Individual internship report

4th year

Assessment of the stream fragmentation of the Afan river

Swansea University
Singleton Park SA2 8PP Wales

Company supervisor:
Carlos Garcia de Leaniz & Pete Jones
Professor & Doctor

Academic supervisor:
Karl Matthias Wantzen
UNESCO Chair: River culture

Clément Ricordel
IMA
2018-2019

Acknowledgements

First, I would like to thank Mr. Karl WANTZEN, my supervisor at Polytech Tours, for helping me discover the AMBER project and make me meet Mr. Carlos GARCIA DE LEANIZ without whom I could not apply for this internship.

Then I would like to thank my two supervisors at the Swansea University for welcoming me in the research group: Mr. Carlos GARCIA DE LEANIZ, Professor of Aquatic BioSciences and Director of the Centre for Sustainable Aquatic Research (CSAR) and Mr. Peter Jones, Postdoctoral Research Officer on the AMBER project.

I also would like to thank Mr. Josh JONES, Postdoctoral Research Officer on the AMBER project for giving me some advice and helping me for my report.

Finally, I would like to thank the entire research team who welcomed me and included me during this internship.

Contents

List of figures

List of tables

Introduction

Since many years, in Europe, rivers have been modified with structures such as dam, weir or culvert, to make it easier to use. As a result, rivers are now fragmented by artificial barriers (Grizzetti et al. 2017). These barriers have also an impact on the stream flow and contribute to a loss of habitat and biodiversity (Jager et al. 2001; Reyjol et al. 2014; Grill et al. 2014).

According to the Water Framework Directive (2000/60/EC), it is essential to maintain the connectivity of rivers for the effective functioning of river ecosystems to obtain a "good ecological status" (European Commission 2000). This “good ecological status” means the free circulation of sediments and living organisms throughout the entire watercourse.

To achieve "good ecological status", sediment continuity is implicitly included according to biological needs. In many river sections, however, sediment continuity is disrupted by barriers. Barriers play a crucial role because they significantly modify the morpho dynamics of the river and interrupt sediment continuity (Sindelar, Schobesberger, and Habersack 2017).

Obstacles are considered as one of the main reasons for the decline of many species, particularly fish in river systems. These barriers impact longitudinal connectivity and disrupt the migration of many fish and invertebrate species (Noonan, Grant, and Jackson 2012; Williams et al. 2012) (Figure 1). This loss of connectivity has an impact , for example, on the ability of fish to move between living, feeding and breeding, and spawning areas (Amoros and Bornette 2002; Nyqvist et al. 2017).

The fragmentation of rivers will increase the isolation of the different species living there (Grant, Lowe, and Fagan 2007; Schick and Lindley 2007) and could impact their resistance to environmental disturbances (Junge et al. 2014). For example, Atlantic salmon (Salmo salar) and trout (Salmo trutta), diadromous species, must migrate in these rivers and are therefore highly impacted (Martignac et al. 2013; Gauld, Campbell, and Lucas 2013). Barriers are therefore a potentially important population on population persistence for many species. This study focuses not only on impassable barriers but also on the smallest barriers that also have effects on continuity (Ovidio and Philippart 2002).

Despite the many negative effects due to barriers, their abundance and distribution are poorly documented (except for high-fall dams). The study conducted in Great Britain by Jones et al (2019) shows that existing data underestimate the barrier density by 68%. The same study indicates that 97% of the river network in Great Britain is fragmented and that less than 1% of catchment areas are free of artificial barriers (Jones et al. 2019) . That is why it is important to identify these barriers in order to provide the best solutions. This is where my internship comes in.

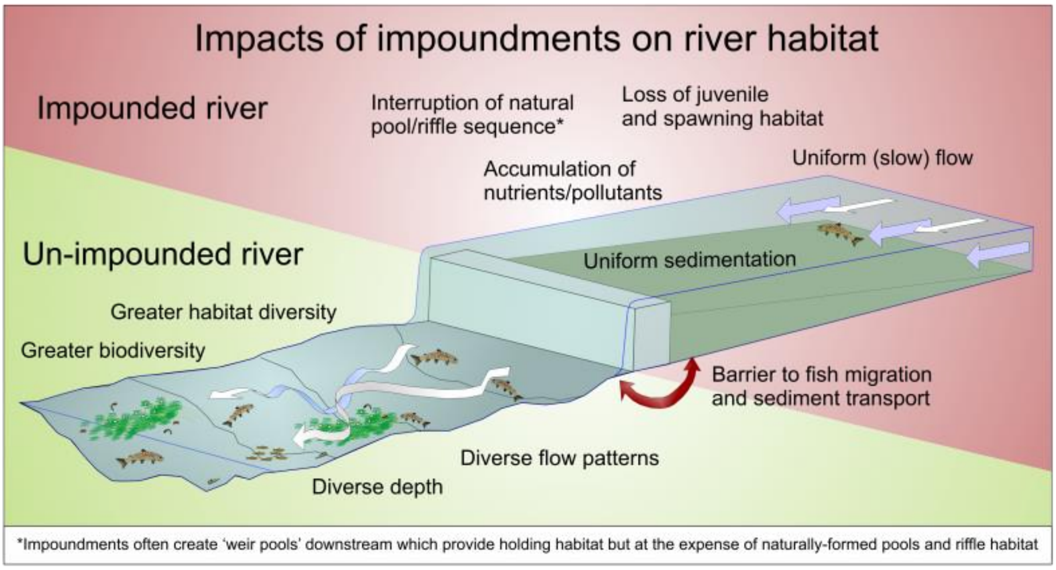


Figure 1: Impact of barriers on river habitat (www.wildtrout.org)

This internship took place in South of Wales (United Kingdom), in Swansea University. The studied river is the Afan river next to Swansea. This river has been modified by many anthropogenic changes, particularly due to mining activities. Ecological continuity is strongly impacted by the presence of many infrastructures: dam, weir, culvert, etc (Figure 2).

Figure 2: Example of barriers on Afan river (photo by C.Ricordel)

Swansea University and the Professor C.Garcia de Leaniz, are two major players and two leaders of a major European project, the AMBER project.
One of the objectives of the AMBER project is to reference all barriers within European river and define their impacts (https://amber.international).

The aim of this work is to assess the stream fragmentation of the river Afan. More specifically, to assess the potential habitat loss due to barrier.
First of all, I started with bibliographic research in order to better understand the subject and the study area. The work carried out breaks down into two parts: a field part and a data processing part. The field part consists of referencing all the barriers present in the Afan River basin in order to obtain a complete database. The second, more theoretical part consists in estimating the width of the watercourse through the creation of a model. This will then allow us to deduce the potential habitat area that this hydrographic network represents for aquatic species. By grouping this work with the referenced barriers, an estimate of the areas of habitat lost due to each barrier will be made.

Presentation of the host structure

Swansea University

The structure that receives me for this internship is Swansea University in Wales. The city of Swansea is located in the south of the country, near to Cardiff, the capital of Wales. It is the third largest university in Wales in terms of student numbers with more than 20,000 students. The university is divided into two campuses: The Singleton campus and the Bay campus. Swansea University has eight higher education institutions that are divided into different departments and host different research groups.
The internship takes place at the Faculty of Science, in the Department of Biosciences in collaboration with CSAR, the Centre for Sustainable Aquatic Research.

AMBER project (Adaptive Management of Barriers in European River)

During my internship, I was invited to join the Swansea team of researchers working on the AMBER project.
The aim of AMBER is to apply adaptive management to the exploitation of barriers in European rivers in order to achieve more effective and efficient restoration of river connectivity. To do that, AMBER develops tools, models and toolkits that will allow river managers to optimize benefits and reduce ecological impacts. This project will also help to protect the global biodiversity of watercourses by reducing fragmentation, improving habitat connectivity and assessing the merits of various restoration measures using developed tools (https://amber.international/).
As part of the AMBER project, the Afan River catchment area is one of the case studies. This project uses new tools such as eDNA to assess biodiversity, the fragmentation of the Afan River by both physical and chemical barriers. My role is to participate in the assessment of the impact of physical barriers.

Thanks to my participation in this project, I had the opportunity to interact with many researchers from various disciplines. I also participated to the " lab meetings " that take part each week and involve about fifteen people.

