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How Northern pike's (*Esox lucius*) traits, environmental factors, and angler characteristics infuence angling vulnerability explored though an angling experiment in Aremarksjøen

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Preface

This study marks the end of my Master's Degree at the Norwegian University of Life Sciences. It was made possible through the collaboration between NMBU, Aremark Gjeddeklubb, Utmarksavdelingen for Akershus and Østfold, Ara-Aspern fiskelag, Havass fiskelag, Regionalpark Haldenkanalen, and Haldenvassdragets Brukseierforening

I extend my sincere gratitude to my supervisor Thrond Haugen, who has taken time out of an exceptionally busy lifestyle to reply to emails, set up meetings and guide me through field work, statistics and writing process. A huge thanks to Martin Buer and Terje Bokerød Strand for meeting with Thrond and I to make the pike angling experiment a reality, and thanks to all the volunteering participants in the experiment! Thanks to my partner who made the work on this thesis much more enjoyable. Lastly, I want to thank Øystein Toverud for making his cabin and boat available for use during the experiment and field work.

Abstract

Pike angling is a popular activity across large areas of the world. This activity has attained substantial research attention recently demonstrating potential impact on population size and composition, including both life-history traits and behaviour traits. In Norway, little research has been done on pike angling and inspired by mostly studies in other parts of the world, I explored pike catch vulnerability both from the pike's perspective (size and activity) and the angler's perspective (effort, angling method, and space use) in addition to environmental conditions. The research questions are: 1. What pike behaviour explained and what environmental conditions contributed to an increased pike angling vulnerability? 2. Were pikes caught by angling bolder than pikes caught in gillnets? 3. What could an angler do in Aremarksjøen to maximize his or her probability of catching a pike?

In total, 26 pikes from the lake Aremarksjøen were caught by gillnet during spawning season or angling rods in late summer, fitted with acoustic tags, and released into a triangulation array of receivers that covered a lake section. Within the receiver array their three-dimensional space use could be quantified and examined.

To search for what could explain the anglers' probability of catching a pike, an angling experiment with 13 anglers in 7 boats ranging over 9 days was conducted in the triangulation area. They angled by trolling or spinning and carried GPSs to track their movements. It was found that the most important environmental factors for predicting catch probability were air temperature and air pressure. Catch rates were increased when pike depth amplitude was low and the air pressure low. The depth amplitude was most efficiently predicted by the air temperature, the length of the pike and whether it was day, night, sunset or sunrise. Warmer temperatures increased depth amplitude, as did both twilight periods. Larger pikes had a lower hourly depth amplitude and dwelled on average deeper than shorter ones. The pikes rarely dwelled deeper than 6 meters. Trolling was shown to be more efficient than spin-angling and both methods increased their catch probability by the anglers moving less. Increased effort increased the catch probability significantly, both for a single boat (number of rods utilized) and the total number of rods used by all boats within every hour (rod hours).

According to my findings, cold weather and low air pressure increased pike angling vulnerability. The angling group was more active in the activity measures distance swum and depth amplitude suggesting bolder personalities. For the anglers, the probability of catch increased when trolling instead of spinning, when increasing effort and moving less. During October, a pike angler therefore should go angling on a cold day with low air pressure and travel straight to areas where the lake is shallower than 10 meters to increase their probability of catch. He/she should utilize as many rods as possible, move slowly and troll rather than spin-fish. The anglers are then more likely to catch larger pikes, as they seem more vulnerable to being caught.

Sammendrag

Gjeddefiske er en populær aktivitet over store deler av verden. Denne aktiviteten har i det siste blitt vist gjennom omfattende forskning å ha mulig påvirkning på populasjonsstørrelse og -sammensetning, som innebærer både livshistorietrekk og oppførsel. I Norge har lite forskning blitt gjort på gjeddefiske og i stor grad inspirert av studier gjort i andre deler av verden, undersøker jeg gjedders sårbarhet for fangst fra gjeddas perspektiv (størrelse og aktivitet) og fra fiskerens perspektiv (innsats, fiskemetode og områdebruk) i tillegg til miljøforhold. Spørsmålene jeg stiller er: 1. «Hvilken gjeddeatferd forklarte og hvilke miljøfaktorer hang sammen med økt gjeddefangbarhet?», 2. «Var gjedder fanget på stang modigere enn gjedder fanget i garn?» og 3. «Hva kan en fisker gjøre i Aremarksjøen for å maksimere sin sannsynlighet for gjeddefangst?».

Totalt 26 gjedder fra Aremarksjøen ble fanget i garn i gyteperioden og på stang på sensommeren, merket med akustiske merker og frigjort i et trianguleringsnettverk av mottakere som dekket en del av innsjøen. Inne i nettverket kunne deres tre-dimensjonale bevegelser bli kvantifisert og undersøkt.

For å søke etter hva som kunne forklare fiskernes fangstsannsynlighet ble et eksperiment med 13 fiskere i 7 båter gjennomført over 9 dager i Aremarksjøen. Fiskerne dorget eller spinfisket og hadde GPS i båten for å logge bevegelser. De viktigste miljøfaktorene som estimerte fangstsannsynlighet var lufttemperatur og lufttrykk. Sjelden oppholdt gjeddene seg dypere enn 6 meter. Fangstene økte når gjeddenes dybdeamplitude var liten og lufttrykket var lavt. Dybdeamplituden ble mest effektivt predikert av lufttemperatur, gjeddas lengde og om det var dag, natt, solonedgang eller soloppgang. Varmere temperaturer, soloppgang og solnedgang økte dybdeamplituden. Større gjedder hadde en lavere dybdeamplitude per time og oppholdt seg i gjennomsnitt dypere enn mindre gjedder. Dorging ble vist å være mer effektivt enn spinfiske og begge metodene økte fangstsannsynligheten ved å flytte seg sakte. Økt innsats økte fangstsannsynligheten betydelig, både for enkeltbåter (antall stenger brukt) og det totale antallet stenger brukt av alle båter innenfor hver time (stangtimer)

Ifølge mine funn skal kaldt vær og lavt lufttrykk ha økt gjeddenes sårbarhet for fangst på stang. Gruppen fanget på stang var mer aktive målt i svømmedistanse og dybdeamplitude som hinter om modigere personligheter. Fiskerne fikk en økt fangstsannsynlighet når de dorget i stedet for å spinfiske, økte innsatsen og bevegde seg mindre. En gjeddefisker bør på bakgrunn av dette dra på fisketur på en kald dag med lavt lufttrykk og dra rett til områder der sjøen er grunnere enn 10 meter for å øke fangstsannsynligheten. Han/hun bør bruke så mange stenger som mulig, bevege seg sakte og dorge i stedet for å spinfiske. Fiskeren har da større sjanse for å fange større gjedder, for det er de som virker mest sårbare for fangst.

Contents

1. Introduction

Humans have been proven to fish with barbed bone tools for at least 90,000 years (Yellen et al., 1995). There were found different sizes of heads for spears and harpoons with various shapes and barb-sizes indicating specialization of the tools. Today, there are specialized gear for every size, species, and habitat you can think of, presumably to increase the selectivity of the gear. Such selective fishing has been shown to alter the genetics of the target species (Árnason et al., 2009). The commercial fisheries have restrictions for what gear can be used according to which species is targeted to minimize the amount of by-catch and induced evolution, though these vary between nations and some do not have sufficient regulation or scientific knowledge (Cushing, 1974; Kvamsdal et al., 2016; Thompson & Ben-Yami, 1983). Marine fisheries are the most thoroughly regulated part of the fishing industry and inland fishing is often economically undervalued (Suuronen & Bartley, 2014). Even recreational fishing can have structural effects in a lake, which needs to be addressed by a responsible manager (Carlson et al., 2007; Klefoth et al., 2011; Matsumura et al., 2011). Worldwide, inland recreational fisheries generate $44 billion USD annually and the densest recreational freshwater-angler population is in Northern Europe at 18.1% of the population partaking in freshwater angling as of 2018 (FAO, 2018). In 2014, 43% of the adult Norwegian population reported to have angled in the past 12 months, with 27% of them doing so in fresh water (Kleiven, 2019). Northern pike (*Esox lucius*), hereby “pike”, is a popular fish for recreational sports angling in Europe. The pike is growing more popular as a game fish in Norway, especially near the Swedish border where the pike naturally migrated (Hesthagen & Sandlund, 2017). Being an ambush predator, the pike strikes the lure aggressively and fights well, often in sudden bursts (Craig, 2008). When angling is such a popular activity it is important to know more of what influences the fish to strike or not, both for the numerous interested anglers and the fishery managers.

When angling, the fish you catch is not randomly selected, as several factors influence the probability of catching a particular fish (Lennox et al., 2017b). According to Lennox et al. (2017b) there are three factors that influence a fish’s vulnerability to being caught: the individual fish’s internal state, encounter with the gear and the characteristics of the encountered gear. The season in temperate climates also determines what gear can be used (e.g. ice fishing in winter and spinning in summer), and thus the characteristics of the gear.

Lennox et al. (2017b) describes the internal fish state as “those factors that induce motivation to eat and strike baits or lures”. This internal state is determined through the fish’s life, but also by its genetics (Philipp et al., 2009). Pike personalities have been demonstrated in lab experiments (Pasquet et al., 2016), and measurements of boldness and activity could manifest themselves in how they were caught (Kobler et al., 2009). In this study, the factors that influence the internal state of the pike in lake Aremarksjøen is examined through sampling pikes with two different methods, angling and gillnets, and testing whether there are differences in the behaviour and catch vulnerability between the two groups. How frequently and how quickly a fish moves between different states is unknown, but diel activity could be an indicator (Baktoft et al., 2012). Baktoft et al. (2012) found that there were significant diel effects on pike’s activity in a temperate lake, but no significant differences in activity levels when comparing seasons. In a different study the researchers found that movement rates were influenced by season, which indicates that the lakes are inherently different, but also influenced by variations in temperature from year to year (Kobler, A. et al., 2008). The pike’s behaviour in Aremarksjøen is therefore hard to estimate based on similar studies done in different lakes. An asset to the present study is the large area covered by a triangulation array and the inclusion of an angling experiment ranging over nine days.

Pike populations are vulnerable to overfishing (Arlinghaus & Mehner, 2004; Paukert et al., 2001), larger pikes especially, as these are sought after as trophy fish prized for their power and photogenic nature. Trophy pike are targeted with larger baits (Arlinghaus et al., 2008). Fisheries with size-selective angling methods will have to implement strategies to cope with the fishing-induced evolution (Matsumura et al., 2011). Harvesting-induced timidity and smaller sizes at maturity in heavily exploited fisheries are well documented effects (Kuparinen & Merilä, 2007). Pike in a controlled experiment did learn to recognize artificial lures, but not live bait (Beukemaj, 1970) and a fish population subjected to the practice of catch and release (C&R) could over time become less prone to striking a lure (Klefoth et al., 2011; Young & Hayes, 2004).

Inspired by similar studies conducted on pike and Eurasian perch (*Perca fluviatilis*) (Arlinghaus et al., 2017; Monk & Arlinghaus, 2018), my goal was to test in a natural environment which factors make the pike vulnerable to being caught by angling from boats and what the anglers can do to increase their probability of catching a pike. The results could be helpful for anglers and help guide fishery managers to a sustainable, long term management of their pike populations. Firstly, I aim to link catch probability to behavioural factors in the pikes and environmental factors to examine if there is an effect in pike angling vulnerability. I predict the water temperature will have a significant impact, as temperature is a well-documented environmental factor to affect fish behaviour (Bigelow et al., 1999; Stoner, 2004). Swimming distance as an activity measurement I also expect will have a positive correlation with the probability of a pike being caught, as high activity is a boldness trait (Pasquet et al., 2016). Secondly, I investigate whether a pike's group affiliation reflects on possible personality traits and hence angling vulnerability. I expect the angled pikes to be a more active group as bolder personalities are more vulnerable to angling . Thirdly, I link the properties of anglers to probability of catching pike. I expect angling effort to be an important factor as Arlinghaus et al. (2017) found an angler's time investment to be the best bet for increasing catch rates. Included in this analysis will be abiotic factors, which I argue can be attributed to the angler as he/she might prefer to go angling on specific days. Abiotic factors have previously been found to influence pike angling success (Kuparinen et al., 2010).

2. Materials and methods

2.1 Study area

This research was conducted in lake Aremarksjøen, a Norwegian lake located in Østfold, Aremark municipality (Figure 1). It is a part of Haldenvassdraget, northwardly connected to lake Øymarksjøen by sluices and connected to lake Aspern in the south. The lake, with its area of 7,46 km^2, is narrow and by Norwegian standards; shallow, with a maximum width of 2 km and a maximum depth of 40 m in the north (Bjar et al., 2013). The southern part is shallower and narrower. Aremarksjøen is encompassed by several sand beaches and farmland. The ecological status was deemed to be moderate in 2013 (Bjar et al., 2013), and Vann-Nett concluded with the same through the latest test conducted in August 2018 (Vann-Nett, 2019). The moderate status is largely a product of the lake being humic and lime deficient. Haldenvassdraget is a lowland water course located under the marine boundary, meaning the surrounding soil is mainly nutrient rich and suitable for farming The marine sediment in combination with agricultural activity affect the water's nutrient content, and this is most apparent in the northern part of the water course. (Bjar et al., 2013; Løddesøl & Smith, 1938).

According to Øystein Toverud, the following fish species have been documented in Aremarksjøen: Perch (Perca fluviatilis), Eurasian ruffe (*Gymnocephalus cernua*), European river lamprey (Lampetra fluviatilis), burbot (*Lota lota*), bream (*Abramis brama*), white bream (*Blicca bjoerkna*), roach (Rutilus rutilus), common rudd (*Scardinius erythrophthalmus*), common minnow (*Phoxinus phoxinus*), crucian carp (*Carassius carassius*), eel (*Anguilla anguilla*), zander (*Sander lucioperca*), brown trout (*Salmo trutta*)), bleak (*Alburnus alburnus*), vendace (*Coregonus albula*), European bullhead (*Cottus gobio*), European smelt (*Osmerus eperlanus*), alpine bullhead (*Cottus poecilopus*), and of course, the pike. In addition to this the European crayfish (*Astacus astacus*) inhabits the lake (Vøllestad, 1989).

