographical distribution, which happens around the lake edges in shallow waters. Males mature sooner than females and come to the spawning grounds earlier (Billard 1996).

There are several factors that influence the survival of eggs and larvae of pike. Larva is especially sensitive of sedimentation, were wave motion and currents in the water can give unfavorable conditions. Water level which affects the yearly success in spawning, high and stabile water level can give a strong cohort. Vegetation plays an important role not only as a nursery area, but also for juvenile/young pike later because it gives them refuge from predators and cannibals (Brabrand 2000).

Pike is a top-predator and on the top of the food chain in freshwater systems. Their diet exists of invertebrates and fish, which include preying on smaller pike. Pike is an opportunistic feeder, availability and abundance of prey determines which prey that is consumed (Craig 2008). Cannibalism in a pike population can have tremendous effects on the population structure. Large pike can forage on small pike and abundance of medium pike. Exploitation of the populations large pike, can reduce the mortality of young pike and give way for a strong year-class (Sharma & Borgstrøm 2008a). One global problem when it comes to fish in freshwater systems is the possibility of high mercury (Hg) concentrations. In freshwater, variables such as which position in the food web structure, sex, size age, growth and diet influences the bioaccumulation (Lepak et al. 2012). With pike being at the top of the food chain, the concentrations are often high (Sharma et al. 2011).

2.3.Fish tagging and data acquisition

2.3.1. Fish sampling

The fish was captured using to different methods, one that involved scaring the pike into gillnet and the other leaving gillnets in water for several hours or overnight. For the analyses five rounds to Borrevannet were needed get data from a whole year. Each time, location of gillnets was randomly placed around the whole lake and each gillnet had WP on the GPS (Etrex). First round was in May of 2013 just after the ice had gone. Two gill nets with mesh size 35-50 millimeters were linked together. Gillnets were placed just outside areas with vegetation and common reed (Figure 3). In order to scare pike into the nets, ores were used to beat on the water surface and we trampled in the boat. After leaving the gill nets for a couple of minutes they were pulled out, pike caught in the net were placed in a black bucket of water, before measuring and tagging them. To ensure that the water was oxygen rich and not to warm, the water in the bucket was replaced several times. This process with scaring was done three times with few caught pike and little success. Second round to Lake Borrevannet was in late May of 2013 and the goal was to recapture marked pike. Instead of trying to scare the pike, gillnets were left in the water for a few hours or left out overnight. The third round to Borrevannet was in November 2013. Gillnets were placed randomly around the whole lake and left over night. The fourth time to Borrevannet was in March of 2014 and the procedure was the same. Fifth and final round were taken in April of 2014 and recapture of pike was the main goal. One gillnet was lost and not recovered, fish that was caught in that particular gillnet were lost.

Figure 3: Gillnets were set just outside the belt of common reed (Photo: Monica B. Aasrum).

2.3.2. Fish tagging and measurements

After retrieving the fish from the gill net, they were stored in 100 l, black plastic trays holding fresh lake water. Soon after, each individual was measured and tagged. Firstly, each pike were covered by a wetted blanket over the head, to keep the pike calm and easier to handle. Total length was measured in centimeter and scales were taken from the side from beneath the dorsal fin. The scales were put into individual-specific paper envelopes with information on each individual (waypoint number, ID, length and sex) and dried for age determination. The sex of each pike was determined by extrusion of sexual products or inspection for presence/absence of oviduct. Determination of sex is difficult and can only be used in reproduction season (Billard 1996). At the base of the dorsal fin each pike was tagged with a Floyd T-Bar Anchor tag (Figure 4), also used by Sharma and Borgstrøm (2008a) in Lake Årungen. After tagging was done, the pike was set free in the lake. When pike was recaptured, total length was measured and scales were sampled. This project was given dispensation from the protection provision/regulations from Fylkesmannen i Vestfold. All pikes were set free, except 13 pike that were killed to get metapterygoid bone and operculum bone, for verification of scale readings, see (Sikveland 2013).

Figure 4: Pike marked with a Floyd T-bag Anchor (Photo: Monica B. Aasrum).

2.3.3. Age determination

For age determination scales were taken from each pike, including recaptured fish. Scales were put in a microfilm-reader to enlarge them. Fish scales consist of two layers that contain (ridges) or circuli, which are focused around a central origin (or focus). Changes in the fishes growth can disrupt the circuli continuity and be used to assess age and to describe seasonal growth (Casselman 1996). From the center of each scale, annuli were marked out on a paper slip and measured, annuli is an area of narrow-spaced circuli (Figure 5 A and B). Scalimetry is preferred as a method to use for age determination, because it is a non-lethal method, but the quality of use differs among species. With the use of scalimetry one does not find very old fish, because the growth on the scale has stagnated and the annuli is difficult to separate. It will then be a constant underestimate of age from scales (Borgstrøm 2000). Sikveland (2013) showed that scale readings in Borrevannet pike provided reliable age estimates for ages below

8-9 years. Regenerated scales were deemed unusable, and are not included in the analysis. Measured radius from the scales will be used to back-calculate length of pike every winter season. Total scale radius of 15 pike, will be used to estimate total length of the fish, because a loss of log book with all the data on the third trip to Borrevannet in November.

A **B**

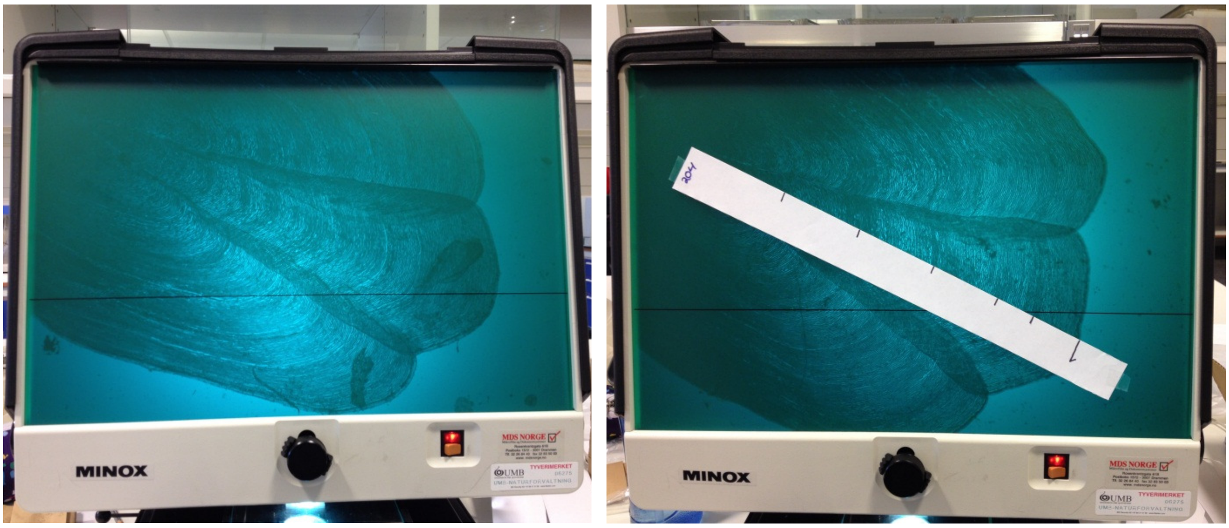

Figure 5: A: Microfilm reader for age determination of scales. **B:** A paper strip was used to mark each annuli radius (Photo: Monica B. Aasrum).

2.3.4. Meteorological data

Meteorological data was obtained from climate database "eKlima" which is managed by the Norwegian Meteorological Institute (eKlima). Air temperatures were taken from weather station Asker (No 19710) – actually being the only weather station with a complete series of observations. Temperatures from May to October were used in in the analyses.

2.4.Data analyses

All statistical analyses were done in programs R (R Development Core Team 2012) and MARK (White & Burnham 1999). Microsoft Excel 2010 was used for compiling raw data.

2.4.1. Individual growth

By knowing the age of fish, estimating their growth rate became possible. Estimating individual growth, von Bertalanffy model was used:

$l_t = L_\infty\left[1 - e^{-K(t-t_0)}\right]$, **Equation 1**

Where l_t is length of the individual at age t, L_∞ is theoretical max length the fish will achieve, K is Brody's growth coefficient (yr^{-1}) and t_0 is hypothetical age at length 0 (Gulland 1977).

