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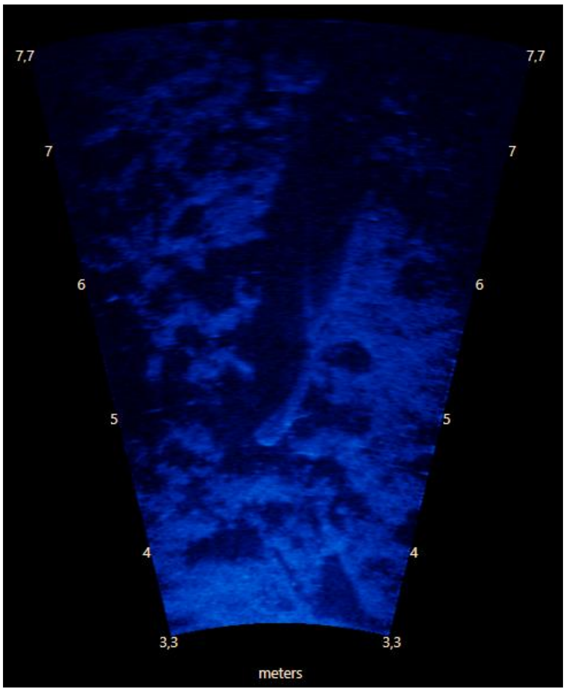
Sampling methods of the wels catfish (Silurus glanis) in freshwater lakes
– Management of a vulnerable species

David Östby



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Sampling methods of the wels catfish (Silurus glanis) in freshwater lakes – Management of a vulnerable species

David Östby

Supervisor: Henrik Jeuthe, Swedish University of Agricultural Sciences, Department of Aquatic Resources

Assistant supervisor: Joep De Leeuw, Swedish University of Agricultural Sciences, Department of Aquatic Resources

Examiner: Kerstin Holmgren, Swedish University of Agricultural Sciences, Department of Aquatic Resources

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Abstract

Sweden hosts the northernmost natural population of wels catfish (*Silurus glanis*) in the world. The populations of the species decreased severely in the 20th century, mainly due to different sources of anthropogenic impact. In recent years, efforts have been made to reintroduce the species to previous inhabited areas, restore degraded habitats and to increase the low genetic variation among the populations. Studies and general recommendations concerning sampling techniques and monitoring of *S. glanis* in temperate lakes are lacking, especially concerning conservation measures. In the current study, the species has been sampled with acoustic camera and electro-fishing, and the results are compared with results from the standardized fishing with fyke nets in the lake. A has also been reviewed to account for other methods that might be viable for sampling *S.glanis*.

Fyke nets sampled lower numbers of catfish of intermediate size, compared to the fish observed by the sonar, which were both more numerous and larger. The acoustic camera was found to be efficient for detecting adult catfish in their natural habitat, with the possible application of making population approximations. The fyke nets sampled few individuas for the given effort, but are still the best available sampling method that provides sampled catfish physically. The electrofishing boat did not manage to sample a single catfish and the method was found to be inefficient in the habitat of this lake. Juveniles of *S. glanis* were underestimated in the samples caught by the gear used in this study, and no larvae were sampled. According to literature, light traps and minnow traps do have some promising properties for sampling these individuals, and future studies should address their viability.

Keywords: sampling, gear, monitoring, Wels catfish, Silurus glanis, management, vulnerable species, electrofishing, acoustic camera, fyke nets, lake

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1 Introduction

1.1 Background

The wels catfish (*Silurus glanis*) is a species of large freshwater fish, which is fairly common in most parts of its range. Its status on the IUCN redlist is of least concern and it is even considered a problem as an invasive species in several countries (Freyhof & Brooks 2011, Copp *et al*. 2009). In Sweden, it is instead classified as a vulnerable species and the population has experienced a sharp decline in the last century. Much of this decline seems to be due to human impact and the catfish is now absent from several waters which it previously inhabited (Hällholm 2016, Nathanson 1987). In Sweden, natural populations of *S. glanis* only survive in Båven, Emån, Möckeln and adjacent waterways of the later mentioned lake (Artdatabanken 2006). The species is protected by the Swedish fishing regulation and it is forbidden to kill, harm or catch the species (Havs- och vattenmyndigheten 2016). Efforts are now being made to preserve *S. glanis* in Swedish waters and the species has been re-introduced to lower Helgeå, where it previously went extinct (Jansson 2012). The county boards are responsible for the execution of a national monitoring programme that includes regular test fishing to follow up population changes. The primary focus of the test fishing is therefore small individuals, which act as indicators of yearly recruitment (Lessmark 2011).

Knowledge of the biological and ecological background is essential for making the right decisions while managing threatened species (Söderling 2016). Much literature is available of *S. glanis* from studies conducted in continental Europe (Copp 2009, Söderling 2016) but many publications differ in their conclusions concerning factors such as the on-set of sexual maturation and life span of the species. This implies that the variation among populations might be significant depending on location. In Sweden, the populations have been isolated from mainland Europe during more than 8000 years, and they are likely to inhabit local adaptations that differ from populations located further south (Söderling 2016). Few studies concerning the species have been conducted in northern Europe and many ecological questions remain uncertain for populations inhabiting this area (Hällholm 2016, Enqvist 2015). How do the populations in these areas differ from other Eurasian populations, how big are the territories of the males and how large is the yearly recruitment? To address ecological questions like these and to manage threatened species, efficient gear and sampling methods are needed (Portt *et al*. 2012).

Few studies address sampling methods and conservation of *S. glanis* as a major issue, possibly due to the species often being common and only locally threatened in much of its range (IUCN redlist). Sampling in continental Europe is often conducted by local fishermen, and the sampled individuals are often killed before analysis of the samples takes place (Söderling 2016). The gear used for sampling the species varies widely but includes electrofishing, angling, gill nets and traps. For the three common North American species of catfish there are several studies and reviews investigating the most convenient sampling methods of the species (Bodine *et al*. 2013), something which is undoubtly lacking for *S. glanis*. In the Swedish monitoring programme of the species, the fyke nets used mainly catches fish of intermediate size, leaving out juveniles as well as larger specimens (Ragnarsson-Stabo 2014, Söderling 2016). According to Lessmark (2011), the fyke nets need to catch a mean of one individual for every net and every night to account for changes in population density with the current methods.

1.2 Purpose

Efficient and valid methods are needed when sampling *S. glanis* in temperate lakes. In Lake Båven, the fyke nets used have been described by some authors as inefficient (Ragnarsson-Stabo 2014), failing to sample juveniles and large individuals. This study evaluates gear and sampling methods with applications for sampling *S. glanis* in temperate lakes, with the aim of finding the most feasible methods for monitoring and conservation. Electrofishing and fyke nets are two sampling methods commonly used to sample *S. glanis*, and the application of these techniques for monitoring catfish are evaluated and compared to each other in the field. As a new promising method for sampling catfish populations in this habitat, observations from an acoustic camera are evaluated for detecting *S. glanis* in Båven. This gear can be used to make underwater observations of the lake habitat and has been used to observe fishes as well as studying their behavior (Burczynski & Johnson 1986, Manik 2011, Knudsen & Saegrov 2002). Therefore, the technique might also be viable to estimate the number of sexually mature individuals in this area. The catch rate per unit effort (CRUE) of electrofishing and fyke nets is also evaluated and compared to the results of the acoustic camera.

Literature is reviewed to account for previous findings, and to evaluate the application of other methods with potential of sampling *S. glanis* in temperate lakes. Not only gear commonly used for sampling *S. glanis* will be mentioned, but also gear used for sampling other species of catfish and species of fish located in similar habitats. As small individuals are of large interest to observe and follow up trends in yearly recruitment, another area of interest is what size categories that are caught by different methods available. Population size and number of sexually mature individuals in Båven have been approximated by genetic studies but the results are based on very low numbers of recaptures and more observations and studies are needed to confirm these results. Some of the questions that this report is intended to answer are listed below.

- Which method is likely to yield the largest samples in vegetation-rich temperate lakes?
- What size classes are caught by the methods and how well do they correspond to the total catfish population?
- Can the methods be used without presenting injure or stress to the individuals being sampled?
- What applications and possibilities do the methods present when used for monitoring a population of *S. glanis*?
- Is direct observation with acoustic camera a suitable method for sampling catfish populations, and what applications does the method have? Can the method differentiate individual lengths and account for all individuals present?
- Which method is likely the most feasible to estimate population size and follow up current trends?

1.3 The wels catfish (*Silurus glanis*)

1.3.1 Biology and ecology

S. glanis is a large species of catfish with a main distribution stretching from western Asia into central Europe. The species have been introduced to at least seven countries in Southern and Western Europe (Freyhof & Kottelat 2008), where it sometimes has been suggested to have invasive impacts (Carol *et al*. 2009, Syväränta *et al*. 2010). The body is elongated and laterally decompressed behind its head, with the anal fin running across two thirds of its body length (Norling *et al*. 2009). As illustrated in Figure 1, the eyes of the fish are very small, providing only restricted vision (Bruton 1996). It primarily relies on olfactory organs distributed on its barbels and body for orientation and hunting. The species is known to grow very large and the largest specimen caught is reported to have been five meters long with a weight of 300 kg, although this is disputed. The largest verified fish in modern time was a 2.73 meter long fish caught in river Rhone which weighted 130 kg (Bouletreau & Santoul 2016).

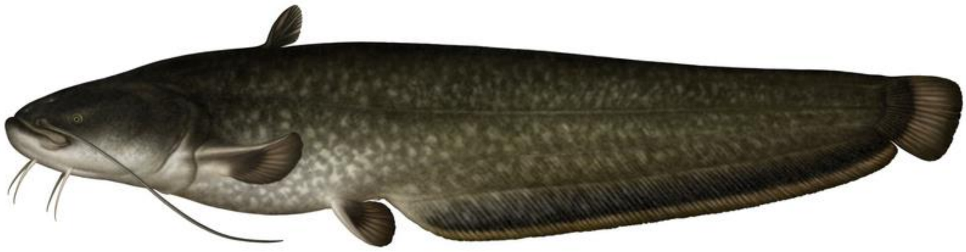

Figure 1. *S. glanis* as illustrated by Linda Nyman for Artdatabanken.

The fish prefers large, slow running rivers and densely vegetated lakes (Wolter & Vilcinskas 1996). It spends the days in so-called resting places, while venturing out and searching for food at night (Copp. *et al* 2009). In a Czech river, *S. glanis* was found to be active during both day and night in summer, with activity peaking during daylight in spring and during dusk in autumn, with minimal activity recorded in winter (Slavík *et al.* 2007). The species is temperature dependent, with an optimum for growth in the range of 25-28º C (Hilge 1985). In southern Europe, individuals reach sexual maturity at an age of three to four years at lengths of 39-71 cm (Copp *et al.* 2009). Experiencing the effects of a colder summer, growth rates in Sweden seems to be slower than further south and the on-set of sexual maturation does probably not occur until an age of at least 10-12 years (Nathanson 1986). The species mainly feeds on cyprinid fish but can prey on a wide range of different species including crustaceans, mollusks and amphibians. Later in life it starts eating large fish and sometimes also birds and small mammals (Carol *et al*. 2009, Syväranta 2010, Orlova & Popova 1987). In the breeding season, the male starts to display aggressive behavior toward other males while competing for spawning areas (Planche 1987). Shallow bays and littoral zones have been reported to be important reproduction- and nursery areas (Nathanson 1987). If available habitat for reproduction is low compared to the number of sexually mature individuals, fights between males will establish the territories (Copp *et al.* 2009). The male then builds a nest, either consisting of a depression with weeds at the bottom, a sort of bed consisting of plant material or a nest out of free-hanging roots of aquatic plants (Copp *et al*. 2009). He mates with a female and guards the eggs until they are hatching (Phillips & Rix 1985), sometimes circulating them and using his tail to ensure that they are not getting deprived of oxygen.