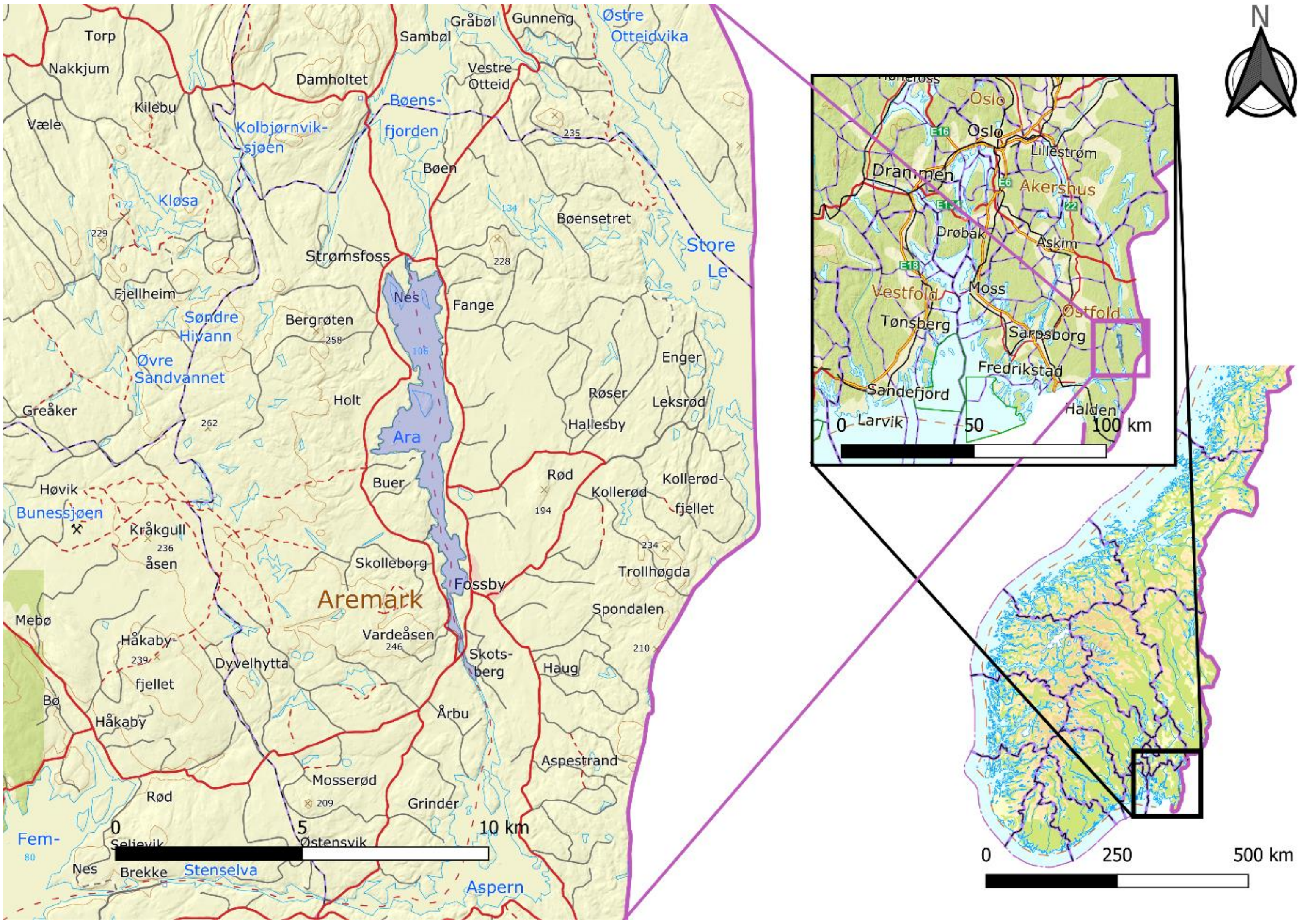


Figure 1. Location of Aremarksjøen in Norway

2.2 Study species

The pike is a native freshwater fish in Eastern and Northern Norway. It can be found in most parts of the world in moderately productive, vegetated waters (Luna & Torres; Skov & Nilsson, 2018). In spring, the pikes aggregate in shallow water, often flooded areas, to spawn. Being a piscivore in all life stages, it usually grows quickly at a young age (Pethon, 2019) Cannibalism is common, both for young and older individuals (Giles et al., 1986; Haugen et al., 2007). Its cannibalistic behaviour can be so severe that the main source of mortality for young pike is being eaten by another pike (Mann, 1982). The pike’s prey can be as big as half its size, and includes fish, amphibians, rodents, birds and macroinvertebrates (Beaudoin et al., 1999). This makes the pike the top predator in the systems it inhabits (Craig, 2008). Dietary preferences vary with prey abundance in pike populations, making them able to inhabit a range of different habitats (Mann, 1982). Large pikes are major predators of medium-sized pikes and therefore regulate the total numbers in the population. Removal of large pike can increase the abundance of pike in a lake because of this (Craig, 2008).

2.3 Capturing the pikes

The pikes were caught in two different ways in this study. One group was caught by gillnets and the other by fishing rod. The gillnet group is the "random sample" as these were caught in the spawning grounds. The group caught by rod are assumed to be bolder, more active fish, as these had to strike a lure to be caught. With gillnets two pikes were caught 9th April and eleven pikes 10th April 2019, for a total of 13. Two of the pikes caught 10th April were recaptures from 2017. In the period 23rd September – 30th, 2019 12 pikes were caught over four angling days. During the experiment, the participants were instructed to call me as supervisor if they caught a pike longer than 80 cm for tagging. Two large pike were caught this way. In total, 14 individuals were caught by angling, one of them a recapture from our gillnet sessions earlier in the year. The fish caught early in the day were kept in a keep net by the surgery location. In the boat was a keep tray getting regularly refilled with lake water. When the tray began to look crowded, the transferred them to the keep net and resumed collecting fish.

For catching pikes in gillnets, two different methods were applied. In daylight, nets were placed parallelly to the reeds and I proceeded to wade in the reeds and beat the water surface with oars. The intention was to scare the pike into the nets. This method proved ineffective however, as only three pikes were caught this way. The second method involved placing the nets at the same locations and letting them stay overnight (9th – 10th April). Ten pikes were caught this way, two of which were the mentioned recaptures. To prevent unnecessary stress to the fish, they were cut out of the nets using a knife. In the spawning period the pikes have a stronger immune system, tougher skin and are generally hardier than normal. Combined with cold water the fish can stay in the net all night without sustaining injuries (Thrond Oddvar Haugen, PhD, personal communication). All pikes were carefully inspected for severe wounds and damage, but all passed the inspection and were deemed to be in a state suited for tagging (Carlson et al., 2007; Haugen, 2018).

Being caught by angling is potentially more stressful to the fish than being caught in a gillnet (Arlinghaus et al., 2009). To minimize the damage sustained by the hooks appropriately heavy gear was used to enable a quick landing when the fish struck. A knotless landing net was used for transporting the hooked fish from the lake into a keep-tray in the boat. In the tray the hook was removed using a pair of pliers. The air time was kept well under the recommended 300 second threshold (Arlinghaus et al., 2009). Caution was exerted to not cause unnecessary bleeding or further damage. No hooked fish were severely bleeding after being dehooked.

2.4 Acoustic telemetry

Acoustic telemetry allows insight into the movement of tagged fish. The acoustic tags are surgically implanted into the fish's abdomen or securely fastened externally and can detect pressure and temperature, among other parameters (Crossin et al., 2017). This study's tags are surgically implanted and detect pressure. This way of monitoring fish populations has the potential to provide new ecological insight by linking a fish's physiology and environment to its movement (Lennox et al., 2017a). Through technological advancements, the size of the tags is growing smaller, which allows tagging even small fry (Hussey et al., 2015). In the present study the pikes were larger. Spawning fish were caught in spring and then several individuals by angling later in the year. In a similar Danish study, they found that the survival and fitness of the fish were not significantly impacted by carrying an acoustic tag (Koed et al., 2006). This supports this study's assumption that the tags do not alter or interfere with the natural behaviour of the pike. Through triangulation each pike's mean position every in 10-minute blocks was obtained. The tags have an estimated battery life of about 32 months (Thelma Biotel, 2019) Several earlier studies have not been able to record data for so long while maintaining a high resolution (Kobler, A. et al., 2008).

Acoustic telemetry relies on sound emitted from the tags to be picked up by an array of receivers. The tags in this project emit eight sound pulses that all need to be picked up by a receiver to register a data point. The tag-ID, time, date, and depth-data are saved. For triangulation to be possible, several receivers must register the eight sound pulses. To maximize the chances of multi-detection the lake is covered by an array of receivers (figure

2). The timings of the detections are what makes the triangulation possible. Because of receiver-clock drift the receivers in the centre of the array have synchronization tags attached to them. These tags send out a pulse every 10 minutes and make us able to synchronize the receiver-clocks by pinpointing the moment they registered synchronization-pings. When the receivers are synchronized, it is possible to estimate a tagged fish's location to within a few meters of its true location.

2.4.1 Receivers

The receivers used in the study were Thelma Biotel TBR700. These are 230 mm long, 75 mm in diameter, weigh 1140 g in the air and 260 g in the water. The batteries are estimated to last about 8-9 months (Thelma Biotel, 2019), but battery life was experienced to be longer and shorter based on the number of pings recorded. Our receivers are programmed to receive 69 kHz frequencies, the same as the tags' outgoing signal, and records ID, depth, and the time of signal receival to the millisecond. Background noise and the strength of the signal are also recorded. Three strips were used to fasten the receivers to the rope that stretched from the anchor to the buoy.

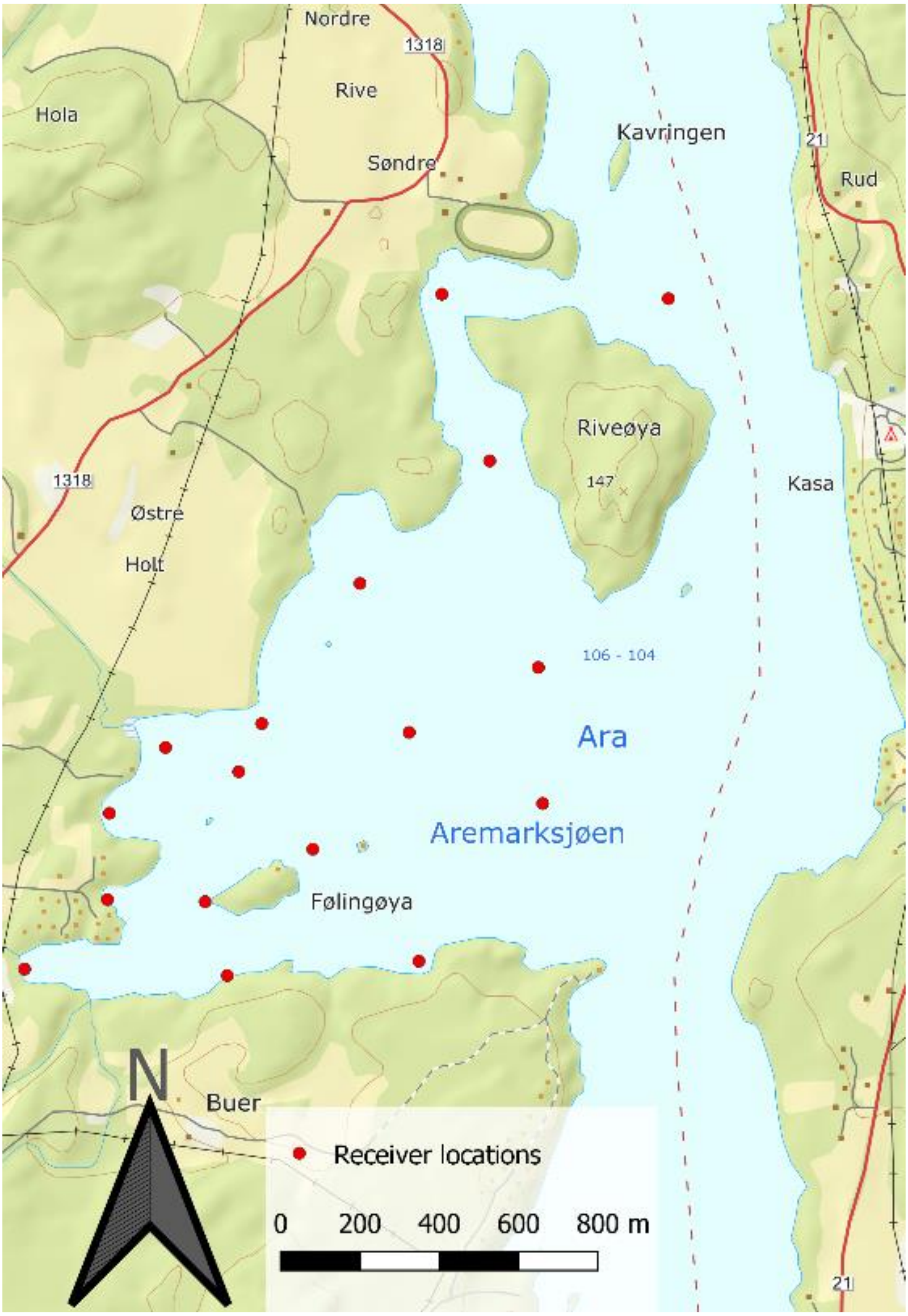


Figure 2. The array of receivers in Aremarksjøen

2.5 Tagging the pikes

In this study, Thelma Biotel's D-LP13 transmitters were used (Thelma Biotel, 2019). These are low-power acoustic tags (150 dB at 1 meter's depth) with the ability to provide depth data. They measure 13x31 mm, weigh 9.7 grams in the air and 5.6 grams underwater and an estimated battery life of 32 months. Our tagged pikes are sizeable compared to the tags, and well within the recommended limits concerning fish safety (Lacroix et al., 2004; Newton et al., 2016). The tags transmit every 60 seconds on average, within random intervals ranging from 30 to 90 seconds. In this way signals are prevented from colliding consistently. Variably some signals will collide, but the data loss is not detrimental to the triangulation process.

The tags need to be surgically implanted into the abdominal cavity of the pike. The permission to do this was given by the Norwegian Food Safety Authority on April 16th 2018 (Norwegian Food Safety Authority, 2018). Benzocaine 200 mg/ml was mixed with lake water with an approximate ratio of 10 ml Benzocaine per 20 l lake water in a rectangular tray. The fish were placed one at a time in this tray (Figure 3). To identify if the pike was unconscious and ready for the procedure, the caudal peduncle was pressed to check for a reaction. If there was no reaction, the fish was deemed to be ready. The incision was made in the abdomen with a scalpel. About 1.5 cm is needed to fit the tag (Figure 4). Prior to cutting some scales had to be removed by scraping the scalpel along the skin where the incision was to be made.

Figure 3. Pike sedated and ready for surgery

Figure 4. Incision made in the abdomen

In order to perform the surgery, tagging, and sampling, appropriate equipment was needed. One keep-net for the waiting pike, two trays, one with benzocaine, and one recovery tray with oxygen-rich lake water were used for keeping the pikes in. For the surgery, the pike were placed abdomen up in a tube with a hole (Figure. 5). The tube is filled with a 50/50 mix of lake water and benzocaine water. It was important to make sure that the gills were submerged and moving through the whole procedure. The incision was made between the pectoral and pelvic fins, closer to the pelvic fins. A little off centre is preferable, as further out it is less likely to hurt internal organs, but too far to the side the skin is too durable to

Figure 5.Pike placed in the surgery-tube. A sponge is keeping it in place.

effectively cut through (Figure 6). To prevent infection the scalpels, acoustic tags, scissors, sutures, and Floy-tag-gun were disinfected. This was done by putting the equipment in ethanol. Prior to insertion the tags were put in chlorhexidine to wash the ethanol off, and the scalpel cleansed in the same solution. The suture used was RESOLON® Suture 4/0 45cm DS-24 Blue 0.20 mm monofilament suture kit, which comes packaged in a sterile atmosphere. To handle the suture needle a pair of small pliers were used (Figure 7).

Figure 6. The incision. When made correctly no bleeding will occur.

Figure 7. Two stitches are needed to keep the incision closed

2.5.1 Tagged pikes

In total, 26 pikes were caught for tagging in the study period, 5 of which were confirmed to be females and 8 confirmed to be males (Table 1). The lengths of the pikes ranged from 52 cm to 83 cm with a mean of 64.4 cm. The sex could only be determined for the pikes caught in April, as they were spawning in this period, except for a pike caught in September which was a recapture from April, marked yellow in Table 1. Tag ID 23 was a recapture from 2017, and already had an acoustic tag, but unfortunately the battery was expired and so the pike was unavailable for triangulation.