2.4.2. Back-calculation of length

In the year of 1910 Lea found out that growth of the scale and length of the fish were almost proportional. Record of the growth history of the fish could therefore be acquired by measuring the distance between the annuli on the scales from the center (Gulland 1977). In my analyses the Dahl-Lea method was used to back-calculate each individual fish length by using scales.

$L_c = L_i\left(\frac{S_i}{S_c}\right)$, **Equation 2**

Where *Lc* length at capture, *Li* is back-calculated length at annulus *i*, *Si* is scale radius to annuli *i* and *Sc* is total scale radius (Klumb et al. 1999).

2.4.3. Capture-mark-recapture analyses

The capture-mark-recapture (CMR) data were analyzed in MARK (White & Burnham 1999). MARK allows for the parameters to be constraint to 0 and 1, and transform the parameters to a logit scale. The 0 represents no capture or presumed dead and 1 represents capture or recapture of one individual (Figure 6 A). Model used for the analyses was the Cormack-Jolly-Seber (CJS) method (Lebreton et al. 1992). The CJS model accounts for the variation in recapture probabilities (p), but the model cannot separate migration from mortality. Therefore, survival estimates in this model under this model represent "apparent survival", given as Φ (Phi). For the spring apparent survival estimates (i.e., φ_1 and φ_4) I fixed them to 1, assuming no mortality during the two-week period spanned by these estimates. This was to ease convergence, but when allowing MARK to estimate these parameters they generally became 1 or very close to 1.

With the use of Akaike's Information Criterion (AIC) (Akaike 1974), the most supported model was chosen (i.e., lowest AIC). The model with the lowest AIC value, is the most model that best balance bias and precision given the specific dataset (Lebreton et al. 1992).

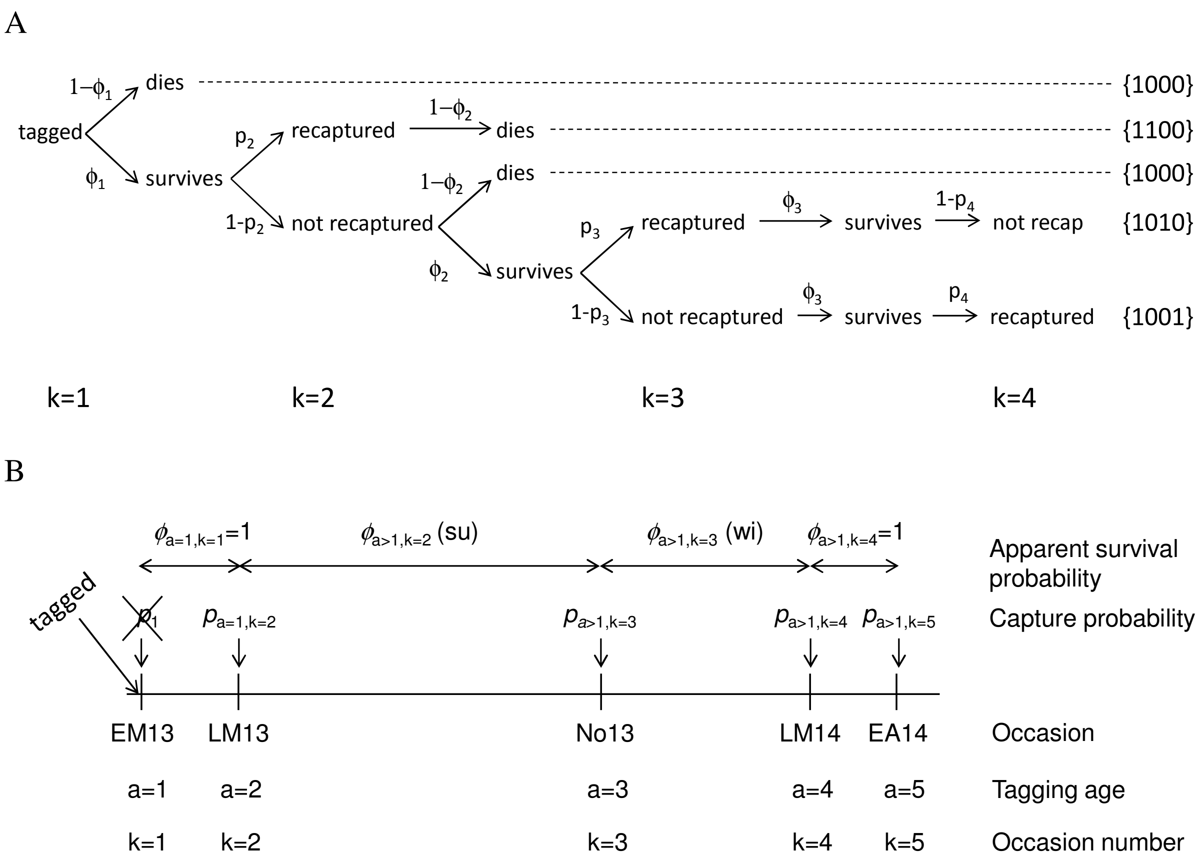

Figure 6: A. Fate diagram for Cormack Jolly Seber model structure data and B. parameterization overview for the current study under CJS model structure. Remark that spring apparent survival (φ1 and φ4) were fixed to 1 (assuming no mortality during the two-week period spanned by these estimates). EM = early May; LM=late May; No=November; LM=late March and EA= early April.

2.4.4. Population size estimates

To estimate the population size, Petersen model and Chapman's modified Petersen model were used (Borgstrøm & Qvenild 2000a).

Petersen model for estimating population size is based on a number of fish that is caught, marked and put back again into the water. Total number of marked fish during the period or interval of marking is recorded and total number of recaptured fish. Under the presumption that the selection is random, the relationship between recaptures (R) and number of marked fish in the recapture round (C), is the same as the total number of marked fish (M) and total population size (N), $\frac{R}{C}=\frac{M}{N}$. Population size is then calculated as:

$$\boldsymbol{N} = \frac{\boldsymbol{M} \cdot \boldsymbol{C}}{\boldsymbol{R}}, \qquad \textbf{Equation 3}$$

Where N is the estimated population, M is the number of marked fish, C is the number of caught individuals and R is the number of recaptures.

Chapman modified Petersen's model of population estimate and making the model more secure statistically:

$$\boldsymbol{N} = \left[\frac{(\boldsymbol{M}+\mathbf{1})(\boldsymbol{C}+\mathbf{1})}{\boldsymbol{R}+\mathbf{1}}\right], \qquad \textbf{Equation 4}$$

Where N is the population estimate, M is the number of marked fish in population, C is the number of individuals capture for control and R the number of recaptures (Ricker 1975; Sharma & Borgstrøm 2008a).

2.4.5. Estimating length from scale radius

On the third trip to Borrevannet in November, the book with all the data were lost to the wind and never seen again. In order to use the data from that day, I estimated the length of each pike from total scale radius, which was marked that day.

In order to estimate the length vs scale radius relationship a Weibull model was fitted (Seber & Wild 2004). This model structure allows for fitting relationships with a typical asymptotic trajectory. The model has three parameters:

$$\boldsymbol{SR}(\boldsymbol{L}) = \mathrm{a}\boldsymbol{e}^{-\boldsymbol{e}^{(\mathrm{b}\ln(\boldsymbol{L})-\mathbf{ln}(\mathrm{c}))}}, \qquad \textbf{Equation 5}$$

The model was fitted using the drc library in R, and length was predicted from Eq. 5 using the ED procedure.

3. Results

3.1. Catch distribution

In total, 292 pike individuals were caught. The average size was 63.2 cm (±9.3 cm, SD, Figure 7). Catch distribution varied from all five rounds to Lake Borrevannet. Circles on the map show how many pike that was caught in each gillnet (Figure 8). Areas with the largest circles have a lot of vegetation cover and premium pike habitat. Two rounds in May of 2013 a total of 95 pike were caught and 6 of them were recaptures. Third trip to Lake Borrevannet in November, gave the least catches. With a total number of 40 pike and only 3 recaptures. The two rounds in April and final trip in May yielded 157 pikes and 24 recaptures.