1. Materials and Methods

1.1. Study area

1.1.1. Afan river catchment area

This study is being carried out at the scale of the Afan catchment area, which is located near to Port Talbot, in south of Wales. The Afan River flows 26 km from its source, the confluence of The Corrwg and The Gwynfi at Cymer to the outlet at Port Talbot in Swansea Bay (Figure 3). The relief is significant in this watershed, with the peak at more than 500 meters. This results in a significant diversity of watercourses with torrents upstream and a plain watercourse downstream.

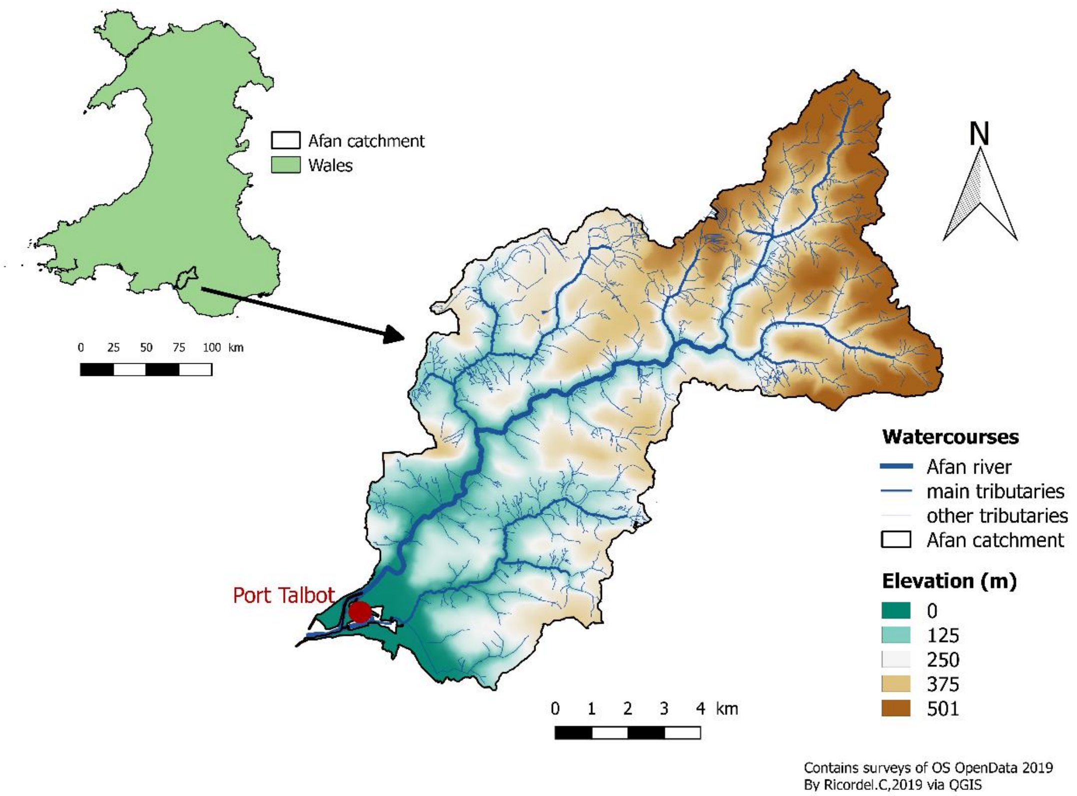


Figure 3: Location of the Afan catchment. Author: Clément RICORDEL

This catchment area has been significantly altered, particularly with mining activities (coal mining) which have produced pollution of either the colour (Figure 4) and toxicity of the water (afanvalleyangling.org), resulting to the quasi-elimination of salmon at the beginning of the 19th century (Natural Resources Wales 2017). However, in recent years, the situation has tended to improve, but four out of the six Afan mass of water failing to meet the EC Water Framework Directive ecological targets for fish.

Figure 4: Example of mining pollution on the Afan river (photos takes 30-05-2019 by Clément Ricordel)

The study of land use using Corine Land Cover (2012 data) highlights a territory with little urbanization except the city of Port Talbot. Most of the territory is occupied by natural areas such as forests or grassland (Appendix 1).

1.2. Method used to model the width

1.2.1. Step 1: wetted width estimation

Strahler and Shreve ranks

The hydrographic network data I use (GIS data) is divided into several sections of known lengths but unknown widths. The sections are split at each confluence, in order to be able to assign a stream order to each of them. For each section the Strahler and Shreve stream order are determined by a GIS analysis. In the same way, it is possible to obtain the surface area of the catchment drained by these sections. Each GIS section is defined by its length, drained catchment area and stream order (Strahler and Shreve). The Strahler and Shreve stream order are determined according to the tributaries of the watercourse (Table 1). In the case of the Afan River the maximum Strahler number is 6 and the maximum Shreve number is 1054.

In order to save time, the choice was made to design a model that estimates the width of the river rather than carry out measurements in the field. The study by McGINNITY et al. (2012) shows that a model allows to obtain values close to reality and to save time.

Table 1: Difference between Strahler and Shreve stream order (Demirkesen 2001)

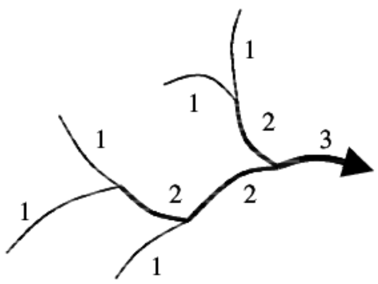
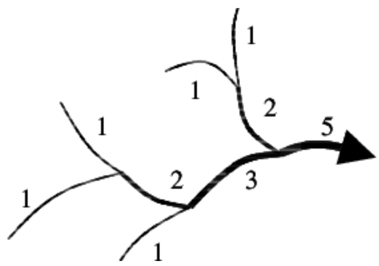
<table>
<tr><th>Strahler</th><th>Shreve</th></tr>
<tr><td>First-order rivers are the most distant tributaries upstream. If two flows of the same order merge, the resulting flow receives a greater number of one. At a confluence, the resulting stream receives the higher of the next two numbers.</td><td>Similarly, first-order rivers are the most distant tributaries upstream.
On the other hand, in the case of a confluence, the numbers are added together.</td></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Photo-interpretation to determine width

To make this model, it is necessary to use known width measurements. In order to facilitate measurements, save time and avoid many trips throughout the watershed, width measurements were made on Google Earth by photo interpretation. It is necessary to measure sections over the entire catchment area, both upstream and downstream. The aim is to have as complete measures as possible in order to strengthen the model created subsequently. The narrowest rivers are in the upstream areas. These areas are often torrents with many natural barriers (waterfalls). The study focuses mainly on the artificial barriers that are located further downstream in the watershed. The decision was made not to integrate river sections with a width of less than 2 metre to create the model. Several measurements were made for the same sections (about 4-5) on Google Earth using the "measure a distance" tool. The average of these measurements gives the width assigned to this section.

Linear regression

Then, the data on the width is processed in Excel with the Xlstat add-on. Two linear regressions are run with Xlstat to determine a model to calculate the widths of the watercourse. The first one has as a dependent variable the width measured on Google Earth and for explanatory variables the surface of the drained watershed and the number of Shreve. The second linear regression is identical except for the Shreve number which is replaced by the Strahler number.

The two models will be compared to define which of them will be applied in this study. This will allow this model to be applied for the entire Afan River and thus obtain the width for all sections.

1.2.2. Step 2: Barriers inventory

Existing data

One of the objectives of the AMBER project is to develop a database of common barriers within Europe. Nowadays many different databases exist and it is complicated to link them all together to obtain complete data. All these databases are not necessarily produced in the same way, which leads to differences in measurements. In order to inventory all the barriers on the Afan River, work was first carried out on existing databases. Data from 1993 were digitized for subsequent inclusion in GIS software. These data were supplemented by national data as well and also data available on AMBER.

Field referencing

The main objective of the field trips is to identify all the barriers on the Afan River in order to have a complete database. However, for this work, precise measurements of each barrier (height, width, etc) will not be done. The first goal is to have a comprehensive database that references all barriers. It would be too time-consuming to measure each barrier with precision equipment, so measurements are made with our eyes.