1.3.2 The wels catfish in Sweden

In Sweden, *S. glanis* is considered a post-glacial relict species from the era of the Ancylus Lake when the climate was warmer. It lives on the border of its distribution, and summer temperatures are likely to limit the natural distribution of the fish's northern distribution (Lever 1977, Shikhshabekov 1978). Many lakes in Sweden were regulated and altered in the 19th and early 20th century for the agricultural purposes and land use. This destroyed many wetlands and affected the species communities in littoral zones. One example is Lake Hjälmaren, where the water level was lowered several meters and the species no longer can be found (Degerman 2004). Today, natural populations of *S. glanis* has survived in three main areas in Sweden; Emån, Möckeln and Båven. The fish has also been re-introduced in lower Helgeå, and has likely been illegally introduced in an unknown number of lakes. All populations in Sweden have low genetic variation compared to populations studied in other parts of Europe (Hällholm 2016). There are several threats that could account for the low genetic diversity and the decline of *S. glanis* in Sweden. During the 19th century, the habitat of *S. glanis* have been affected by water regulations, dredging, emission of pollutants and illegal fishing (Nathanson 1987). Water regulation seems to be one of the more important threats, since the species is strongly dependent on the littoral zone (Paulovits *et al*. 2007).

1.3.3 The situation in Båven

The total population size of sexually mature individuals was estimated to be 264-396 individuals based on estimated number of sub-populations and few re-captures of the catfish caught in Båven. Water regulation and habitat alterations seem to have been the more important threat to *S glanis* in Båven (Hällholm 2016). The water level in Båven has been lowered in stages and is today lowered during the summer months in favor of the local agriculture (Nyköpings vattenkraft AB 2015). Palm (2008) estimated the genetically effective population in Lake Båven to be as low as 13 individuals while Hällholm (2015) estimated it to be 16 individuals, which indicates a very low genetic diversity. Martin Enqvist (2015) concluded that there is room for 12 to 15 territorial males in northwestern Båven. Coupled with the surprisingly large estimated population size, this suggests that the poor genetic variation is related to a lack of suitable spawning habitat rather than small population size or few sexually mature individuals (Hällholm 2016, Ragnarsson-Stabo 2014). A lack of suitable habitat is also supported by spawning-related injuries on caught catfish (Enqvist 2015). There are still many questions about the ecology of catfish in Båven, including knowledge about spawning localities, behavior during the breeding season and location of fry. The fyke nets used for monitoring catfish in Båven are sampling few individuals, and individuals caught have been described to be of a limited size range, leaving out very young fish as well as the largest specimens (Ragnarsson-Stabo 2014).

1.4 Overview of potential sampling methods for S. *glanis*

Studies and reviews concerning sampling methods of catfish have mostly focused on management and ecology of the three most common North American species in the sport fish industry; channel catfish (*Ictalurus punctatus*), blue catfish (*Ictalurus furcatus*) and flathead catfish (*Pylodictis olivaris*) (Kwak *et al*. 2011). Before choosing sampling methods, it is important to consider the questions to be answered, and which type of data that is relevant for this. A good sampling method generally catches large samples for given effort but there are many other factors to take into account. What species is to be sampled, what age class is to be sampled, what type of data is to be analyzed and what environment is to be sampled? Depending on these factors, it is possible that one of the methods mentioned might be enough, but it is also possible they worked best combined with other methods (Portt *et al*. 2012).

Deep holes and obstructions like logs and stones on the lake bottom, as well as vegetation rich littoral zones are important habitats of *S. glanis*. The littoral zones are also used when spawning (Copp *et al*. 2009, Artdatabanken 2006). Gear which can be used in these areas and efficiently sample them are of primary interest when sampling *S. glanis*, even if less specialized gear might also prove efficient. Juveniles and larvae of catfish are of large interest since the first years are of critical importance for the survival of fish in general (Blaxter & Ehrlich 1974). Abundance estimations of juvenile fish and larvae may also provide invaluable in stock assessment (Ahlstrom 1965) and can be used as indications of successful reproduction (Hrabik 2007). Therefore, sampling methods which can target these small individuals are also of large interest.

Since *S. glanis* is a threatened species in Sweden it is important that the methods used are sampling catfish without injuring or killing the individuals sampled. Many studies which have been targeting *S. glanis* have been conducted in rivers and lotic ecosystems. Since the ecology and abiotic factors are very different between lakes and rivers, there are different factors influencing the choice of sampling method (Portt *et al*. 2012). The three most common methods for sampling the species and previous use of these methods are reviewed bellow, followed by an additional number of methods which are also worth of taking into consideration when finding good sampling methods for *S. glanis* in temperate lakes. Some of these gears and methods are illustrated in Figure 2.

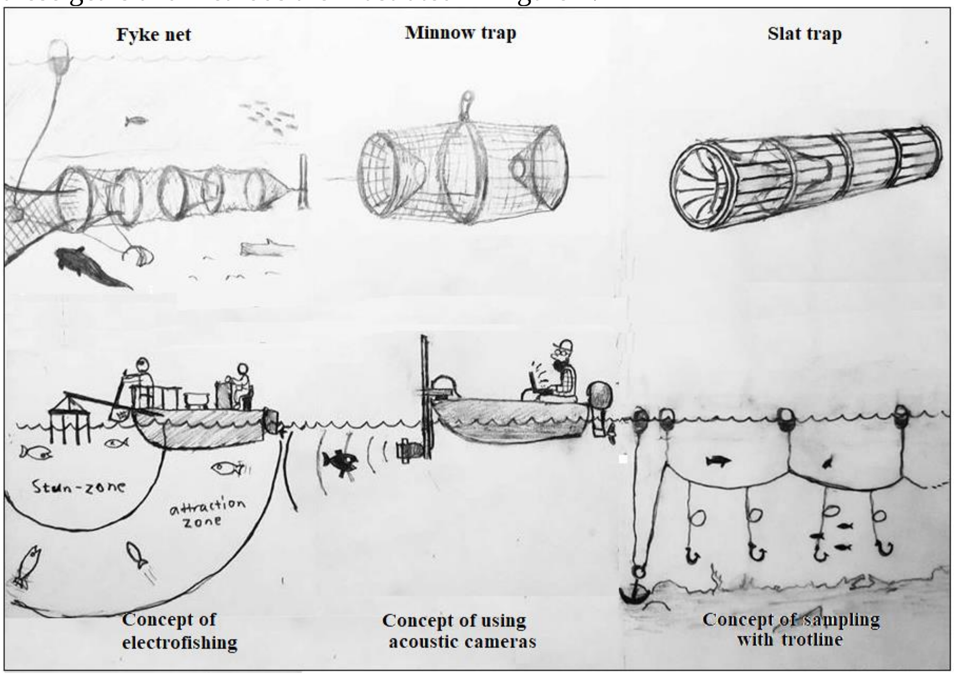

Figure 2. Illustrations of potentially useful gear and methods when sampling *S. glanis*.

1.4.1 Electrofishing

Electrofishing is a common method for sampling freshwater fish and consists of three main variations; backpack electrofishing, streamside electrofishing/shore units and boat electrofishing. The first two methods mentioned are performed by two people wading in the water and therefore require shallow water and a walkable bottom substrate to be safe. There is also a gear called electric seine but which is used much less frequently (Portt *et al*. 2012). All methods involve the use of electrodes to create an electrical field in the water. As illustrated in Figure 2, fish approaching the electrodes will experience involuntary swimming behavior in the direction of the electrodes, and then gets stunned by the electrical field when approaching close enough to them (Smith-root 2015). In North America, electrofishing has successfully been used in several studies to collect and sample individuals of flathead catfish, blue catfish and channel catfish. On average, it is reported to be the gear sampling the highest number of blue catfish and flathead catfish. Buckmeier & Schlechte (2008) noted that the method caught relatively unbiased samples of the Blue catfish population, with no size class being underrepresented. The method seemed to work best in running waters but in some cases also lakes and reserves, even if less data were available from these habitats (Bodine *et al*. 2013).

Electrofishing has been used to sample *S. glanis* for studies concerning genetics, and its diet in introduced areas, but few have assessed or mentioned sampling efficiency (Carol *et al*. 2009, Galli *et al*. 2003, Slavik *et al*. 2007, Triantafyllidis *et al*.1999). Many of these studies have been conducted in river habitats or reservoirs distinct from the type of environment existing in temperate lakes. Dewey (1992) recommended not using electrofishing in turbid and vegetated water since the catch rate was only 5% under these circumstances compared to 80% in vegetation free and relatively clearing water. Under these circumstances, fish was not easily detected and the vegetation worked to both obscure electrified fish and stop them from emerging from the water.

Only a few studies specify the voltage and current used when electrofishing for *S. glanis* and there appear to be no standard method used when electrofishing for the species by boat (Jeuthe *et al*. 2017). Nielsen (1998) noted that the increased mortality rates for electrofishing for young fish or larvae could be detrimental for endangered species, while Dolan and Miranda (2002) proposed that electrofishing should be deployed with great care or simply avoided when sampling endangered species. In this study, channel catfish were less affected by injuries and mortality related to electrofishing than largemouth bass (*Micropterus salmoides*) and bluegill (*Lepomis macrochirus*). According to Sharber (1994), fish rarely die of DC electrofishing but may be affected by physiological trauma or physical injuries.

1.4.2 Hoop nets & fyke nets

Hoop nets are cylindrical nets held together by frames and fykes. Fyke nets are similar to hoop nets, but also consist of a lead or wings designed to guide fish to the mouth of the trap (Portt *et al*. 2012). They can be used in marsh-like habitats rich in vegetation, but setting them up in habitats with soft bottoms may be problematic. These nets are selective on cover-seeking, mobile species but catches also depend on placement in the lake (Hoffman *et al*. 1990). Different measures of hoop net frames can be used to target different size classes (Portt *et al*. 2012). Mortality rates for entrapment gear like fyke nets and hoop nets are typically low (Hubert *et al*. 2012). According to Gustafsson[1], the test fishing with fyke nets in Båven have reportedly only resulted in minor injuries not related to any mortality caused by the sampling method. The test fishing conducted in Möckeln did not result in any major injuries to the catfish caught (Söderling 2016). Hoop nets have been described as selective for flathead catfish and channel catfish (Holland & Peters 1992), with interlinked hoop nets being more efficient than any other sampling method for channel catfish (Michaletz 2001, Buckmeier & Schlechte 2008). Compared to these species, the mean CPUE of several North American studies is much lower for blue catfish (Bodine *et al*. 2013), both when defining CPUE as average number of individual fish for each net and night and as averaging catches per person-hours.

The nets used in the Swedish test fishing for catfish are specially designed to catch catfish in Swedish waters and have been developed by the county administration boards of Kronoberg and Kalmar (Jansson 2012). According to the monitoring programme used in Sweden, two persons working from a boat are able to control the catch of 25-50 fyke nets and set them up in a new area within one workday (Lessmark 2011). In Båven, the fyke nets used have been left unbaited and arranged in tandems of 10 interlinked nets, with test fishing occurring in 10 stations. Sampling takes place in two occasions for every station.