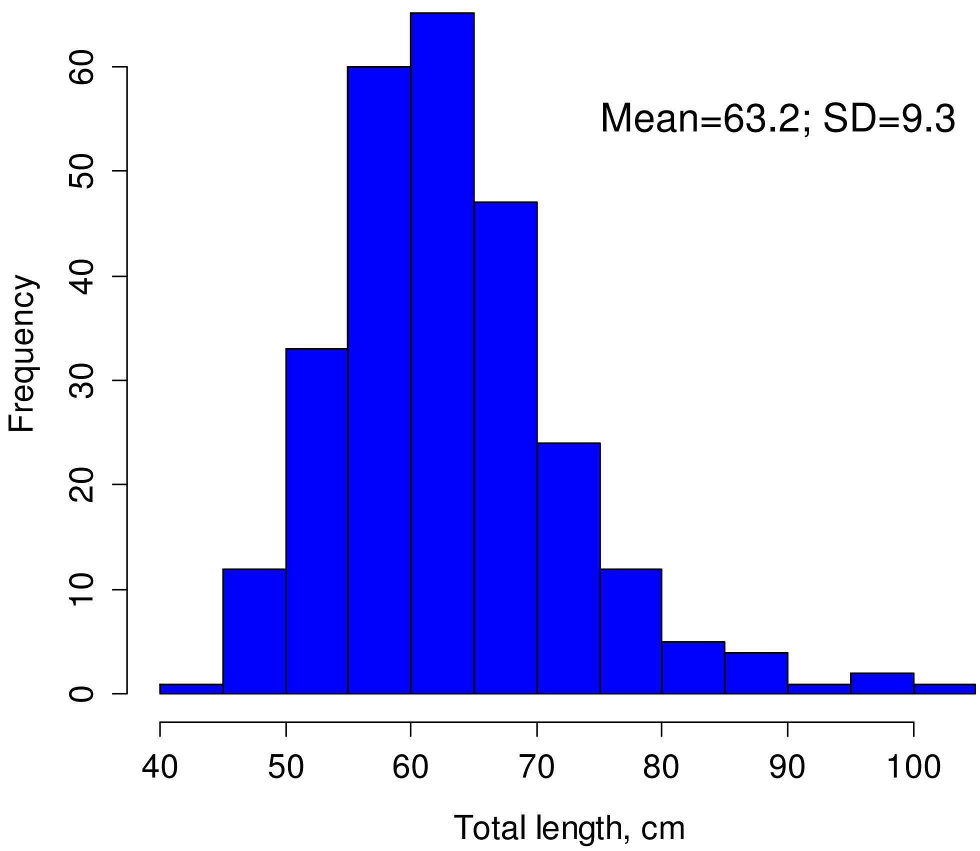

Figure 7: Length distribution of the 292 Borrevannet pike individuals caught during the cause of the study.

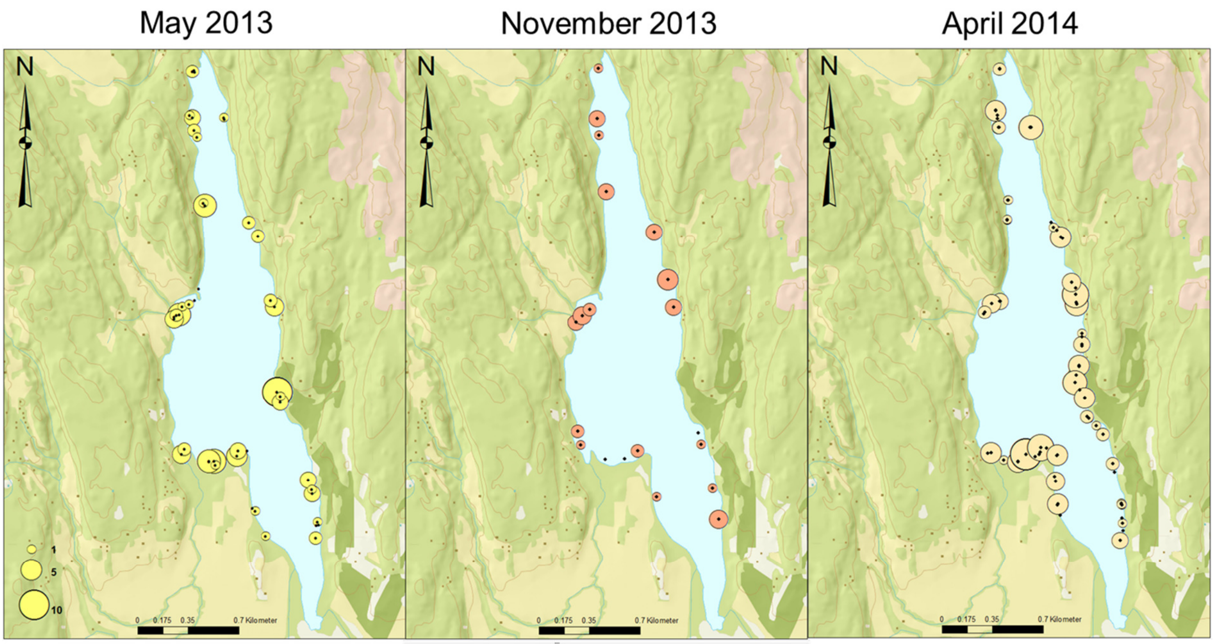

Figure 8: Map over catch distribution in Borrevannet, with circles being proportional with number of pike caught per gillnet. Black dots without surrounding circles represent empty nets.

3.2. Growth analyses

3.2.1. Predicting length from scale radius

Parameter estimates for Weibull model was: a=2.63±0.21 (±SE), b=37.03±0.39 and c=41.97±0.77. Prediction from the model is shown in Figure 9 . Predicting length from scale radius was possible up to a certain point. When the pike was larger than about 60 cm, it was not possible to estimate length from the scales. The three black circles were not included in the analyses because of much larger scale radius.

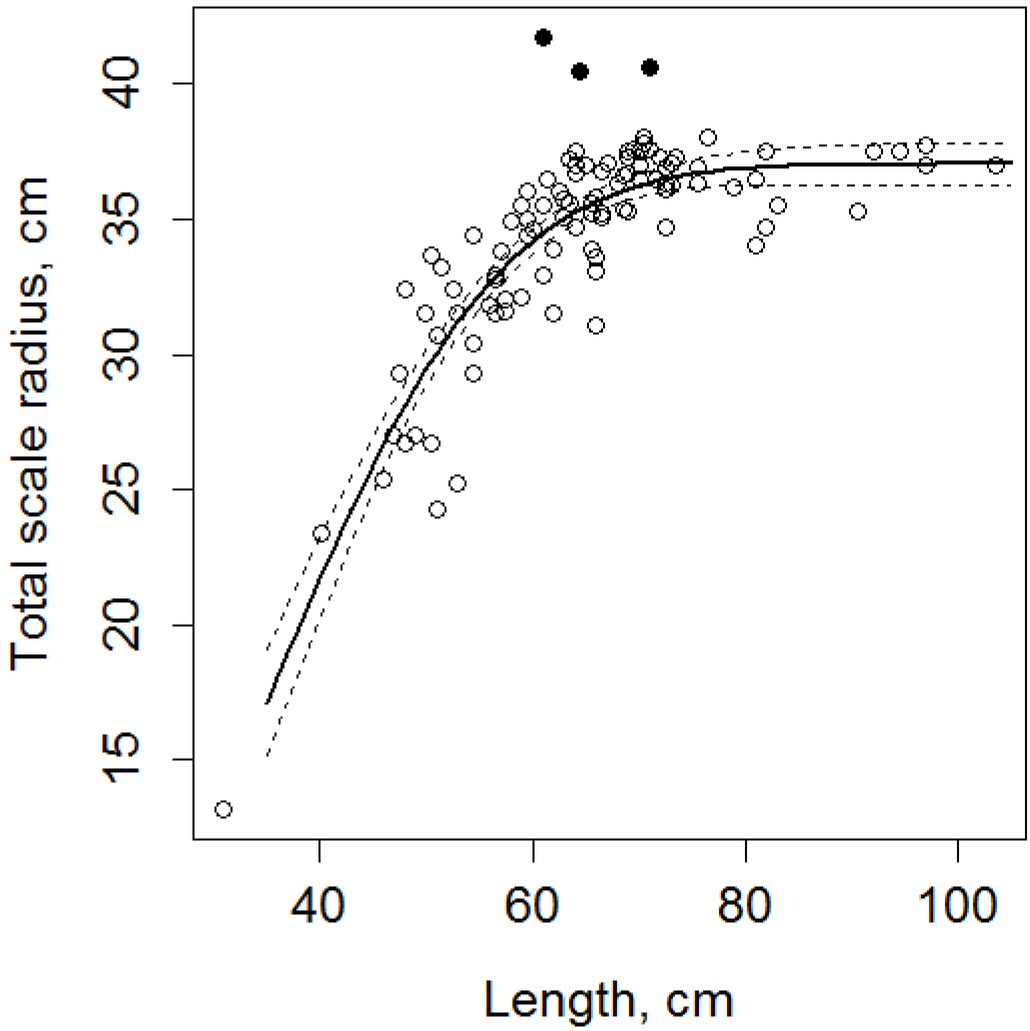

Figure 9: Scale radius vs total fish length relationship with corresponding Weibull model prediction curve. Dashed lines represent 95% confidence bounds. Filled black dots represent data not used in the analysis due to deviating scale radii.

