Trabajo Fin de Máster

EVALUACIÓN DEL HÁBITAT FÍSICO PARA LA ESPECIE LEFUA ECHIGONIA MEDIANTE SIMULACIÓN EN EL RÍO YAGAWA, JAPÓN

Intensificación: ORDENACIÓN, RESTAURACIÓN Y GESTIÓN DE CUENCAS

Autor:
MARINA DE MIGUEL GALLO

Tutor:
DR. FRANCISCO MARTINEZ-CAPEL

Cotutor:
DR. TAKAMITSU KAJISA

DR. SHINJI FUKUDA

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RESUMEN

El rápido desarrollo que ha tenido lugar en los últimos años, como consecuencia del incremento poblacional y la aparición de distintos avances tecnológicos, tiene como consecuencia directa una degradación de los ecosistemas naturales, y por tanto una pérdida de la biodiversidad. Las actividades humanas, tales como la urbanización o la abstracción de agua resultan en presiones ejercidas sobre los sistemas naturales, sobre los que cabe destacar los ecosistemas acuáticos. Estas presiones pueden presentarse en diversas formas, alterando el ecosistema y dificultando a las especies que habitan en él el completar sus ciclos vitales y perpetuarse en el tiempo, conllevando así una pérdida de la biodiversidad, y por tanto de la resiliencia del sistema. En este contexto, Tokio adquiere un gran importancia, por ser una de las ciudades con mayor extensión del mundomás de 2000km^2), representando por tanto un problema de gran envergadura en Japón. Dada la enorme extensión que ocupa, afectando a una gran proporción del terreno japonés, y dado que la tendencia es creciente, es de vital importancia recuperar y mantener su biodiversidad, realizando actuaciones que ayuden a mejorar las condiciones de estos ecosistemas profundamente alterados. Por eso, este estudio se centra en un pequeño río urbano, en el que habita *Lefua echigonia*, una especie nativa de Japón en peligro de extinción, con el objetivo de simular su hábitat, y proponer alternativas de mejora que ayuden a proteger esta especie, y mantener la biodiversidad. Para ello, se ha elaborado un modelo de idoneidad de hábitat, basado en curvas de idoneidad para *Lefua echigonia*, y se ha evaluado el hábitat a lo largo de un periodo temporal de 24 meses.

Este estudio aporta por tanto una información muy valiosa en aras de mantener y recuperar la biodiversidad en un entorno tan grande como el de Tokio, la urbe más grande del planeta; dado que es uno de los primeros estudios de idoneidad de microhábitat realizados en Japón, al margen de los salmónidos, muy estudiados en todo el mundo, centrándose en una especie endémica en peligro de extinción, de gran importancia para la sostenibilidad de los ecosistemas; y siendo al mismo tiempo fundamental en la realización de estudios de caudales ecológicos posteriores. Por otro lado, al haberse realizado en un río urbano, adquiere una gran importancia, al estudiar así un tipo de río muy presente en esta gran metrópolis, que a pesar de haber sido normalmente ignorados en este tipo de estudios, son de vital importancia en el mantenimiento de ecosistemas clave para ciertas especies que en ellos habitan. Al mismo tiempo, las medidas de restauración propuestas para el caso de estudio pueden ser extrapolables a otros ríos cercanos que presenten la misma problemática.

PALABRAS CLAVE

Biodiversidad; Sostenibilidad; Simulación de Hábitat; Especie en Peligro de Extinción; Río Urbano; Ecohidráulica; *Lefua echigonia*.