Table 1. The pikes that were tagged for the experiment in 2019 sorted by tagging date. Pike ID 59 was caught twice and is marked in yellow the second time it occurs in the table.

Date	Tag ID	Length (cm)	Sex	Floy-ID	Capture method
09.04.2019	58	69	Female	C0551	Gillnet
09.04.2019	59	52	Male	C0552	Gillnet
10.04.2019	60	58	Male	C0553	Gillnet
10.04.2019	61	66	Female	01052	Gillnet
10.04.2019	62	55	Male	C0555	Gillnet
10.04.2019	63	80	Female	C0554	Gillnet
10.04.2019	64	66	Female	C0556	Gillnet
10.04.2019	65	62	Male	C0557	Gillnet
10.04.2019	66	53	Male	C0558	Gillnet
10.04.2019	67	74	Female	C0559	Gillnet
10.04.2019	68	55	Male	C0560	Gillnet
10.04.2019	69	56	Male	C0561	Gillnet
10.04.2019	23	65	Male	01012	Gillnet
23.09.2019	70	52	NA	C0564	Angling rod
23.09.2019	71	67	NA	C0565	Angling rod
24.09.2019	72	60	NA	C0566	Angling rod
24.09.2019	59	52	Male	C0552	Angling rod
24.09.2019	73	60	NA	C0567	Angling rod
26.09.2019	74	58	NA	C0568	Angling rod
26.09.2019	75	78	NA	C0569	Angling rod
26.09.2019	76	71	NA	C0570	Angling rod
30.09.2019	77	58	NA	C0571	Angling rod
30.09.2019	78	56	NA	C0572	Angling rod
30.09.2019	80	77	NA	C0573	Angling rod
30.09.2019	81	63	NA	C0574	Angling rod
12.10.2019	82	83	NA	C0575	Angling rod
13.10.2019	83	80	NA	801	Angling rod

Experiment

In the period from 12.10 to 20.10 an experiment was conducted involving anglers with boats in the study area. The anglers registered for the experiment by providing an anonymous nickname and their age. The participants rated their skill as pike anglers on a scale of 1-7, where 1 meant clueless and 7 meant expert. The same scale was used when asked for their familiarity with angling in Aremarksjøen. They also answered whether they lived in Aremark municipality to make us able to identify locals. Lastly, their preferred pike angling method was registered. Boxes could be ticked for trolling or spinning, but alternative methods could also be provided. (Appendix A.3)

The participants were provided with GPSs to track their movement on the lake. The GPSs saved their location on average every 27 seconds, which gave us their detailed movement. In the boats they had instructions regarding how to operate the GPS, how to fill in the angling effort and catch form (appendix A.1) and a map of the designated experiment area (appendix A.2). Aremark pike angling club is an advocate for C&R, and the anglers all had experience with this practice prior to experiment participation. Even so, they were briefed on proper handling of the pike to avoid unnecessary harm from C&R (Arlinghaus et al., 2009). Upon landing a pike they were instructed to gently remove the hook, check for an exterior tag, and record the length of the fish before releasing it. At the end of the day, each angler sent their form via MMS or e-mail to me or put the form in a mailbox (location marked by a red square on the map in appendix A.2). The forms made it possible to calculate the effort with each method. Start and end times were provided on the forms and thus the GPS-tracks were cut down to strictly angling, and not transportation. When the anglers took breaks, they recorded an end time. When angling resumed, a new starting time was recorded. The lake depths at the capture locations were determined using a depth map made by Norges vassdrags- og energidirektorat (NVE)(Appendix A.4).

2.5.2 Participants

The participants for our experiment were drafted through the local Aremark pike-angling club (www.aremarkgjeddeklubb.com/Wordpress/wordpress/). Through a meeting with the leaders of the club, the terms of the experiment were set. Using the leaders' personal networks and club webpage, experimental anglers were recruited. With ages ranging from

12 to 70 all age groups were presented, the youngest boat-owner being 14 and the oldest 70 (Table 2). Our volunteers were humble despite several of them being anglers their whole life, as nobody rated their angling skill above 5 out of 7. Only one participant rated their skill 2 out of 7, which is the lowest registered rating. 7 of the total 13 volunteers lived outside of Aremark municipality, and 6 lived within. Every non-local rated their knowledge of Aremarksjøen to 3 out of 7 except "Brannmann Sam" who dared score himself more knowledgeable at 4. That means that the lake was familiar to the traveling anglers prior to the experiment. The locals had a wider range of Ara-knowledge scores, which ranged from 2 to 6. The two youngest scored themselves at 2 and 3 out of 7. The preferred methods report counts 5 for spinning and the more popular trolling counts 8. Respectively, the two method groups score their skill 4.4 and 3.875 on average.

Table 2. Overview of the participants in the angling experiment.

Person ID	Age	Self-rated skill	Local	Reported knowledge of Ara	Preffered method
KALLE	28	5	No	3	Spinning
team.colibri	41	5	No	3	Spinning
KOMA-RHYMES	24	4	No	3	Spinning
HAVDYP	25	2	No	3	Trolling
OBS	14	3	Yes	3	Trolling
TBS	35	5	Yes	6	Trolling
Tracker 2	37	5	Yes	6	Spinning
Brannmann Sam	39	4	No	4	Trolling
CBS	12	3	Yes	2	Trolling
Bovva	70	5	Yes	5	Trolling
Tracker 1	31	3	No	3	Spinning
Bøle	14	4	Yes	6	Trolling
Ole	42	5	No	3	Trolling

2.6 Water temperature

HOBO temperature loggers (model number UA-001-64) were mounted on a central buoy within the receiver array. They were placed at 1, 3, 5 and 20 m depth. To preserve battery, they were programmed to log the temperature every two hours. This enabled us to measure the water temperature through the study period and the depth intervals enabled measurements above and below the thermocline. From the loggers' mounting day, the temperature was steadily declining as winter approached. In our experiment period there was an ongoing turnover (Figure 8). This means that during the experiment the water column was similar in temperature down to about a depth of 15 meters. During the experiment, the coldest surface temperature was 10.07°C, the warmest 10.58°C and the average 10.28°C.

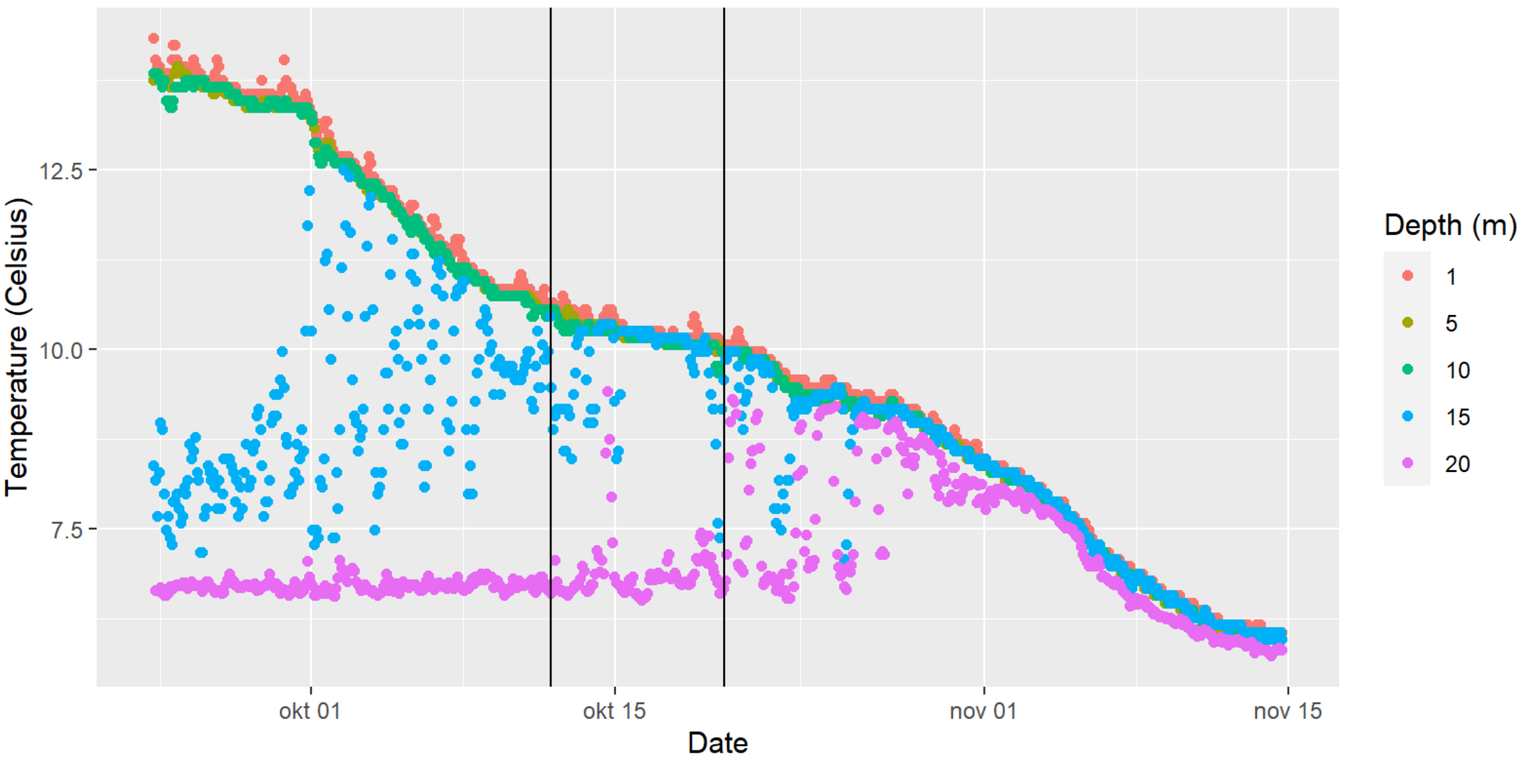


Figure 8. Water temperatures for Aremarksjøen at five different depths from September 23rd to November 14th. Within the two vertical lines is the experiment period.

2.6.1 Surface temperature prediction:

Assuming a similar thermal depth profile throughout the study area, it was possible to make a model to predict the temperature anywhere at any depth. A generalized additive model (Hastie & Tibshirani, 1990; Wood, 2006) was fitted using the temperature data from the HOBO-loggers (appendix A.5). This model predicted the temperatures between 0 and 20 meters in the water

column. According to the adjusted R^2, the model explains 96% percent of the variation in temperature. These values are therefore used to predict what the temperature a pike currently is in based on the depth it occupies. In this study, the predicted surface temperature was tested as a predictor in some of the analyses.

2.7 Weather data

Weather data was provided by eKlima (eKlima, 2020). This service is hosted by the Norwegian Meteorological Institute and is free to use for registered users. Daily precipitation data was collected from Strømsfoss Sluse, while daily average air temperature and air pressure were collected from a weather station in Aurskog (Figure 9). Aurskog was the closest station which could provide these data. The day lengths retrieved are representative for Aremark municipality (Time and Date AS, 2020) .

2.7.1 Abiotic factors in experiment period:

The weather data used for analysis included the experiment period plus two weeks before and after to account for sudden weather changes. The earliest date is then September 28, 2019 and the latest October 3, 2019.

During the experiment, the highest air pressure was 1011.1 hPa, and the lowest 975.1 hPa. The precipitation ranged from 0 mm rain fall in a day to the maximum of 38.2 mm. The heaviest rainfall was 23.0 mm within the experiment period. The air temperatures ranged from 11.1°C to -2.3°C. The temperature and air pressure change from day to day, delta temperature and delta pressure, were calculated as well. These delta values lay between -5.3°C and 4.7°C and between -16.1 hPa and 13.1 hPa, respectively.

The parameter called “sun phase” is split into “sunrise”, “day”, ”sunset”, and “night” and was made using the R-package called StreamMetabolism (Sefick, 2016). The timing factor is split into “two weeks before experiment” (28th September to 11th October), “during experiment" (12th October to 20th October) and "two weeks after experiment" (21st October to 3rd November).

Figure 9. Locations of weather stations. Aurskog station in the north and Strømsfoss in the south.

2.8 Data and analyses

All data handling and analysis were conducted using R version 3.6.1. (R Core Team, 2019) with associated packages, working on scripts with the tool R Studio (RStudio Team, 2015). The plots are made with the R-package ggplot2 (Wickham, 2016). Home range and. Linear mixed effect analyses were performed using the lme4 package (Bates et al., 2015). The telemetry dataset which all analyses of pike behaviour are based upon consists of 10-minute mean positions created by the mean-position-algorithm presented by Simpfendorfer et al. (2002), called positioning averaging (PAV). This method triangulates a rough position of a pike by using weighted means, where receivers that pick up more tag ping weighs heavier, thus dragging the mean position towards it. To generate a position this way, at least three receivers must pick up a tag signal in the 10-minute window, and the positions can only be interpolated within the array. It is a method useful for activity estimates, but too inaccurate to be used for home range estimation (Simpfendorfer et al., 2002). Because of this, the focus in the pike activity analyses have been to look at activity measurements like distance swum and depth use.

In all model selection, except for the water temperature model, candidate models were compared using AICc (Akaike, 1974; Anderson, 2008). When selecting the models, I preferred to fit at least one factor in each following category: behavioural traits (swimming activity, depth amplitude), fish- and angler-characteristics (e.g. length of fish, skill of angler), abiotic factors (weather conditions, sun phase, time of day and hour of day depending on model fidelity) and group affiliation. The pikes' group affiliation was prioritized to be included as I aim to find a link to the group and behaviour of the fish. Similarly, the method used when angling was prioritized to be included in the catch-chance analyses. A simpler model is preferred over a more complex model to avoid "data dredging" and overfitting (Burnham & Anderson, 2002; Burnham & Anderson, 2004), which resulted in a lower ranked model to be selected when comparing survival-models (Table 9). By the same principle one could argue that group should be left out as a parameter in the swimming distance model selection because the model ranked 2nd is simpler and within 2-ΔAICc-range (Burnham & Anderson, 2002; Burnham & Anderson, 2004), but the group affiliation fits the theme well. In the catch-probability analysis from the pikes' behaviour point of view, the model selection process yielded several models which were relatively similar in ΔAICc. The model ranked 1^{st} in Table 8 was selected because it had fewer predictors than many candidate models in 2-ΔAICc-range in addition to containing an environmental factor.

2.8.1 Home range estimation

The purpose of the anglers' home ranges is to clearly map where the anglers prefer to spend their angling time and look for a potential pattern. Home range kernels were found by using the adehabitatHR R-package (Calenge, 2006). For the kernel density plots of the anglers' home ranges, a common smoothing factor (bandwidth) were used for all boats. The bandwidth value was chosen to be the mean bandwidth chosen by the "reference bandwidth method" for every unique boat for every day. The boats had a mean bandwidth of 130. The grid value was set to 500. The home-range estimations for the pikes were so inaccurate that they are not included in this study.

2.8.2 Depth use analysis

To increase the chances of encountering a fish during angling it is helpful to know which depth it most likely occupies. To examine what influences Aremarksjøen's pikes' depth use the mentioned weather data and predicted lake surface temperature were included in the dataset. Linear mixed effects models with the ID of each individual fish as the random factor were tested. To better recreate light conditions through the day, the cosine of time of day was used. A "timing" factor was added in order to test for differences in depth use when angling occurred and when it did not. The length of the pike was the only biological factor included here.