3.2.2. Growth trajectories

The back-calculated length of male and female pike shows similar growth (Figure 10). Female pike have a higher growth coefficient and reaches a larger size faster than males.

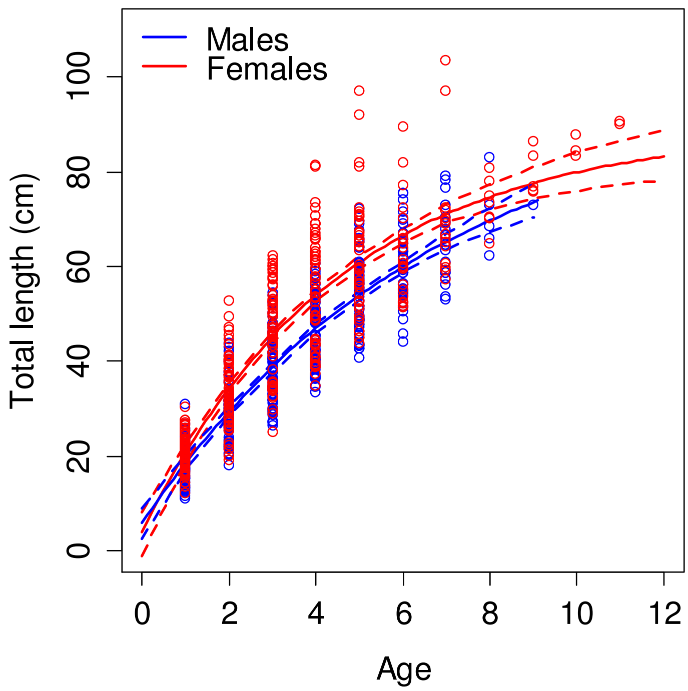

Figure 10: Total length vs age growth trajectory over males and female pike with corresponding confidence interval.

In Table 1, estimation on growth for male and female pike by the use of von Bertalanffy model. It shows estimated maximum length (L_{∞}) with corresponding upper and lower levels of confidence. Coefficient of growth (K) is estimated to 0.197 for males and 0.282 for female pike.

Table 1: von Bertalanffy parameter estimates for growth with a 95 % confidence interval (CI) both upper and lower levels, male and female

	Males			Females		
Parameter	Estimate	LCL	UCL	Estimate	LCL	UCL
$\mathbf{L_{\infty}}$	86.01	75.35	105.53	84.45	76.82	95.60
K	0.197	0.133	0.265	0.282	0.212	0.361
$\mathbf{t_0}$	-0.286	-0.649	-0.011	-0.029	-0.317	0.194

Difference in specific growth rate for second, third and fourth year is shown in Figure 11. The growth rate is highest the second year (and most variable) and declines for the third and fourth year..

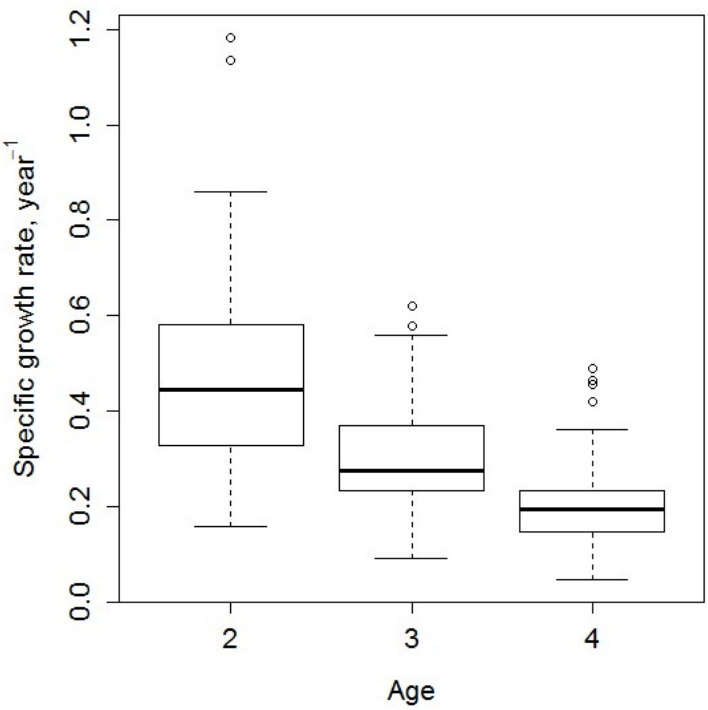

Figure 11: Specific growth rate from second, third and fourth year. The dotted lines shows the span of 10th and 90th percentiles, bold horizontal lines represent the median and 50% of the observations are included in the boxes. The individual dots circles are outliners.

3.2.3. Temperature effect on growth

First-year lengths for both male and female pike were plotted against mean summer air temperature. For male pike, mean summer temperature was positively correlated with length the first year. For the length of females, it is had a negative correlation with mean air summer temperature (Figure 12). Second-year length showed none or a negative effect, with

September temperatures with the most significant p-value (Figure 13). Third-year lengths had a negative trend in May-July and they were most significant (Figure 14).

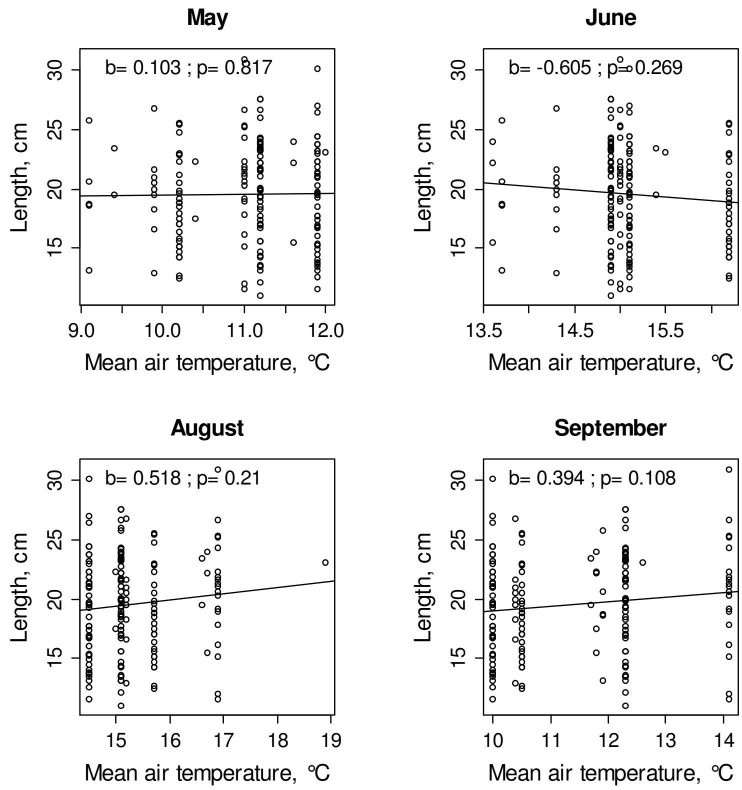

Figure 12: First year growth vs mean air temperature for May-October. Corresponding trend line and effect of temperature (p-value) and slope (b).