RESUM

El ràpid desenvolupament que ha tingut lloc en els últims anys, com a conseqüència de l'increment poblacional i l'aparició de diferents avanços tecnològics, té com a conseqüència directa la degradació dels ecosistemes naturals, i per tant, pèrdua de biodiversitat. Les activitats humanes, tals com la urbanització o l'abstracció d'aigua resulten en pressions exercides sobre els sistemes naturals, sobre els quals cal destacar els ecosistemes aquàtics. Aquestes pressions poden presentar-se en diverses formes, alterant l'ecosistema i dificultant a les espècies que habiten en ell completar els seus cicles vitals i perpetuar-se en el temps, amb la conseqüent pèrdua de biodiversitat i, per tant, també una disminució de la resiliència del sistema. En aquest context, Tokio adquireix un gran importància, per ser una de les ciutats amb major extensió del món (més de 2000 km2), representant un problema de gran envergadura al Japó. Donada l'enorme extensió que ocupa, afectant a una gran proporció del terreny japonès, i atès que la tendència és creixent, és de vital importància recuperar i mantenir la seva biodiversitat, realitzant actuacions que ajuden a millorar les condicions d'aquests ecosistemes profundament alterats. Per això, aquest estudi se centra en un petit riu urbà, on habita Lefua echigonia, una espècie nativa de Japó en perill d'extinció, amb l'objectiu de simular el seu hàbitat, i proposar alternatives de millora que ajudin a protegir aquesta espècie, i mantenir la biodiversitat. Per a això, s'ha elaborat un model d'idoneïtat d'hàbitat, basat en corbes d'idoneïtat per Lefua echigonia, i s'ha avaluat l'hàbitat al llarg d'un període temporal de 24 mesos. Per tant, aquest estudi aporta una informació molt valuosa que permet mantenir i recuperar la biodiversitat en un entorn tan gran com el de Tokio, l'urbe més gran del planeta; atès que és un dels primers estudis d'idoneïtat de microhábitat realitzats a Japó, al marge dels salmònids, molt estudiats a tot el món, centrant-se en una espècie endèmica en perill d'extinció, de gran importància per a la sostenibilitat dels ecosistemes; i sent al mateix temps fonamental en la realització d'estudis de cabals ecològics posteriors. D'altra banda, en haver-se realitzat en un riu urbà, adquireix una gran importància, en estudiar així un tipus de riu molt present en aquesta gran metròpolis, que malgrat haver estat normalment ignorats en aquest tipus d'estudis, són de vital importància per al manteniment d'ecosistemes clau per a certes espècies que en ells habiten. Al mateix temps, les mesures de restauració proposades per al cas d'estudi poden ser extrapolables a altres rius propers que presenten la mateixa problemàtica.

PARAULES CLAU

Biodiversitat; Sostenibilitat; Simulació d'Hàbitat; Espècie en Perill d'Extinció; Riu Urbà; Ecohidràulica; *Lefua echigonia*.

ABSTRACT

The rapid development that has taken place during the last decades, as a result of the population increase and the appearance of different technological advances, is a direct cause of the natural ecosystem degradation. Human activities, such as urbanization or water abstraction, result in pressures exerted on natural systems, among which aquatic ecosystems can be highlighted. These pressures affect the ecosystems in different ways, altering them or making it difficult for the inhabiting species to complete their life cycles, and last in time; leading to a loss of biodiversity and therefore to the resilience of the system. In this context, Tokyo acquires a great importance, being one of the largest cities in the world (over 2000 km2), turning into a big problem in Japan. Due to the enormous area that it occupies, affecting a large proportion of the Japanese land, and given the growing trend, it is essential to recover and maintain its biodiversity, performing actions that help improving the habitat conditions of this deeply disturbed ecosystems. This study focuses on a small urban river, inhabited by Lefua echigonia, an endangered native species from Japan, in order to simulate its habitat, and proposing different alternatives for improvement, to protect this species and maintain biodiversity. To this aim, a habitat suitability model was developed, based on suitability curves, and the habitat was evaluated for a 24-months-period.

Therefore, this study provides valuable information in order to maintain and recover biodiversity in an environment as large as the one of Tokyo, along with the fact that it is one of the first microhabitat suitability studies carried in Japan (apart from the salmonids ones, very studied around the world), focusing on an endemic endangered species with a great importance for the ecosystems sustainability. The information obtained is essential while realizing later ecological flows studies accomplishment. As it was carried in an urban river, it acquires a great importance when studying similar rivers, with a great presence in this metropolis, which, in spite of having been often ignored in this kind of studies, show a vital importance in the maintenance of the key ecosystems for certain species. At the same time, the proposed restoration measures for the case of study may be extrapolated to other nearby rivers presenting the same problem.

KEYWORDS

Biodiversity; Sustainability; Habitat simulation; Endangered species; Urban River; Ecohydraulics; *Lefua echigonia*.

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1. INTRODUCTION

The quick development that has occurred during the last century has had a huge impact on the different natural ecosystems. Among those, aquatic ones are one of the most affected, by different human constructions such as dams, or canalizations, which lead to an important problem limiting the connectivity of the habitat, and therefore damaging the inhabitant species. The affection of these elements set on the natural rivers can affect to the environment in different ways, being able to profoundly change the natural flow regime, and hindering this way the completion of the life cycle of various species, and causing a loss of connectivity, both longitudinal, transversal, or vertical, among other impacts. The execution of these works usually implies a negative effect in the environment, which should be minimized as far as possible. In the case of Japan, these alterations can be observed in most of the rivers, mostly as canalizations, or dams constructed in order to save the water for the moment in which it would be more necessary.