2.8.3 Depth amplitude analysis

To quantify vertical pike movement, a depth amplitude analysis was made possible by the construction of a dataset which consisted of the difference between the minimum and maximum depth value for every pike, every day for every hour, in a period ranging from two weeks before the experiment to two weeks after. Values of 0 were removed to account for pikes that wandered out of the TBR array. These empty values were an artifact of how the dataset was constructed, where hours with no data got a 0, which meant the mean would be significantly reduced. In this analysis' linear mixed-effect models, the pike ID was a random factor and the same predictor variables and factors were fitted as in the depth use analysis.

2.8.4 Swimming distance analysis

To explore what impacts the daily swimming distance of a pike, a linear mixed-effect model with pike ID was a random factor was fitted. This dataset included swimming distances every day for every pike from 22nd September to 12th November 2019, the mentioned weather data, and the pike characteristics. The swimmingl-distance calculations were performed by the adehabitatLT R-package (Calenge, 2006)

2.8.5 Catch-probability analyses

The catch chance models approach the research questions in two ways: from the angler's perspective and from the pike's perspective. For the anglers, I search for significance in the anglers' reported characteristics (age, knowledge of Aremarksjøen, reported angling skill, etc.), method used and the angling effort (the number of rods utilized at the same time) of each boat. Weather conditions are also included here as an angler is assumed to favour angling in certain weather. The GPS-data from the anglers is accurate and yields both reliable positions and angling-distances. The angler's perspective was explored using a Cox proportional hazards model (Cox, 1972), with the event being a pike being caught. This survival analysis was performed by the use of the Survival R package (Therneau, 2015).

The pike's perspective was explored using an ordinal logistic regression model (McCullagh, 1980), with the three levels being no pike caught, one pike caught, and two or more pike caught in an hour of angling. The ordinal logistic regression was performed with the MASS R package (Venables & Ripley, 2002). In this dataset a different parameter for the effort was used. Effort was calculated by adding up every individual boat's rod hours within every hour. The effort within every hour ranged from 0.33 total rod hours to 15.52, with a mean of 5.46 rod hours. The same mentioned weather conditions were tested as predictors.

3. Results

3.1 Anglers' movement

From the GPS-data a kernel home range estimation was conducted on the angler's boat's movement. Using this 50% home range for every boat for every day was calculated (Figure 10). Three areas stand out as angling hotspots (Figure 11). The anglers seem to prefer "Rivegrunna" which is south of the Rive Island (1), east of Følingøya (2) and in the bay northeast in the experiment (3). Common for these areas are relatively shallow waters (<10 m) when compared to the rest of the lake. Of the around 98 hours of angling time in the study, 33.5 of them are within hotspot 1, 8.1 in hotspot 2 and 6.7 in hotspot 3. That means the angling time spent within these hotspots are 34.2%, 8.3% and 6,8%, respectively. In total 49.3% of the angling time was spent within the hotspots, areas which make up 22% of the utilized area during the experiment. Angling occurred in all parts of the experiment area, but only 7 of the 22 pikes were caught outside the most popular spots, and 10 pikes were caught within hotspot 1. 3 pikes were caught in hotpot 2 and 1 pike was caught in hotspot 3 (Figure 11). Outside of the hotspots, 0.14 pikes were caught per hour, while inside the hotspots 0.30 pikes were caught per hour.

On average, the distances covered by spin-anglers were shorter than those of troll-anglers (Figure 12), with an average trip length of 4647 meters and 9310 meters, respectively. The effort per trip is also on average more for trolling. At the most, the trollers had 6 rods in action at the same time, while the spinners never exceeded 2.

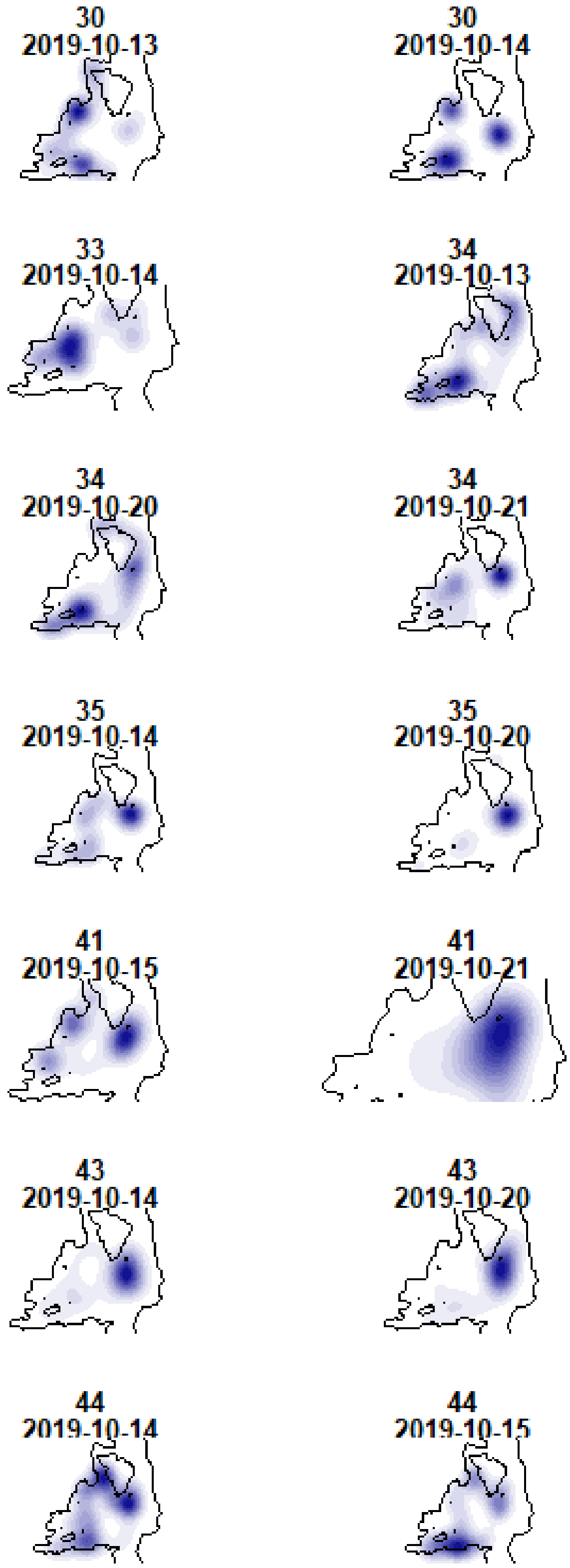


Figure 10. The home ranges of every boat for every angling day. The top numbers are the unique GPS IDs every boat had onboard during angling. The date is provided for every mini map.

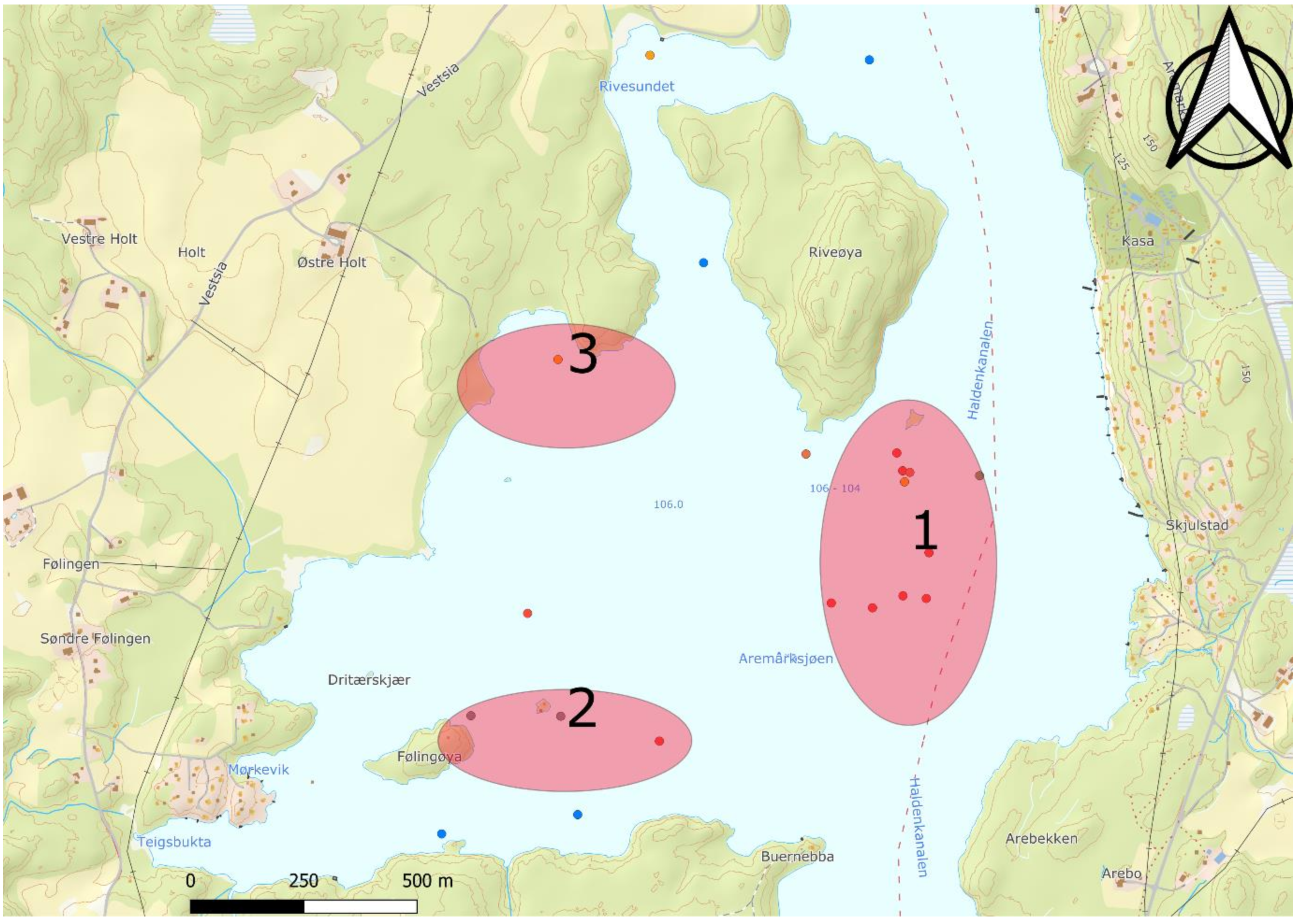


Figure 11. The three angling hotspots are represented by the red ovals with attached ID numbers. The points are the locations of caught pike during the experiment.

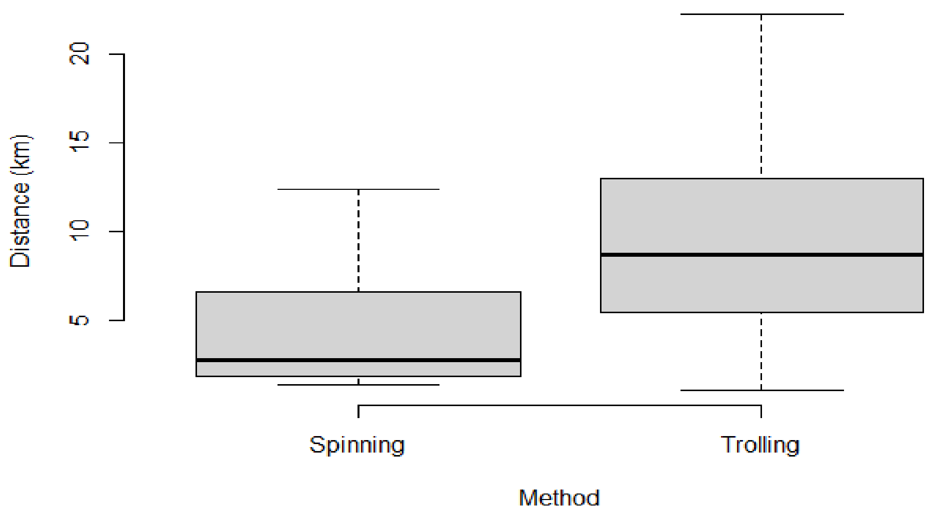


Figure 12. Each trip's distance in kilometres for each of the methods used. Spinning is on the left and trolling on the right

3.2 Pikes' movement

3.2.1 Depth use

The candidate depth-use model that attained highest AICc support in the data, included the time of day, the length of the pike, the timing of the period (as mentioned: Before, during and after the experiment) and the interaction between these three, along with which group the pike belonged to as predictors (Table 3). The length of the pike by itself did not seem to directly affect the depth but influences the effect of both time of day and the timing category (Table 4). According to the model, the pikes were at their deepest in the middle of the day and at their shallowest at midnight. On average, a tagged pike in the gillnet-group found itself dwelling shallower than an angled-group pike of equal size. Timing was significant, with the pikes dwelling shallower during the experiment than before and after. The factors time of day, length and timing all impact depth use differently depending on each other's' values, making this a complex model. During the experiment, the model predicted longer pikes to be the deepest dwellers on average (Figure 13).

Table 3. The top 10 models for explaining the variation in the pikes' depth use. The selected model is highlighted by bold lettering.

Rank	Model structure:	K	AICc	ΔAICc
1	**Time of Day * length * timing + group**	**15**	**6211175**	**0**
2	Time of Day * length * Day of Year + group	11	6235828	24653.07
3	Time of Day * length * Day of Year	10	6235829	24654.21
4	Time of Day * length + timing + group	9	6243156	31980.94
5	length * sun phase * Day of Year + group	19	6251534	40358.79
6	length * DayNight * timing + group	15	6255734	44559.65
7	Time of Day * length + Day of Year + group	8	6258955	47780.6
8	Time of Day * length + Day of Year	7	6258957	47781.76
9	Sun phase * surface temperature	10	6263363	52188.21
10	Time of Day:length + Day of Year + group	6	6268227	57052.48

Table 4. Parameter estimates of rank 1 depth model (Table 3) and the corresponding chi-square model test statistics. The intercept value represents the predicted mean depth for a pike in the angling group in the timing category "two weeks after the experiment". The time of day is reflected in the parameter cos(ToD).