The first field trip was made upstream of the river, in a mountainous area and this highlighted a problem: the number of natural barriers (waterfalls, boulders) was very important. Subsequently, natural barriers will not be referenced because we don't have enough time and money.

The equipment used during the excursions is very simple and space-saving, with only a map to locate the river, a mobile phone with the "Barrier Tracker" application and possibly a camera. This application was recently created and is part of the AMBER project. The purpose of the application is to facilitate and standardize referencing. This application is available for download on smartphones and is accessible to everyone. Typical data collected include a photo of the barrier, the location of the barrier and the height of the barrier (https://amber.international) (Figure 5).

Figure 5: Referencing a barrier via the application

Once obstacles have been registered with the Barrier Tracker application, they can be viewed on the AMBER Citizen Science Portal. All the barriers you submit will be checked and verified before being used to complete the first European Barrier. The Atlas data will be made accessible and reusable for all users.

How to reference a barrier via the Barrier Tracker App?

First, the user must take a picture of the barrier. (Figure 6, 1) Then, he must choose the type of barriers (Figure 6, 2 and Table 1). After that, he must give the height of the barrier (Figure 6, 3). The height of the barrier is estimated at a glance and must be classified in one of the following categories: < 0.5m; 0.5m-1m; 1m-2m; 2m-5m; 5m-10m; > 10m.
The objective is then to estimate the impact of the barrier, looking at whether the barrier extends across the entire width of the watercourse (Figure 6, 4), whether the obstacle is in good condition (Figure 6, 5), and to add further comments if desired. (Figure 6, 6) The last step is to locate the barrier. (Figure 6, 7)

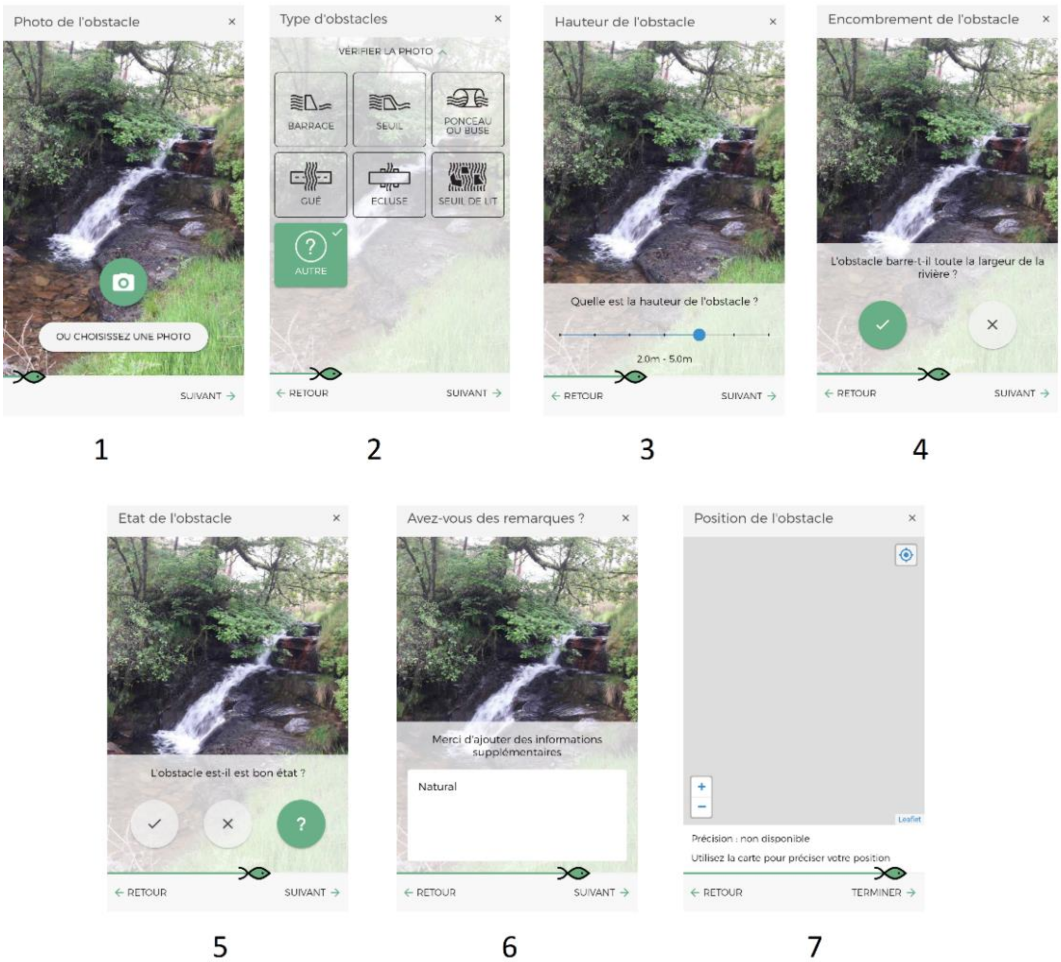


Figure 6: Steps to reference a barrier via the application

Table 2: The different barriers to be referenced in the AMBER project (https://portal.amber.international)

Types	Definition and characteristics	Pictures
Dam	A dam is a barrier that blocks or constrains the flow of water and raises the water level, forming a reservoir. Dams come in many shapes and sizes. Dams are often used to provide water supply and for generation of electricity. It causes a significant alteration of flow and sediment discharges and a complete interception of bedload.	
Weir	A weir is a barrier aimed at regulating flow conditions and water levels or at intercepting sediment or at reducing the channel slope for stabilizing the channel bed of a river or stream. Water often flows freely over the top of a weir. Weirs come in many shapes and sizes but often have a height of less than 5 meter.	
Culvert	A Sluice is a movable barrier aimed at controlling water levels and flow rates in rivers and streams. By opening or closing the sluice, water levels and flow rates can be altered.	
Ford	A Ford is a structure in a river or stream which creates a shallow place for crossing the river or stream by wading.	
Sluice	A Culvert is a structure aimed at carrying a stream or river under an obstruction. Culverts are often embedded in soil and come in many shapes and sizes, varying from round and elliptical to box-shaped.	
Ramp	A Ramp or a bed sill is a structure aimed at stabilizing the channel bed and reducing erosion. Ramps and bed sills come in many forms.	

1.2.3. Step 3: Determination of the potential habitat area lost due to barrier

The aim of this study is to obtain a general idea of potential habitat loss for aquatic species. Habitat areas are not calculated for a specific species. To simplify this estimation, the habitat areas will correspond to the wetted surface of the river. The width of the watercourses was obtained using the model, so it is only necessary to multiply the width obtained for each section by its length to obtain a "wetted" surface that will be considered as a habitat area.
In this way, the habitat area for the entire basin will be obtained. Subsequently it will be possible to split this habitat through the referencing of barriers. Any referenced barriers will be considered as boundaries between two habitats, even if they can be crossed by some species.
This will allow us to obtain the impact of each barrier on habitat fragmentation. It will be possible to give the lost habitat area for each of them.

2. Results

2.1. Width estimation

Two different methods were tested to determine which one was the most accurate and efficient for determining the width of the river. In both cases the width is determined by the area of the drained catchment area and by a stream order Shreve (Figure 7and Table 3) or Strahler (Figure 8 and Table 4) or the altitude (Figure 9 and Table 5).