Within this context, the society has developed a growing concern about environment, and all it implies, pushing science through a way of improving and searching for new methods of habitat evaluation, in order to make decisions about environment and water management easier and somehow more objectively. The IFIM methodology, developed in the late 1970's (Bovee and Milhous, 1978), was a response to this concern, showing a new scheme of work, in which different interested entities or stakeholders in water-related projects were considered, in order to provide enough information, from different points of view, held and achieve a solution. The Physical Habitat Simulation was created then as an essential part of the IFIM methodology to solve water-related conflicts, based on objective technical and scientific information and the consequent negotiation of the main stakeholders.

This study focuses on the habitat simulation for the species *Lefua echigonia*, currently endangered, in the Yagawa River, a natural spring-fed river in the metropolitan area of Tokyo, Japan. For this task, I used the recently developed software SEFA, System for

Environmental Flow Analysis, which follows the scheme of IFIM methodology. Tokyo is well known for being one of the biggest metropolis in the world, occupying an area of over 2000km^2 (Wikipedia, 2018). This extensive urban area has diverse environmental issues, such as the degradation of the overlapped ecosystems; therefore, it must be properly study, for the importance that represents for the whole country, and even at a world scale. In this area, the water courses are predominantly urban channelized streams and rivers, that should be naturalized or rehabilitated in some degree, given the great importance that they represent for the survival of the native species inhabiting Japanese rivers.

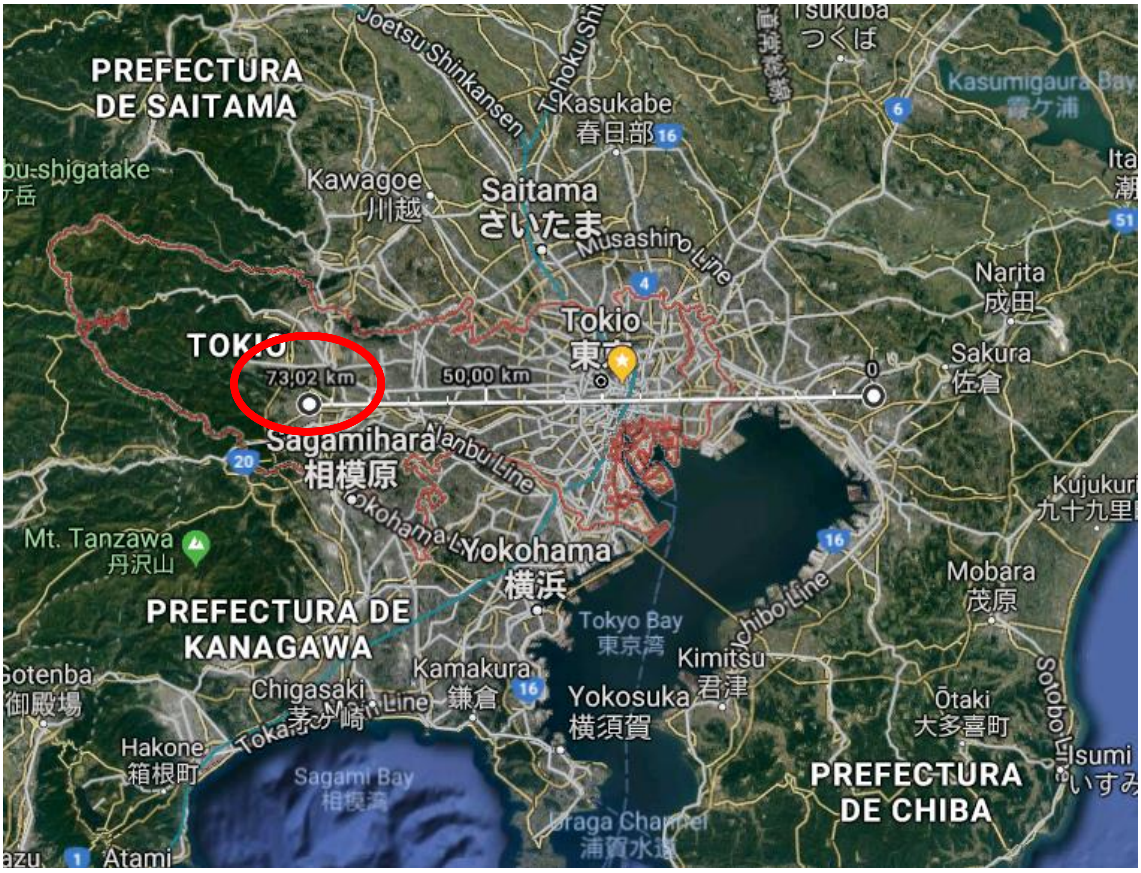


Figure 1. Area of Tokyo. Approximated width of 70km (W-E direction).