Parameter estimates

Term	Estimate	Std. Error
(Intercept)	3.426	2.174
cos(ToD)	-0.087	0.019
length	0.001	0.033
timingBefore	0.352	0.022
timingExperiment	-0.707	0.021
groupAngling	1.133	0.636
cos(ToD):length	-0.010	0.000
cos(ToD):timingBefore	-2.480	0.030
cos(ToD):timingExperiment	-0.758	0.029
length:timingBefore	0.004	0.000
length:timingExperiment	0.021	0.000
cos(ToD):length:timingBefore	0.031	0.000
cos(ToD):length:timingExperiment	0.013	0.000

Chi-square model test statistics

Term	χ^2-value	Df	P-value
cos(ToDc)	2.80E+05	1	<0.001
length	6.57E-02	1	0.798
timing	6.16E+04	2	<0.001
group	2.76E+00	1	0.097
cos(ToDc):length	8.63E+01	1	<0.001
cos(ToDc):timing	2.38E+04	2	<0.001
length:timing	4.27E+03	2	<0.001
cos(ToDc):length:timing	4.11E+03	2	<0.001

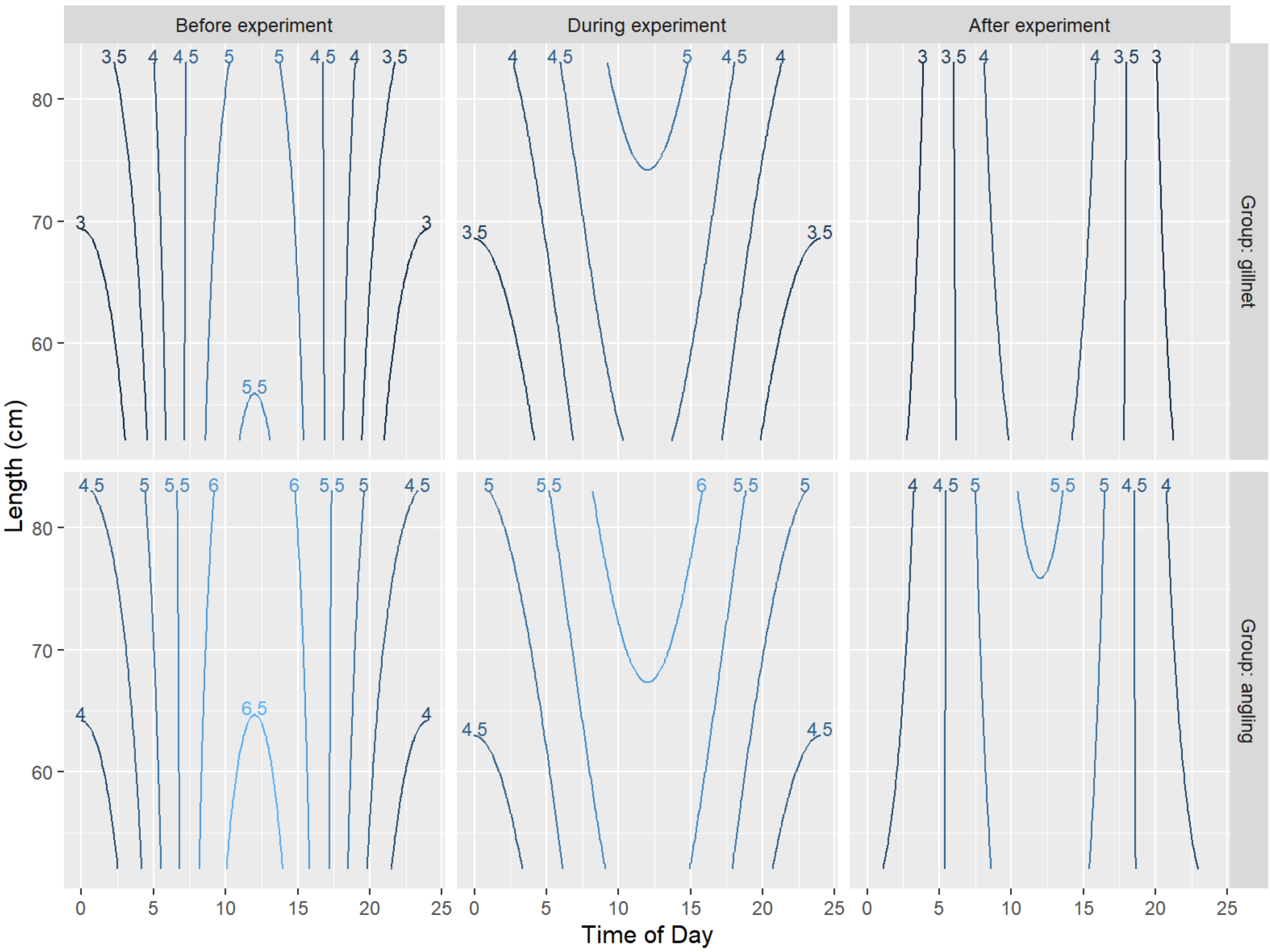


Figure 13. Predicted depth use from the most supported depth use model in Table 3. Predicted pike depth use as a function of Time of Day, length, angling, and timing. On the x-axis is the time of day in hours and on the y-axis is length in centimetres. The figure is faceted by the two group the pike is in and by the timing in relation to the experiment. The gillnet group is on the top row and the angling group on the bottom row. "Before experiment" is the period between 28th September to 11th October, "During experiment" between 12th October to 20th October and "After experiment" between 21st October to 3rd November.

3.2.2 Depth amplitude

The model that most efficiently explained the variation in hourly pike depth amplitude included the length of the fish, the sun phase, the group of the pike and the interactions between all these three and the air temperature (Table 5). An increased length is predicted to decrease the depth amplitude. Relative to daytime, the pikes move vertically less at night and at sunset, while at sunrise pikes of the same length and group move vertically on average 1.77 meters more (Table 6). The depth amplitude increased with an increasing air temperature as well, at an average of about 7 mm per increased °C for equal pikes. Sunset and sunrise are the sun phases that show the highest depth amplitudes (Figure 14). At sunset, the angling group showed more variation in depth amplitude based on the length of the pike.

Table 5. The 10 top models for explaining the variation in depth amplitude. The selected model is highlighted by bold lettering. Temperature is air temperature, sunphase is "day, night, sunset and sunrise", DoY is Day of Year.

Rank	Model structure	K	AICc	ΔAICc
1	**length * sun phase * group + temperature**	**19**	**52366.35**	**0**
2	length * sun phase * group + surf.temp	19	52367.71	1.36
3	length * sun phase * group	18	52368.29	1.95
4	length * sun phase * group + air.pressure	19	52368.48	2.13
5	length * sun phase * group + precipitation	19	52370.26	3.92
6	length * sun phase * temperature + group	19	52407.56	41.21
7	length * sun phase + group + temperature	12	52411.26	44.91
8	length * sun phase + group	11	52413.23	46.88
9	timing * length * sun phase + group	27	52415.35	49
10	DoY * length * sun phase + group	19	52417.21	50.86

Table 6. Parameter estimates of the selected depth-use model (Table 5) are provided to the left and the corresponding effect test statistics to the right.

Parameter estimates

Term	Estimate	Std.Error
(Intercept)	2.379701	0.684427
length	-0.02195	0.010787
sunphaseNight	-0.55384	0.382815
sunphaseSunrise	1.773375	0.873006
sunphaseSunset	-0.27277	0.951195
groupstang	0.915601	0.832641
temperature	0.007454	0.003749
length:sunphaseNight	0.003171	0.006123
length:sunphaseSunrise	-0.01755	0.013734
length:sunphaseSunset	0.010652	0.01521
length:groupstang	-0.00499	0.012918
sunphaseNight:groupstang	-1.81339	0.455293
sunphaseSunrise:groupstang	-3.11344	1.049934
sunphaseSunset:groupstang	1.340653	1.122762
length:sunphaseNight:groupstang	0.022148	0.007182
length:sunphaseSunrise:groupstang	0.04549	0.016343
length:sunphaseSunset:groupstang	-0.02484	0.017707

Effect test statistics

Term	F	Df	P-value
(Intercept)	10.0722	1	0.0046967
length	3.4802	1	0.0764622
sunphase	2.7918	3	0.0388965
group	0.9735	1	0.3357636
temperature	3.9252	1	0.0475879
length:sunphase	0.9620	3	0.4095922
length:group	0.1133	1	0.7399655
sunphase:group	8.4210	3	1.375e-05
length:sunphase:group	6.3575	3	0.0002657

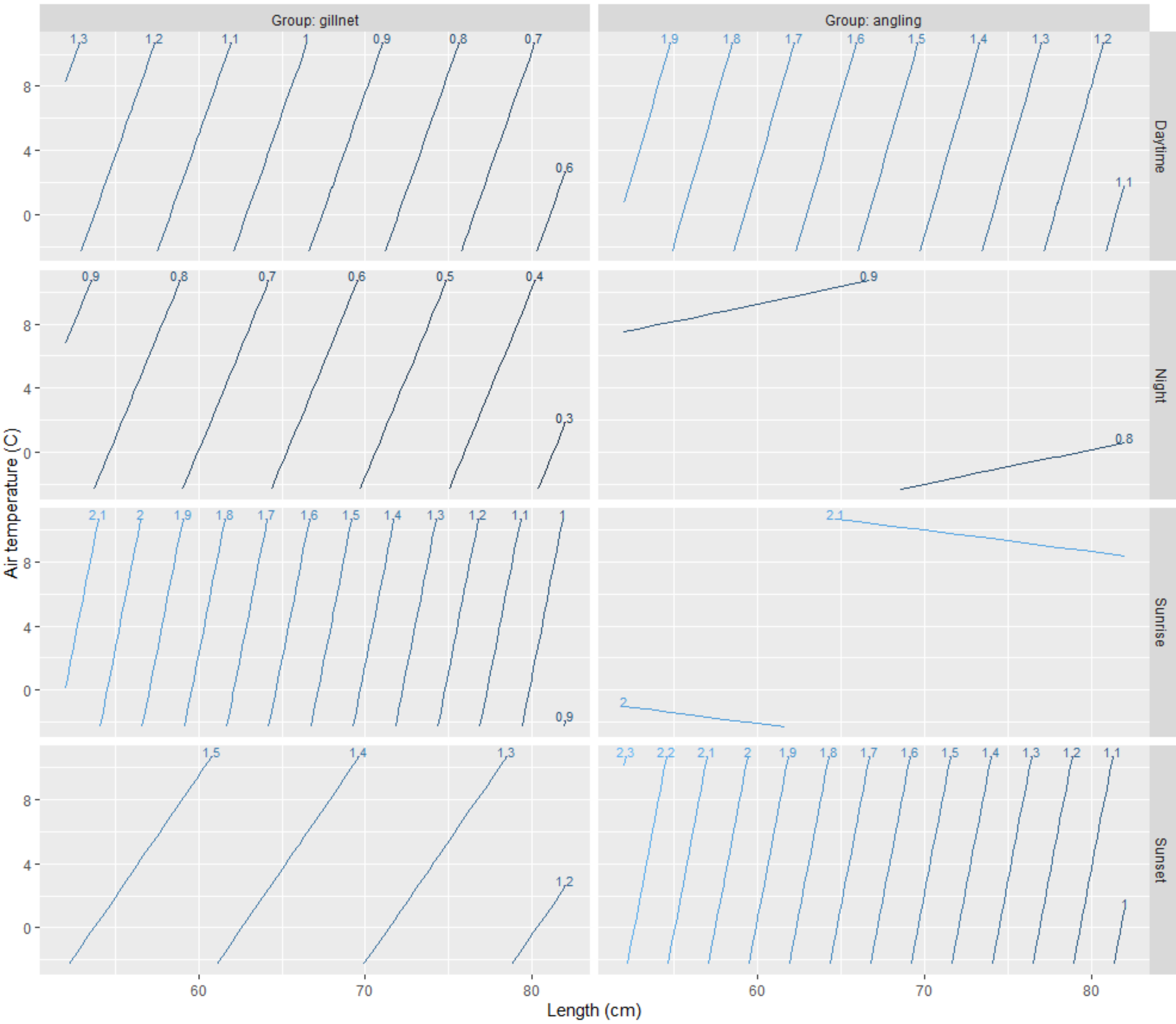


Figure 14. Prediction plot made with the most supported depth amplitude model. The predicted depth amplitude as a factor of the length of the pike and the mean air temperature in a day. The figure is faceted by pike group affiliation and sun phase, with sun phase as rows and groups as columns. On the x-axis is pike length and on the y-axis is air temperature. The contours are the predicted depth amplitudes.

3.2.3 Swimming Distance

The model that most accurately described the pikes' distance swum in a day incorporated the day of year, the length of the fish, these factors' interaction, pike's group affiliation (Table 7). Both the day of year and length have negative coefficients and the interaction between the two is positive. The group caught by angling is predicted to have swum further on average than an equally long pike at the same day (Table 8). Long pikes seem more affected by the day of year, as the variation in swim distance increased with the length (Figure 15). Longer pikes are predicted to have swum less before around day 290 and more after.

Table 7. The top 10 models for explaining the variation in swim distance for Aremarksjøen's pikes. The selected model is highlighted by bold lettering.

Rank	Model structure	K	AICc	ΔAICc
1	**Day of Year * length + group**	**7**	**18970.35**	**0**
2	Day of Year * length	6	18971.32	0.97
3	Day of Year * length * group	10	18972.76	2.41
4	Day of Year * length * group + surface temp	11	18973.95	3.61
5	Air temp * length * group	10	18980.13	9.78
6	Surface temp * length + group	7	18980.87	10.52
7	Air temp * length * group + precipitation	11	18981.47	11.12
8	Length * surface temp	6	18981.89	11.54
9	Air temp * length * group + air pressure	11	18982.04	11.7
10	surface temp * length * group	10	18982.84	12.49

Table 8. Parameter estimates of the selected depth-use model (Table 7) and the corresponding effect test statistics. The intercept is the predicted swimming distance of a pike with length 0 on day 0 of the gillnet group but does not make sense to interpret. DoY represents Day of Year.

Parameter estimates			Effect test statistics			
Term	Estimate	Std. Error	Term	F	Df	P-value
(Intercept)	135272.53	25167.78	(Intercept)	30.32	1	<0.001
DoY	-436.08	84.11	DoY	28.61	1	<0.001
length	-2328.38	390.51	length	36.59	1	<0.001
Group						
angling	2971.11	1656.97	group	0.63	1	0.429
DoY:length	8.07	1.30	DoY:length	40.91	1	<0.001

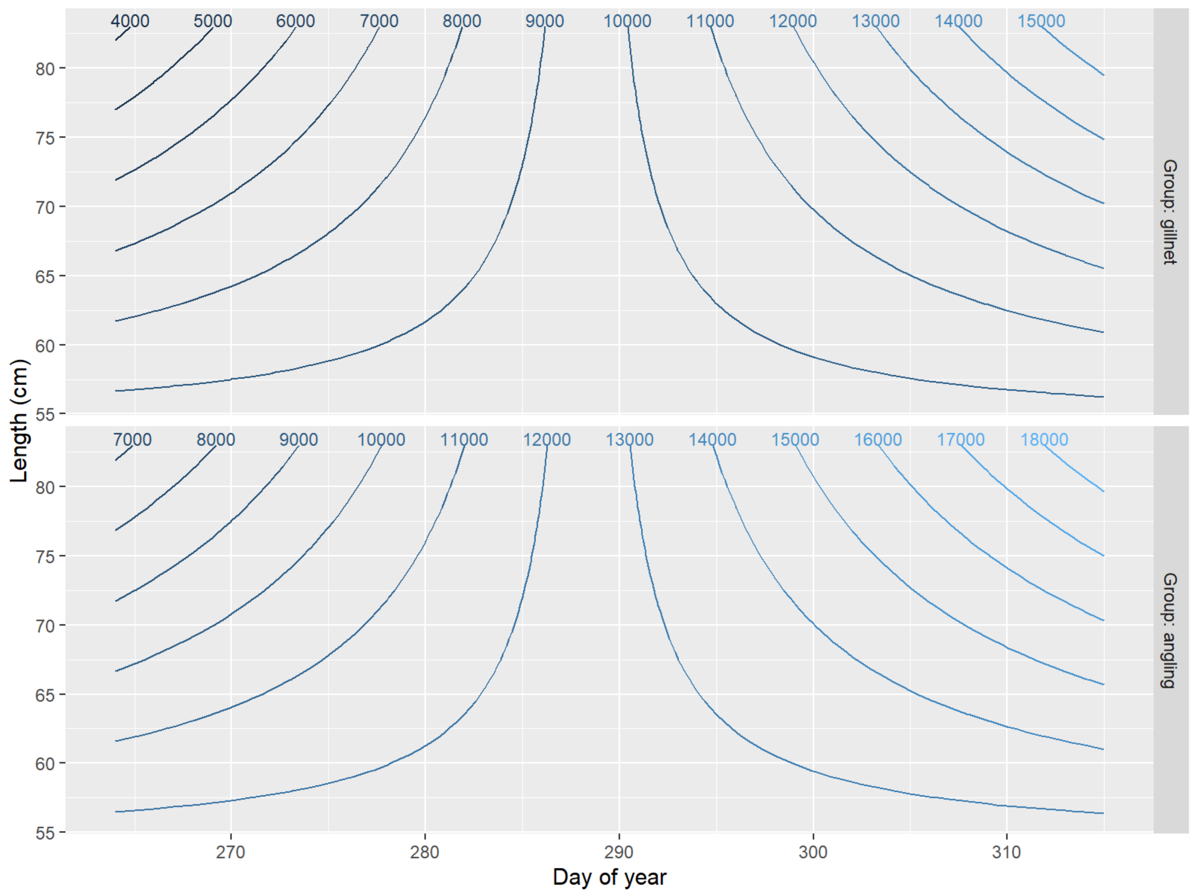


Figure 15. Prediction plot from the most supported swimming distance model in Table 7. Predicted pike swimming distance in a day as a function of day of year and pike length, split into the two group affiliations, angling and gillnet. On the y axis is the pike length and on the x axis is the day of year. The top row of is the gillnet group and the bottom is the angling group. Day number 270 is 27th September, day 310 is 6th November.