2.1.1. With Shreve stream order

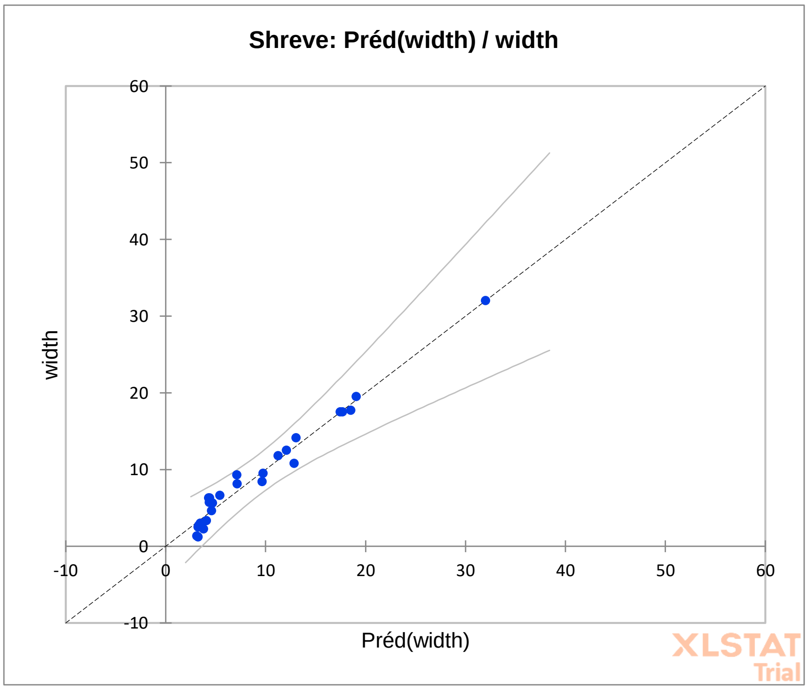


Figure 7: Linear regresion with Shreve stream order (XL Stat)

Table 3: Correlation matrix with Shreve stream order (XL Stat)

	US_Accum*	Shreve	Width
US_Accum*	**1**	0.844	0.929
Shreve	0.844	**1**	0.608
Width	0.929	0.608	**1**

*US_Accum : Catchment drained area

Model equation: width = 3.122 + 8.821E-05 * US_Accum - 1.528E-02 * Shreve
R^2: 97%

The linear regression obtained with the parameters of the drained watershed and the Shreve stream order gives the following equation: width = 3.122 + 8.821E-05 * US_Accum - 1.528E-02 * Shreve.
The R^2 being 97%, this model is therefore very close to reality. The correlation matrix shows a high correlation (93%) between the "US_Accum" parameter and the width. Looking more precisely at the differences in width between the measured and modelled widths, there are some differences. In general, the model overestimates small widths (between 1 and 4 meters). On the other hand, it tends to underestimate the average widths (between 5 and 10 meters). For widths of more than 10 meters the model is very close to reality (Appendix 2).

2.1.2. With Strahler stream order

The same work was done by substituting Shreve by Strahler (Figure 8 and Table 4).

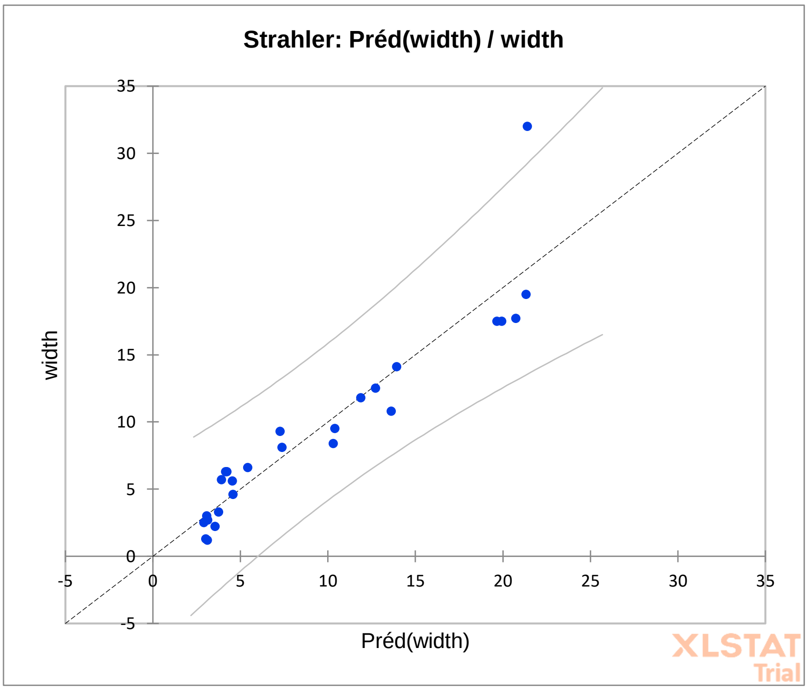


Figure 8: Linear correlation with Strahler stream order (XL Stat)

Table 4: Correlation matrix with Strahler stream order (XL Stat)

	US_Accum	Strahler	Width
US_Accum	**1**	0.861	0.929
Strahler	0.861	**1**	0.790
Width	0.929	0.790	**1**

Model equation: width = 4.768 + 7.488E-05 * US_Accum - 0.770 * Strahler

R^2 : 86%

The linear regression obtained with the parameters of the drained watershed and the Strahler stream order gives the following equation: width = 4.768 + 7.488E-05 * US_Accum - 0.770 * Strahler.
The R^2 being 86%, this model is therefore close to reality. The correlation matrix shows a high correlation (93%) between the "US_Accum" parameter and the width. Looking more precisely at the differences in width between the measured and modelled widths, there are some differences. The model obtains a large difference for the largest width with an estimate that differs by 10 meters (21 meters for the model versus 32 meters measured). Otherwise, the model generally estimates the widths well. The most important differences are at the extremes (width < 33 meters or >17 meters). This model is therefore quite similar to the Shreve model (Appendix 3).

2.1.3. With altitude and upstream area

The same work was done by substituting Shreve by Strahler (Figure 8Figure 9Figure 9 and Table 5).

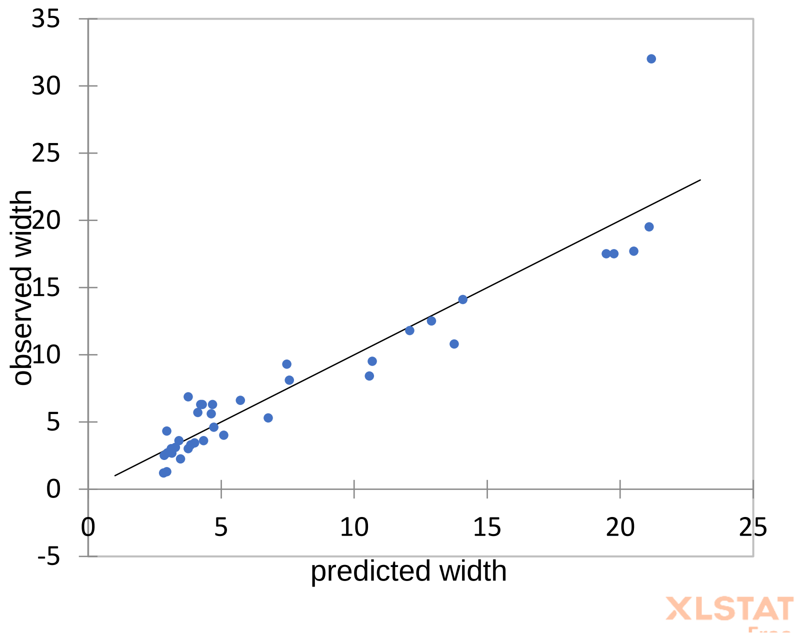


Figure 9: Linear correlation with altitude and upstream area (XL Stat)

Table 5: Correlation matrix with altitude and upstream area (XL Stat)

	Altitude	Us_Accum	Width
Altitude	**1**	-0.685	-0.672
Us_Accum	-0.685	**1**	0.969
Width	-0.672	0.969	**1**

Model equation: width = 3.341 - 8.156E-04 * Altitude + 4.794E-05 * US_Accum
R^2 : 87%

The linear regression obtained with the parameters of the drained watershed and the altitude gives the following equation: width = 3.341 - 8.156E-04 * altitude + 4.794E-05 * US_Accum.
The R^2 being 87%, this model is therefore close to reality.
This model does not use a stream order but the elevation of the stream and the upstream area to determine the width of the stream. Except for the largest width, which is poorly modelled, the model is generally good for the other estimates.

2.1.4. Widths obtained with the Shreve model

To calculate the widths, we use the model using Shreve because it is more accurate (R^2=97%). This makes it possible to obtain stream widths for the entire Afan catchment area. According to the model, the watercourses have an average width of 3.4 meters, the maximum is 34.9 meters and the minimum is 2.4 meters (Table 6).

Table 6: Statistic about model width

	Width (m)
Average value	3.4
Maximum	34.9
Minimum	2.4

The majority of the river system is composed of small streams, with 70% of streams less than 4 meters wide compared to 20% of streams over 10 meters wide (Figure 10). The map highlights the importance of small streams in this watershed. The widest river is the Afan River, which is easily identified on the following map.

