# Predict sex in salmonids using motion-triggered cameras and artificial intelligence

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# Abstract

As the EU water directive starts to be implemented in Swedish law a new national plan of negotiating new environmental permits for every hydropower plant. This process will most likely result in the building of many new fish passages and ladders around the dams to allow fish and other aquatic life to pass them. Those new passages will have to be evaluated to ensure high effectiveness. To accomplish all those studies a new methodology to census fish in a cost-effective and non-labour-intensive way.

This project aims to develop and test a new model which can predict if a specific salmon or trout is male or female. Further on to compare the new model with already existing census methods used to study migrating species of fish. To collect the data needed for this study a camera unit developed by the company TIVA AB to count fish was placed in a salmon trap in the mouth of Umeälven near Obbola, Västerbottens län. The pictures displaying salmon and trout from the camera were then annotated in Labelstudio to have a dataset to train the model with. To build the model a pre-built algorithm called Yolov5 was used as a base. This algorithm is an improvement to previous AI-learning algorithms as it only looks at the pictures once which increases working speed in comparison to previous models which looked at every picture multiple times.

The results from the two tests conducted show an accurate model when tested on data from the same camera station where light conditions and other parameters match the training data. When tested on data from another site in Stornorrfors with a different camera setup the results are not as accurate.

Unfortunately, the project suffered from big data losses which made the dataset too small to build a very precise model. However, the results show that it is possible to build a model that can predict the sex of a salmon or trout. This is a step towards identifying unique individuals with the help of AI. When more extensively developed, this method will be a very useful and non-invasive tool to get new insights into the lifecycles of aquatic fauna.

*Keywords: Census method, Salmon, Trout, AI, Camera technology*

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# Abbreviations

| | |
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| SLU | Swedish University of Agricultural Sciences |
| AI | Artificial intelligence |
| HaV | Havs- och Vattenmyndigheten |
| WFD | Water framework directive |

# 1. Introduction

## 1.1 Hydropower in Sweden

Since waterpower is a renewable source of energy it is of great importance for the development of Sweden's goal of a totally renewable power supply system. The hydropower plants today stand for about half of the total electric power production in Sweden (Hirth 2016). It is also a plannable power resource when water is stored in regulation dams and then led through the turbine when the demand is high. This also makes wind power more beneficial since the plannable hydropower can even out the power-delivering curve from renewable resources (ibid). Although hydropower is a power source that is cheap, plannable, and has a small carbon footprint hydropower plants and regulation dams have a big impact on the ecological systems of the waterbodies and their surroundings (Lundqvist et al. 2008).

In 2000 the European Water Framework Directive (WFD) was adopted by the European Parliament and Council (2000/60/EC). This was followed by a Swedish law in 2004 ("Ordinance on Water Quality Management" - SFS 2004:660). In 2020 a national plan for the implementation of the WFD was decided by The Swedish Government. Between 2022 and 2040 the plan is intended to provide new environmental permits for more than 2000 hydropower plants (Havs- och vattenmyndigheten 2018). The plan was based on an agreement between the Swedish Agency for Marine and Water Management, the Swedish Energy Agency, and the transmission system operator "Svenska kraftnät". The resulting compromise between environmental measures and electricity generation aimed at a level of 1.5 TWh (2.3%) of the Swedish average annual generation could be used for the implementation of WFD. In 2022 the newly elected Swedish government declared an ambition to pause the plan temporarily, due to increased energy demands in Europe and Sweden (ibid).

## 1.2 The future process

A plausible result of the renegotiations of hydropower plants environmental permits is that several new fish passages will be built in order to ensure natural breeding as well as upstream and downstream connectivity for several species (Havs- och vattenmyndigheten 2018). When constructing a new fish passage, it is important to follow up on the results to assure that the passage is working properly (Aarestrup et al. 2003). This will be done on a very big scale during the following years which increases the demand for effective follow-up methods. This follow-up could be done with one of the methods mentioned below (Rivinoja et al. 2006; Leander et al. 2020; Saboret et al. 2021). It will be very labour intensive, and a lot of money would have to be spent. This would also require a lot of tagged fish to be able to study the effects of the new fishways. The usage of cameras would drastically reduce the cost of this process. Not a single fish would have to be marked either (Bilodeau et al. 2022).

## 1.3 Atlantic Salmon and Trout

The Atlantic Salmon (*Salmo salar*) is a migratory species of great economical, ecological and social value in both Europe and North America (Bull et al. 2022). It lives the majority of its adult life in saltwater but reproduces in freshwater (Bull et al. 2022). When the salmon hatch from the egg it stays in the particulate creek of its birth until smoltification when the smolts start to migrate towards the sea (Hedger et al. 2013). After spending a couple of years in the sea the salmons sexually mature and migrate up the same river where they were born (Birnie-Gauvin et al. 2019). The crucial migration is impeded by hydropower plants which in turn severely decreases the breeding success of the rivers salmon population (Lundqvist et al. 2008). This is also true for the threatened anadromous populations of trout (*Salmo trutta*) (Degerman et al. 2012). The salmon and trout populations in Sweden are today crucially supported by compensatory releases of farmed fish. The farmed individuals are raised in hatcheries often located in the river system (Rivinoja et al. 2001). The purpose of these is to compensate the local fisheries for the losses in reproduction due to the hydropower plants (Blanchet et al. 2008). The same is true for the brown trout in those affected systems. To make it possible to examine if an individual is born in a hatchery or in the wild the adipose fin is removed on fish raised in a hatchery. This fin never regrows which makes this a permanent and easily recognizable mark (O’Grady 1984).