3.3 Anglers' catches

In total, 24 pikes were caught by the participants in our experiment. The fish were caught between 08:00 and 17:00. The hours of day that yielded the most catches were 10 o'clock and 15 o'clock, with 8 and 6 catches respectively (Figure 16) The pikes were caught at depths ranging from 2 to 26 meters. These depths represent the maximum depth at the catch location, which means the pike could have occupied any depth within 0 and the maximum depth. A clustering of catches is found at the depths 6 to 10 meters, and these are the only depths in which more than 2 pikes were caught (Figure 17). No pattern could be seen in Figure 18 where the time of day and depth are plotted as points.

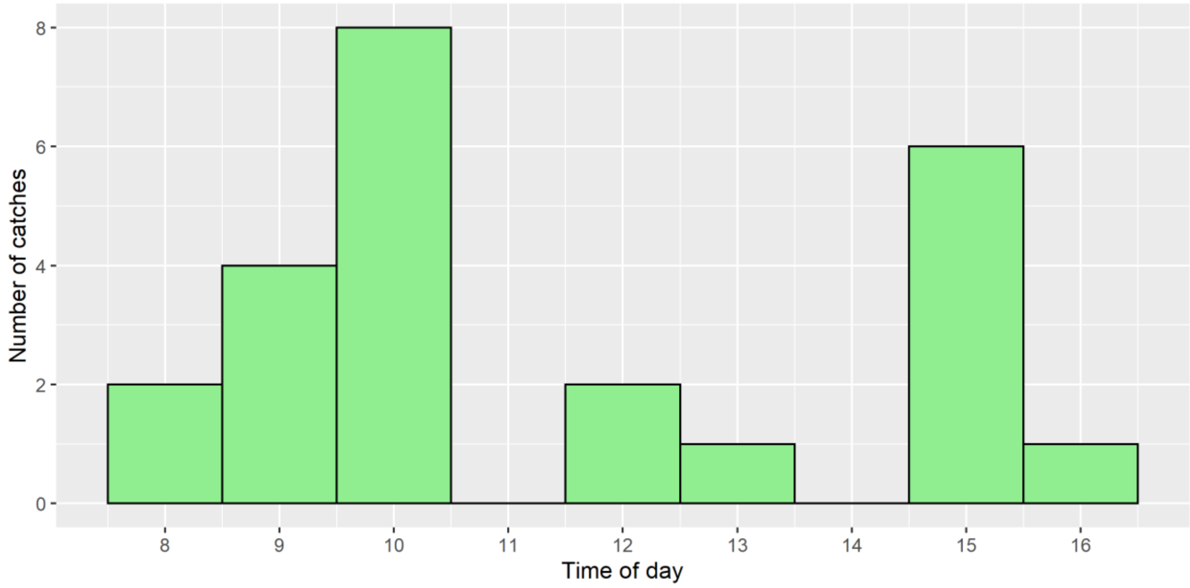


Figure 16. Each catch sorted into each hour of day. Each column is an hour, starting at X:00 and ending at X:59.

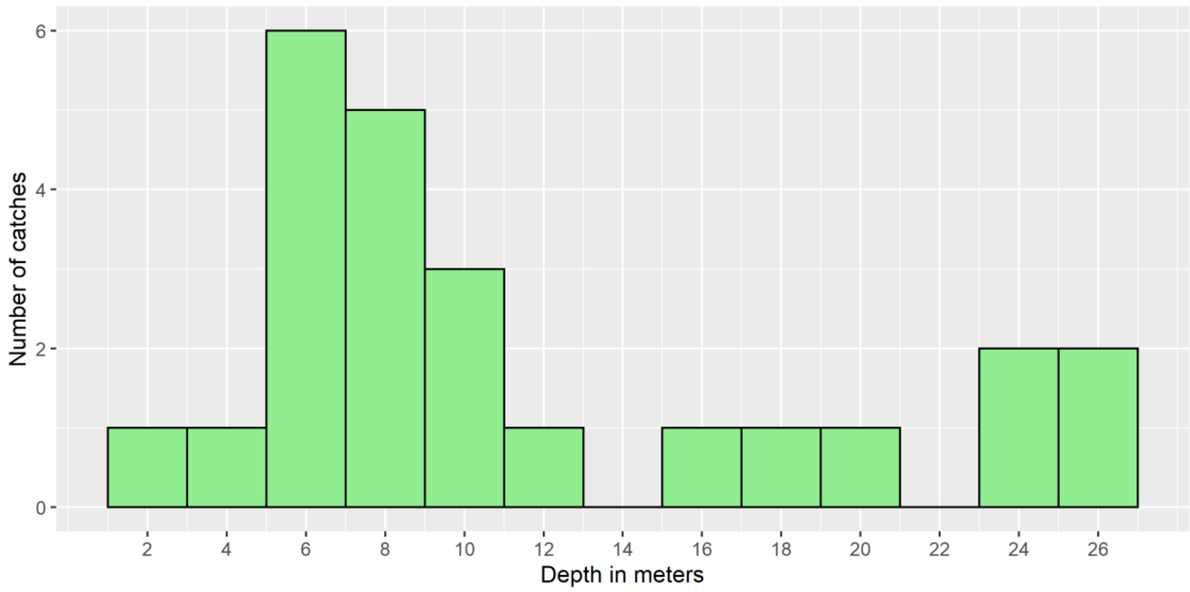


Figure 17 Amount of pike caught within each 2-meter depth category. Here, depth is the lake depth at catch location, meaning the pike could have occupied any depth down to it.

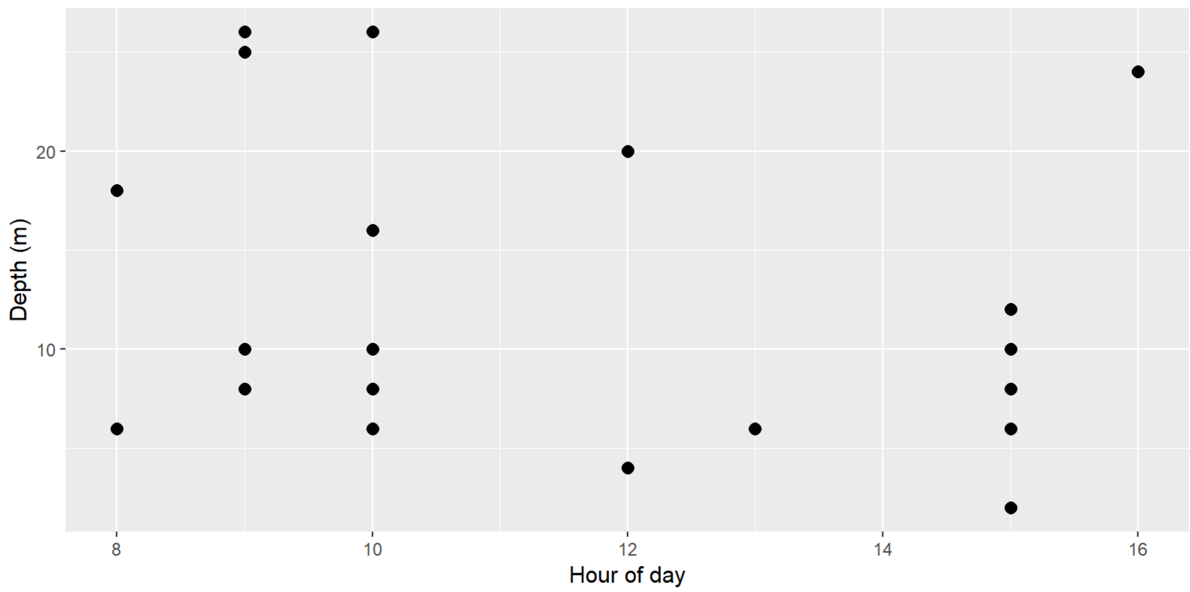


Figure 18: The distribution of depth of catches within all days. On the x-axis hour of day is displayed and it is cropped to only include the hours in which angling occurred. On the y axis the catch-location's maximum depth is presented.

3.4 Catch parameters

3.4.1 Anglers' perspective:

The factors that were found to have the most influence on catch probability were the method used, the distance travelled, the number of rods utilized and the interaction between distance and number of rods (Table 9). Trolling is estimated to have increased the probability of landing a pike when compared to spin-angling. Distance travelled had a negative impact, which meant a higher chance of catch with less angler movement. More rods utilized yielded a higher catch probability. From the interaction factor, it is apparent that the number of rods affected the impact of distance travelled and vice versa. The chi-squared test deems all the factors to be significant except the angling method used (table 10). Spinning was very negatively impacted by travel distance compared to trolling and when more rods were utilized, and the predicted probability of catch was reduced less by travel distance (Figure 19)

Table 9. The top ten models for explaining the probability of catching a pike. The selected model is highlighted by bold lettering.

Rank	Model structure	K	AICc	ΔAICc
1	lake knowledge * distance * num rods + method	8	99.76	0
2	**method + distance*num rods**	**4**	**99.81**	**0.06**
3	reported skill * distance * num rods	7	100.87	1.11
4	temperature * num rods + method	5	102.34	2.58
5	delta air pressure + num rods * distance	4	105.23	5.48
6	method * distance * num rods	7	105.41	5.66
7	delta temperature + num rods * distance	4	105.74	5.98
8	lake knowledge * distance * num rods	7	106.11	6.35
9	num rods * distance * method + precipitation	8	107.62	7.87
10	air pressure + num rods * distance	4	108.43	8.67

Table 10. Parameter estimates of the selected catch probability model (Table 9) and the corresponding chi-square model test statistics. Num. rods is the number of rods in action and distance is the angling boat's distance travelled in meters.

Parameter estimates			Chi-square model test statistics			
Term	Estimate	Std. Error	Term	χ^2-value	Df	P-value
Method trolling	2.985	1.153	method	2.8918	1	0.089
distance	-0.0002	0.0002	distance	35.2076	1	<0.001
num.rods	0.875	0.282	num. rods	5.6708	1	0.017
distance:num.rods	-0.0001	<0.0000	distance:num.rods	6.9765	1	0.008

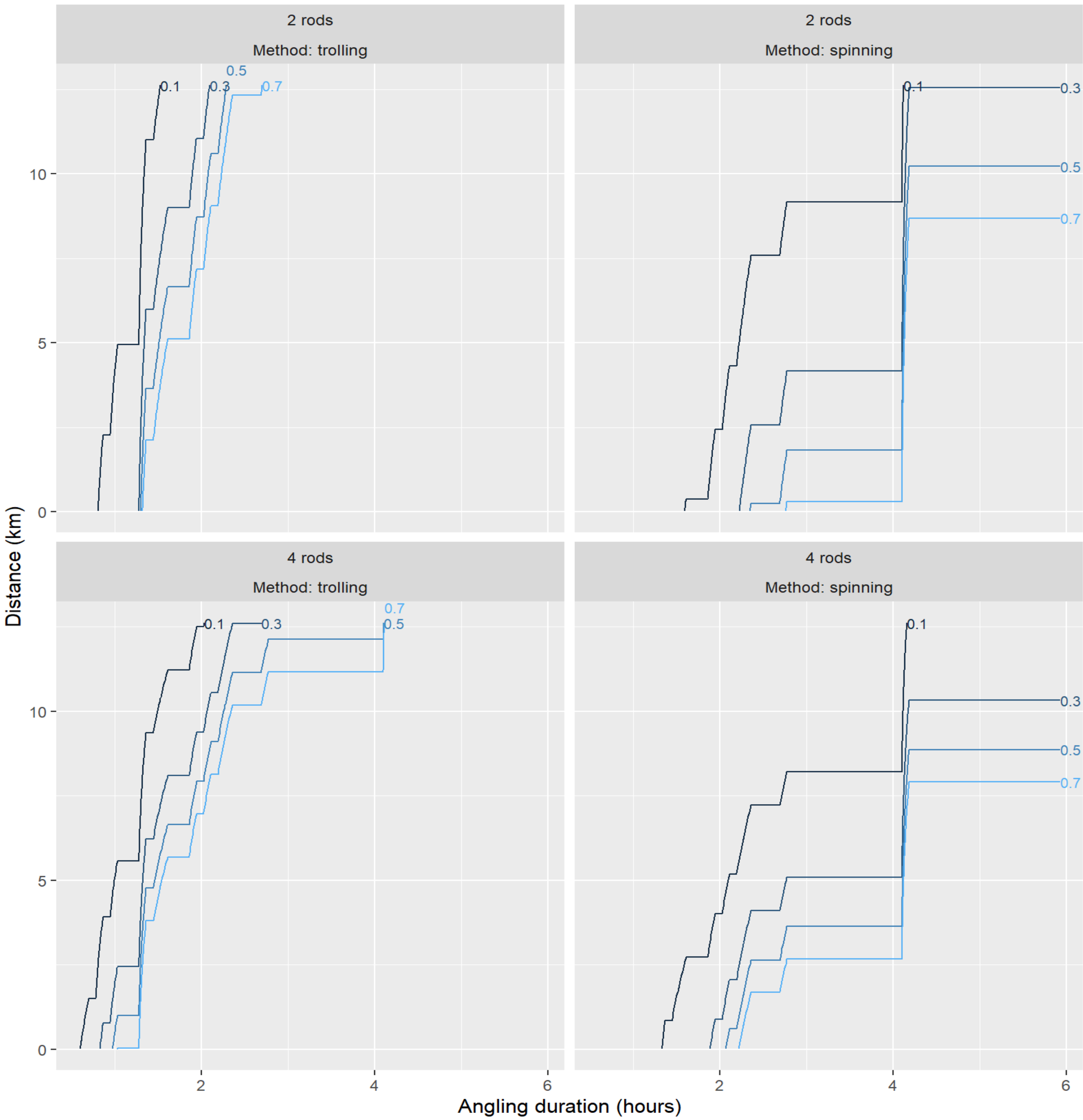


Figure 19. Prediction plot of the most supported Cox proportional hazards model in Table 9. This is the predicted probability of catching a pike as a function of distance travelled in a trip and the duration of the trip. The trolling method is on the left side and spinning on the right. The top panels are for 2 rods at the same time and the bottom panels are for 4. The lines are probability contours. The probability increases with more time spent fishing but decreases with increasing distance travelled. Trolling as a method has longer trips, some stretching for 6 hours, while spinning has few trips lasting longer than 3 hours.