Thereby, the present study is very important in order to protect these species, since it helps us to understand the current state of the habitat, and how to improve it in an efficient way. For this, the following scheme of work was followed, as a summary. First of all the field survey was made, during which elevation data along the whole river were collected, along with substrate composition, velocity and depth information; secondly, habitat suitability curves for that fish species were developed, based on information collected during 24 months by the professor Dr. Fukuda; finally, SEFA software was used to develop a hydraulic model in which the habitat quality for *Lefua echigonia* was evaluated, and the relations of habitat quality versus river flow, as well as time series of habitat quality, were developed. To this aim, Dr. S. Fukuda, from the Tokyo University of Agriculture and Technology, provided presence/absence data collected during several field surveys that were conducted in the same river.

After the first phase of the study, the river survey, a database was created, and the standard SEFA file was created as the input for the hydraulic model, including all the information related to the different transects, the measured points with their data of elevation, depth, flow velocity, vegetation and substrate composition.

Since the ecological information of the fish species is fundamental, the data provided by Dr. Fukuda were used to develop habitat suitability curves (univariate model), and also to fit a Generalized Additive Model (hereafter, GAM), carrying out several trials with the available data working as predictive variables, and using the presence/absence data as response variable. For the GAM, different degrees of freedom were tested, in order to use the best option of this parameter, trying to obtain a model with a good adjustment to reality, while not having a lack of ecological sense due to an excessive adjustment (overfitting).

In the last phase of the study, a hydraulic model was developed, with the data from the field survey, using SEFA software, in which different flows were simulated in order to calculate the Weighted Usable Area, available for *Lefua echigonia* in the Yagawa River for the calibration flow, as well as the for different simulated flows, and its evolution along the period of 24 months. Although in the common terminology the habitat indicator is called Weighted Usable Area (WUA), in the software SEFA, the authors corrected this name to call it Area Weighted Suitability (AWS); thus this is the terminology adopted in this piece of research.

This study was made with the help of the PROMOE grant, given by the Universitat Politècnica de València, within the period between April 2018 and August 2018, and presented as an oral communication in the 12th International Symposium on Ecohydraulics, in August 2018, in Tokyo.

2. OBJECTIVES

The main propose of this study is to simulate the habitat in terms of Area Weighted Suitability (AWS) for the fish species *Lefua echigonia* in the Yagawa River, and to propose measures to improve the habitat conditions. In order to achieve this general objective, the following partial objectives were achieved:

- To construct and calibrate a representative hydraulic model for the Yagawa River in the software SEFA (System for Environmental Flow Analysis).
- To develop a habitat suitability model for *Lefua echigonia*, suitable for the Yagawa River, that can be used to apply the physical habitat simulation method.
- To develop a function relating the habitat indicator, Area Weighted Suitability (AWS) with different flow rates, to assess the changes of AWS with flow along the annual cycle (one year), and within a 2-year-long time series.
- To analyse the problems existing in the river that may harm the habitat for this endangered fish, and to identify some key actions to improve the habitat conditions.

3. METHODS

1. Study area

Yagawa River is a 1500-meter-length natural-spring-fed located in the surroundings of Tokyo, Japan (Matsuzawa, Ohira, & Fukuda, 2017). This small river is a clear example that in small rivers, finding ecosystems with a great ecological value is still possible, because of the importance they can represent for certain species, such as *Lefua echigonia*. Despite the alterations that the Yagawa River has suffered, as a cause of anthropogenic activity, that could be observed during the field survey, it represents a valid ecosystem for this endangered species, providing a space in which it can complete its life cycle, conferring this river a great ecological importance.

In order to show the hydrologic behavior of the river along the year, data provided by Dr. Fukuda from the Tokyo University of Agriculture and Technology, covering 24 months measured, were used to calculate the monthly average flow, and to obtain a hydrograph. As the graph in Fig. 2 shows, the months with the highest flow are those of September and October, while those with the lowest flow correspond to the period between January and July, fact that can be highlighted due to the existing difference compared to the Mediterranean flow regime in many Spanish rivers. The field data collection in this study took place between the months of May and June, and the average flow rate was approximately 0.04 m^3/s, which shows that this year the flow was slightly above the data previously collected for these two months.