## 1.4 Camera technology

Camera technique has been used to monitor mammals on land and in recent years the use of this technology has increased (Williams et al. 2014; Schneider et al. 2019; Bilodeau et al. 2022). By mounting the cameras in a specific pattern across the studied area the results could answer most of the questions that traditional field inventory methods could do (Bilodeau et al. 2022). The development of the method has now led to the possibility to identify separate individuals of species with patterns and markings which are unique to the individual (Schneider et al. 2019). In recent years the development and usage of motion-triggered cameras in underwater applications have increased markedly (Fig. 1). These cameras are typically mounted in some sort of housing with an attached tunnel with lightning to accommodate different light conditions and clarity of the water (TiVA AB 2015). This makes them easy to transport and adapt to different locations. The use of a camera to identify every individual generates a large number of pictures, often several of the same individual fish. To accommodate this an AI-software could be used. The lack of predeveloped and open-source software is currently one of the shortcomings of this method. This is often the case for new technologies and emerging methods (Schneider et al. 2019). A problem which this project aims to work with.

## 1.5 Census methods for fish

In the past different catch and recapture techniques have been used to study the movements of fish (Aarestrup et al. 2003; Leander et al. 2020; Saboret et al. 2021). Most of these census methods require a surgical intervention to fasten the tracking device to the fish. Either an internal device is used such as PIT tags and acoustic transmitters (Cook et al. 2014) or external radio transmitters or floy tags (Baxter et al. 2003). These methods all include a first catch of the fish to enable the tagging of it. Acoustic (telemetry) transponders send out sound impulses. These impulses are then picked up by a network of receivers placed in a grid across the waterbody. The receivers are placed underwater. If the impulse sent out by the transmitter is picked up by three or more receivers it is possible to triangulate the position of the fish and plot it on a map (Leander et al. 2020). The PIT tags use special antennas to pick up the signals from the transmitters placed inside the body of the fish passing the antenna (Gheorghiu et al. 2010). Radio transponders are usually manually located with a handheld receiver antenna or registered by a permanently mounted station.

A widely used method to census migratory fish species is different kinds of traps. The fish are led into the trap by articulated arms and since they have entered the trap it is hard for the fish to find the way out of the trap, either upstream or downstream. This gives the research team an opportunity to mark the fish (Tuohy et al. 2019). The trapping of fish is labor intensive since the fish manually have to be transferred out of the trap. It also has to be cleaned from debris that gets trapped in the construction. Trapping is also used as a supplement to some of the previously mentioned census techniques to trap fish which can be marked for upcoming studies.

Fish counters of the type used in this project are already in use today with a camera station that works together with an AI model. As of today, these are usually limited to predicting species, fungus infections, length of the fish, and if it's a wild or framed fish (TiVA AB 2015). This approach gives a wide variety of data about the fish population (Bilodeau et al. 2022).

An important measure to consider when managing salmon and trout stocks is the sex ratio. Especially the number of adult females in the system contributes to calculations of egg deposition rates which can help to predict reproduction success in future years (King et al. 2022). As of today, most of these assessments rely upon catchment data which is only tracked in some rivers. To separate salmonid males and females, different signs must be considered. The best physical traits to distinguish between male and female salmonids are located on the head of the fish where males tend to have longer lower jaws than females. In some cases, male salmonids can develop a hook shape at the very tip of the lower jaw. This varies quite a lot between species, individuals, and seasons. Furthermore, the general head shape of a male salmonid tends to be more funnel-shaped than its female counterparts. The shape of the body and color of the fish (later in the season) can also be used as signs to determine the sex (King et al. 2022)

The purpose of this thesis is to develop a camera-based survey method that can identify salmon and trout individuals in a picture and determine their sex. Once the model is created it will be compared to common census techniques used to study migratory fish species.

# 2. Materials and methods

## 2.1 Geographic location

The data collection for this study took place in the outlet of river Umeälven into the ocean. The trap with the mounted camera was located in the river outside Obbola, Västerbottens län, Sweden. The part of the river that is located here is slow flowing with an approximal depth of 7 – 17 m in the main channel of the river/bay. The river Umeälven connects with the river Vindelälven in Vännesby approximately 38 km upstream of the trap. To be able to enter the river Vindelälven, which is one of the unregulated national rivers of Sweden, the salmons have to pass the hydropower plant in Stornorrfors and the fish ladder designed for salmon there. The fish ladder is the second largest in Europe and of "Ice harbour" type (Lindberg 2016). Most of the salmons passing this dam enter the river Vindelälven to migrate higher up in the system to the spawning areas. Both rivers have their source in the mountains close to the Norwegian border.

The trap in which the camera was mounted was placed at the exact location of 7074955, 763392 (SWEREF 99 TM (N,E)) on a depth of 11-12 meter. The trap is built as a long tunnel of net with an intake funnel that leads the fish into the trap while swimming downstream since the trap has two catch arms stretching out to the sides of the trap and forces the fish to navigate into the trap. This makes the potential catchment area of the trap approximately 150 meters wide. The camera house was placed directly in front of the intake funnel of the trap. This means that all fish that would have been caught in the trap instead passes through the camera tunnel and were recorded. The back of the trap was open to let recorded fish start traveling upstream (Fig. 2).