The results of using fyke nets in Båven has been described as low, and less than sufficient to make good population approximations because of very few re-captured individuals (Hällholm 2016, Ragnarsson-Stabo 2014). In Möckeln, the fyke nets caught relatively small individuals compared to hook and line methods and different method were seen as complementing each other well (Söderling 2016). In the lower parts of River Helgeå, the fyke nets caught a mean of 0.26 individuals for every effort (Jansson 2012). Fyke nets have been used extensively in River Emån with 924 sample efforts catching 209 catfishes in 2006, where one effort was defined as a single hoop net fishing for 24 hours. The method seemed to leave out the larger individuals with only a few specimens larger than one meter and the majority being less than 40 cm. Catfish was the fish species most commonly caught by the nets (Berger & Kjellberg 2006).

1.4.3 Hydro acoustics

High frequency acoustic sonars are relatively new and fast developing techniques useful for detecting aquatic organisms (Horne 2000). These techniques have been deployed to determine population size and size distribution of fish in natural habitats (Burczynski & Johnson 1986, Manik 2011, Knudsen & Saegrov 2002). Acoustic sonars belong to direct observation methods and does not collect the fish

[1] In footnote: Rickard Gustafsson, Sportfiskarna, 2017-10-21

physically and thus cannot provide DNA samples or provide the fish directly. This makes them useful for non-invasive sampling, which is a very desirable trait when sampling threatened species but also for conservation and environmental management at a large scale (Baumgartner et al. 2006). If distinction of fish species is possible, the technique might be helpful to determine population size, size distribution and fish habitat for *S. glanis*. It is also possible that the method can be used together with other sampling methods to locate fish of specific size or habitat and then collect it for sampling or further analysis. Acoustic cameras can be used efficiently in both clear and turbid waters even if very turbid waters can impair details at longer distances (Maxwell & Gove 2007).

The primary disadvantage of hydro acoustic sonars is that they may provide little information of species, and sometimes even size of the fish. These problems arise because of distortion of the generated images due to angle and environmental factors. Multi-beam sonars address some of these problems since they result in video-like footage which is easier to interpret (Olsen 1990, Horne 2000, Knudsen & Saegon 2002). Dual-frequency identification sonars (DIDSON) further improves the techniques and can provide more reliable footage with longer range and species identification being possible for species with unique shapes and fin positioning (Horne 2000, Crossman *et al.* 2011, Martignac 2013). Size approximations made with horizontal acoustic sonars seem to vary in quality for different species and smaller sizes seemed to cause larger errors of length approximation (Hightower *et al.* 2013).

1.4.4 Other methods

Angling gear incorporates many different methods and variations of gear-type. Examples are simple fishing rods and long lines, which consists of a main line in a horizontal direction with many vertically oriented, hook-provided lines attached. The terminology for this type of gear varies with location and species that are targeted but common names include trotlines, set lines and drift lines (Rounsefell & Everhart 1953). When summarizing the literature for catches by hook and line methods of North American species of catfish, Bodine (2013) found the mean number of individuals caught for each hook per night and mean number of individuals for each hook per set to be less than 0.5 for all species investigated. Several studies on *S. glanis* have used hook and line methods, trot lines or utilized local fishermen for sampling the species with angling gear (Alp *et al*. 2004, Syväranta *et al*. 2010, Alp *et al*. 2010). Söderling (2016) used a hook size of 2/0 with unspecified bait while Ragnarsson-Stabo (2014) used a size of 3/0 and used fish as bait. Another study used a 20 cm long cyprinid fish (Carassius spp) as live bait (Boulêtreau *et al.* 2016).
Ragnarsson-Stabo (2014) noted that hook and line methods were suitable for catching large individuals of *S. glanis* in Båven. In Möckeln, the larger size of catfish caught by long lines and rods were seen as a good complement to the smaller sizes collected by fyke nets. In this study, Söderling (2016) noted that fyke nets were performing better in late spring-early summer while the long lines caught

more individuals of *S. glanis* in late summer. Similar numbers of catfish were caught for both methods. Fish caught by hook and line methods may experience high mortality rates (Muoneke and Childress 1994), which could present a significant problem when sampling catfish for the purpose of conservation. When measures have been taken to address this problem, hook and line methods have also been used to sample *S. glanis* without causing significant harm to the sampled individuals (Söderling 2016).

Gill nets are passive gears often used when sampling channel catfish and blue catfish (Bodine *et al*. 2013). Considering that they are routinely used when monitoring fish communities in lakes, gill nets can provide low-cost samples. The gear yielded smaller samples compared to tandem hoop nets for channel catfish, and smaller samples of blue catfish compared to electrofishing (Argent & Kimmel 2005, Yeh 1977, Michaletz 2001). When summarizing literature of North American studies to measure mean number of caught individuals per net and night for American species of catfish, Bodine found mean sampling efficiencies of 4.3 individuals for channel catfish, 4.0 individuals for blue catfish and 1.1 individuals for flathead catfish (Bodine *et al*. 2013). *S. glanis* have been sampled by gill nets in various studies, especially when using gill nets for determine structures of fish communities or searching for invasive species (Miranda *et al*. 2010, Šmejkal *et al*. 2015). Depending on mesh size, different gill nets can be highly selective for fish of specific sizes, but experimental gill nets can be used to catch wider size-categories (Portt *et al*. 2012). Floating debris, obstructions near the surface and shallow water can obstruct the use of gill nets. Many fishes are often damaged or killed when using this sampling method (Hubert *et al*. 2012).

Pot gears are portable traps with opening in which the fish being captured enter. They are effective in capturing bottom-dwelling species seeking food or shelter (Hubert *et al*. 2012, Everhart & Youngs 1981). No studies investigating mortality rates and injuries related to pot gears have been found, but entrapment gears are in general not known to cause any major harm to sampled fish (Hubert *et al*. 2012). Minnow traps are inexpensive pot gear, which can also be used in areas with dense vegetation. Minnow traps have been described as species selective, and are only catching small fish (Lake 2013). When sampling sticklebacks with minnow traps, one study found mean catch rates per hour to vary between means of 0.20 and 1.31 individuals (Merilä & Lakka 2013). Slat traps are another pot trap that is popular for sampling catfish in North America, and is often reported as being selective for catfish (Shephard & Jackson 2004, Ellis & Coon 1967, Hubert *et al*. 2012). Ellis and Coon (1967) reported slat traps to catch higher numbers of pond-reared catfish than hoop nets. Shepherd and Jackson reported mean lengths of around 40 cm in slat traps, and that smaller specimens could escape from models with large interslat spaces.

Enclosure traps are also entrapment gear, which are reported to work efficiently in waters with dense vegetation and little current (Portt *et al*. 2012, Chick *et al*. 1992). They are good for sampling discrete, small-scale habitat which might produce a bias when estimating fish diversity. There are two classes of enclosure traps. The first are including drop traps, pull-up nets and buoyant pop nets while the second class consists of throw traps. The gears in the first class are all requiring habitat modification to work successfully while this is not the case for throw traps (Jordan *et al*. 1997). The traps are mainly targeting small species and juvenile fish (Chick *et al*. 1992). Producing representative samples of the fish community in densely vegetated freshwater habitats seems to be good indications for using these gears to catch *S. glanis* in vegetation rich littoral zones, but few studies are focusing on the success of catching catfish species with this gear type. Steele *et al*. (2006) noted mean catch rates of 24.9, 34.1 and 29.8 individuals for each effort when using three types of enclosure traps to sample communities in estuaries of southern California. These catch rates were biased for Arrow goby (*Clevelandia ios*).

1.4.5 Sampling juvenile catfish and larvae

Most studies found concerning larvae and juveniles of *S. glanis* species where focusing on commercial fisheries and artificially bred individuals in ponds and impoundments. No studies that focused on sampling larvae in natural habitats were found. Marchetti & Moyle (1999) used drift nets and light traps in a small Californian stream to sample larvae of different fish species and also caught larvae of channel catfish. Bodine *et al.* 2013 noted that most gear commonly used for sampling adult individuals of North American species of catfish were inefficient for sampling larvae and juveniles of the same species. Fish larvae have more often been sampled in marine environments, and many of the methods used are likely to be less efficient when applied in fresh water. Methods that have been used include buoyant nets, purse-seines and various specially-designed traps (Bagenal & Nellen 1980).

Juvenile fish of different species are generally less difficult to sample than larvae, and methods used for catching juvenile fish includes some previously mentioned gear also used for catching adult fish like traps nets and electrofishing. The choice of method for catching larvae and juvenile fishes is aided by knowledge of spawning habitat as well as nursery areas (Balon 1975). Illuminated glass traps have been used to sample larvae and juveniles of different species of fish that are positively phototactive including members of *Clupeidae*, *Cyprinidae*, *Atherinidae*, *Percichthyidae*, *Centrarchidae*, and *Percidae*. When used for sampling pike (*Esox Lucius*) the light traps sampled quite low numbers of larvae with mean catch rate varying between 0.09 and 0.32 individuals for every trap (Pierce *et al*. 2007). Marchetti & Moyle (1999) also used light traps when sampling larvae of different fish species, but channel catfish were only sampled by the drift nets.

2 Matherial and methods

2.1 Study area

Lake Båven hosts the northernmost natural population of *S. glanis* in Sweden and is located in in the municipality of Flen in the province of Södermanland. It is a large lake consisting of many arms, sheltered bays and islands with a shoreline of over 500 km in length (VISS 2018). The lake hosts many wetlands and a rich bird life. The only larger settlement in direct connection to the lake is Sparreholm. The surroundings include forest, wetlands as well as pastures, mansions and minor settlements. The current study was conducted in northwestern Båven and included the connected lakes Lillsjön, Hornsundssjön and Kvarnsjön. This area was chosen because of previous knowledge of the environmental conditions and the presence of *S. glanis* in these areas, since Enqvist (2015) mapped the area for parameters relevant for the spawning grounds of *S. glanis*. The study area and Lake Båven are shown in Figure 3.

The Lakes in the current study contain many sheltered littoral zones with soft bottoms, floating mats and overhanging vegetation. Bordering Lillsjön, a large marsh called Ugglekärret is located. In sheltered areas both white (*Nymphaea alba*) and yellow (*Nuphur lutea*) waterlilies thrive. There are many reed belts as well as floating mats, consisting of common reed (*Phragmites australis*), common alder (*Alnus glutinosa*) and other vegetation (VISS 2017). Lake Lillsjön and Hornsundssjön houses a population of large, reproducing individuals of *S. glanis*. Kvarnsjön has been pointed out as a home for many young specimens, as well as a place where reproduction takes place (Norling *et al*. 2009).