3.4.2 Pikes' perspective

The ordinal logistic regression model that most efficiently explained the probability of catching no pike, one pike or two or more pikes incorporated depth amplitude, pike group affiliation, rod hours, and air pressure as predictors (Table 9) . Depth amplitude had a negative coefficient which means the anglers had a better chance of catching a pike when the tagged pikes were less vertically active. An increased number of angling rods in use within an hour increased catch probability. The angled group activity seemed to increase the catch chance more than the gillnet group. The catch probability was the highest for low air pressure, and the probability of catching two or more pikes seem to be most affected by this predictor (Figure 20).

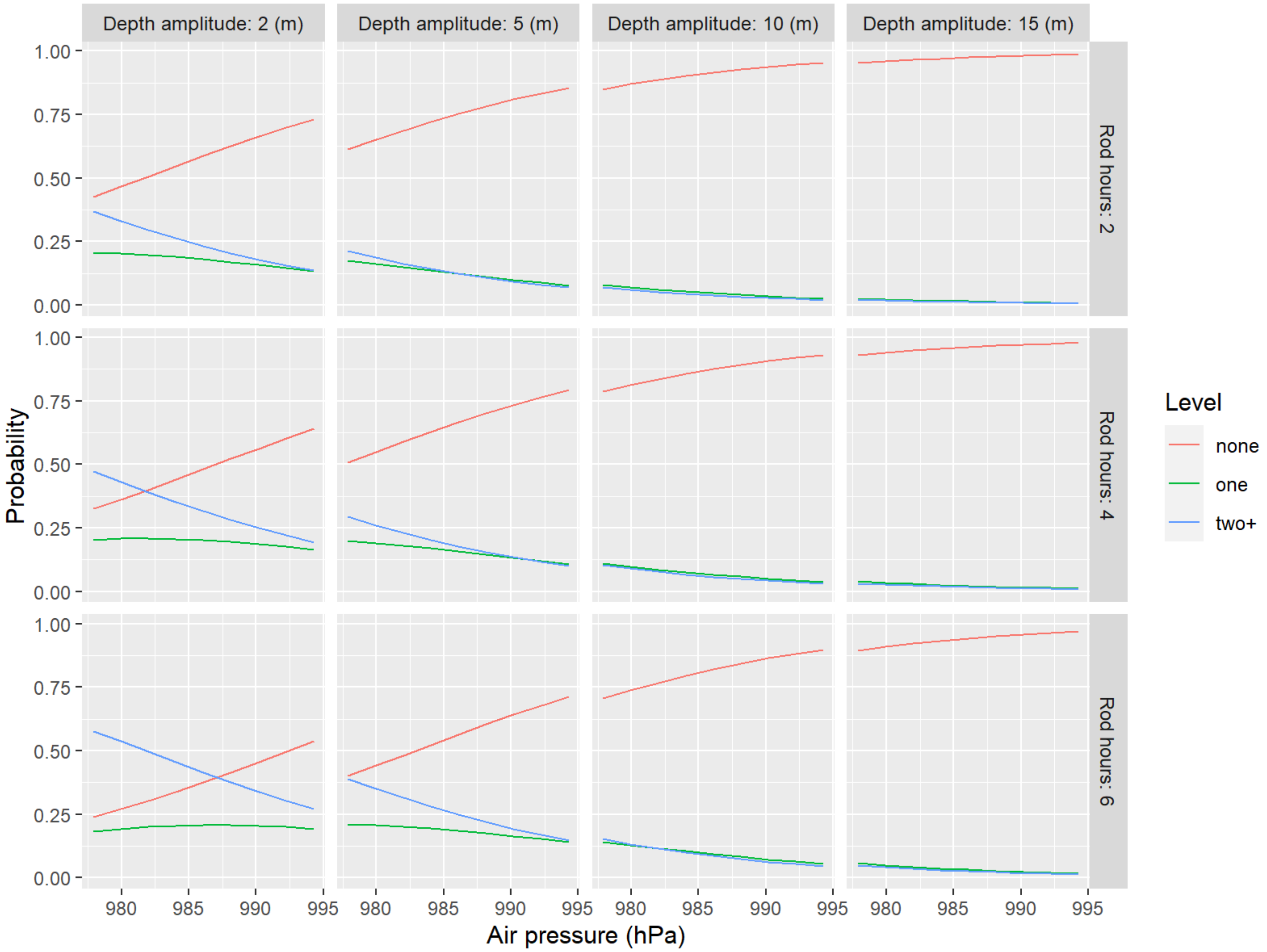
Table 8. The top 10 models for explaining the variation in probability of the anglers f catching none, one or two or more pikes within an hour. The selected model is highlighted by bold lettering.

Rank	Model structure	K	AICc	ΔAICc
1	**depth amplitude + group + rod hrs + air pressure**	**6**	**150.02**	**0**
2	depth amplitude + group + rod hrs + air pressure + temperature	7	151.22	1.19
3	depth amplitude + group + rod hrs	5	151.35	1.33
4	depth amplitude + rod hrs + air pressure * group	7	151.87	1.85
5	depth amplitude + group + rod hrs + air pressure + precipitation	7	151.92	1.9
6	depth amplitude * group + rod hrs + air pressure	7	151.92	1.9
7	depth amplitude + group + rod hrs + delta air	6	151.93	1.9
8	depth amplitude + rod hrs + delta air	5	152.42	2.4
9	depth.amplitude*precipitation + rod.hrs + group	7	152.76	2.73
10	mean.swim.distance*depth amplitude + rod.hrs	6	152.78	2.76

Table 9, Parameter estimates of the selected catch probability model (Table 8) and the corresponding chi-square model test statistics

Term	Estimate	Std. Error	Term	χ^2-value	Df	P-value
depth amplitude	-0.25391	0.127949	depth amplitude	4.2129	1	0.040118
group angled	0.6074	0.553219	group	1.1605	1	0.281369
rod hrs	0.21456	0.066289	rod hrs	10.59	1	0.001137
air pressure	-0.07967	0.000914	air pressure	3.4087	1	0.064855
Intercepts:						
0|1	-78.2921	0.0176				
1|>1	-77.4473	0.2287				

A.


Depth amplitude: 2 (m)
Depth amplitude: 5 (m)
Depth amplitude: 10 (m)
Depth amplitude: 15 (m)
Rod hours: 2
Rod hours: 4
Rod hours: 6
Probability
1.00
0.75
0.50
0.25
0.00
980
985
990
995
Air pressure (hPa)
Level
none
one
two+

B.

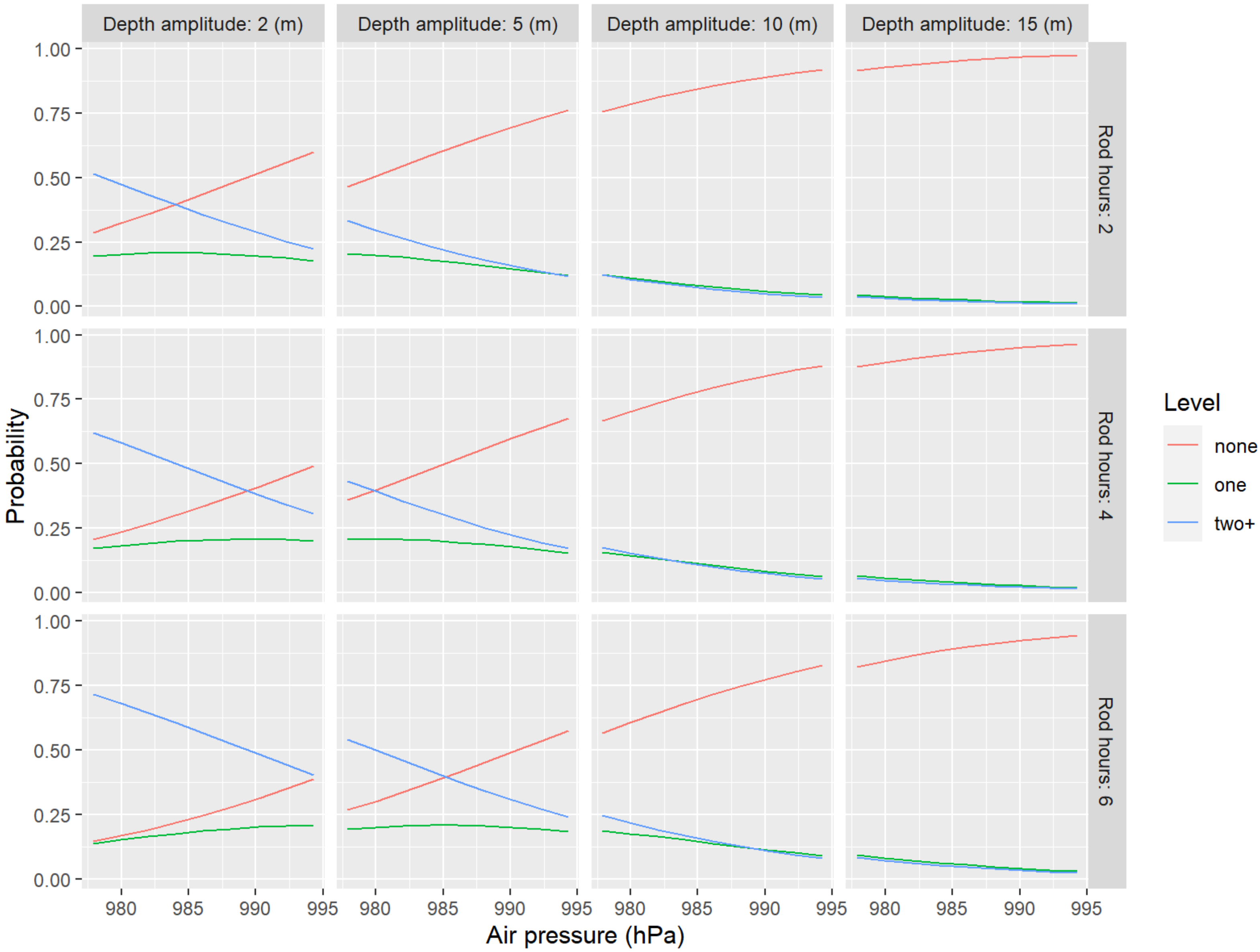


Figure 20. Prediction plot of the most supported ordinal logistic regression model from Table 8. On the x-axis is air pressure, on the y-axis is the probability of one of the outcomes to occur. The red line is predicting no catch, the green one pike, and the blue line two or more pikes caught. The figure is faceted by three levels of rod hours (rows) and four levels of depth amplitude (columns). The groups each make up their own figure: ***A*** *predicts catch chance of the gillnet group and* ***B*** *predicts the angling group.*

4. Discussion

4.1 Effect of abiotic factors on pike behaviour and catch probability

The day of year was found to have an impact on daily pike swimming distance. It is difficult to determine what about the day had the biggest impact. The temperature decreases inn all layers of the lake, the day length gets shorter, the agricultural activity could be altered and in turn affect the water's turbidity. Daily mean surface temperature was tested as a factor, but was outcompeted by day of year, though temperature has been found to significantly increase swimming distance and space usage in pikes in similar studies (Haugen, 2018; Kobler, Alexander et al., 2008). The increase could be explained by the gradual loss of vegetated habitats which the pikes use for refuge and hunting cover (Skov & Nilsson, 2018) and the prey fish use for refuge (García-Berthou, 1999; Jepsen & Berg, 2002). When the prey fish lose their refuges towards and during winter, they tend to clump up (Jepsen & Berg, 2002) and so the pikes may need to swim greater distances to find them, instead of them being evenly distributed and readily available. This study has no data of when the submerged macrophytes collapsed, so this is something for future studies to investigate. Swimming distance was expected to be the behavioural parameter to most efficiently explain catch probability because of similar findings by Kuparinen et al. (2010), where the catch rates increased when the pikes generally were most active (Kobler, Alexander et al., 2008).

Air temperature was found to be the environmental factor to most impact the depth amplitude of pikes. Temperature affects all cold-blooded aquatic animals' movements, foraging, and metabolism (Brown et al., 2004). For pikes, the optimal temperature is from 19-21 °C (Casselman, 1978), which could explain the increase in vertical activity, but research has only been made on water temperature. An angler most likely will not be able adjust the position of his/her lure at such small increments that the air temperature will be meaningful to measure before angling. Given the small variation in depth amplitude, the pikes do not move much vertically in an hour. When angling, then, I would suggest that if an angler does not catch anything at a certain depth, try angling deeper or shallower to reach the pike, especially if the water is turbid and the pike's sight is reduced.

Air pressure was the environmental factor that from pike perspective most efficiently explained catch probabilities. In other studies, air pressure has been a significant predictor of fish movement (Guy et al., 1992; Heupel et al., 2003) (Peterson, 1972). Given the possible impact on pike movement it is likely that it can influence feeding activity as well. Kuparinen et al. (2010) found no evidence of catch rate being affected by air pressure, which shows that the lakes or the population could be inherently different or that there is something else that explains the increase..Associated with air pressure is wind speed and cloud cover among other things which could be the actual drivers.

In a perfect (angling-)world the angler would know how deep the largest pikes dwell and can angle specifically for them. The interactions between length, time of day and timing period are complex and all they all influence each other’s effect. Longer pikes were determined to dwell deeper, which was also the case in earlier studies (Chapman & Mackay, 1984; Haugen, 2018). The group affiliation affected the depth use, the angling group stayed about a meter deeper on average. When comparing what depths the pikes are caught at to the predicted dwelling depths, it seems likely that the pikes stayed close to the bottom for camouflage (Kobler et al., 2009). Given that day of year, air and surface temperatures were all outcompeted by timing, the depth analysis seems to lack an important candidate factor. This could be day length, wind speed and direction, or lunar cycle, which have all been found to possibly impact pike behaviour (Haugen, 2018; Kuparinen et al., 2010).

4.2 Catch probability in relation to angler characteristics

Both catch probability analyses indicated catch probability to increase with increasing effort. In previous angling experiments, positive correlations were found between catch rate and angling skill , but effort has been corrected for as far as I have found. Though (Arlinghaus et al., 2017) suggested increasing invested time was beneficial, it seems effort is an obvious means of increasing ones catch (Rothschild, 1972), which would be why commercial and recreational fishermen are restricted not only in term of what gear and methods they can use, but also in maximum effort (how many/long lines, nets, etc.) (fiskeridepartementet, 2005; Fiskeridirektoratet, 2020). This finding is not surprising, but a longer experiment could be conducted to see if there comes a point where increased effort decreases catch, which was found in the experiment conducted by Arlinghaus et al. (2017).

Pikes have been proven to learn what artificial lures look like (Beukemaj, 1970). Aremarksjøen is a lake subjected to substantial recreational fishing, both from land and by boat. There are actors who lend their cabins and boats to tourists, who often are highly specialized with advanced fish localization equipment (Øystein Toverud, personal communication). The angling pressure prior to the experiment, therefore, could have either sped up the artificial lure recognition process or the population could have been less vulnerable to being caught from the start. C&R practises in the lake, which most traveling anglers also partake in, could have mitigated some or most of the selective effects angling has on a population (Arlinghaus et al., 2009; Philipp et al., 2009) but in Aremarksjøen this has not been investigated.