*Figure 1. The traps used to catch salmon. The yellow one furthest to the left has the camera mounted in the center.*

## 2.2 Data collection

Data collection was made with a camera built and run by the company TIVA AB and accessed through the web portal fiskevårdsteknik.se. Each video recording lasted until the fish passed the camera and the file were stored in the portal. The camera is built into an air-filled steel cone attached to a tunnel, which the fish are able to swim through. The main camera has a big image sensor which allows it to switch between recording passing fish in colour during the day and switching to an infrared mode during the night. The camera then gets help from infrared light to capture material in high quality and resolution (TiVA AB 2015). The tunnel is equipped with light panels to assure quality since the camera was placed 11-12 meters down in the water. To have a tunnel make all the fish pass through at a known distance in front of the camera lens. This helps to get a correct size estimate of the fish to be able to compare different individuals.

*Figure 2. The camera tunnel inside of the trap.*

## 2.3 Data preparation

To prepare the data collected in video format for the building of the categorizing model it first had to be divided into separate frames. The separating of the frames was done through a script in Python 3.11.2 which picked out every 10th frame from the video files. When the data was then separated into frames, they were transferred to a different labeling program called Label studio 1.7.2. Label studio works with separated labels instead of categories with different combinations of labels. The setup of the labeling includes nine labels which are put into a script in the setup menu for the labeling tool. The labels used in this project are *Salmon* and *Trout* to distinguish between the two species of interest. A label *Unknown* was also added to make the model sort out other species of fish which are not of interest in this study. Labels *Fungus* and *Healthy* to train the model to find fungus-infected individuals. To make the model learn about farmed and wild fish labels *Farmed* and *Wild* were used. The last two labels are *Male* and *Female* to determine between the sexes. Individuals which were impossible to distinguish between male and female were left without a label for sex. Those are presented as Unknown in the result.

This project used bounding boxes to define the area of interest in the image. A box is drawn to match the outlines of the object to let the model know in what area it should try to find patterns and structures. This process makes it easier for the model to separate objects from the background.

When the data is imported to Label Studio the program shows one picture at a time. In the picture, a box is drawn around the object of interest. This box is then given multiple labels to describe the object (Fig. 3). For example, a farmed salmon male with fungus will be given the labels Farmed, Salmon, Male, and Fungus. One picture could contain and display more than one object of interest. That picture is then given another box with belonging labels. The new data is stored in the program and could be exported in many different formats. However, in this study the format YOLO was used since it best suits the model used.

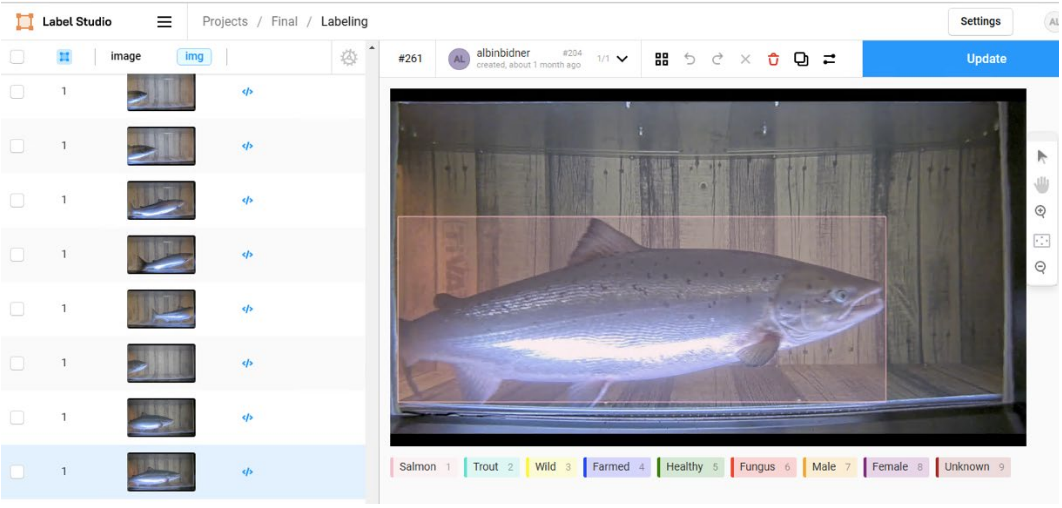

*Figure 3. This figure shows the working environment of Label studio and how annotations are made. This picture in particular displays a wild, healthy salmon male.*

## 2.4 The model

The algorithm used to build the model for this project is Yolov5 (you only look once) (Redmon et al. 2016). Yolov5 is a later version of the original Yolo algorithm. This is an object detection algorithm based on convolutional neural networks. Previously, more classic algorithms were used for object detection which worked by looking at the same pictures multiple times. In the first step areas of interest are detected and predicted. Those areas are then classified in the next step where the algorithm looks through the picture again. This process takes time since the trained model loops over the images multiple times. The results tend to be accurate. Yolov5 improves this process by only looking at the pictures once and doing all the previously mentioned steps in one pass. This improves the operating speed of the predictions and gives more accurate decisions. The model starts by applying a grid over the picture and then searches every cell of this grid for objects of interest. When every one of the cells is analysed, the cells of the grid are combined to create the bounding box around an object (Redmon et al. 2016).