The Yagawa River has a very small catchment and the surface flow depends and responds directly to the rainfall. The main source is therefore the spring water, that increases around October, after the rainfall events brought by typhoons in August/September. Even if there is no long-term study to proof this in the target river reach, this is the conclusion I can have, based on the provided data, monthly surveyed over three years.

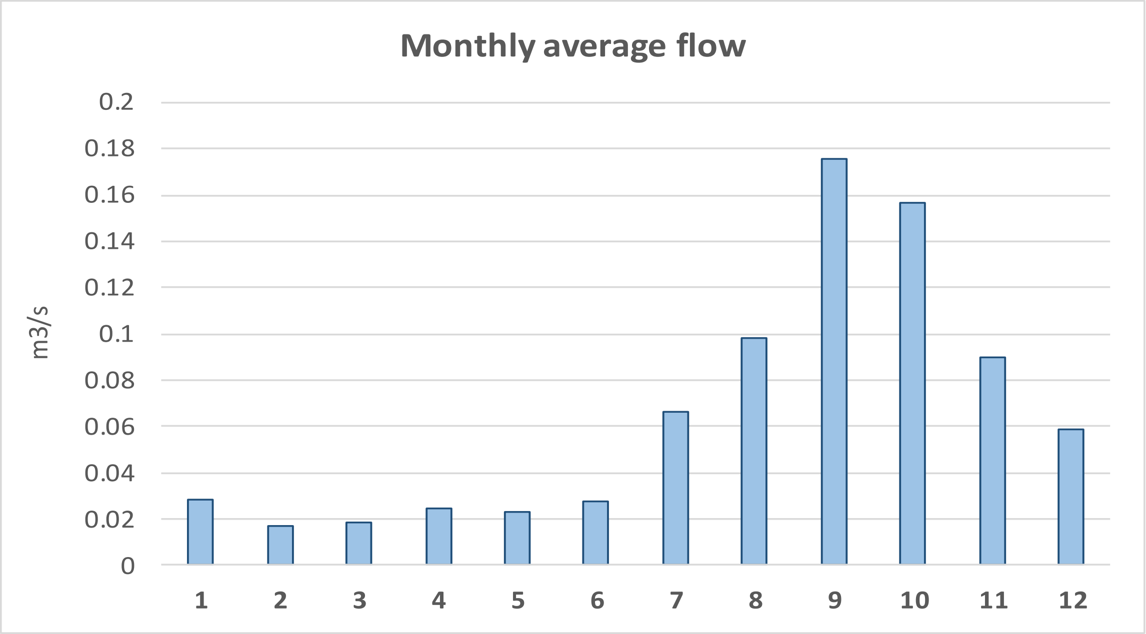


Figure 2. Hydrograph for the Yagawa River, showing the monthly average flow (where 1 means January and 12 means December)

It is worth mentioning the great longitudinal variability of the study reach, ranging from forested areas with a natural look, to those that were more channel alike, flowing through human constructions, as it is shown in Fig. 2 below.

Figure 3. Area of study

2. Physical characterization of the river

In order to physically characterize the river, several box-plots were made, using the data monthly collected during years 2015, 2016 and 2017 regarding width, depth, and velocity. It is important to notice that the data from year 2015 were taken just from June to December, while the data taken during the year 2017 were obtained just until May, as the box-plots will be displayed for every year, along with the whole period.

3. Field survey

For the field works the following tools were used:

- Optical level and leveling rod, to measure cross-sections and water level.
- Measuring tape.
- Graduated rod to measure water depth (m).
- Two electromagnetic current meters (KENEK®) to measure mean water column velocity (m/s).

Figure 3. Electromagnetic current meters used in the survey

A total of 108 transects were placed along the whole river, from downstream to upstream, set perpendicularly to the flow, for which the topographic profile was measured, as well as the depth, mean velocity and composition of the substrate in each point. At the same time both the direction of the cross section along with the bearing angle towards the next cross section were measured.

The topographic work was carried along the whole river, by using measuring rob together with optical level, taking a minimum of five points instream for each transect, placing two of them on the intersection between the water surface and the ground, while the points left were placed across the channel. In the channelized sections, among others, additional points were measured outside the channel, in order to obtain a good representation of the bankfull section (low water channel and banks). For the transects located inside the reach containing a secondary channel, a complete measurement of both channels, as well as the island in between, was accomplished.