According to my results, the anglers should move as little as possible to maximize the probability of catch. This could be a result of the anglers knowing the best fishing spots beforehand. They were drafted from a dedicated pike angling club, as well, which should mean they have experience seeking out promising pike angling spots. If the participants were seeking shallow parts of the experiment area, this indicates that the anglers have knowledge of the lake and a belief, either through experience or rumours, that the pikes prefer shallower water. According to our depth data, this certainly seems to be the case, as the pikes rarely dwell deeper than 6 metres. Additionally, there were no restrictions on how many anglers could be in the same area, which meant that when a picture of a good size pike was shared with the participants nothing stopped them from being drawn to the location of the photographer.

4.3 Catch probability in relation to pike characteristics and behaviour

The purpose of the group affiliation was to sort into bolder pikes that were more likely to strike a lure and a random group of pikes which were caught in gillnets when aggregating for mating (Kobler et al., 2009; Pasquet et al., 2016). The assumption was that bolder pikes were more likely to strike a lure and my results hint at the angling group being bolder than the gillnet group by them being more active, with an increased swimming distance and depth amplitude. In addition to this the activity of angling group pikes yielded higher catch probabilities in the catch probability analysis from the pike perspective. Covering larger distances is a boldness trait because it makes the animal more vulnerable to predation, but in return pays by offering more resource gaining opportunities (Ward et al., 2004). By swimming more, the chance of a lure encounter increases, which is a necessity for being caught (Alós et al., 2016; Lennox et al., 2017b; Uusi-Heikkilä et al., 2008). Higher catch rates were therefore expected when the pikes were active. Still, the distance swum was not the pike behavioural trait that most efficiently explained catch rates in the experiment. Though encountering the lure is necessary, the pike is not always in a vulnerable state (Lennox et al., 2017b). When encountering a lure or bait, its personality or temperament might decide if its vulnerable (Réale et al., 2007). Such personality traits have been shown to be heritable in pikes by testing larvae boldness and activity among other traits (Pasquet et al., 2016).

The pike length effect was found to have an impact on swimming distance and depth amplitude. Increasing pike length decreased the depth amplitude and the probability of catch was raised with lower depth amplitudes. This speaks of angling being a selective towards larger pikes. Larger pikes have been found to be more active (Klefoth et al., 2011; Skov & Nilsson, 2018) and more possible vulnerable to angling (Arlinghaus et al., 2017). The increased activity has mainly been attributed to less predation risk, a major threat to smaller pikes (Giles et al., 1986; Haugen et al., 2007; Mann, 1982). Activity, as mentioned, can be inherited, and so targeting big pikes can lead to structural changes in the pike community and lower expected catches in the fishery (Arlinghaus et al., 2010), even in C&R fisheries (Arlinghaus et al., 2009).

Depth amplitude was the behavioural trait that most efficiently explained the catch probability. The amplitude was highest during sunset and sunrise which could correlate to pike feeding activity. Pikes are visual predators that hunt by sight (Skov & Nilsson, 2018). In an experimental setting, Dobler (1977) found that pike in an aquarium ate the most prey fish at low light levels. It seems that they have an optical advantage in these light conditions. My findings are that the catch rates increase when the vertical movements are low, though in twilight hours the depth amplitude is increased. Prey fish behaviour could offer an explanation. By feeding crepuscularly, prey fish minimize the risk of predation compared to foraging by day (Eklöv & VanKooten, 2001) and better foraging opportunity because of zooplankton moving to the pelagic zone during the night (Lauridsen & Buenk, 1996). My suggestion is from this that the pikes could have chosen to rather prey on real fish when they emerged from their refuges, and more prone to strike a lure by day when real prey was less abundant. As mentioned, submerged macrophytes may be collapsed during the experiment period. This can affect refuge availability for both prey fish and smaller pike. The diel pattern of potential prey fish may therefore change as the refuge landscape changes over seasons. The lures could more easily be identified as artificial next to prey fish, or simply less likely to be encountered as the prey fish migrate into the angling area. At sunset, the depth amplitude of the angling group pikes varied a lot, which could imply the longer pikes were more vulnerable to being caught at that time. Though it is at night that the vertical movements were smallest, suggesting even better angling conditions. No anglers were active at night, so naturally there are no catch-rates for night-time, but that would be interesting to investigate for a future experiment.

The probability of catching two or more pikes increases quicker than the probability of catching only one pike. During the experiment, there were more hours that caught two or more pikes than hours that caught one, which most likely produced this result. This could indicate that the pikes share a common factor for what determines their angling vulnerability.

4.4 Shortcomings and improvements

4.4.1 Acoustic telemetry

In this study, a rough position averaging triangulation method was used. Due to a technical flaw where some synchronization tags were given IDs that overlapped with pike IDs, the process of separating overlapping signals became too cumbersome within the timeframe of this project. In near future this issue will be resolved, and a novel positioning system will be used to gain high-resolution positions at ping-level (Baktoft et al., 2019). Given higher fidelity triangulation data with increased interpolation accuracy and about 10 times the amount of points (position for every tag-ping versus 10-minute-means) accurate home ranges could have been constructed for the pikes. In addition to this more precise distance data would have been available. The low accuracy of the distance data could have been detrimental to some of the analyses, as activity measures were found to be underestimated with longer log-intervals (Guzzo et al., 2018), but this is unknown until the compatibility issue has been resolved.

The westernmost acoustic receiver in the grid was lost during the experiment. Its rope most likely caught an angler's lure and was dragged to a greater depth. The data saved on this receiver would most likely make the PAV-positioning more accurate. As mentioned, the PAV-method only interpolates positions within the receiver array, and the exclusion of this receiver meant that angling hotspot 1 was not within this array. It is likely that the calculated swimming distances would have been different if the receiver were retrieved. The depth-values are unaffected by this loss though, as they are independent from triangulation.

Tagged pikes that move out of range from the triangulation array will not available for triangulation. The data loss from this is substantial, as several days had empty values or few logs from some pikes. Emigration out of range is assumed to be randomly distributed between all the pikes, meaning every pike has an equal chance to do so. To counteract this problem, the whole lake would have to be a part of the receiver array.

4.4.2 Experiment

The conducted experiment was the first of its kind at NMBU and so I would like to point out some parts which can be improved upon. The problems I encountered when handling the data was mainly the different ways the participants handled their GPSs. Some meticulously turned it on and off according to if they were angling or not, as is the preferred method. The majority, however, left it on for the entire day. Prior to the experiment more detailed information about GPS-usage should be given. Additionally, when an improved experiment is conducted in Aremarksjøen, it is advisable to improve the report forms. My version failed to capture who was angling when no fish were caught. This could be important data when examining the individual angler's effect on the catch rate. I was only able to perform analysis on the owners of the boats and the anglers who caught a pike, which made the sample size smaller than what it could have been.

To improve the experiment even further, the angling spots could be predetermined by the researchers and then balloted out to the participants. This way, much of the spot-choosing bias is eliminated and the anglers are distributed in all types of habitat. Additionally, the angling gear can be chosen for the anglers. In this experiment, the angling gear was not classified beyond method used, which could mean that an effect of lure type was lost. Arlinghaus et al. (2017) found that lure type was important in their experiment, and the effect should be investigated in a Norwegian lake. Several other studies found the skill of the anglers to be important, but in this experiment the effect was unseen. There was such a large difference in the effort between the boats that this probably covered other angler traits. A researcher interested in angler traits different from effort, should specify how many rods should be used at a time and let the participants fish at the same time to make sure the abiotic environment is roughly the same across all anglers.

5. Conclusion

This study has found the following in October in Aremarksjøen:

1. The pikes appeared to have an increased angling vulnerability when their depth amplitude was low, and the air pressure was low. The depth amplitude was negatively impacted by lower air temperatures, suggesting that cold weather made them more vulnerable
2. Pikes caught by the selective method angling were found to have increased swimming activity both vertically and horizontally when compared to a random sample group caught by gillnets during spawning, suggesting bolder pike personalities are caught by angling.
3. The anglers' probability of catching a pike increased when trolling compared to spinning. Longer time spent angling positively impacted catch probability and more distance moved decreased it. This suggests that troll anglers should have moved slowly and spin anglers implement a sit-and-wait strategy.

In addition to this the results hint at larger pikes being more vulnerable to angling than smaller pikes due to lower vertical activity which was positively correlated to probability of catch.

To limit catch rates, a manager could be interested in limiting the number of rods an angler can utilize and set a maximum limit of anglers in the fishery at the same time. A manager could limit angling efforts when the air pressure and air temperature are very low to prevent the highest catch rates, but I imagine that would make the manager and the fishery unpopular.

Summarized, during October, a pike angler therefore should go angling on a cold day with low air pressure and travel straight to shallow areas increase their probability of catch. He/she should utilize as many rods as possible, move slowly and troll rather than spin. The anglers are then more likely to catch larger pikes, as they seem more vulnerable to being caught.

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Appendix A

A.1

Dato:	Båteier	GPS #	Metode (slå ring): Dorging / Spinning

Annen metode:

Start: | Slutt:

Fangstrapport

Tidspunkt	Waypoint #	Fisker (kallenavn)	Redskap	Lengde (cm)	Evt. merkenummer

Lage waypoint:

For å markere hvor fisken er tatt er det viktig at dere markerer et waypoint på GPS'en dere har med.

1. Velg **Mark waypoint/veipunkt** fra hovedmenyen

2. Skriv ned nummeret på waypointet i skjemaet over

3. **<u>VIKTIG</u>**: Velg **Done/Ferdig**

A.2

Instruks

Pakkeliste:
- Nok mat
- Termos med kaffe eller annen varm drikke
- Klær til all slags vær
- Flytevest
- Fiskeutstyr
- Tang til skånsom fjerning av krok

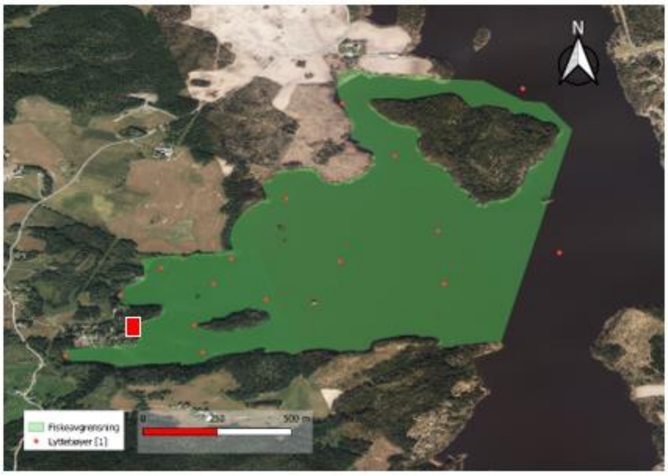
Husk å ta med i båten:
- GPS med batterier til en hel dag
- Målebrett/bånd
- Håv
- Blyant
- Flere rapporteringsskjema og skriveplate

1. Skru på GPS'en **i det dere drar ut med båt**. Den logger posisjonen deres.
2. Start fiske: skriv starttid for fiskemetoden dere bruker. **Bytter dere metode må dere bruke nytt skjema**
3. Fisk innenfor det angitte området:

Eksperimentet gjennomføres i det markerte området. Her har vi best dekning av lyttebøyer.

Lyttebøyene er markert som røde punkter

Postkasse i Mørkevika er markert som stor rød firkant



4. Når dere får en gjedde:
   a. Ta den skånsomt opp i båten
   b. Mål fisken
   c. Marker et waypoint på GPS'en
   d. Se etter hvitt merke i ryggen. Dette kan være overgrodd av alger.
   e. Fyll ut skjemaet
5. Når fisketuren er over: ta bilde av skjemaene og send til 46429580 (mms) eller aksel.skaland.roste@nmbu.no (epost). Eller legg i postkasse på brygga i Mørkevika (se kart). Ta vare på skjemaet dersom du ikke legger i postkassa! Kos deg på fisketur!

A.3

Registreringsskjema for deltakere i gjeddeeksperimentet i Ara

For å gjøre deltakelsen anonym må dere lage dere et kallenavn. Bruk noe du husker.

Ditt kallenavn:

____

Din alder:

____

Vurder din egen ferdighet som gjeddefisker. Sett ring rundt tallet du mener passer.

1	2	3	4	5	6	7
Uerfaren						Ekspert

Bor du i Aremark kommune? Ja ☐ Nei ☐

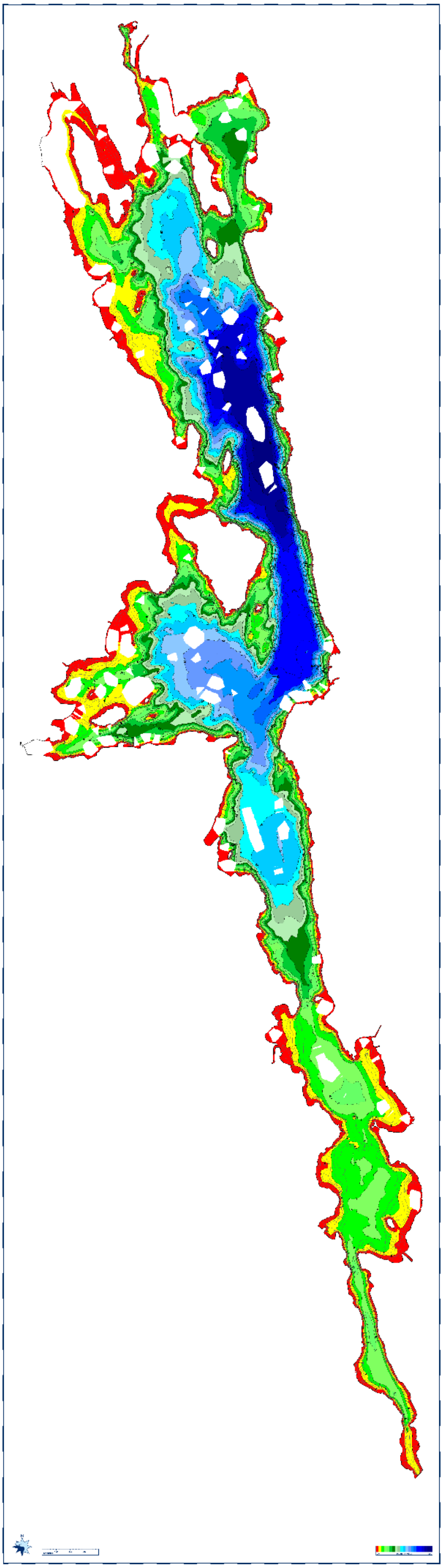
Vurder din kjennskap til gjeddefiske i Ara. Sett ring rundt tallet du mener passer.

1	2	3	4	5	6	7
Ingen kjennskap						Svært god kjennskap

Hvilken metode bruker du mest når du fisker gjedde om høsten? Sett kryss.

Dorging/trolling ☐ Spinnfiske ☐ Annen metode ☐ Hvilken: ____________

A.4



A.5

The temperature model is a generalized additive model and takes both the day of year and depth into consideration. The two factors are connected using a spline.

Term	edf	F	p-value	R^2 (adj)
s(julian day, depth)	28.78	2609	<2e-16	0.96

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