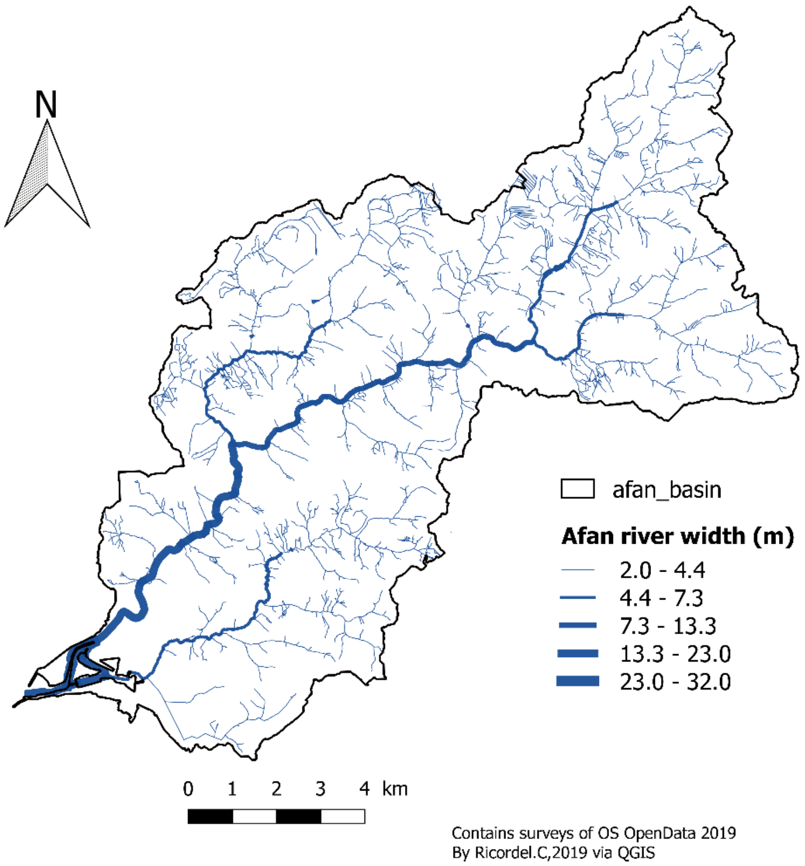


Figure 10: Width estimated with the created model. Author: Clément RICORDEL

2.2. Barrier referencing

On the map we can see that the number of barriers on the watershed is very high, about 110 barriers (Figure 11). This inventory is not completed because the field campaigns to reference all the barriers are not finished (particularly due to bad weather). This number is therefore underestimated compared to reality. Taking into account the entire hydrographic network on the map, it is 409 kilometres long. This gives an average of one barrier every 3.7 kilometres. However, all the referenced barriers are located on river sections with a width greater than 3.5 meters. If we do not take into account small rivers (less than 3.5 meters) where barriers are not present, the hydrographic network is 65 kilometres long. On this water section, there is an average of one barrier every 600 meters. A study by (Jones et al. 2019) estimates that there are 0.63 barriers/km of river, or about one barrier every 1600 metres in Wales. This figure can be used to compare with the figure obtained for the watershed once all the barriers have been referenced.

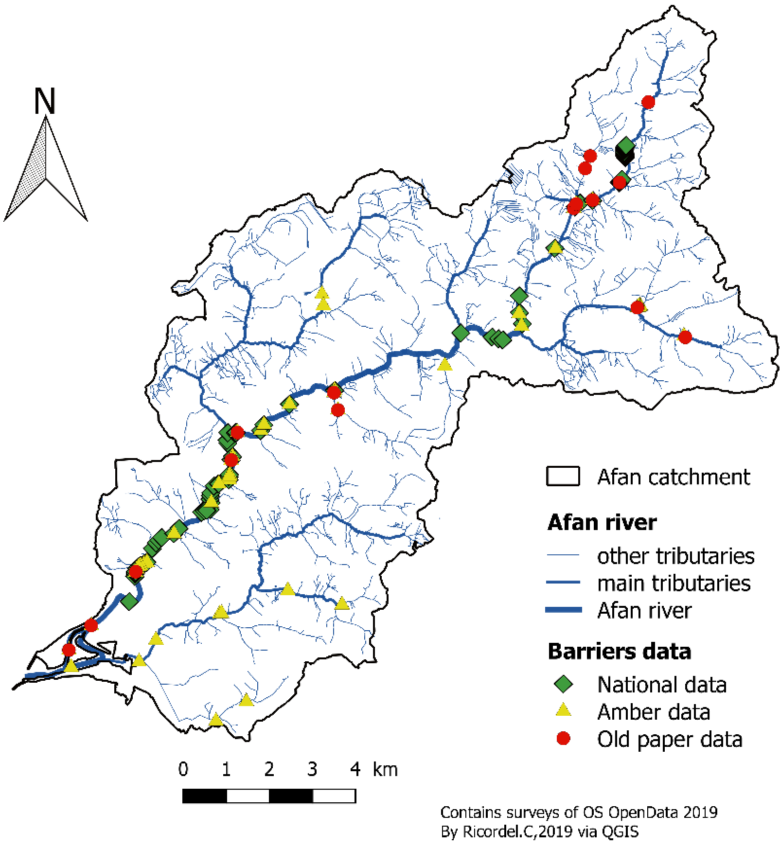
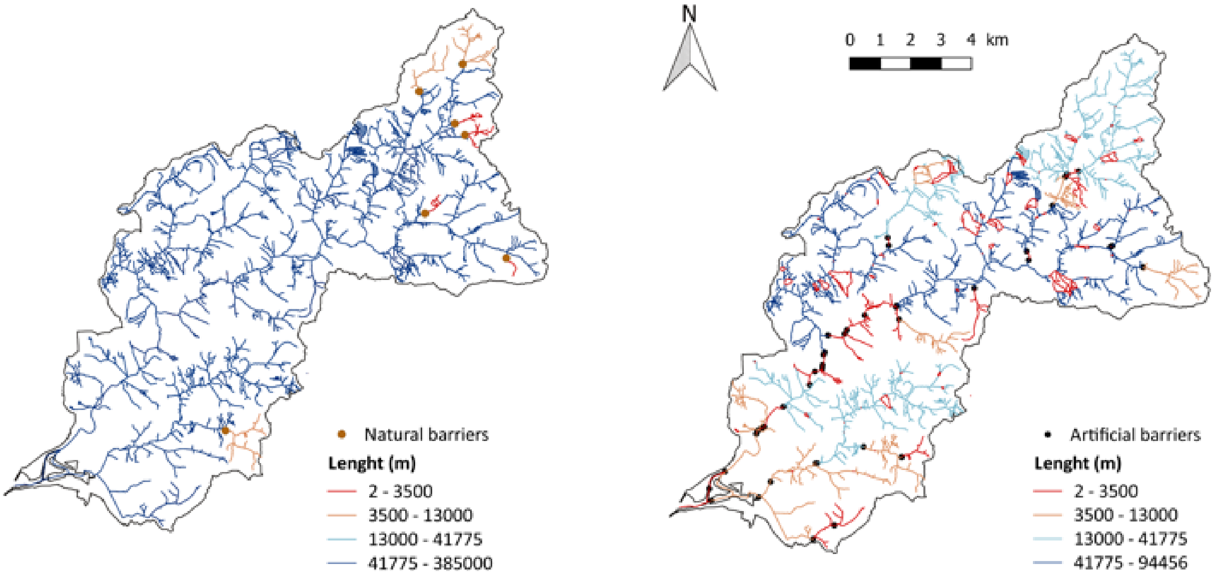


Figure 11: Barriers on the Afan river. Author: Clément RICORDEL

Not all types of barriers are always identified. However, about fifteen weirs are referenced with an average height between 0.5 meters and 1 meter. These weirs are mainly located in the lower half of the watershed. More than 70 ramp-bed sills are also referenced. For many of them, they are small size barriers (<0.5m).

2.3. Estimating potential habitat area lost

The various steps presented above are intended to assess the fragmentation of the Afan River. A comparison between fragmentation caused by natural obstacles (waterfalls) and artificial obstacles was made (Figure 12). This highlights the importance of artificial barriers in the Afan watershed. The presence of these obstacles reduces the free length barrier areas which have an average length of 2.8 kilometres. Obstacles are mainly present on the main watercourse and less on tributaries.