To train the model for the project-specific case of fish it was fed with images and the corresponding annotations mentioned earlier. Based on what the model sees in those images it adapts to be able to weigh different parameters. In this specific study, the model was fed with 600 annotated pictures. The quality varies throughout the dataset. Some of the pictures only display part of a fish and it could therefore be impossible to determine sex or if the fish is wild or farmed to give some examples.

In this project, a technique called transfer learning was used to speed up the learning process of the model (Weiss et al. 2016). The technique refers to the use of a previously built model which was built for a different purpose and trained with different data to use as a starting point for the new model. In this specific case, a model called FishAI was used. This model was built by Vattenfall AB last year to recognize other fish characteristics. The model did already know how to recognize a fish which is favourable when working with such a small dataset and a limited amount of time.

The results presented in the following part are the first part of running the model on data from the same camera station as the training data. This means the image quality will be the same as the data the model was trained on. The second part will display data from testing the model on a different dataset. The second dataset is from the same river, but a camera station situated in the fish ladder in Stornorrfors. Image quality is different between the two locations since the cameras used are not the same. The camera station in Stornorrfors also suffered from technical problems causing worse image quality.

# 3. Results

Since the project focuses on developing the method, only results regarding the new perspective of categorizing individuals according to their sex will be presented and discussed.

## 3.1 Model run on data from the same site

Those results are from a test made on data from the same camera station as the training data. Different pictures than those used for training were used to carry out this test. The model predicted 313 individuals to be females out of 395 true females. This represents 79 % true predictions for females. For males, the model predicted 242 out of 314 true males correctly. This corresponds to a true prediction rate of 77%. The dataset contained 493 unknown observations (pictures where sex could not be determined) and the model predicted 338 of those to be unknown (Fig. 4).

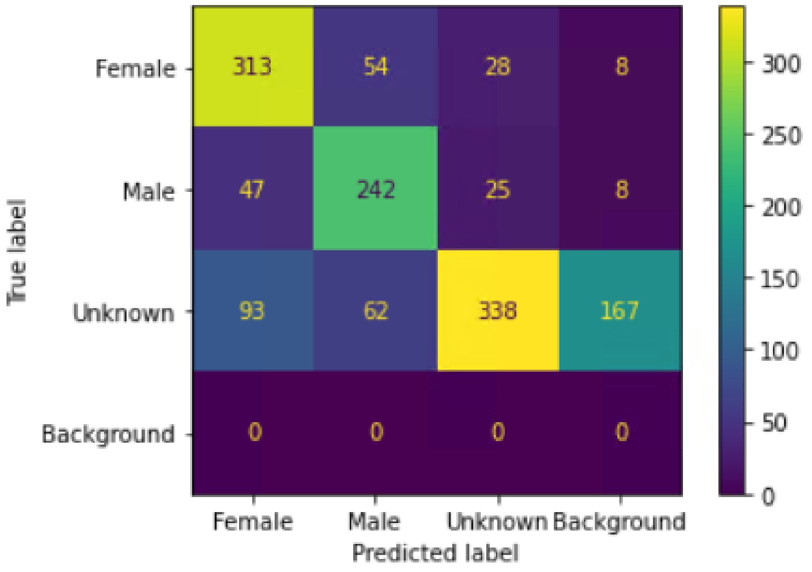

*Figure 4. Displayed in this diagram are the results of running the finished model on a dataset from the same site as the training data. The numbers are showing actual annotations made by the model*

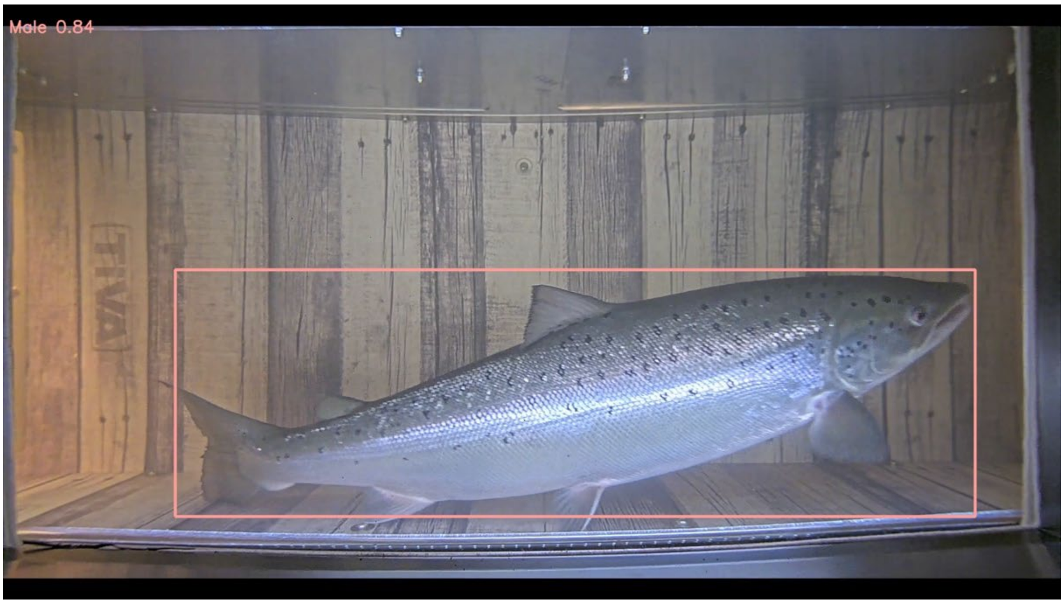

*Figure 5. The picture shows how the model has annotated the fish and what area of the picture it looks at. As displayed in the top left corner this salmon was annotated as a male with the probability of 84%.*