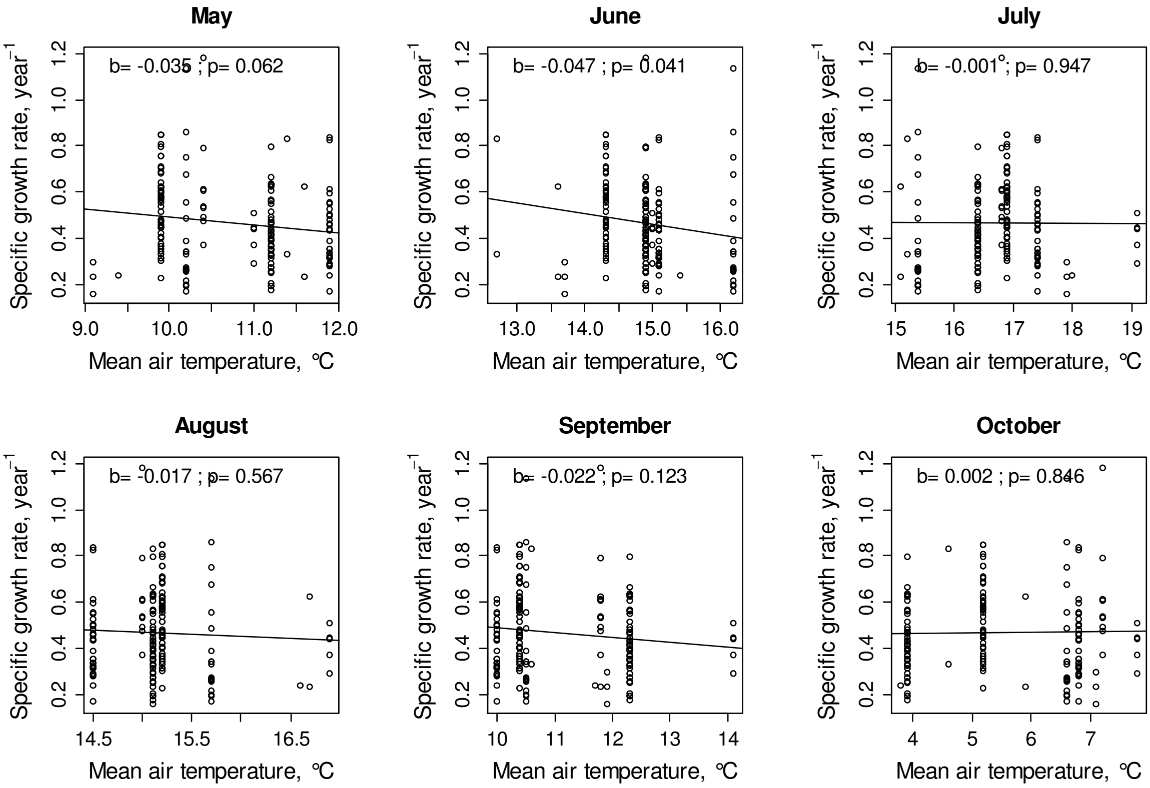

Figure 13: Second-year growth vs mean air temperature for May-October. Corresponding trend line, effect of temperature (p-value) and slope (b).

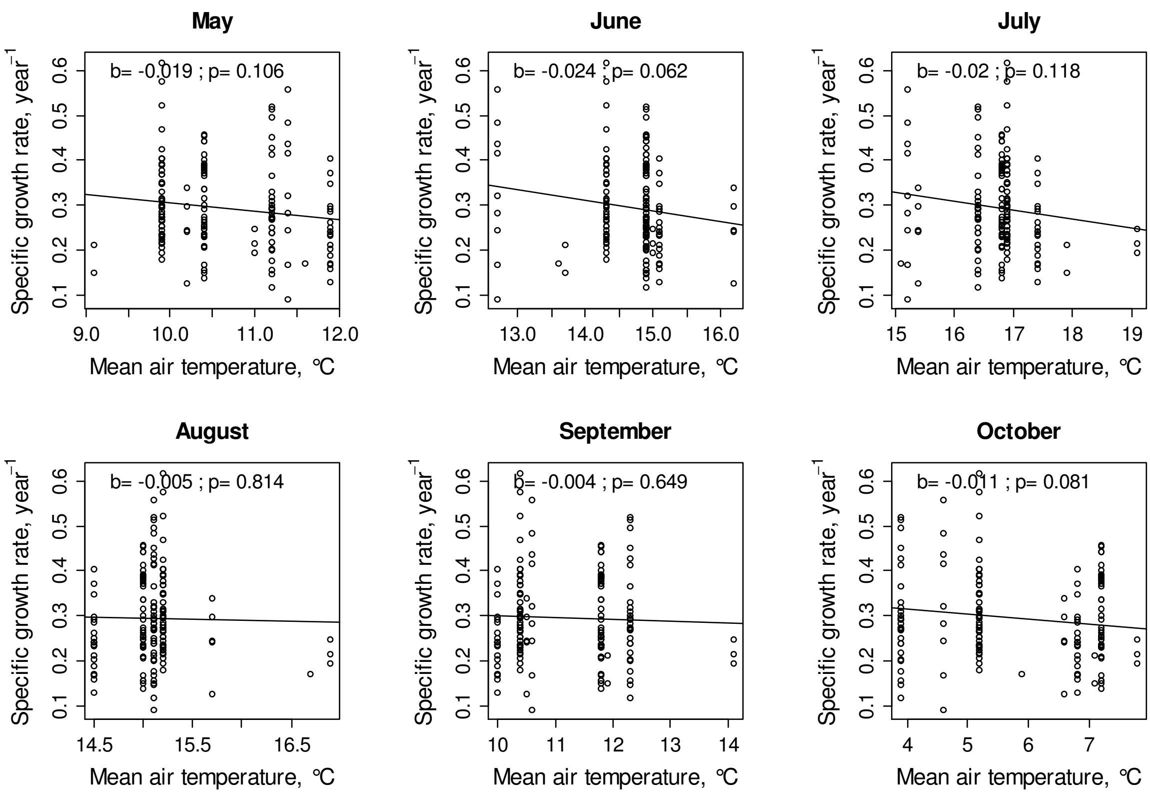

Figure 14: Third-year growth vs mean air temperature for May-October. Corresponding trend line, effect of temperature (p) and slope (b).

Figure 15 is the prediction from the most supported generalized linear model (GLM) over first year growth and mean summer temperature. Female pike show a negative effect from temperature but for the males there was a positive effect from temperature on growth. The GLM prediction plot explains 12 % of the variation in the model.

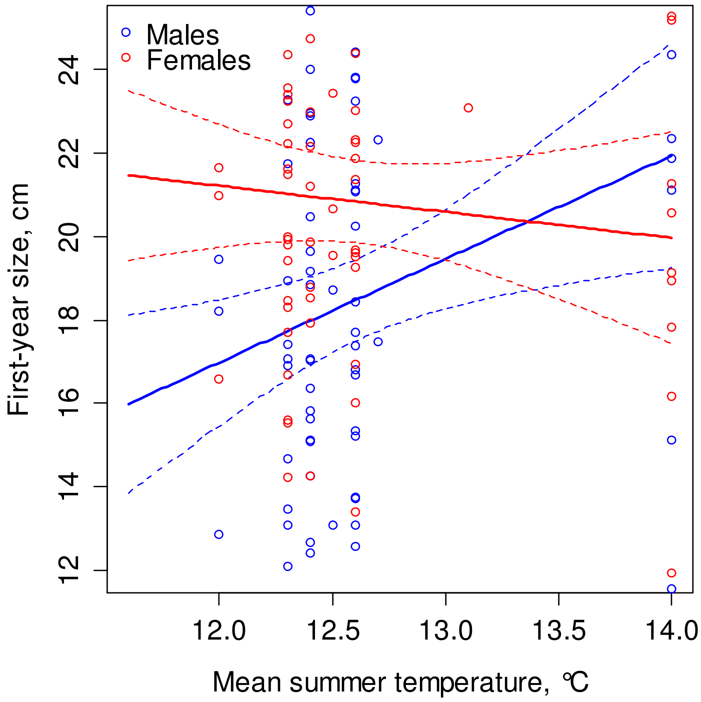

Figure 15: GLM prediction plot for first year size vs mean summer temperature, for both male and female with corresponding confidence bounds.

Table 2: Parameter estimates for male pike and mean summer temperatures pike

Parameter estimates				
	Estimate Std.	Std. Error	t value	Pr(>Itl)
Intercept	28.6785	11.0264	2.601	0.0104 *
Sex[Male]	-41.4187	16.1681	-2.562	0.0116 *
Mean summer temp.	-0.6224	0.8717	-0.714	0.4765
Sex[Male]*mean.SU.temp	3.0994	1.2786	2.424	0.0168 *
ANOVA table					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Sex	1	167.27	167.266	10.3114	0.001678 **
Mean summer temp.	1	26.70	26.700	1.6459	0.201867
Sex*mean.SU.temp	1	95.32	95.316	5.8759	0.016769 *

3.3. Population size

In 2013, the estimated population size in Borrevannet pike was 468 with the Chapman model and 592 with the use of Petersen model. Population size yielded in 2014 with Chapman model 473 and 511 with the Petersen model (Table 3). Even though the number of marked individuals (C) was larger in 2014, the difference in population size was not that significant. Figure 16 shows the Petersen estimation of population size.