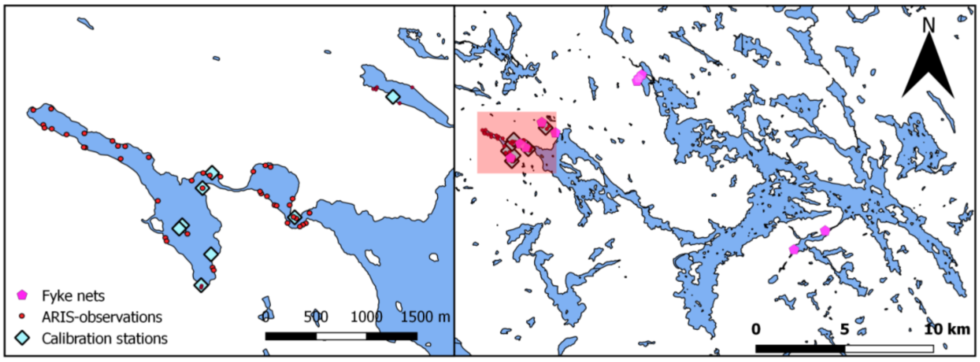

Figure 3. Maps of the study area in Lake Båven, also showing the coordinates were data was collected. The right map shows Båven and where fyke net samples have been made since 2011. The left map shows the part of the study area where ARIS observations were made and electrofishing took place, as well as the calibration between the methods. Electrofishing took place in all parts of this area besides of the inner parts of the northwestern bay in Hornsundssjön. Note that every fyke net position represents 10 interlinked fyke nets.

2.2 Collection of data

2.2.1 ARIS-observations

To evaluate efficiency and size of catfish observed with acoustic camera, observations with this gear were recorded during twelve occasions in June, July and September. These observations were focused on locating individuals in the lake and observe their behaviors. The time spent for recording observations in the field varied between different occasions but always took place between 08:00 and 01:00. The acoustic camera used was ARIS Explorer 1800 (Sound Metrics.corp, Bellevue, Washington, USA). This model operates in two available modes defined by the frequency used. Identification mode works at a frequency of 1.8 MHz and provides more details of subjects up to a range of 15 meters. Detection mode works at a frequency of 1.1 MHz and provides a range of 35 meters, with less detailed visuals. The device was mounted to a metallic pole, which was in turn mounted to a motorboat. The device was power-supplied with a large battery (12 V, 845 Ah), and a laptop was used to control and monitor the device. The motorboat used was the Sun model of the Buster brand (Yamaha Motor Europe N.V, Schiphol-Rijk, North Holland, Netherlands).
Point sampling were recorded in the littoral zone and transect sampling were recorded in both the littoral and the pelagic zone. The samples taken were chosen in the field to include all types of littoral habitats and cover as much of the study area as possible (Figure 3). The samples included floating mats, reed belts, belts of white- and yellow water lilies, hard bottom littoral zones shaded mostly by oak or coniferous trees, the underside of jetties and littoral zones with over-hanging alder trees. Transects sampled where chosen in the field and mostly included a defined transect in the littoral and pelagic zones.

When recording transect samples, the ARIS was aimed in the direction of the boat, or with an angle of maximum 45º toward the shoreline if taking a sample in the littoral zone. To keep a high quality of the recorded material, we tried to go as slow as possible with the boat, at a speed of roughly 5 km/hour. When recording a point sample, the boat was positioned by anchors with the aim to get the best possible view of a littoral zone. In the aim for a clear view without obstructions shading the area, local geography and shoreline were also taken into account when scanning an area with the equipment. The ARIS and lap top were then used to search the littoral zone along the shoreline for *S. glanis*. The lengths of the recordings were usually 3-10 minutes long, but differed depending on local geography, numbers of individuals and activity of individuals. Size of the area included in single observations also varied depending on obstacles and placement of the boat. The camera range was most often set at 15 meters and the camera was panned over a range up to 180º, which amounts for an area of approximately 353 m^2. Sometimes multiple recordings were made at a single place to compensate for vegetation or obstructions that were blocking the range of the ARIS.

2.2.2 Fyke nets

To compare the observations from the acoustic camera with the standardized fyke netting, data sheets from previous years of fyke netting for Länsstyrelsen Södermanland were analyzed. I participated in the standardized test fishing in Båven during 2017. The test fishing is conducted every second year by the county administrative board of Södermanland. The method is standardized for all three main locations of *S. glanis* in Sweden to estimate population size, recruitment and trends.

Data collected during the test fishing included coordinates, location, station, environment, number of fyke nets used, length and weight of catfish caught, additional species captured among other information. In the test fishing, 10 different stations are distributed in different parts of Båven including Kvarnsjön, Lillsjön, Hornsundssjön, Edebysjön and Skarvnäsviken (Figure 3). In 2011 and previous years, a number of different areas where also included. Since 2013, the stations have been located in the same areas every year. Since these areas are all located in Båven and includes similar habitats, the results from all areas were included for analysis. For every station, double fyke nets are used from a boat with 10 fyke nets constituting one link at each station. The fyke nets used are double fyke nets of a model otherwise used for catching eels. Total length of one double fyke net is 18 meters, including an eight-meter long wing at the entrance.

2.2.3 Electrofishing

To evaluate the efficiency and possible application of the method, electrofishing was conducted during three days in September. We used two boats, one with electrofishing equipment of the SR-16E model (Smith-Root, Vancouver, Washington, USA) and the regular motorboat containing the acoustic sonar. The ARIS was sometimes used in the first place to scan a transect for fish. The electrofishing boat

was then used in the area, with the other boat following the electrofishing boat to review and collect stunned fish that the first boat might have failed to collect. This method was used in channels between the lakes, in littoral zones and in pelagic water. Coordinates were to be noted as well as individuals of *S. glanis* that had been caught. To not cause unnecessary mortality, we started out by setting the electric current and pulse frequency at modest levels. At first, we used a frequency of 30 pulses per second, an electric current of 4.5 ampere and a voltage of 500 DC. We later increased these settings to a frequency of 80 pulses per second and a current of 7.5 ampere, and then again to a current of 12.5 ampere. These settings where used until the afternoon of the second day when we increased the frequency to 120 pulses per second and the current to 8.32 ampere.
The electrofishing was conducted with a "trial and error" method, where fishing was performed in different environments with different frequencies used to discover which method that was most feasible for catching *S. glanis* under the prevailing conditions. The electrofishing focusing on catching *S. glanis* was conducted in two days, both in daylight and during late evening between 09:00 and 00:00. In areas with adjacent floating vegetation and wetlands, the sonar was first used to note if catfish was present, and electrofishing was then carried out in the same area while the behavior of present individuals was examined with the sonar. At one point, the electrofishing equipment was also used at the edge of the floating mats. While electrofishing we then attempted to trap fish that was present under the vegetation within the electric current and "drag out" the fish from the vegetation by going backwards with the boat.

2.2.4 ARIS compared to electrofishing

On the third day of electrofishing, a customized method was used to compare the fish caught by electrofishing with fish observed by the acoustic camera. Eight different areas were examined, all located in Hornsundssjön, Lillsjön and Kvarnsjön (Table 1). These stations were chosen in the field to include different types of habitats within the area. Areas were also chosen for their local geography. Structures and shorelines that hindered the escape of fish were preferred. Therefore, many stations consisted of sheltered bays and littoral zones, as well as areas with large boulders and other complex structures that could stop fish from escaping into open water. First, the station to be examined was defined in the field by local environmental features. The ARIS was then used to closely examine the area, followed by using the electrofishing boat in the same area, as illustrated in Figure 4. The settings used for the electrofishing gear were a frequency of 120 pulses per second, a current of 16.64 Ampere and a voltage of 500 DC. Coordinates, fish species and individual lengths of fish were noted at millimeter level for all areas. ARIS-observations were later examined, number of fish observed was counted and fish length approximated to the nearest fifth cm, since the accuracy of more exact length approximations from our available data was considered low.

Figure 4. Electrofishing being conducted at station 1 after observaitions with the acoustic camera have taken place

Table 1. Attributes of the eight stations, which were used for the calibration between the electrofishing and ARIS-observations. The areas of the stations are approximated by analyzation and calculations of the recorded ARIS-material.

Station	Features and environment	Location	Area (m3)
1	Hardbottom littoral, large boulder	Hornsundssjön	400
2	Vegetation-rich littoral, floating mats	Hornsundssjön	150
3	Hardbottom littoral, large boulders	Hornsundssjön	350
4	Hardbottom littoral, sheltered bay	Hornsundssjön	300
5	Hardbottom littoral, headland	Hornsundssjön	1000
6	Littoral, overhang, boulders	Hornsundssjön	400
7	Vegetation-rich littoral, floating mats	Lillsjön	75
8	Hardbottom littoral	Kvarnsjön	350

2.3 Analysis and statistics

To measure how many catfish that were observed by the ARIS-equipment, the recorded material was analyzed after observations had been recorded. The number of individuals observed for each effort was noted and their lengths were estimated using the built-in measuring tool in the ARIScope software. For calculating number of catfish observed for each effort, a single effort was defined as a single video recording where the area of interest had been thoroughly scanned. Only the point samples were used in the analysis, since the quality of transect recordings were limited and individual fishes were hard to notice. For each day when ARIS-observations had been recorded, only one recording was used for each location where observations had taken place. If more than one recording was recorded at a single location during the same day, the recording with largest examined area was used, as long as vegetation or obstructions did not obscure the field of view to a large extent. In addition, the ARIS material from the calibration with electrofishing was also analyzed with observed numbers of fish and fish lengths being noted for each station.

For the fish caught by fyke nets, data from the test fishing conducted during 2011-

2017 were used to calculate number of individuals caught for the unit effort while data from 2007-2017 was used to calculate mean lengths. In 2008, only fyke netting data from August-September was used, since the length estimates for fyke netting in June were intermixed with length data from other gear. Data from 2007-2009 were not used to calculate number of individuals caught for the sampling effort since the total number of fyke nets used was difficult to determine from the data given. The fishing took place in four main areas in Båven; Edebysjön, Lillsjön & Hornsundssjön, Kvarnsjön & Dragnäsån and Skarvnäsviken. All these areas are part of Båven and previous authors have argued that they also hold the same population of *S. glanis* (Hällholm 2016, Enqvist 2015). For these reasons, and because of low annual catches, data from all these areas were used. A single sampling effort was defined as one fyke net fishing for one coherent night.

For all statistical tests and analysis but a few exceptions, which are noted in this text, Minitab 18 was used. To account for how many individuals each method detected and how useful they might be to make population approximations, number of catfish observed by the ARIS for the unit effort was compared to the CPUE calculated for the fyke nets. The ARIS-observations and fyke nets often resulted in no caught or observed individuals of *S. glanis*, leading to many zero-observations in the count data. This is a common case when sampling for rare species, especially if they exhibit patchy distributions. To account for the many zero-observations and over-dispersion, negative binomial regression was used to determine if there was a significant difference in CPUE for each method (O'Hara & Kotze 2010, Sileshi 2006). This analysis was performed in R-statistics. Microsoft Excel was used to calculate CPUE and standard deviations in CPUE for the sampling methods. The datasets used for length analyzation did not meet the requirements of normality according to visual inspection and Kolmogorov-Smirnov normality tests, not even after log transformation. Because of this, a Mann-Whitney test was performed to test if there was a difference in length for individuals caught by the different methods.

Statistical tests were also used to evaluate if numbers of fish and fish lengths observed by the ARIS corresponded to the fish caught by electrofishing, and to account for possible sampling bias. A linear model was used to see if there was a correlation between the number of fish observed by the ARIS and number of fish caught by electrofishing at the different sampling stations. For the length analyzation, the datasets from the methods was not normally distributed according to visual inspection and Kolmogorov-Smirnov normality tests, not even after log transformation. A Mann-Whitney test was used to see if there was a significant difference in the length of fish caught by the two methods. Mann-Whitney tests were also used for corresponding comparisons for every station to account for local variations in the data.