## 3.2 Model test on the dataset from Stornorrfors

For the model test on the dataset received from the fish ladder in Stornorrfors (Figure 6), which consisted of 93 different images. Here the model was tested on the effectiveness to determine the sex of those individuals. 37 actual males (annotated by Åke Forssén, Vattenfall) were recognized as males by the model. At the same time, 15 actual males were predicted to be females by the model. This gives a correct prediction rate of about 65%. 5 actual males were also classified as unknown. For the total of 35 actual females, the predicted number of females when running them through the model was 12. The model predicted 18 out of the 35 actual females to be males. 5 of the females were predicted as unknown by the model. In the dataset from Stornorrfors, only one individual was annotated as unknown sex. That individual was predicted as a male by the model (Fig. 6).

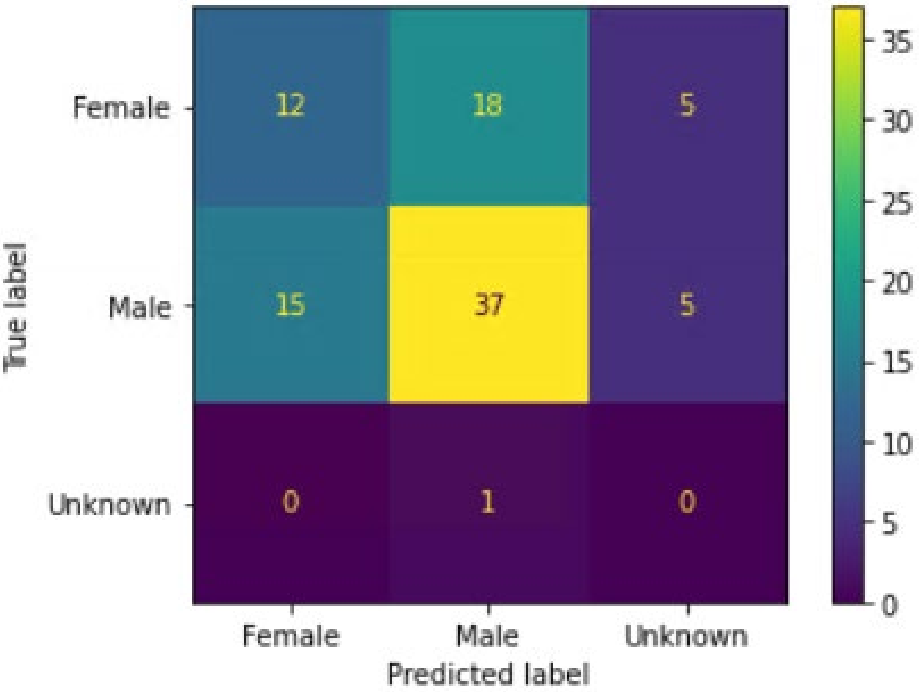

*Figure 6. Displayed in this diagram are the results of running the finished model on the separate dataset. The numbers are showing actual annotations made by the model.*

*Figure 7. The picture shows how the model has annotated the fish and what area of the picture it looks at. As displayed in the top left corner this salmon was annotated as a female with the probability of 76%.*

# 4. Discussion

As seen in figure 4 the results from the same camera station as the training data are accurate. This shows that it is possible to build a sex prediction model with good functionality. With more input data the sex prediction model will work better with datasets from various locations where light and water conditions vary. Regarding the recognition of the fish itself, this is working properly in both test runs (Fig. 5 and 7). The results seen in figure 6 show that this particular model needs further development and more input data to become more reliable at different locations. In this case, the model is clearly more accurate at predicting males correctly. The explanation for this could be the more noticeable sex characteristics in salmonid males compared to females.

The project has suffered from quite big data losses since the power supply to the camera station was not reliable. This made the camera work inconsistent. A power cable had been mounted incorrectly which caused the circuit breaker to break. Another problem was caused by a leaking hard drive storage box. These hard drives were supposed to store data from a PIT-tag antenna mounted in the camera tunnel. The data generated by this antenna were supposed to be used to verify the identification model. This made it impossible to build and test a model which would identify specific individuals since it would not be possible to validate it.

Since the model work and the results are as expected with the amount of input data it would most likely be possible to improve with a larger dataset. A bigger dataset would not just improve the number of annotations but also give a wider range of phenotypic diversity. The expected effects of this would be a more accurate model and would also improve the model’s versatility. It would be suited for a wider range of situations. It could be differences in visibility, phenotypic differences, light conditions, and more. Within the 75 filmed individuals, diversity does not reach high levels which would have helped when building the model.

Some risks of working with a small dataset in those situations could be overfitting and the model finding dependencies that do not exist in real life. To give an example, let us assume that all the pictures taken in infrared (black and white) would display males. The model would then assume that all black-and-white pictures display males. This shows the importance of having a balance between the different classes in the training data. If there is no balance, the model will find those kinds of false connections and the accuracy will be affected (Redmon et al. 2016).