Table 3: Parameter estimates over population size with the use of Chapman and Lincoln-Peterson model. M is marked individuals, C number of caught individuals under recapture round and R is number of recapture.

	2013		2014	
	Chapman	**Lincoln-Petersen**	**Chapman**	**Lincoln-Petersen**
Parameter	**data/estimate**		**data/estimate**	
M	71		33	
C	25		124	
R	3		8	
N	**468.0**	**591.7**	**472.2**	**511.5**
var	35006.4	33192.5	15216.0	14650.4
UCL	835.7	949.7	714.6	749.3
LCL	100.3	233.7	229.8	273.7
SE	187.1	182.2	123.4	121.0

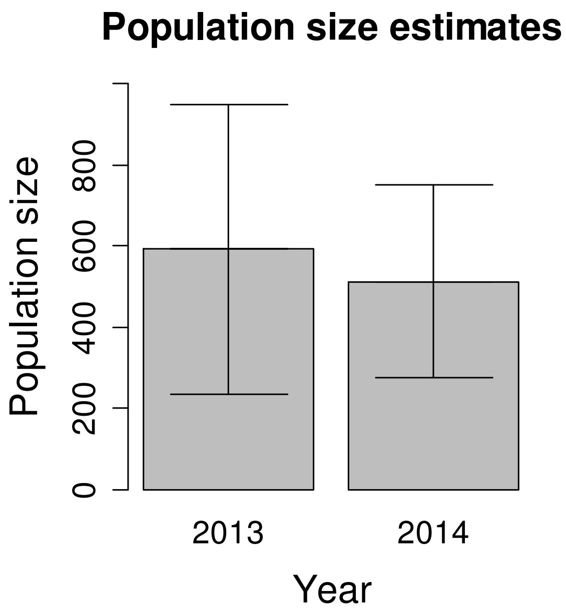

Figure 16: Lincoln-Petersen population size estimates for pike in Borrevannet in 2013 and 2014 with upper and lower levels of 95% CI.

3.4. CMR analysis – survival and recapture probability

The AIC table for candidate CJS-models is provided in Table 4. Some models were excluded from the AIC-table due to non-estimable parameters. The most supported CJS model contained a constant monthly survival rate of 0.959±0.044 (SE) throughout the year (Table 5). There was different size-dependent recapture probability for small individuals during spring and fall seasons (Table 4, Figure 17) where recapture probability of pike in the fall was predicted to be smaller for the larger individuals. In the spring, the probability of recapture increases with increasing size of the individuals.

Table 4: The 15 most supported candidate CJS models fitted in the CMR analyses. phi=appent survival, p=recapture probability; su=summer; wi=winter; (.) =constant; L=length, g=size group (small: <65 cm, large: >65 cm)

Model	AICc	Delta AICc	AICc Weights	Model Likelihood	Num. Par	Deviance
Phi(.) p(g*t*L(-su(.)))	193.0539	0	0.25052	1	8	176.0676
Phi(.) p(g*t*L(-su))	194.9327	1.8788	0.09792	0.3909	8	177.9464
Phi(.,su(L)) p(g*t*L(-su(.)))	194.9465	1.8926	0.09725	0.3882	9	175.7052
Phi(.,wisu(L)) p(g*t*L(-su(.)))	195.1403	2.0864	0.08826	0.3523	9	175.8989
Phi(.,wisu(L)) p(g*t*L(-su1))	195.1403	2.0864	0.08826	0.3523	9	175.8989
Phi(.,wi(L)) p(g*t*L(-su(.)))	195.3076	2.2537	0.08118	0.324	9	176.0663
Phi(.,wi(int+L)) p(g*t*L(-su(.)))	195.6019	2.548	0.07007	0.2797	10	174.0741
Phi(.,wisu(L)) p(g*t*L(-su)2)	197.1605	4.1066	0.03214	0.1283	9	177.9192
Phi(.,su(int+L)) p(g*t*L(-su(.)))	197.2094	4.1555	0.03137	0.1252	10	175.6816
Phi(sm(su(int+L+Lsq)(.)) p(g*t*L(-sp))	197.6593	4.6054	0.02505	0.1	8	180.673
Phi(sm(su(int+L)(.)) p(g*t*L(-sp))	197.6593	4.6054	0.02505	0.1	8	180.673
Phi(.,wisu(G)) p(g+t+wi(L))	198.1227	5.0688	0.01987	0.0793	8	181.1364
Phi(G*t,sm(su(int+L)) p(g*t*L(-sp))	198.2395	5.1856	0.01874	0.0748	9	178.9982
Phi(.,wisu(L)) p(g+t+wi(L))	198.2691	5.2152	0.01847	0.0737	8	181.2828
Phi(sm(su(L+Lsq)(.)) p(g*t*L(-sp))	199.1156	6.0617	0.01209	0.0483	8	182.1293

Table 5: Logit parameter estimates for the most supported CJS model.

Parameter	Beta	Estimate	SE	LCL	UCL	
Phi	Intercept(spring)	0.00	0.00	0.00	0.00	fixed
	Intercept(all seasons)	3.14	1.11	0.97	5.31	
p	Intercept(large)	-1.71	0.46	-2.62	-0.80	
	Intercept(small)	0.77	0.70	-0.60	2.15	
	Intercept(spring13)	-0.43	0.70	-1.81	0.95	
	Intercept(fall)	-2.80	1.21	-5.16	-0.43	
	Intercept(spring14)	-2.07	1.07	-4.17	0.03	
	Intercept(small, spring)	-18.71	34.42	-67.65	67.28	
	Length(small, fall)	-1.36	0.97	-3.27	0.54	
	Length(small, spring)	0.41	0.72	-0.99	1.81	

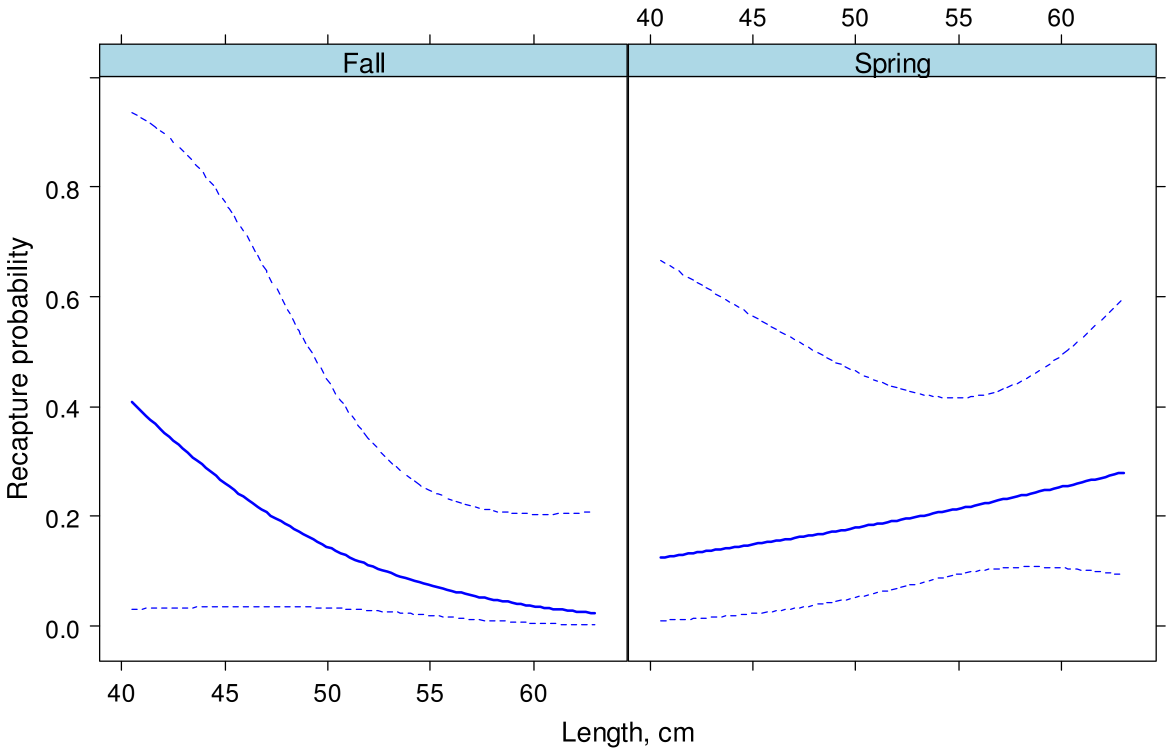

Figure 17: Predicted recapture probabilities of pike in fall and spring for 40-65 cm pike. Predictions have been made from the most supported CJS model (Table 5). Dashed lines represent 95% confidence bounds.