Reviewed literature of possible sampling methods for *S. glanis* were summarized in a table, where different factors influencing the application of the methods were listed and quantified. The factors to be analyzed were if the gear had been previously used on *S. glanis*, sampling efficiency of *S.glanis*, sampling efficiency of other species belonging to the order *Siluriformes*, invasiveness, size categories caught and viability in habitat. Qualitative and quantitative information of the factors was weighted together and compared between papers and the different methods. Invasiveness was defined as likelihood of injuries and mortality of the different method, not only referring to *Silurus glanis* but sampled fishes in general. Size category was referring to size of fishes caught by the gear.

3 Results

3.1 ARIS-observations and fyke net catches

Catfish larger than approximately 40 cm was easily distinguished from other fish species present in Lake Båven due to the wide head with characteristic placement of pectoral fins, and the elongated body with characteristic swimming movements. Smaller fish than this were often hard to species determine due to the visuals not providing enough details or resolution. The quality of the footage varied a lot depending on environment and distance to the fish. Water lilies, roots, other vegetation and bottom obstructions could at times create shadows where nothing could be observed behind the obstructions. When less robust but dense vegetation or algae was present, the vision instead got blurred. In good conditions, most individuals could be clearly observed in a distance of 15 meters, in bad conditions the corresponding distance was 6-10 meters. In general, catfish were easier to observe while swimming around than when lying still on the bottom floor.

Figure 5. The left image depicts a typical example of habitat where catfish was found, with floating mats and macrophytes present. The images to the right shows two examples of observations recorded by ARIS, with four individuals of *S. glanis* clearly visible in each image but with more individuals being present after closer examination.

For the statistical analysis, 82 observations were used, containing 211 observations of individual catfish. It is likely that many of these individuals were observed multiple times since several locations were sampled on more than one occasion. Sampled individuals could also have moved between the locations. The catfish discovered with ARIS were mainly located under cover of floating vegetation mats or in their close proximity. A typical example of these environments is shown in Figure 5. Most individuals were located in groups of two or more fishes, and many areas were quite densely populated with more than 10 individuals in close proximity to each other. By examining the recorded material, behaviors and activity of individual *S. glanis* could also be observed. The standardized fishing by fyke nets had resulted in a total catch of 84 individuals from 940 fyke net efforts during the years of 2011, 2013, 2015 and 2017. There was some variation between the different years, with only 13 individuals caught in 2017 and 32 individuals caught in 2013. It is also worth noting that during 2011, 70% more fyke net efforts were made compared to the next three years when fyke netting had taken place (Table 2). All catches but five in 2011-2017 were from the previously mentioned four main areas of fyke netting.

Table 2. Number of individuals caught in fyke nets and number of fyke nets used for each year the test-fishing of *S. glanis* has occurred in Båven since 2007.

Year	Efforts	Edebysjön	Kvarnsjön & Dragnäsån	Lillsjön & Hornsundssjön	Skarvnäsviken	Other area	Total
2007	Unknown	1	6	5	1	0	13
2008	Unknown	0	5	11	1	4	21
2009	Unknown	2	0	4	8	3	17
2011	340	7	3	7	10	5	32
2013	200	12	1	7	4	0	24
2015	200	7	0	2	4	0	15
2017	200	6	1	4	2	0	13

3.2 ARIS observations compared to catches by fyke nets

The acoustic camera sampled more individuals of *S. glanis* per effort compared to the fyke nets (Figure 6). Number of catfish caught in fyke net efforts ranged between zero and three, but it was very uncommon with larger catches than one individual. Choice of method was a significant predictor for fish length in the regression model, which was confirmed with a P-value <0.001. Simulations of new datasets from our regression model strongly resembled the original data and confirmed that the negative binomial model fitted the data used in this analysis (Figure 7).

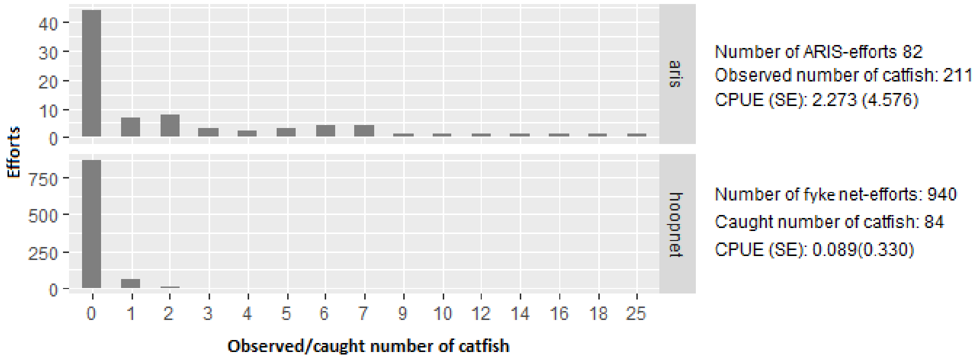

Figure 6. Frequencies of observed/caught number of catfish for each effort. Number of occurrences represents how many times a specific number of individuals were observed or sampled for each method. The chance of sampling a catfish for every effort differed significantly between the methods ($p < 0.001$, $Z=15.11$).

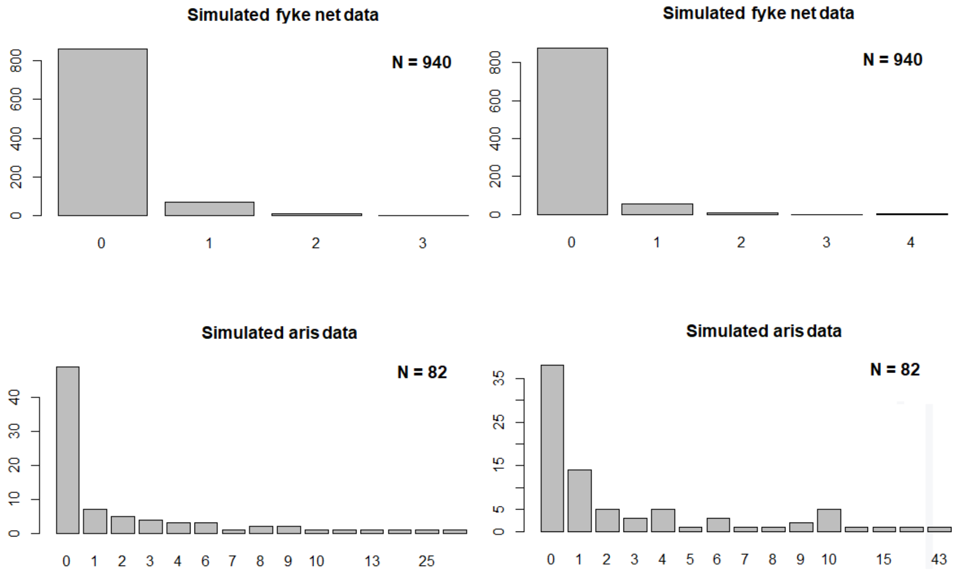

Figure 7. Simulations of new datasets from the negative binomial regression model used to fit the datasets from fyke net and ARIS efforts

Fish observed by ARIS was significantly larger than fish sampled by fyke netting. Fish observed by ARIS was after length approximation calculated to mean length of 1.05 m (Figure 8). The largest fish observed was approximated to be 2.00 m in length, while the smallest was approximated to be 0.30 m. For catfish which had been caught by fyke nets the mean length was 0.51 m (SD = 0.23). The largest individual caught was 1.17 m in length, while the smallest was approximated to be 0.13 m in length. The individuals sampled by ARIS were confirmed to significantly differ in body length compared to individuals sampled by fyke nets.

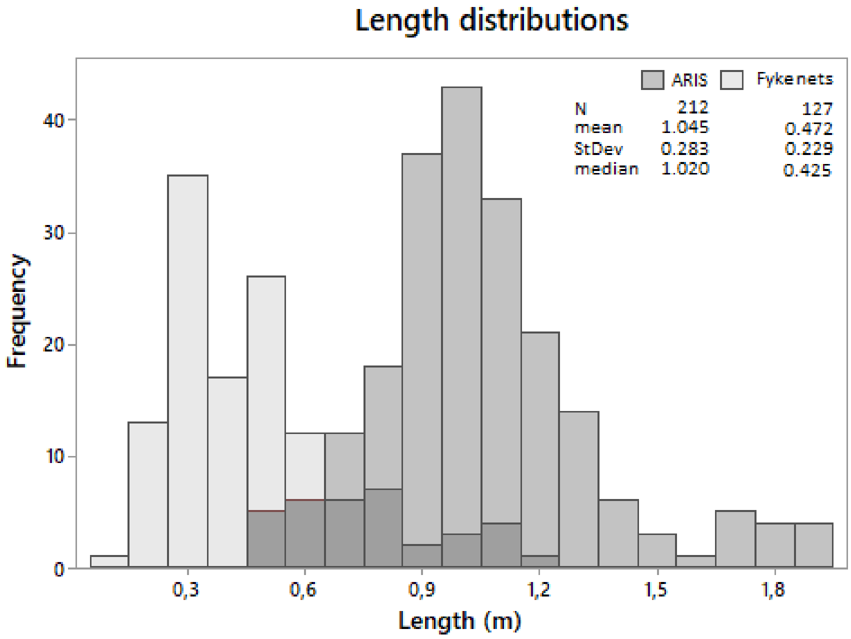

Figure 8. Lengths of *S. glanis* observed by ARIS and individuals caught by fyke nets. The frequencies (number of observations) of individuals of the different sizes are shown with histograms. The areas where the histograms of the two methods intercept are marked in darker grey. The median size of sampled individuals differed significantly between the two different methods ($p < 0.001$).

3.3 Electrofishing of catfish

No individuals of *S. glanis* were caught with electrofishing. Many other fish species present in the lake were caught, some in large numbers. Two individuals, which were observed hiding under adjacent floating mats, escaped further into the vegetation when we started an electrofishing session. Other fish remained motionless under the floating mats, while some schools exhibited unnatural movement and swimming behaviors typical of fish being subjected to this method, but remained under the floating vegetation out of reach for the electrofishing participants.

3.4 Calibration between ARIS-observations and electrofishing

After analyzing the videos recorded by ARIS, a total of 239 fish of 10 different species were observed at the eight different stations. The stations where the smallest numbers of fish were caught were both being located in areas with abundant, floating vegetation. These areas were also the smallest. The largest number of fish observed for a single station was 79 individuals while the smallest were 4 individuals. Sizes of observed individuals were small and individual characters were often hard to observe. It is likely that some individuals were observed more than once, since differentiation of the many individual fishes could be problematic. In total, 304 fish were caught by electrofishing (Table 3). The largest number of fish caught at a single station was 161 individuals and the smallest number was a single individual. The linear model showed a significant correlation between the number of fish caught by electrofishing and number of fishes observed by ARIS at the same stations (Figure 8). The model also showed that numbers of fish caught by electrofishing increased faster than fish observed by ARIS for stations with higher numbers of fish.

The median of approximated length for fish observed with ARIS was 150 mm while the median length of fish caught by electrofishing was 107 mm. A p-value of < 0.001 confirmed that there was a significant difference in length for fish collected by the two sample methods (Figure 9 and Table 4). However, the Mann-Whitney tests conducted for each station (Figure 10 and Table 4) indicated that much variation also existed in this pattern. Significant results for difference between the methods were obtained in cases were the length of fish observed by ARIS were larger than length of fish caught by electrofishing, but also in some situations where the opposite pattern was found. At some stations, differences between the methods were not significant.