When comparing the model trained by me with the dataset from Stornorrfors the differences in image quality are notable. The light conditions in Stornorrfors are not as favourable as they are in the trap. The darker pictures probably favour the predictions of males since many of the black-and-white pictures from the trap displayed males (Fig. 9).

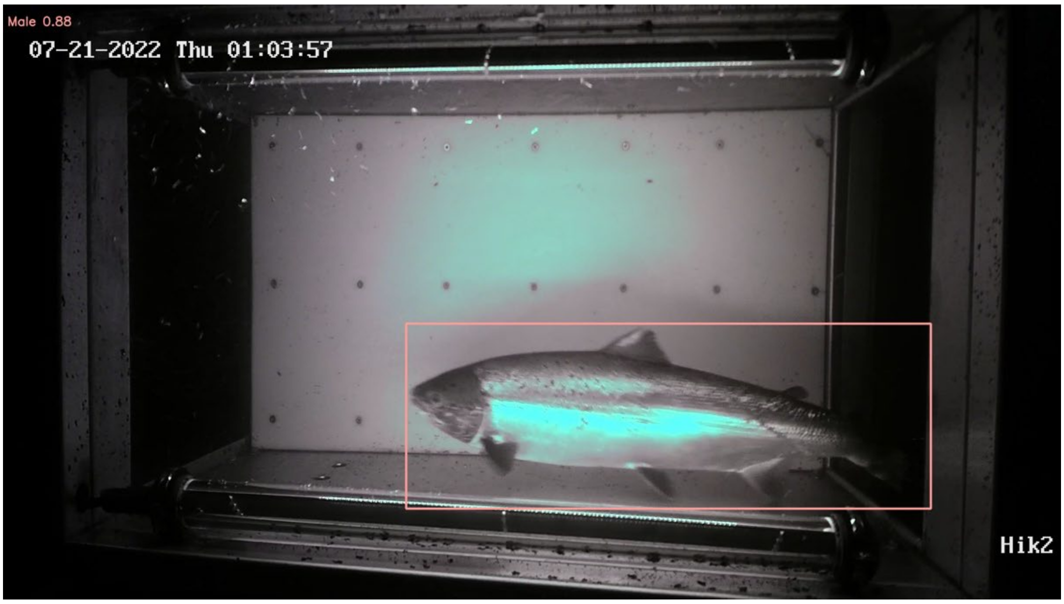

*Figure 9. An example to display the problem mentioned in the paragraph above. The image clearly shows that this salmon is a female. However, the model predicts it to be a male most likely because of the dark light conditions.*

The biggest problem with constructing a model of this type is that it is heavily dependent on the input annotations. In this specific case, this was not a big problem, but it is of great importance to evaluate. If there are any errors in the data that will follow into the model and its future output. To get a more reliable model it would be necessary to put together a team of people with adequate knowledge of the subject to conduct the annotation. According to me the best way of annotating would be to let everyone in the team annotate the pictures by themselves to then compare their results and discusses the pictures which are hard to annotate. That procedure would probably give the most reliable input data to base the model on. However, it would be an extremely time-consuming way of annotating and is therefore not very practical. Another way of annotating could be to start with pictures from the later parts of the season when the sex characteristics of salmonids are more pronounced and the differences bigger.

There is more than one way to annotate pictures for future use in an AI model. In this project bounding boxes were used to define the boundaries of the area of interest in the pictures. This creates an area of background in every annotation since a fish is not rectangularly shaped. It is the most time-efficient way of annotating but also necessary when using Yolov5 why it was used in this project. Newer versions of the algorithm can handle polygonal labels and to increase the accuracy of the model it would be favourable to use this technique where the annotation area is drawn to perfectly match the object of interest, in this case, the fish. A drawback would be that this technique is even more time-consuming.

The type of technology this project aims to test and evaluate will most likely develop even more in the upcoming years and be implemented at a larger scale within the industry. It has the potential to replace many of the older census methods used to monitor fish movements and characteristics. This is due to the high amount of output data produced by the pictures and the AI model processing the images. It does not require much labour when the model is developed and working properly. Even though this project did not reach its initial goal of identification of individuals due to the severe data losses it has given me good insights about the method. The goal of identification is probably not unreachable for species with permanent markers such as salmon and trout. To be able to recognize the same individual over timescales that exceed most other device battery life and functionality and would give viable information about mortality and processes in the life cycle of the fish. In the best of worlds, all this information and techniques would be standardized and shared between different stakeholders. It would then be possible to create a network of open-source data for future research but also as a base for fishing quotas and disease monitoring.

How does this method then compare to more traditional census methods developed for fish? The first positive aspect of using cameras to census fish is the non-invasive methodology. This minimizes the chance of causing the fish any harm. As mentioned in the introduction most fish have a very sensitive outer layer that could be damaged by human hands. Most common census techniques mentioned previously require the fish to be taken out of the water for tagging and some methods also include sedating and surgery which causes further stress (Baxter et al. 2003; Larsen et al. 2013; Cook et al. 2014; Saboret et al. 2021). The stress increases mortality which can be eliminated using the camera-based census method. To reach the full potential of the method it has to be developed towards individual recognition. This would widen the use of a method like this when two cameras could be used to monitor a fish ladder to give an example. The first camera would detect and identify an individual which is then communicated to the second camera at the top of the ladder. When the second camera detects the same individual information about the condition and time spent in the ladder could be stored.