3.5.Migration

In total, 32 individuals were recaptured during the cause of the study. In general, the recaptures were near to where the individuals were tagged (Figure 18). The cumulated probabilities of distances showed that 25% had swum less than 43 m, 50% less than 163 m and 75% less than 528 m (Figure 19). Maximum distance was 2318 m.

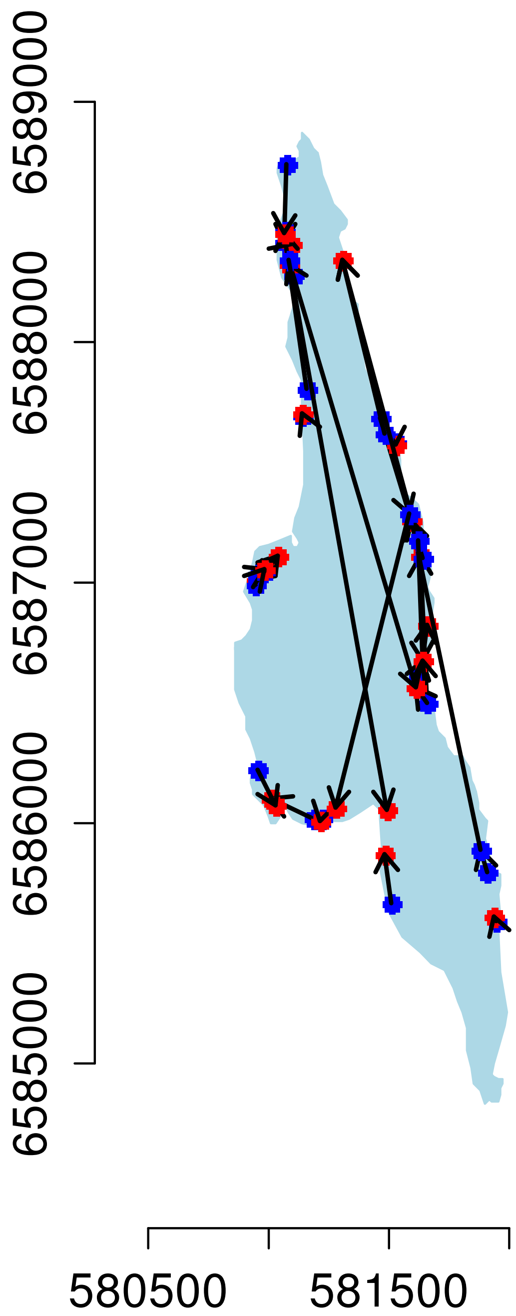

Figure 18: Migration of recaptured pike in Borrevannet during May 2013 to March 2014. Blue dots represent tagging positions and red dots (at the end of the arrows) recapture position. Scale is metric, UTM32 N.

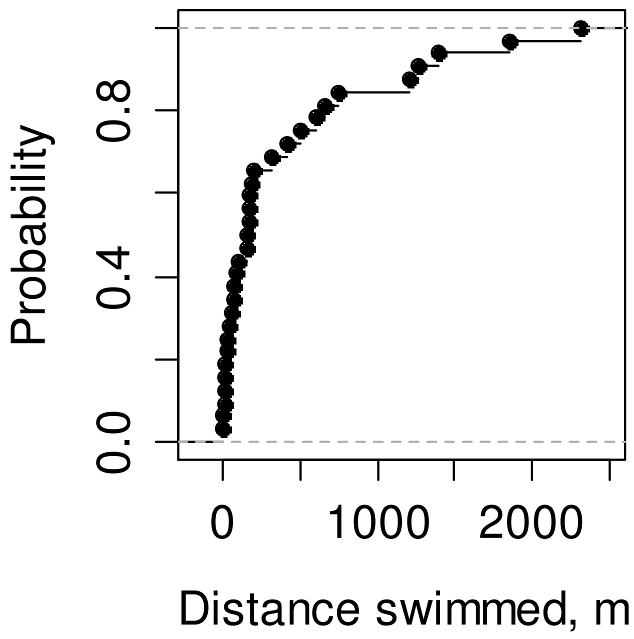

Figure 19: Cumulated distribution of dispersal distances in pike from Borrevannet during May 2013 to March 2014.

4. Discussion

Pike normally spawn in the spring during April-May and is in that period most active (Billard 1996). It is in that time period ideal to carry out a mark-recapture trial, because they are easier to catch. The problems we had by not catching many pike in our first round in Borrevannet might have something to do with the ice breaking during the last days of April. Normally Borrevannet is covered in ice from November-December until early in April (Fylkesmannen i Vestfold 2011). Most of the pike population may not have begun spawning that early after the ice had broken or a part of them spawned under the ice. Many of both male and female pike had, by examining them not spawned yet. So we cannot say for sure that some may have spawned under the ice. This in our case resulted in many null catches, even in areas with optimal spawning habitat. Which forced us to switch from scaring pikes into gillnet, to leaving them in the water for longer periods of time-eventually overnight. We did not have permission to fish for pike in the southernmost part of the lake, because of the bird sanctuary. This area has optimal habitat for pike spawning and most probably affected my population estimates so as to making them biased downwards.

4.1.Population size estimates

In 2013, I got three recaptures and in 2014 I got eight recaptures to be included in the population estimates. Number of recaptures could have been much higher in 2013, but only one angler sent an email when he captured one of our tagged pike. Even though the landowner Bjørn-Tore Freberg had put up posters all around the lake, the feedback was close to zero. This resulted in making it impossible to estimate harvesting rate in the population.

The pike population size in Borrevannet was estimated to be 468 in 2013 and 472 in 2014 with the Chapman model. In the lake Årungen in Akershus County, a comparable to that of Borrevannet, catchment area around is dominated by agriculture and forests. The lake is eutrophic and in the summer blooms of bluegreen algae (Sharma & Borgstrøm 2008a). The main difference is that Borrevannet is a little bit bigger in size (Fylkesmannen i Vestfold 2011; Sharma & Borgstrøm 2008a). With all the similarities one could think that the population would be roughly the same, but the last population size Sharma and Borgstrøm (2008a) estimated in Lake Årungen was in 2006 with 1850 pike. That is almost twice as much as estimated in Borrevannet in both 2013 and 2014. The data is not entirely transferable, since all systems vary, but it is a big difference nonetheless. In freshwater systems, densities of pike population vary considerably. In Windermere number of pike varied in per square meter (m^2) from 0.0002 – 0.0117 (age 2 and older), in Årungen density varied from 0.006 – 0.0013 (total body length > 45 cm), in small Wisconsin lakes it varied from 0.000028 – 0.00038 and in lakes in Minnesota density varied from 0.00003 – 0.00059 (Edeline et al. 2010). The density of pike in Borrevannet was estimated to be 0.00034 in 2013 and 0.00054 per m^2 in 2014 using the population estimate from Lincoln-Peterson model. This is almost half of the lowest density in Årungen. Possible errors in our estimates must be taken into consideration, because we were not given permission to capture pike in the southernmost part of Borrevannet.

4.2.Age determination

Pike in Borrevannet reached maximum ages of 11 years. Problems with reading age from scale are fake annuli. The results from reading age from pike scale, shows that determining age of 8-10 is achievable, but beyond this the determination becomes more difficult. This may be because, growth is little that season or have stagnated, which affect the deposition of annuli on the scales (Borgstrøm 2000). Increasing with age, an underestimation of age is most likely and must be taken into consideration (Casselman 1996). Six pike in Borrevannet was determined to be 9+ years or older, and this confirms what Borgstrøm (2000) wrote, that when only using scales to determine age, the number of old fish is low. From the data, an assessment can be made that up to the age of 10, the estimate of how old they are is probably right. Sikveland (2013) found in her results, by using scale for age determination on pike in Borrevannet that even though the estimate of age was 11 years old, the maximum deviance was two years. In addition, by comparing age by scale and operculum bone there was a tendency of underestimation of age using scales.