Table 3. Fish species and number of fish caught for each station when electrofishing.

	Stations								
Species	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Total**
Abramis brama	1	0	0	0	20	11	0	0	32
Abramis bjoerkna	1	3	0	5	24	4	0	1	38
Alburnus alburnus	9	1	1	1	28	10	0	0	50
Esox lucius	0	1	0	0	0	0	1	1	3
Gymnocephalus cernuus	0	3	0	0	21	1	0	3	28
Osmerus eperlanus	0	0	0	0	6	0	0	0	6
Perca fluviatilis	10	39	5	3	52	8	0	8	125
Rutilus rutilus	2	1	1	1	6	1	0	2	14
Sander lucioperca	0	0	0	3	4	0	0	0	7
Tinca tinca	0	0	0	0	0	1	0	0	1
All species	23	48	7	13	161	36	1	15	304

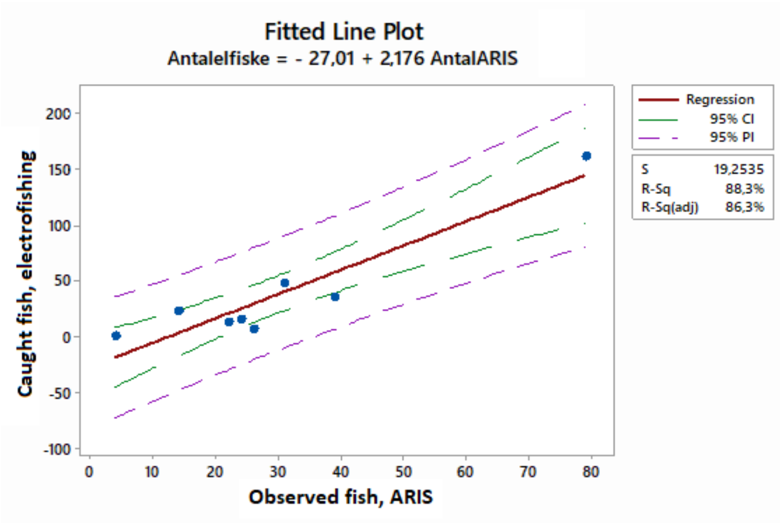

Figure 8. Linnear model of the relationshop between number of fish observed by ARIS and number caught by electrofishing (E.F) at the different stations. The analysis of variance confirmed a significant association between the number of fish for the two methods (p = 0.001).

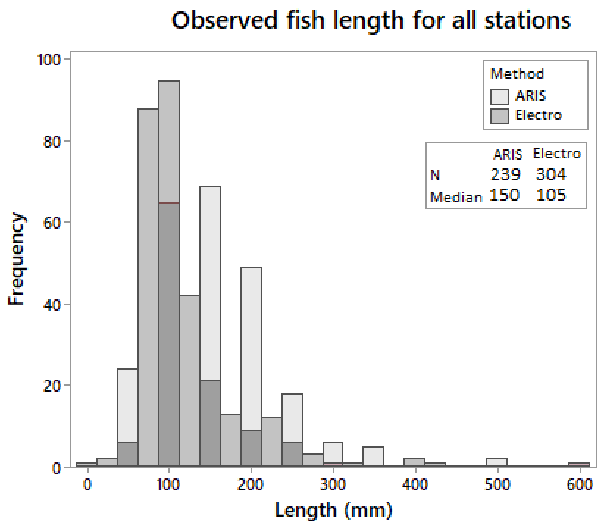

Figure 9. Fish lengths of individuals observed by ARIS and caught by electrofishing (E.F) at the different stations. The mean length of fishes differed significantly between the two methods (p< 0.001, W=76606.50). The darker shade of grey is where the histograms of the methods intercept. Statistical tests comparing the methods for every station can be seen in table 4.

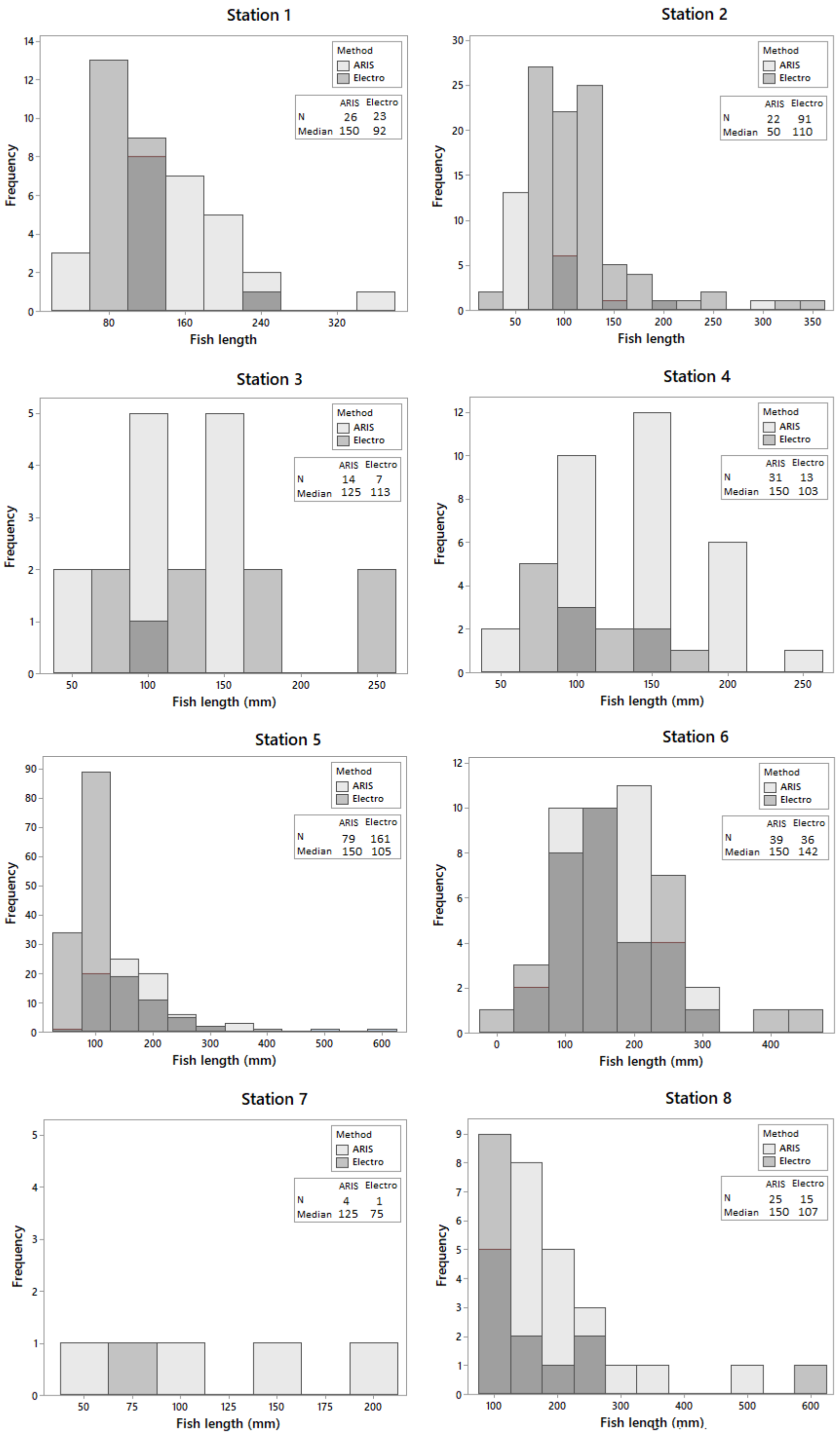

Figure 10. Length frequencies of individual fish observed by ARIS and caught by electrofishing ("electro") at the different stations, with total numbers of sampled individuals and medians noted. The darker shade of grey is where the histograms of the methods intercept. Statistical tests comparing the methods for every station can be seen in table 4.

Table 4. Results from the Mann-Whitney-tests comparing fish length for electrofishing and ARIS-observations for both separate stations and for all stations pooled together. The error for the test at station 7 results from lack of sufficient data.

	ARIS		Electrofishing		Estimation for difference		Test		
Station	**N**	**Median length (mm)**	**N**	**Median length (mm)**	**Difference**	**CI for difference**	**Achieved confidence**	**W-Value (adj for ties)**	**P-value (adj. for ties)**
1	26	150	23	92	35	(14 ; 77)	95.15%	788.00 (788.00)	0.006 (0.006)
2	22	50	48	98	-22	(-42 ; -10)	95.08%	569.50 (569.50)	0.008 (0.007)
3	14	125	7	113	9.5	(-34 ; 66)	95.20%	154.00 (154.00)	1.000 (1.000)
4	31	150	13	103	25	(5 ; 63)	95.24%	791.00 (791.00)	0.017 (0.015)
5	79	150	161	105	52	(40 ; 72)	95.01%	12924.50 (12924.50)	< 0.001 (< 0.001)
6	39	150	36	142	-2	(-35 ; 34)	95.08%	1469.00 (1469.00)	0.895 (0.894)
7	4	125	1	75	ERROR	ERROR	ERROR	ERROR	ERROR
8	25	150	15	107	43	(-6 ; 91)	95.20%	524.50 (524.50)	0.204 (0.200)
All st. pooled	239	150	304	105	35	(29 ; 44)	95.00%	76606.50 (76606.50)	< 0.001 (< 0.001)

3.5 Literature analysis

Information of the literature analysis is summarized in table 5 below. Only four of the methods investigated were confirmed to have caught *S.glanis* before. Electrofishing, hoop/fyke nets and angling gear were among the more commonly used methods for catching the species. The sampling efficiency were low for both hoop netting and angling, with mean catch rates often cited as less than one individual for the unit effort. For electrofishing and gill nets, no data or results that could be used to determine sampling efficiency of *S.glanis* were found. When looking at other species of catfish, electrofishing was often reaching high measures of CPUE. This was also true for hoop nets but to a lesser degree, with some species not being sampled in high numbers. Gill nets provided moderate catch rates in relation to other gear, while angling gear and pot gear provided lower catch rates.
Gill nets and electrofishing were the most invasive gear investigated, since these gears are often injuring and sometimes also mortalities among different species of sampled fish. Angling gear can cause injuries and mortality but have also been reported to not do so when measurements and care have been taken. Passive gear like hoop nets and pot gear are known to have comparatively low mortalities and few injuries. Since pot gears are more selective for size (Lake 2013), there is less risk of predation among trapped fish. In previous studies, angling gear was often catching large specimens of *S. glanis*. Hoop nets were often catching smaller individuals of intermediate size. Electrofishing seem to catch mixed sizes of fish and is reported to not be significantly size biased when sampling blue catfish. Pot gear and enclosure traps are selective for small fish, while light traps are used for catching larvae. When it comes to functionality in different habitats, both electrofishing and gill nets seem to have problems when fishing in dense vegetation, which was a common feature where *S. glanis* occurred in the study area. Hoop nets and angling gear have previously proved to be applicable in the study area. Acoustic camera, pot gear, enclosure traps and light traps have not been used in Båven previously, but the literature does not present any environmental restrictions of these methods that are found in the area investigated in the current study.