Stream fragmentation by natural barriers

8 different sections
Average length: 51 kilometres
Maximum: > 350 kilometres

Stream fragmentation by artificial barriers

140 different sections
Average length: 2.8 kilometers
Maximum: 94 kilometres

Figure 12: Barrier free lenght. Author: C.Ricordel

3. Discussion

3.1. Model estimation for width

The comparison between the two models using stream order to estimate the width of the river shows that both models give satisfactory results. However, the model that uses the Shreve stream order is more accurate than the one that uses Strahler. The model used is therefore the one that uses upstream catchment and the Shreve number as variables. Shreve stream order provides a model that is closer to reality because the method of calculating the Shreve number allows a better distinction between sections than the Strahler number (Demirkesen 2001). These results are logical, the width is one of the parameters that depends on the liquid flow (QL) and the solid flow (QS). The width will therefore be related to the upstream area.

However, the use of the stream order depends on the work scale. Two different datasets can give a different stream order for the same river depending on its resolution. To correct this, it is possible to use the altitude instead of the stream order. This gives good results but a little less precise. But they have the advantage of being repeatable in another catchment.

The results obtained with the model are good and make it possible to estimate the width of the watercourse over the entire hydrographic network. They are some advantages to use a model, it saves time, avoids field trips and money, the methodology can be replicated in other catchments, etc. However, it is simply a model, it is intended to give a general idea of the width of the watercourse. It cannot be used for precision work, this would require more accurate field measurements.

For example, small streams are not or only slightly integrated into the model. Indeed, the resolution of Google Earth aerial images makes it difficult to measure small sizes (less than 2 meters). The narrowest rivers are mainly localised in the upstream area and are mainly torrents. Barriers in narrowest rivers are mainly natural (e. g. waterfalls) which is not taken into account in this study. Artificial barriers are mainly located further downstream. After reflection, it was decided to carry out measurements on these small rivers during field work in order to strengthen the model and refine the width estimate (this field work is planned for 28/06/2019 and is therefore not integrated into the model presented above). Once these measures are integrated into the model, they will strengthen it and provide a better estimation.

Another limitation of this model is that it does not take into account possible installations impacting the width of the watercourse, such as embankments. However, the hydrographic network is poorly dammed by embankments except downstream in the town of Port Talbot.

3.2. Barrier referencing

The referencing of the entire barrier is not complete at the time this report is being written, so the number of barriers presented is underestimated compared to the number of barriers actually present. However, the data already available allow us to give some information. Barriers are mainly present on watercourses with a larger width, with a density of 1 barrier every 600 meters when watercourses with a width of less than 3.5 meters are not taken into account. When the entire watershed has been covered in order to identify all the barriers, it will be possible to determine the ratio of barriers referenced in this study that were not present in the existing data. In the United Kingdom, the study by Jones et al (2019) shows that existing data underestimate the barrier density by 68%. This will show the interest of this work in order to obtain complete and standardized databases.

The main purpose of this referencing work is to quantify the number of barriers, precise measurements of each obstacle are not carried out. The purpose of this database is to inform everyone about the importance of barriers on the Afan River. On the other hand, for restoration work it is essential to carry out additional measurements in order to define more precisely the impact of each dam. In addition, the referencing is participatory, thanks to the application anyone who wants, can refer barriers. These

data are checked before being integrated into the Amber database. However, differences in referencing can exist between the different operators: Different definitions of a barrier, an operator can refer a barrier that is not a barrier for example.
During field trips, it is possible to realize the difficulty of access to some areas of the catchment. The areas further upstream, are mountainous, climbing and steep, it is difficult to follow the river. It could be considered to use a drone that flies over the steepest areas to check whether or not barriers are present.

3.3. potential habitat area lost

It is important to note that the purpose of this study is to show the impact of the fragmentation of the Afan River on potential habitat areas. This gives a general idea of the impact of the different barriers on the entire watershed. However, the data are not precise enough to study a single barrier independently of the others. If work is to be carried out on one of the barriers, it is necessary to carry out a complementary study.
In this study, areas of potential habitat only take into account the "wetted" surface of the river. However, the areas of preferential habitat change between each species. For example, some species require a connection to the alluvial plain (Thomaz, Bini, and Bozelli 2007). This connection is not taken into account in our study, the presence of potentially floodable alluvial plains will increase the calculated habitat area. This study therefore underestimates the size of these areas and therefore the impact of barriers. Moreover, this study does not take into account seasonal fluctuations. In summer the stream will be at low water, with a more restricted habitat while in winter the habitats will be larger.

However, this study provides an overall picture of the fragmentation of the Afan watershed and potentially identifies the most problematic barriers. However, if a prioritization of the work is to be carried out, it is necessary to develop this study. Indeed, priority setting must take into account the specific movement and dispersal capacities of each species (Radinger et al. 2018). Moreover, it is not always necessary to remove all barriers to maximize population balance. Indeed, the study by (Ioannidou and O'Hanley 2019) reveals that the elimination of all barriers could lead to a marginal increase in the risk of near extinction. This shows the importance of taking into account the spatio-temporal dynamics of fish populations in planning for the restoration of river connectivity.

Conclusion:

The purpose of this study is to assess the stream fragmentation of the Afan River. Resources and means being limited, solutions needed to be developed. For example, the model has been created to makes it possible to estimate the width of the watercourse according to its Shreve number and its drained watershed. This solution is quite effective and is therefore a good alternative. The advantages are that it is faster to set up a model than to carry out all the measurements in the field. On the other hand, the results obtained are less accurate. In this study, the aim is to have an idea of stream fragmentation so the model is a good solution. Nevertheless, for works requiring more precise data, field surveys are essential. In the coming days (my internship ends on 19th of July), some field measurements will be carried out, particularly on narrow watercourses, to strengthen this model.

The referencing of all artificial barriers is not yet complete. This is a fairly long process because it requires travelling the entire river system. On the other hand, this work makes it possible to create a complete database in order to better understand the watershed. This study does not take into account natural barriers to focus on artificial barriers. It could have been interesting to reference also natural barriers in order to compare natural and artificial fragmentation and the accumulation of both of them.

This work leads to an estimate of the loss of potential aquatic habitat area. This is a fairly quick work to set up and does not require a lot of field work (except referencing all barriers). It is not very precise but allows to have a global vision of the catchment. The Afan River will be part of a future project led by the Swansea University. This work will be use to better understand the field and better identify the various issues. Additional studies will then be carried out as part of the project for example with eDNA study or fish study.

This project is part of the European AMBER project. The work is carried out at the scale of a catchment area in Wales. However, this work can easily be replicated in other catchment areas in Wales and in Europe. The main objective is to reference the barriers in order to have a better understanding of their impacts.

This internship allowed me to apply the knowledge and skills I acquired during my training at Polytech. During this internship, I worked in great autonomy, which can be quite confusing at first. However, this allows you to learn to manage on your own. For example, I had to define my internship subject more precisely when I arrived in Swansea, with the help of Peter Jones and Josh Jones. This internship took place in Wales, English-speaking country, which allowed me to practice English every day and therefore to improve. I learn to understand better English and also to make myself better understood, especially with scientific terms. Finally, I worked a lot on GIS, which now allows me to be more comfortable with this kind of software. This internship allowed me to do some field work on mountain water courses, which I hadn't had the opportunity to do before (Figure 13).

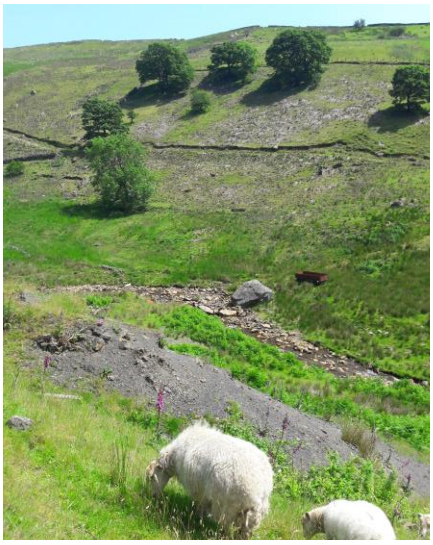


Figure 13: Landscape of the Afan River

This internship gave me the opportunity to discover the scientific research community. For three months I was able to belong to a multidisciplinary research team, which broadened my knowledge and overall culture. In particularly, I was able to attend the weekly "lab meetings" that bring together the entire team of researchers in the field of aquatic biology. During these meetings, external speakers sometimes came to present their research. I was able to attend three of these presentations, one of which was of particular interest to me. It was a Chinese team that came to present their work on the world's largest dam, the Three Gorges Dam in China. All these presentations and the exchanges that followed allow me to see different points of view about river management.