By using scales for age determination one avoids killing the fish and it keeps it commercial value and could be used in further capture-recapture analysis. Knowing the age of the pike, you can divide them into groups of young and older fish. With the use of scales and back-calculation of growth rates, you can get information of growth the first years their lives. This is valuable information to use in capture-recapture analysis to get additional information about survival, harvest effort, migration and population estimates.

4.3.Growth

Individual growth trajectories for pike in Borrevannet are quite similar to those studied by Sharma and Borgstrøm (2008a) in Årungen. According to general literature on pike, it is expected and normal for females to grow faster and reach a larger size than males (Casselman 1996). Temperature had different effects on growth for male and female pike in Borrevannet the first year. Males had a positive effect on growth when the temperature increased. Female pike had a negative effect on mean summer temperature.

Individual growth was modelled as function of mean summer temperature for first, second and third year. One would expect that having an early spring and long growth season would have a positive effect on individual growth. However, temperature had little or no effect on growth. Even though the temperature was ideal in the summer months, pike in Borrevannet did not respond accordingly, as others have found. In the areas where the pike lived, prey abundance of roach/perch may not have been enough or predation from larger pike may be a factor. Haugen et al. (2007) studies in Windermere show that effects of competition and abundance of prey on pike older than two years, is related to temperature. When the temperature was high and perch abundance increased, it decreased survival of small pike. They seemed to grow better, when it was lower competition from fellow conspecifics.

4.4. CMR-analyses: survival- and recapture probability

Recapture probability results for pike, 40-65 cm has a big confidence interval (Figure 14). Some of the static in the data could be, because the loss of the log book and then not having sex determined every individual. In my results the recapture probability did not, in account of this, depend on size. Various probability of recapture was on the other hand different between sizes throughout the season. This can be explained by different activity levels and habitat choice between small and large pike in the fall and spring. In the spring, large pike is most active in the spawning grounds. When fall comes, they are calmer and less active then the smaller individuals who move around more.

CMR-analyses indicated monthly survival probability at 0.97, but spread out over the year (0.97^{12}) it equals only 0.61. For pike in Windermere, they found that large males had a higher probability of survival than small. Which could be related to pike biology and that they are more active during spawning period (Haugen et al. 2007). We could not distinguish survival between male and female pike, but the confidence limit was high and points to a difference. On our last field trip, most of the pike we caught were male pike because they mature faster and arrive at the spawning grounds earlier than female pike (Billard 1996). Through this project, to be able to determine what sex is important in analyzing the data and running different models. Determining sex under the spawning period is easy, but it is not that easy in the fall and winter. One possibility is to open them up, but then one have to kill the fish and it cannot be used further in capture-recapture analyses. One method that is used more and more with salmonidae fish, is by testing the genetics by taking a tissue sample. Male behave differently than females, this is important and should be taken into account when doing analyses of pike populations.

4.5.Migration

From Figure 18 most of the marked pike did not wander far from tagging site, but some swam longer distances. Pike in Windermere in England was found to disperse because of abundance of prey (small and large) and density (large pike). The possibility of dispersal is larger for males than females. Pike can swim long distances during one day (Haugen et al. 2007), so we cannot rule out that several more pike, disperse throughout the lake in one day. Older pike that has been capture may stay in the nearby area, but that young pike may disperse more after release (Craig 1996). The probability of pike in Borrevannet to swim shorter than 2000 meters was 0.90 (Figure 19). To further explore dispersal of pike in Borrevannet and how habitat choice and behavior differs from each seasons, positional telemetry is a possibility. In a shallow and eutrophic lake in Germany, Kobler et al. (2008) found that pike moved more around the lake in the summer and during twilight period. In the winter pike did not have peaks of activity during specific time periods and chose to be closer to shore. Distance to shore and movement rate was related to size of the individuals. Dispersal of pike varies from system to system and it is therefore possible that pike in Borrevannet disperse different throughout the seasons in that of what Kobler et al. (2008) found.

4.6.Ecological status and size selectivity

Pike is an important piscivore in temperate lakes and can with its predation alter the ecosystems composition. Pike uses vision in hunting for prey and for smaller pike important for avoiding predation. Visibility is determined by water clarity or turbidity. When there is high turbidity the visual range is low and can affect the behavior for pike and its prey (Nilsson et al. 2009). Borrevannet is eutrophic and water turbidity is high. To improve the water quality in Borrevannet, using biomanipulation is one out of many options. By increasing the stock of small pike and large perch and thereby reducing the population of roach by piscivory (Sharma & Borgstrøm 2008b). This can be achieved by selectively removing the larger individuals of pike from the population. Experiences from such measures in Årungen did not provide compelling results in terms of improved water quality. This was due to many factors – one being a large harvest rate of medium-sized pike by local anglers and thus not yielding the sought roach predation level. Also, new cyprinid species were introduced to Årungen during the study period (tench and rudd). So – in order to succeed with pike biomanipulation it is pivotal to control other aspects of the fish and harvesting regime at the same time. Pikeperch was introduced to the water as a measure to forage on roach and common bleak in Borrevannet. Having a stable common bleak population is a goal in the management plan for Borrevannet (Fylkesmannen i Vestfold 2011), to achieve that goal the intensity of stocking may have to be increased.

Since this measure for trying to better the water quality seems to not have worked. For Borrevannet the best ecological state and "function" is to have a population with few large pike and a big abundance of medium size pike since they are the most effective predator on roach (Sharma & Borgstrøm 2008b). Not having large trophy sized pike in Borrevannet may come in conflict with what the sports anglers want. But having a population with abundance of medium sized pike is more aimed for families who enjoy fishing. More rapidly growing and medium sized pike will also lead to benefits such as reduced mercury accumulation in pike as a positive side effect (Sharma et al. 2009).

Selective harvest of large pike can lead to changes in the selective regime in the lake, which is contrary to what natural selection favors in pike (Carlson et al. 2007). Size selectivity of cannibalism and size selectivity through fishing favors different sizes of pike. Smaller pike is under pressure from larger cannibalistic individuals to grow faster and thus minimize their risk of predation from larger conspecifics. Selection towards growing slowly and becoming a part of the harvestable part of the population late can happen when harvesting large individuals, which is against natural selection (Carlson et al. 2007). The mark-recapture analysis at this point shows any size-dependent mortality and therefore it is not possible to be certain about the size-dependent harvest selection and size-dependent natural mortality for pike in Borrevannet. By still keeping up the mark-recapture study of pike in Borrevannet, estimates of size-dependent mortality and size-dependent harvest selectivity are possible to attain.

Natural selection can drive evolution and local adaptions, but on the same population we can also have harvest selection (Matsumura et al. 2011). When there is selective harvest, pike invest in reproduction much earlier (Arlinghaus et al. 2009). Edeline et al. (2007) found out that exploitation of pike in Windermere selected towards low growth rate, thereby overriding natural selection, but the selectivity decreased over time. Natural selection prevailed and with combined selection, the somatic growth increased when the high pressure of fishing was not maintained.

4.7.Conclusion

This study shows that the population size of Borrevannet pike at sizes larger than 40 cm approximate 500 pike. The density of pike is much lower than many other lakes that are similar. The estimated population size is biased down, since the whole lake was not sampled. For the estimate to be more accurate, the southern end of the lake should be sampled for pike. Monthly survival in Borrevannet was 0.97, but spread out over a year it was 0.61. Distinguishing between survival of male and female was not possible, owing to the fact that not all pike was gender determined. To get estimates on size-dependent natural mortality and size-dependent harvest mortality the mark-recapture study must continue on. The mean summer temperature had a positive effect on individual growth for male pike the first year, but female pike had a negative effect. Pike who was marked did not migrate far from original marking point when they were recaptured, but a few individuals had dispersed up to 2000 m.

In order to manage the pike population in Borrevannet in a sustainable and justifiable way, the landowners association should determine if they want to have a population with large pike directed for sports anglers or a population few large pike and abundance of medium-sized pike directed against recreational family fishing. Medium-sized pike is a very effective roach predator and therefor very important in terms of improving the water quality in Borrevannet. What they decide may depend on how much effort they are willing to put in to improving the water quality in Borrevannet, since the attempt of stocking roach to improve the water quality.

5. Reference

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