Table 5. Litterature of methods that could possibly be used to sample *S.glanis* in temperate lakes summarized. The methods and accompanying literature is more thoroughly presented in "Overview of potential sampling methods for *S. glanis* earlier in this paper. Invasiveness was defined as likelihood of injuries and mortality of the different method, not only referring to *S.glanis* but sampled fishes in general. Size category refers to size of fish caught by the gear. Viability in Båven refers to the author's assessment of the potential to utilize the method in the study area. Cells with italic typing refers to conclusions drawn by the author when comparing the litterature to local surcumstances, which are not stated in the litterature. For each gear in the table, references are presented with numbers referring to the alphabetically ordered list, which is presented bellow the table.

Method/Gear	Prev used for S.glanis	Sampling efficiency *S.glanis*	Sampling efficiency *Siluridae*	Invasiveness	Size category	Viability in habitat	References
Hoop nets/Fyke nets	Often	Low	Low-high	Intermediate	Intermediate	Yes	5, 6, 7, 17, 18, 19, 20, 22, 23, 28, 41
Electrofishing	Often	Uncertain	High	High	Small-Large	*Uncertain*	6, 7, 8, 11, 12, 15, 31, 35, 37,40 , 42
Acoustic camera	No data found	No data found	Uncertain	Low	Large	*Probably*	4, 10, 16, 23, 25, 26,
Angling gear	Yes	Low	Low	Intermediate	Large	Yes	1, 2, 6, 30, 34, 40, 41
Gill nets	Sometimes	Uncertain	Moderate	High	Small-Large	*Probably*	3, 6, 28, 29, 38, 43
Pot gear	No data found	No data found	Low-moderate	Low	Small-Intermediate	*Probably*	13, 14, 18, 21, 27, 36
Enclosure traps	No data found	No data found	Low / lack of data	Intermediate	Small	*Probably*	9, 33, 39
Light traps	No data found	No data found	No data found	*Low*	Larvae	*Probably*	24, 32

1. Alp *et al.* 2004
2. Alp *et al.* 2010
3. Argent & Kimmel 2005
4. Baumgartner *et al.* 2006
5. Berger & Kjellberg 2006
6. Bodine *et al.* 2013
7. Buckmeier & Schlechte 2008
8. Carol *et al.* 2009
9. Chick *et al.* 1992
10. Crossman *et al.* 2011
11. Dewey 1992
12. Dolan & Miranda 2002
13. Ellis & Coon 1967
14. Everhart & Youngs 1981
15. Galli *et al.* 2003
16. Hightower *et al.* 2013
17. Holland & Peters 1992
18. Hubert *et al.* 2012
19. Hällholm 2016
20. Jansson 2012
21. Lake 2013
22. Lessmark 2011
23. Manik 2011
24. Marchetti & Moyle 1999
25. Martignac 2013
26. Maxwell & Gove 2007
27. Merilä & Lakka 2013
28. Michaletz 2001
29. Miranda *et al.* 2010
30. Muoneke and Childress 1994
31. Nielsen 1998
32. Pierce *et al.* 2007
33. Portt *et al.* 2012
34. Ragnarsson-Stabo 2014
35. Sharber *et al.* 1994
36. Shephard & Jackson 2004
37. Slavik *et al.* 2007
38. Šmejkal *et al.* 2015
39. Steele et al. 2006
40. Syväranta et al. 2010
41. Söderling 2016
42. Triantafyllidis *et al.* 1999
43. Yeh 1977

4 Discussion

4.1 Implementation of studied methods

4.1.1 ARIS

The acoustic camera proved to be a successful tool for sampling *S. glanis*. The recordings provided information of fish numbers, size, habitat and behavior. Compared to fyke nets the equipment sampled far more individuals for every effort and the sampled individuals were much larger than individuals sampled by fyke nets. The smaller the fish, the harder species determination becomes due to individual features becoming less prominent in the video recordings. Individuals smaller than 0.4 meters were very hard to species determine with this method, as well as being much harder to detect.

In the calibration between ARIS-observations and fish caught by electrofishing, length of fish observed by ARIS were significantly longer than fish caught by electrofishing, and lower numbers of fish were recorded by the ARIS compared to fish sampled by electrofishing. The reasons for this might be that the ARIS equipment fails to visualize the smallest fishes, leading to over-estimations of median length and underestimations of number of fish present. Larger fish were also observed by the ARIS to swim away when electrofishing was being conducted, and this is probably also a reason why lengths of fish recorded by ARIS were greater than for fish sampled by electrofishing. While number of fish in the ARIS observations were positively correlated to number of fish caught by electrofishing, the ARIS-equipment is better at recording larger individuals compared to small fish. Observations made by acoustic cameras also provide non-invasive methods that do not cause any apparent harm or stress to *S. glanis* being sampled. The observations made during the current study provided new information of the species behavior and spatial location in the area, which would not had been easy to obtain with other methods due to turbid waters and inaccessible habitats. This information could potentially be used to improve other methods used to provide fish directly, for example by allowing more accurate placement of gear and customizing the methodology to local circumstances and abundances of the individuals. Since the equipment provides quick and foreseeable insight into the habitat of *S. glanis*, the method is potentially both more effortless and more accurate for making population approximations than methods used for collecting individuals directly.

Observations recorded with this equipment are generally relatively effortless and takes short time, with an area corresponding to roughly 150-400 m^2 to be recorded in 5-20 minutes depending on objective and details of interest. Point sampling is recommended over transect sampling, since transects result in lower quality material and makes observations of areas under vegetative cover problematic. In a survey aimed to estimate number of catfish present, two people working from a boat could approximately record 15-30 good observations of individual areas in one day of fieldwork. In the fieldwork of the current study, the observations made with ARIS were not exclusively directed to make population estimates for the area covered. Many places were observed at several occasions for other purposes than just counting the number of individuals present, and data recorded was also used for another study. With the goal of covering the area to make population approximations, 3-4 days of field work for two participants are estimated to be needed to cover the area used in this study.

4.1.2 Fyke nets

The fyke nets proved to be much less efficient at sampling *S. glanis* for the given effort compared to acoustic cameras in Båven. The fyke nets used in the standardized test fishing are probably too small to catch the largest specimens, and the likelihood of fish finding its way into the trap decreases with size. They also fail to target larvae and only provide a limited number of juveniles, possibly being too big for containing these individuals. According to Lessmark (2011), the fyke nets need to catch a minimum average of one individual for every effort to make good population approximations of *S. glanis*, and the CPUE was much lower in this study. According to the literature, other efforts with fyke nets in Sweden have produced higher catch rates compared to those in this study, but still much less than one individual for every sample effort (Jansson 2012, Berger & Kjellberg 2006). However, the gear catches smaller fishes, which were harder to detect and species-determine with the acoustic camera. In contrast to the acoustic camera, fyke nets are also providing sampled individuals directly. Fyke nets are attractive considering the low number of injured fish and lack of mortality (Hubert *et al*. 2012, Söderling 2016). Therefore, fyke nets are still useful for sampling *S. glanis* until a more efficient method is found for sampling small and intermediate sizes of the species.

According to the Swedish monitoring programme for *S. glanis*, two persons are able to control and set up 25-50 fyke nets within a workday. Four weeks of fieldwork are required for each county housing one of the four main populations of the species (Jansson 2012). The observations from acoustic cameras could be used to improve the results of fyke nets if location of observed individuals is correlated to certain habitats and environmental conditions. In the case of Båven, it seems like most individuals are located under the floating mats and fyke nets could be placed in close association to these areas to yield higher samples. For population analysis and counts, fyke nets could also be complemented with observations made by ARIS to account the larger sizes not represented by this method. For sampling larger individuals, larger models of fyke net could possibly be used. If the fyke net design is complemented with large wings, a series of nets could possible enclose littoral zones with floating vegetation. If a catfish would venture out to the lake when searching for food, this design could force them to enter the fyke nets and entrap themselves. For some reason, fyke nets in Båven are seemingly catching few individuals compared to the fyke nets fishing in the other main populations in Sweden. This could be due to environmental factors, since Båven is a completely lentic ecosystem in comparison with the other areas which are at least partly characterized by lotic conditions.

Figure 11. Individuals of *S. glanis* being sampled from the annual test fishing with fyke nets in Båven

4.1.3 Electrofishing

The electrofishing did not succeed in capturing a single individual of *S. glanis*, and the results suggest that electrofishing might be unsuitable for sampling this species in large, temperate lakes. Many studies suggest that electrofishing is less efficient in lake habitats (Bodine *et al*. 2013), and *S. glanis* have almost exclusively been fished with this method in lotic systems. The method is also reported to be inefficient in densely vegetated littoral zones (Dewey (1992), a habitat in which *S. glanis* was often associated with in the current study. While electrofishing, we observed how fish remained under the floating mats, and how two individuals of *S. glanis* escaped further into the vegetation while electrofishing was being performed. This further indicates that dense, floating vegetation severely limits the potential of electrofishing. It is still possible that electrofishing might be viable when sampling for the species in temperate lakes, but further studies performed in areas with less vegetated littoral zones are needed to confirm this.

The electrofishing in this study was performed by a boat, but there are also other options available like the electric seine and back-pack electrofishing. However, these method does not provide solid solutions to the problem of the inaccessibility in densely vegetated areas, and the soft bottoms in combination with deep water and dense vegetation makes the required wading dangerous while electrofishing. Studies in habitats with less floating vegetation could possibly determine if electrofishing is still a viable method for sampling *S. glanis* in temperate lakes when vegetative cover in the littoral zone is not extensive. However, the method is also known to often involve mortality or physical trauma for sampled fish (Sharber *et al.* 1994, Nielsen 1998), which is a major problem when sampling endangered populations.

4.2 Possibilities of other available methods

According to available literature, there are several other methods and gear available with potential sampling *S. glanis*. Some of these have been widely used to sample the species but not been evaluated for this purpose. Others have not been used for sampling *S. glanis,* but are often used for sampling other species of catfish, mainly the American species. The application and potential use of these methods are worth discussing if they exhibit promising properties in the goal of finding useful methods for sampling this species in temperate lakes. This is especially true for methods with potential of capturing juveniles and larvae, since the common methods used for sampling *S. glanis* fails to sample these individuals.

In many studies hook and line methods like fishing rods and trot lines have been used to target *S. glanis* (Alp *et al*. 2004, Syväranta *et al*. 2010, Ragnarsson-Stabo 2014, Söderling (2016). In Båven the method was reportedly much more efficient than fyke nets and in Möckeln it was reported to be a good complement to fyke nets, targeting larger fish. A severe drawback is the potential harm these methods might cause to the sampled individuals. However, the method has been successful at capturing *S. glanis* without causing significant harm to individuals when the right care and measurements have been taken (Söderling 2016). Previous studies indicate that long lines and fishing rods might be similar to fyke nets and hoop nets when it comes to CPUE of *S. glanis* (Söderling 2016, Ragnarsson-Stabo 2014), but this probably depends a lot on environmental conditions, experimental set up and gear used.

Pot gears and enclosure traps have the potential of being used in densely vegetated areas, and slat traps has been reported as selective on North American species of catfish (Hubert *et al*. 2012, Everhart & Youngs 1981). The efficiency of capturing *S. glanis* with pot gear like minnow traps is uncertain, but their abilities to capture small, cover-seeking species in dense vegetation seem tempting for the purpose of catching juvenile individuals of *S. glanis* in temperate lakes. Being entrapment gear, minnow traps are not likely to cause any significant harm to fish being sampled. They are also cheap, easy to set up and does not require wading (Hubert *et al*. 2012). Much of this is also true for enclosure traps, but these traps have seemingly not been used to sample catfish species

No study where light traps have been used for sampling catfish has been found, but if the larvae are phototactic, it is possibly a functioning method for sampling small individuals of the species. The method is often used in marine environments, but has successfully sampled larvae of several fresh water-species and families (Pierce *et al*. 2007). The application of efficient methods for sampling young *S. glanis* in temperate lakes requires further studies. The efficiency of other gear with potential to catch *S. glanis* seems doubtful at best in large, temperate lakes. *S. glanis* have been caught in gill nets, but their implication can be problematic in areas with obstructions and floating debris. In addition, mortalities are often high among sampled fish (Hubert *et al*. 2012).