However, despite this good experience in Swansea, I do not see myself being carrier in research community. I would like to be able to work in a multidisciplinary environment. In the research community, often, each researcher has his or her main discipline. In addition, I would like to start working next year and I don't see myself pursuing another 3 years to get a doctorate.

Finally, this internship also gave me the opportunity to live an experience abroad, which was the first for me. Integration was quite complicated at first, mainly because of the language barrier. Later on, it allowed me to meet people different from the one I used to meet, which allowed me to have a better open mind. Welsh culture is quite different from French culture, it takes time to adapt but it remains a very good experience. There are many foreign students in Swansea so I was also able to discover other cultures which is very enriching.
This internship abroad remains a very good professional and personal experience that I hope to be able to enhance on my CV.

Bibliography

Amoros, C., and G. Bornette. 2002. 'Connectivity and Biocomplexity in Waterbodies of Riverine Floodplains'. *Freshwater Biology* 47 (4): 761–76. https://doi.org/10.1046/j.1365-2427.2002.00905.x.

Demirkesen, Ali. 2001. 'Constructing a Prior Information Base for River Mapping from Digital Images and DEMS by an Advanced Image Interpretation System /', January.

European Commission. 2000. 'Water Framework Directive (2000/60/EC)'. *Official Journal of the European Communities*, no. 43: 1–72.

Gauld, N.r., R.n.b. Campbell, and M.c. Lucas. 2013. 'Reduced Flow Impacts Salmonid Smolt Emigration in a River with Low-Head Weirs'. *Science of the Total Environment* 458–460 (August): 435–43. https://doi.org/10.1016/j.scitotenv.2013.04.063.

Grant, Evan H. Campbell, Winsor H. Lowe, and William F. Fagan. 2007. 'Living in the Branches: Population Dynamics and Ecological Processes in Dendritic Networks'. *Ecology Letters* 10 (2): 165–75. https://doi.org/10.1111/j.1461-0248.2006.01007.x.

Grill, Günther, Camille Ouellet Dallaire, Etienne Fluet Chouinard, Nikolai Sindorf, and Bernhard Lehner. 2014. 'Development of New Indicators to Evaluate River Fragmentation and Flow Regulation at Large Scales: A Case Study for the Mekong River Basin'. *Ecological Indicators* 45 (October): 148–59. https://doi.org/10.1016/j.ecolind.2014.03.026.

Grizzetti, B., A. Pistocchi, C. Liquete, A. Udias, F. Bouraoui, and W. van de Bund. 2017. 'Human Pressures and Ecological Status of European Rivers'. *Scientific Reports* 7 (1): 205. https://doi.org/10.1038/s41598-017-00324-3.

Ioannidou, Christina, and Jesse R. O'Hanley. 2019. 'The Importance of Spatiotemporal Fish Population Dynamics in Barrier Mitigation Planning'. *Biological Conservation* 231 (March): 67–76. https://doi.org/10.1016/j.biocon.2019.01.001.

Jager, Henriette I, James A Chandler, Kenneth B Lepla, and Webb Van Winkle. 2001. 'A Theoretical Study of River Fragmentation by Dams and Its Effects on White Sturgeon Populations', 15.

Jones, Joshua, Luca Börger, Jeroen Tummers, Peter Jones, Martyn Lucas, Jim Kerr, Paul Kemp, et al. 2019. 'A Comprehensive Assessment of Stream Fragmentation in Great Britain'. *Science of The Total Environment* 673 (July): 756–62. https://doi.org/10.1016/j.scitotenv.2019.04.125.

Junge, Claudia, Jon Museth, Kjetil Hindar, Morten Kraabøl, and L. Asbjørn Vøllestad. 2014. 'Assessing the Consequences of Habitat Fragmentation for Two Migratory Salmonid Fishes'. *Aquatic Conservation: Marine and Freshwater Ecosystems* 24 (3): 297–311. https://doi.org/10.1002/aqc.2391.

Martignac, F., J.l. Baglinière, L. Thieulle, D. Ombredane, and J. Guillard. 2013. 'Influences of a Dam on Atlantic Salmon (Salmo Salar) Upstream Migration in the Couesnon River (Mont Saint Michel Bay) Using Hydroacoustics'. *Estuarine, Coastal and Shelf Science* 134 (December): 181–87. https://doi.org/10.1016/j.ecss.2013.02.003.

McGINNITY, P., E. De Eyto, J. Gilbey, P. Gargan, W. Roche, T. Stafford, M. McGARRIGLE, N. Ó' Maoiléidigh, and P. Mills. 2012. 'A Predictive Model for Estimating River Habitat Area Using GIS-Derived Catchment and River Variables: PREDICTIVE MODEL OF RIVER AREA'. *Fisheries Management and Ecology* 19 (1): 69–77. https://doi.org/10.1111/j.1365-2400.2011.00820.x.

Natural Resources Wales. 2017. 'Know Your Rivers - Salmon and Sea Trout Catchment Summaries'. https://naturalresources.wales/guidance-and-advice/business-sectors/fisheries/know-your-rivers-salmon-and-sea-trout-catchment-summaries/?lang=en.

Noonan, M.J., J.W.A. Grant, and C.D. Jackson. 2012. 'A Quantitative Assessment of Fish Passage Efficiency'. *Fish and Fisheries* 13 (4): 450–64. https://doi.org/10.1111/j.1467-2979.2011.00445.x.

Nyqvist, D., P. A. Nilsson, I. Alenäs, J. Elghagen, M. Hebrand, S. Karlsson, S. Kläppe, and O. Calles. 2017. 'Upstream and Downstream Passage of Migrating Adult Atlantic Salmon: Remedial

Measures Improve Passage Performance at a Hydropower Dam'. *Ecological Engineering* 102 (May): 331–43. https://doi.org/10.1016/j.ecoleng.2017.02.055.

Ovidio, Michaël, and Jean-Claude Philippart. 2002. 'The Impact of Small Physical Obstacles on Upstream Movements of Six Species of Fish'. In *Aquatic Telemetry: Proceedings of the Fourth Conference on Fish Telemetry in Europe*, edited by Eva B. Thorstad, Ian A. Fleming, and Tor Fredrik Næsje, 55–69. Developments in Hydrobiology. Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-94-017-0771-8_8.

Radinger, Johannes, Franz Hölker, Pavel Horký, Ondřej Slavík, and Christian Wolter. 2018. 'Improved River Continuity Facilitates Fishes' Abilities to Track Future Environmental Changes'. *Journal of Environmental Management* 208 (February): 169–79. https://doi.org/10.1016/j.jenvman.2017.12.011.

Reyjol, Yorick, Christine Argillier, Wendy Bonne, Angel Borja, Anthonie D. Buijse, Ana Cristina Cardoso, Martin Daufresne, et al. 2014. 'Assessing the Ecological Status in the Context of the European Water Framework Directive: Where Do We Go Now?' *The Science of the Total Environment* 497–498 (November): 332–44. https://doi.org/10.1016/j.scitotenv.2014.07.119.

Schick, Robert S., and Steven T. Lindley. 2007. 'Directed Connectivity among Fish Populations in a Riverine Network'. *Journal of Applied Ecology* 44 (6): 1116–26. https://doi.org/10.1111/j.1365-2664.2007.01383.x.