It is also less labour intensive to use the camera method, at least once the software is developed than to use any of the other methods. When the camera is placed it runs itself most of the time with some service (TiVA AB 2015). If not checked upon the fish never face the risk of suffering from stress as in a trap to give an example (Tuohy et al. 2019). Data are sent to servers in real-time which allows for quick measures if something is not working correctly.

One problem with the usage of cameras compared to the other methods is the limitation of angles. There might be an injury or something else on the side of the fish which does not face the camera. This injury would have been seen if the fish were manually handled. In future camera stations, this might be solved with multiple cameras, filming the fish from different angles. This could also make it easier to determine the sex. It will also be harder to get samples from fish when not handled. Usually, a scale is taken to be analyzed for DNA.

## 4.1 Conclusion

Using cameras to census migratory fish species non-invasive will become more and more common in the coming years. Further development of the method will be needed to reach the goal of identifying individuals. This will probably require large datasets with variation in both fish phenotypes but also for light conditions and camera setup. However, it is still possible to create a functioning AI model that can predict the sex of a salmon or trout, even with limited amounts of data.

# References

Aarestrup, K., Lucas, M.C. & Hansen, J.A. (2003). Efficiency of a nature-like bypass channel for sea trout (Salmo trutta) ascending a small Danish stream studied by PIT telemetry. *Ecology of Freshwater Fish*, 12 (3), 160–168. https://doi.org/10.1034/j.1600-0633.2003.00028.x

Baxter, J.S., Birch, G.J. & Olmsted, W.R. (2003). Assessment of a Constructed Fish Migration Barrier Using Radio Telemetry and Floy Tagging. *North American Journal of Fisheries Management*, 23 (3), 1030–1035. https://doi.org/10.1577/M02-043

Bilodeau, S.M., Schwartz, A.W.H., Xu, B., Pauca, V.P. & Silman, M.R. (2022). A low-cost, long-term underwater camera trap network coupled with deep residual learning image analysis. *PLOS ONE*, 17 (2), e0263377. https://doi.org/10.1371/journal.pone.0263377

Birnie-Gauvin, K., Thorstad, E.B. & Aarestrup, K. (2019). Overlooked aspects of the Salmo salar and Salmo trutta lifecycles. *Reviews in Fish Biology and Fisheries*, 29 (4), 749–766. https://doi.org/10.1007/s11160-019-09575-x

Blanchet, S., Páez, D.J., Bernatchez, L. & Dodson, J.J. (2008). An integrated comparison of captive-bred and wild Atlantic salmon (Salmo salar): Implications for supportive breeding programs. *Biological Conservation*, 141 (8), 1989–1999. https://doi.org/10.1016/j.biocon.2008.05.014

Bull, C.D., Gregory, S.D., Rivot, E., Sheehan, T.F., Ensing, D., Woodward, G. & Crozier, W. (2022). The likely suspects framework: the need for a life cycle approach for managing Atlantic salmon (Salmo salar) stocks across multiple scales. *ICES Journal of Marine Science*, 79 (5), 1445–1456. https://doi.org/10.1093/icesjms/fsac099

Cook, K.V., Brown, R.S., Daniel Deng, Z., Klett, R.S., Li, H., Seaburg, A.G. & Brad Eppard, M. (2014). A comparison of implantation methods for large PIT tags or injectable acoustic transmitters in juvenile Chinook salmon. *Fisheries Research*, 154, 213–223. https://doi.org/10.1016/j.fishres.2013.11.006

Degerman, E., Leonardsson, K. & Lundqvist, H. (2012). Coastal migrations, temporary use of neighbouring rivers, and growth of sea trout (Salmo trutta) from nine northern Baltic Sea rivers. *ICES Journal of Marine Science*, 69 (6), 971–980. https://doi.org/10.1093/icesjms/fss073

*Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy* (2000). *OJ L*. http://data.europa.eu/eli/dir/2000/60/oj/eng [2023-01-05]

Gheorghiu, C., Hanna, J., Smith, J.W., Smith, D.S. & Wilkie, M.P. (2010). Encapsulation and migration of PIT tags implanted in brown trout (Salmo trutta L.). *Aquaculture*, 298 (3), 350–353. https://doi.org/10.1016/j.aquaculture.2009.10.004

Havs- och vattenmyndigheten (2018). *Frågor och svar om den nationella planen. Havs- och vattenmyndigheten*. [text]. https://www.havochvatten.se/arbete-i-vatten-och-energiproduktion/vattenkraftverk-och-dammar/nationell-plan-for-omprovning-av-vattenkraft/fragor-och-svar-om-den-nationella-planen.html [2022-11-28]

Hedger, R.D., Sundt-Hansen, L.E., Forseth, T., Diserud, O.H., Ugedal, O. & Finstad, A.G. (2013). Modelling the complete life-cycle of Atlantic salmon (Salmo salar L.) using a spatially explicit individual-based approach. *Ecological Modelling*, 248, 119–129. https://doi.org/10.1016/j.ecolmodel.2012.10.003

Hirth, L. (2016). The benefits of flexibility: The value of wind energy with hydropower. *Applied Energy*, 181, 210–223. https://doi.org/10.1016/j.apenergy.2016.07.039