4.3 Recommendations for monitoring programmes

The ARIS-equipment provided detailed observations and insight into littoral zones with abundant individuals of *S. glanis*, if placement of the gear enabled a view free from obstructions. If used during the reproductive period when adult individuals are most likely to visit these areas, acoustic cameras could be a viable option to make population estimates of sexually mature *S. glanis*. For this purpose, acoustic cameras would likely amount both for better accuracy and less hours of fieldwork compared to the fyke nets, which are now being used. The method also provides information about important habitats and behavior of fish, which can be useful concerning management and conservation actions directed at the species. However, identification of fish smaller than approximately 0.4 meters is problematic and the method should not be used for identifying juveniles or larvae of *S. glanis*.

In cases where individuals of the species are tagged with transmitters for identification, studies of long-term behavior and when conducting genetic studies, physical samples of individual catfish are needed. For most types of measures, fyke nets and angling gear appear to be the sampling methods available that are currently providing most individuals of *S. glanis* for given unit effort. These methods target different size categories and could be combined to give a feasible representation of the population inhabiting the area. To yield more fishes caught for the sampling effort, information from ARIS observations could give hints of where the gear should be used. While providing few individuals of less than 200 mm in length, the fyke nets still provide information about fish smaller than individuals observed by the acoustic camera. Fyke nets could therefore be used as a complement when it comes to smaller individuals. Angling gear such as longlines can result in similarly low mortality rates if the right measurements are taken, and care is given when deploying the gear.

There are currently no satisfying methods of collecting larvae and the smallest individuals of *S. glanis*. For a monitoring programme, efforts should currently follow up reproduction and locating spawning areas by other means than sampling juveniles and larvae, until better sampling methods are found. Much literature is available of habitat preferences in the reproductive period of *S. glanis*, which can be used to locate these places. Observations by acoustic camera could then give important information about behavior and activity of fish in the reproductive season.

4.4 General remarks

Earlier studies of *S. glanis* have mostly focused on the species invasive potential in southern and Western Europe, and the role of the species in aquaculture. Electrofishing, fyke nets and hook and line methods (often utilized with the help of local fisheries) are often used for sampling the species in these studies, but no studies found have been focusing on evaluating these methods for this purpose. In addition, very few studies found have focused on threatened or vulnerable populations of *S. glanis* or management implications for conservation of the species. The reasons for this could be that the populations are considered stable and viable in other parts of its range, making management and sampling less of an issue. In other words, one could say that the populations of *S. glanis* in continental Europe face a very different situation than the vulnerable populations located in Sweden. In addition, many of the previous studies of *S. glanis* have been conducted in river habitats located in continental Europe. These waters are different in many ways compared to the temperate lakes that the species inhabits in the northern parts of its distribution, being lotic waters with differing climates and habitats. This could possibly affect sampling procedures and the efficiencies of different methods.

Because of the different situation facing *S. glanis* in its northern range and the need of efficient management strategies in this area, the purpose of this study was to evaluate sampling methods of the species for conservation and monitoring in large, temperate lakes. The study has focused on two of the most common methods for sampling *S. glanis* – electrofishing and fyke nets, and it is the first study to evaluate the application of acoustic cameras as a new method for monitoring and sampling this species. As previously mentioned, the implementation of this technique presents new opportunities for managing the species in this area. The usefulness of acoustic cameras is likely not restricted to our study area or purposes, and could possibly be implemented to sample the species in other habitats and for different means. Examples include behavioral studies or possibly pest control if the species demonstrates invasive properties in an area.

The results provided by this study can potentially help authorities and administration boards to improve their future management of *S. glanis* in temperate lakes and adopt sampling methods that better fulfills their objectives. The latter statement also goes for researchers looking for convenient sampling methods that fulfill their purposes. Beside of the methods tested in this study, there are also a number of less commonly used methods available, which could potentially be efficient for the purpose of sampling *S. glanis* in temperate lakes. These methods include angling gear, pot gear like minnow traps and slat traps, enclosure traps and light traps. To expand our knowledge of sampling and management of *S. glanis* in temperate lakes, future studies could test the potential of these traps in the field. This is especially relevant for sampling juveniles and larvae of the species, since the more common available methods fails to sample these individuals.

5 Conclusions

The aim of this study was to evaluate some of the most common methods used when sampling *S. glanis* for the purpose of managing the species in temperate lakes, and to also evaluate acoustic cameras as a method for this purpose. The acoustic camera proved to be an efficient and non-invasive sampling technique, which sampled larger and more numerous individuals for every effort compared to the fyke nets used in the monitoring programme of the species. When making population approximations, the method is potentially both more effortless, less invasive and more accurate than methods used for collecting *S. glanis* physically. The fyke nets proved to be much less efficient at sampling *S. glanis* for the given effort compared to acoustic cameras in Båven. However, the method caught smaller fishes, which were harder to detect and species-determine with the acoustic camera. The fyke nets also provided the sampled individuals physically without causing any significant harm, and they are therefore still a viable method for sampling *S. glanis* of intermediate size. The electrofishing did not succeed in capturing a single individual of the species. Other studies have noted that the method is less efficient in lentic habitats and problematic in areas with extensive vegetation. The risk of injuring fish is also comparatively high. Therefore, electrofishing is likely not always viable for sampling *S. glanis* in large temperate lakes. There are currently no satisfying methods of collecting larvae and the smallest individuals of *S. glanis*. Minnow traps or light traps could possibly be used as feasible methods, but studies and surveys are needed to test them for this purpose.

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Fångstmetodik och bevarande av den sällsynta malen

David Östby

I den sörmländska sjön Båven gömmer sig en av världens största sötvattensfiskar; den europeiska malen (Silurus glanis). Båven är det nordligaste området där malen förekommer i ett naturligt bestånd, men beståndet minskade kraftigt under 1900-talet. Kunskapen om malens ekologi och levnadssätt i tempererade sjöar på denna breddgrad är fortfarande begränsade, och statusen för de hotade populationerna är fortfarande osäker. Som bot på detta behövs effektiva åtgärdsprogram och fångstmetodiker. I denna studie har en elfiskebåt använts för att fånga mal och en akustisk kamera har använts för att inventera denna hemlighetsfulla fisk. Resultaten har jämförts med fångster från ryssjor och dessutom diskuteras annan utrustning och fångstmetoder för att hitta bästa tillämpbara inventeringsmetodik för bevakning av mal i tempererade sjöar.

En exotisk jätte

Den europeiska malen är en värmeälskande jätte som hör hemma i ett område från Centrala Europa till Västra Asien. Här är det den största fiskarten som spenderar hela sitt liv i sötvatten och den kan med säkerhet bli 270 cm lång och väga över 180 kg. Malen lever ett hemlighetsfullt liv i långsamt rinnande floder och stora, varma sjöar med mycket vegetation och gömslen. Under natten beger sig fisken ut för att leta efter föda och använder då sina sex skäggtömmar för att lokalisera ett byte, som sedan sväljs helt. I Sverige har arten minskat kraftigt under 1800-talet och 1900-talet, då den blev alltmer sällsynt och dessutom försvann från flera områden. Anledningen till denna utveckling var troligtvis en kombination av olika faktorer, men sjösänkningar, vattenreglering och mänsklig påverkan på artens lekplatser och livsmiljö anses vara betydande orsaker. Idag är fisken fridlyst från fiske och arten har återintroducerats till platser där den tidigare försvunnit. Den anses fortfarande som sårbar och ett provfiske genomförs vart annat år för att kunna följa beståndens utveckling.

Att fånga en mal

Två av de vanligast förekommande metoderna som använts för att fånga den europeiska malen är genom ryssjor och elfiske. I denna studie användes en elfiskebåt för att försöka fånga mal i Båven. Elfiske med båt fungerar genom att två strömförande elektroder placeras hängande ned i vattnet framför båten. Dessa elektroder skapar ett elektriskt fält som lockar fiskar närmare elektroderna och paralyserar dem när de kommit tillräckligt nära. Trots långvariga försök med varierad metodik fångades dock inte en enda mal och vi kunde konstatera att elfiske inte var en effektiv metod för malfiske i tempererade sjöar. Detta beror troligtvis på att elfiske är mindre effektivt i sjöar jämfört med rinnande vatten och att omfattande vegetation försvårar genomförandet av metoden.

Vi provade också på att använda en akustisk kamera som verktyg för att upptäcka mal. Denna utrustning skickar ut ljudsignaler som studsar tillbaka från närliggande objekt och sedan bearbetas till videolika visualiseringar av omgivningen, likt ett ekolod. Tekniken visade sig vara väldigt effektiv då vi hittade stora grupper malar på flera platser i studieområdet. Utöver att plötsligt kunna se hur många malar som uppehöll sig i ett område kunde vi också uppskatta storleken på individerna och observera beteenden. Akustiska kameror lämpar sig troligtvis för att göra populationsuppskattningar då stora ytor snabbt kan täckas av och det inspelade materialet också talar om vilka miljöer malarna uppehåller sig i. Däremot upptäcktes få mindre malar och det var svårare att artbestämma mindre fiskar som observerades.

Utöver detta analyserades flera år av provfiskedata där ryssjor använts som fångstmetod. Ryssjor är cylinderformade nät som sänks ned i vattnet, vilka fiskar simmar in och fastnar i. Även om många malar fångats på detta sätt totalt, så var fångsten liten i jämförelse med hur omfattande fisket varit och hur stora ansträngningar som gjorts. Däremot har ryssjor fördelen att fiskarna erhålls direkt och fysiskt. Detta gör det möjligt att till exempel sändarmärka malar, väga dem och ta prover för genetiska studier. Dessutom fångade ryssjorna malar av mindre storlekar jämfört med malar som upptäcktes av den akustiska kameran, även om antalet malar mindre än 20 cm fortfarande var lågt.

Rekommendationer för åtgärdsprogram

I ett bevarandeprogram för den europeiska malen rekommenderas användandet av akustisk kamera för att undersöka populationsstorlekar, se vart malarna uppehåller sig samt studera malens lokala ekologi. Ifall behovet uppstår att genomföra genetiska studier eller sändarmärka individer är ryssjor ett gott komplement även om dessa individer är mindre i storlek jämfört med de som observeras av ARIS. Tidigare studier har visat att fiske med handredskap som spö och långrevar kan vara ett bra komplement för att fånga individer av större storlekar. För att undvika skador på fångade malar eller riskera dödsfall är det viktigt att vidta försiktighetsåtgärder med dessa metoder. Ingen av metoderna vi undersökte visade sig vara effektiv för att fånga eller observera larver eller små juvenila malar. Så kallade ”pot gears” och ”light traps” är passiva fällor som inte tidigare använts på den europeiska malen, men som är intressanta i och med att de är effektiva på juvenila och unga fiskar i allmänhet, samt kan användas framgångsrik i vegetationsrika områden. Framtida studier kan förhoppningsvis testa möjligheten att fånga mal med dessa metoder.