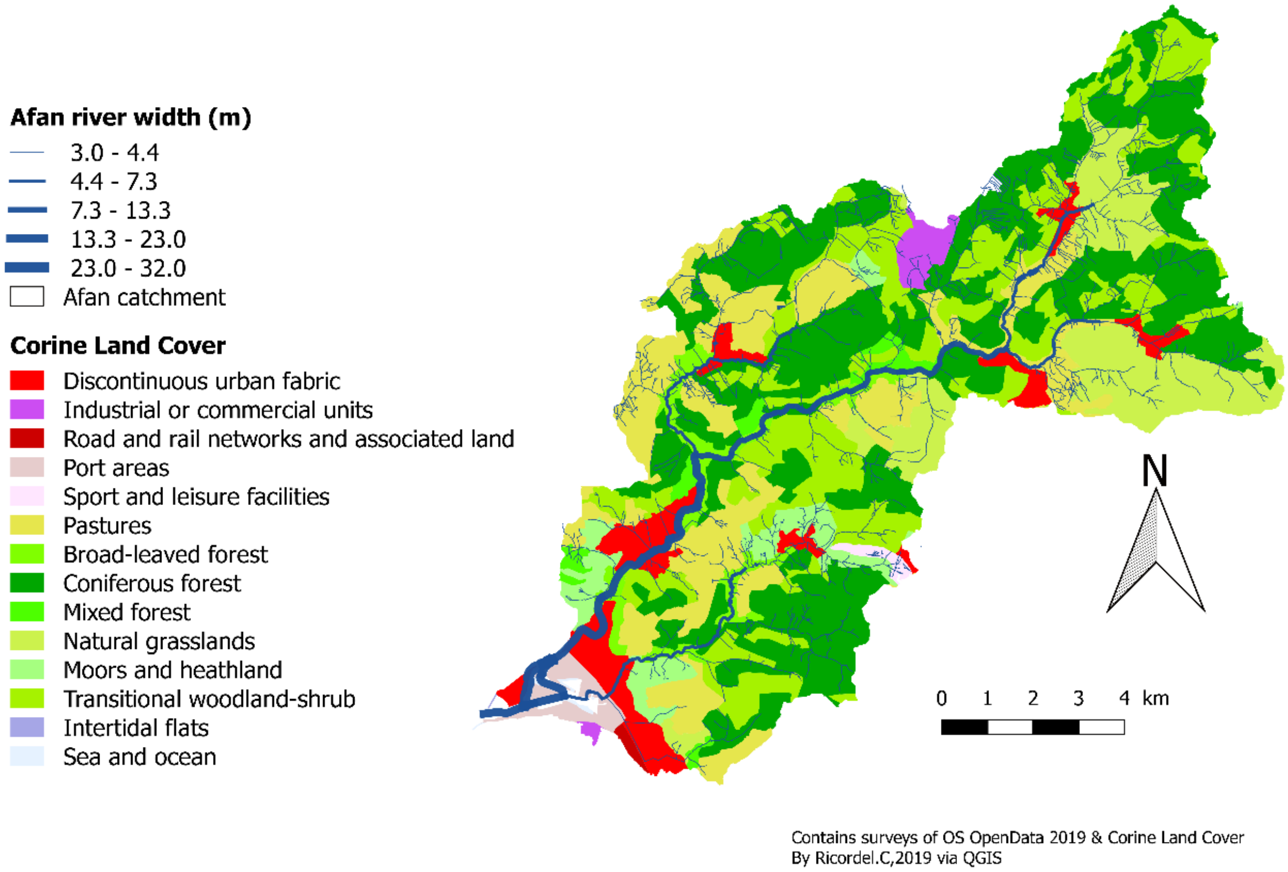
Sindelar, Christine, Johannes Schobesberger, and Helmut Habersack. 2017. 'Effects of Weir Height and Reservoir Widening on Sediment Continuity at Run-of-River Hydropower Plants in Gravel Bed Rivers'. *Geomorphology* 291 (August): 106–15. https://doi.org/10.1016/j.geomorph.2016.07.007.

Thomaz, Sidinei M., Luis Mauricio Bini, and Reinaldo Luiz Bozelli. 2007. 'Floods Increase Similarity among Aquatic Habitats in River-Floodplain Systems'. *Hydrobiologia* 579 (1): 1–13. https://doi.org/10.1007/s10750-006-0285-y.

Williams, J.G., G. Armstrong, C. Katopodis, M. Larinier, and F. Travade. 2012. 'Thinking like a Fish: A Key Ingredient for Development of Effective Fish Passage Facilities at River Obstructions'. *River Research and Applications* 28 (4): 407–17. https://doi.org/10.1002/rra.1551.

Appendices

Appendix 1: Land use with Corine Land Cover (2012); author: Clément RICORDEL via Qgis



Appendix 2: Difference between measured width and model width (Shreve)

Observation	width	Préd(width)	Résidu	Résidu std.
Obs17	1.200	3.254	-2.054	-1.616
Obs6	1.300	3.139	-1.839	-1.447
Obs9	2.230	3.801	-1.571	-1.236
Obs21	2.500	3.271	-0.771	-0.606
Obs19	2.700	3.308	-0.608	-0.479
Obs22	3.000	3.494	-0.494	-0.389
Obs24	3.300	4.093	-0.793	-0.624
Obs4	4.600	4.593	0.007	0.005
Obs3	5.600	4.702	0.898	0.707
Obs14	5.700	4.384	1.316	1.035
Obs2	6.300	4.318	1.982	1.559
Obs23	6.300	4.414	1.886	1.484
Obs18	6.600	5.437	1.163	0.915
Obs10	8.100	7.183	0.917	0.722
Obs13	8.400	9.677	-1.277	-1.005
Obs16	9.300	7.144	2.156	1.697
Obs20	9.500	9.763	-0.263	-0.207
Obs1	10.800	12.862	-2.062	-1.622
Obs15	11.800	11.254	0.546	0.429
Obs8	12.500	12.103	0.397	0.312
Obs5	14.100	13.068	1.032	0.812
Obs11	17.500	17.465	0.035	0.028
Obs26	17.500	17.691	-0.191	-0.150
Obs7	17.700	18.531	-0.831	-0.654
Obs12	19.500	19.075	0.425	0.334
Obs25	32.000	32.007	-0.007	-0.005

Appendix 3: Difference between measured width and model width (Strahler)

Observation	width	Préd(width)	Résidu	Résidu std.
Obs17	1.200	3.116	-1.916	-0.692
Obs6	1.300	3.029	-1.729	-0.625
Obs9	2.230	3.550	-1.320	-0.477
Obs21	2.500	2.912	-0.412	-0.149
Obs19	2.700	3.131	-0.431	-0.156
Obs22	3.000	3.081	-0.081	-0.029
Obs24	3.300	3.754	-0.454	-0.164
Obs4	4.600	4.574	0.026	0.009
Obs3	5.600	4.545	1.055	0.381
Obs14	5.700	3.927	1.773	0.641
Obs2	6.300	4.229	2.071	0.749
Obs23	6.300	4.150	2.150	0.777
Obs18	6.600	5.419	1.181	0.427
Obs10	8.100	7.373	0.727	0.263
Obs13	8.400	10.311	-1.911	-0.691
Obs16	9.300	7.276	2.024	0.732
Obs20	9.500	10.399	-0.899	-0.325
Obs1	10.800	13.619	-2.819	-1.019
Obs15	11.800	11.889	-0.089	-0.032
Obs8	12.500	12.728	-0.228	-0.082
Obs5	14.100	13.939	0.161	0.058
Obs11	17.500	19.669	-2.169	-0.784
Obs26	17.500	19.941	-2.441	-0.882
Obs7	17.700	20.744	-3.044	-1.100
Obs12	19.500	21.319	-1.819	-0.657
Obs25	32.000	21.407	10.593	3.828

POLYTECH TOURS
35 ALLÉE FERDINAND DE LESSEPS
37200 TOURS

Clément Ricordel
2018-2019

Assessment of the stream fragmentation of the Afan river

Abstract:
This work consists in studying the stream fragmentation of the Afan River because of the different barriers. To do this, first was created a model to determine the width of the watercourse over its entire length. Then, this makes it possible to identify potential habitat areas. The other part of the work consists in referencing all the barriers present in the watershed. The objective is to determine the impact of barriers on the loss of potential habitat areas for aquatic species (fish, invertebrates, etc.).

Keys word: *stream fragmentation, barrier, ecological continuity*

Swansea University
Singleton Park SA2 8PP Wales

Company supervisor:
Carlos Garcia de Leaniz & Pete Jones
Professor & Doctor

Academic supervisor :
Karl Matthias Wantzen