King, R.A., Toms, S. & Stevens, J.R. (2022). Evaluating the importance of accurate sex ratios on egg deposition targets and conservation limit compliance for Atlantic salmon (Salmo salar L.) in the River Tamar, south-west England. *Fisheries Management and Ecology*, n/a (n/a). https://doi.org/10.1111/fme.12609

Larsen, M.H., Thorn, A.N., Skov, C. & Aarestrup, K. (2013). Effects of passive integrated transponder tags on survival and growth of juvenile Atlantic salmon Salmo salar. *Animal Biotelemetry*, 1 (1), 19. https://doi.org/10.1186/2050-3385-1-19

Leander, J., Klaminder, J., Jonsson, M., Brodin, T., Leonardsson, K. & Hellström, G. (2020). The old and the new: evaluating performance of acoustic telemetry systems in tracking migrating Atlantic salmon (Salmo salar) smolt and European eel (Anguilla anguilla) around hydropower facilities. *Canadian Journal of Fisheries and Aquatic Sciences*, 77 (1), 177–187. https://doi.org/10.1139/cjfas-2019-0058

Lindberg, D.-E. (2016). Flow preferences of upstream migrating Atlantic salmon (Salmo salar). *Acta Universitatis Agriculturae Sueciae*, (2016:6). https://res.slu.se/id/publ/77484 [2023-03-27]

Lundqvist, H., Rivinoja, P., Leonardsson, K. & McKinnell, S. (2008). Upstream passage problems for wild Atlantic salmon (Salmo salar L.) in a regulated river and its effect on the population. I: Dufour, S., Prévost, E., Rochard, E., & Williot, P. (red.) *Fish and Diadromy in Europe (ecology, management, conservation): Proceedings of the symposium held 29 March – 1 April 2005, Bordeaux, France*. Dordrecht: Springer Netherlands. 111–127. https://doi.org/10.1007/978-1-4020-8548-2_9

O'Grady, M.F. (1984). The Effects of Fin-Clipping, Floy-Tagging and Fin-Damage on the Survival and Growth of Brown Trout (Salmo trutta L) Stocked in Irish Lakes. *Aquaculture Research*, 15 (2), 49–58. https://doi.org/10.1111/j.1365-2109.1984.tb00408.x

Redmon, J., Divvala, S., Girshick, R. & Farhadi, A. (2016). You Only Look Once: Unified, Real-Time Object Detection. 779–788. https://doi.org/10.1109/CVPR.2016.91

Rivinoja, P., Leonardsson, K. & Lundqvist, H. (2006). Migration success and migration time of gastrically radio-tagged v. PIT-tagged adult Atlantic salmon. *Journal of Fish Biology*, 69 (1), 304–311. https://doi.org/10.1111/j.1095-8649.2006.01101.x

Rivinoja, P., McKinnell, S. & Lundqvist, H. (2001). Hindrances to upstream migration of atlantic salmon (Salmo salar) in a northern Swedish river caused by a hydroelectric power-station. *Regulated Rivers: Research & Management*, 17 (2), 101–115. https://doi.org/10.1002/rrr.607

Saboret, G., Dermond, P. & Brodersen, J. (2021). Using PIT-tags and portable antennas for quantification of fish movement and survival in streams under different environmental conditions. *Journal of Fish Biology*, 99 (2), 581–595. https://doi.org/10.1111/jfb.14747

Schneider, S., Taylor, G.W., Linquist, S. & Kremer, S.C. (2019). Past, present and future approaches using computer vision for animal re-identification from camera trap data. *Methods in Ecology and Evolution*, 10 (4), 461–470. https://doi.org/10.1111/2041-210X.13133

TiVA AB (2015). *TiVA - fiskräkning och fiskräknare med AI*. https://tiva.se/ [2022-11-29]

Tuohy, A.M., Skalski, J.R. & Gayeski, N.J. (2019). Survival of Salmonids from an Experimental Commercial Fish Trap. *Fisheries*, 44 (9), 423–432. https://doi.org/10.1002/fsh.10292

Weiss, K., Khoshgoftaar, T.M. & Wang, D. (2016). A survey of transfer learning. *Journal of Big Data*, 3 (1), 9. https://doi.org/10.1186/s40537-016-0043-6

Williams, K., De Robertis, A., Berkowitz, Z., Rooper, C. & Towler, R. (2014). An underwater stereo-camera trap. *Methods in Oceanography*, 11, 1–12. https://doi.org/10.1016/j.mio.2015.01.003

# Popular science summary

Most people have heard about using cameras to monitor wildlife on land, but could they also be used underwater to monitor migrating fish? This study shows that this is possible. It will even be possible to determine the sex of a salmon or trout passing through the camera tunnel.

The aim of this study was to investigate the possibilities to build an artificial intelligence (AI) model which could process pictures from an underwater camera and predict sex in salmon and trout individuals passing by. Knowing the sex ratio helps to build predictions of future reproduction success in fish stocks. This will be an important development of the ability to examine the effectiveness of for example natural like bypass channels built around hydropower plants in the future.

To accomplish this data was collected with a camera inside a commercial salmon trap in Umeälven. The base model called Yolov5 was then trained with this data after it was processed through a labelling program. The results shows that the model is accurate when tested on data from the same site but needs more input data to work properly on data from different sites with other conditions.

This means that this method will work if only the input data is greater, and the timeframe of the project are not the limitation factors.

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