In case of being measuring a channelized cross section, the high of the wall was measured jus in an approximated way, by looking at the high marked by the measuring rob.

The distance separating the transects was measured using a measuring tape, with decimeter accuracy.

Using several stations for the optic level was required, as the study reach was too long to be measured from a single station.

Accordingly, a total of 21 stations were set along the river. While changing the stations, a connecting point was measured from both the last used station and the one to be used afterwards, in order to allow a posterior transformation of the data, so that they are in the same reference system

While measuring the elevation of the points, the depth value was taken by watching the high of the water surface when intersecting with the measuring rob.

The mean velocity was measured in each of the previously measured points, using two current meters. The velocity was measured at an approximate depth of 40% from the bottom of the river. For each of the points two measurements of 20 seconds were made, obtaining the average value that would be use afterwards in the model.

For each measured point the existing substrate was evaluated, following the same criteria followed in the previous studies whose data have been used in this work. The method used for this was estimating the percentage of vegetation in the point, setting a value between 0 and 100%. The substrate was also evaluated, classifying it in five different types, namely: sand /clay, small gravel, medium gravel, large gravel, and concrete; and providing a weight to each of these types of substrate to achieve a total value of 100%. For each of these substrate types, a code necessary for the subsequent analysis was given, that would be recognized by the program SEFA, as shown in Table 1.

Table 1. SEFA codes for the substrate types.

Vegetation	VEG
Sand/clay	S
Small-sized gravel	F
Medium-sized gravel	G
Large-sized gravel	C
Concrete	BED

4. Habitat suitability modelling

For the habitat model, two data sets were used, at microhabitat and mesohabitat scale, until the one working better was chosen. Two different procedures for habitat modelling were used, both habitat suitability curves and generalized additive models (GAMs). At the beginning we only had mesohabitat data, so we worked with them, in developing a GAM, but later we could get a new microhabitat data, for which we developed a new

GAM. Finally, we worked on a model based on habitat suitability curves with the microhabitat data, and this was the habitat model used for the habitat evaluation.

Microhabitat data

As the first provided data were taken at a mesohabitat scale, not so compatible with a microhabitat study, a second set of data was provided, by the Tokyo University of Agriculture and Technology, being in this case taken at a microhabitat scale, by measuring fish occurrence, dominant substrate, depth and velocity at the same point, while percentage of vegetation and percentage of substrate were measured at a cross-section scale. In this case the data were collected for adult individuals.

Mesohabitat data

The presence-absence data for the endangered freshwater fish, *Lefua echigonia*, were collected in the Yagawa River. Fifteen 10-m-long reaches were defined for surveying fish fauna and physical habitat conditions in order to understand the longitudinal distribution of *L. echigonia* and other fish species. Fish were collected by a hand-net and two fyke nets, keeping all fish in a reach, for 10 minutes by 2 people, keeping the same sampling effort across the surveyed reaches. They were identified at species level, and then released in the same reach. Also the following relevant microhabitat variables in the reach were measured: mean flow velocity (cm/s), mean water depth (cm), width (cm), percent vegetation coverage, percent coverage of large-sized gravel (> 64 mm), percent coverage of medium-sized gravel (16-64 mm), percent coverage of small-sized gravel (2-16 mm), percent coverage of sand and clay (< 2 mm), and percent coverage of concrete lining; as well as the presence/absence of *Lefua echigonia*, and *Nipponocypris temminckii* (as a translocated fish species in this habitat, a direct competitor to *L. echigonia*), together with the number of species present at that moment. The survey was conducted every month from June 2015 to May 2017 (Matsuzawa et al., 2017).

Data pre-processing

Merging vegetation

As the software used in this study uses vegetation as a part of the substrate, it was necessary to merge the percentage of vegetation with the substrate information. The method used for this was to set the measured percentage of vegetation as the available percentage, maintaining its original value. On the other hand, the percentages of the different types of substrate were modified, adapting them to the percentage of substrate remaining after subtracting the vegetation percentage value, so that after performing this procedure for all the data, and adding their final percentages, a total value of 100% should be obtained, ensuring that there was no error. Hence, the new value was calculated using the next formula:

$$Sn_1 = (100 - V) \cdot Sn_0$$

Where,

- Sn: percentage of a substrate category
- n: substrate category. This can be:
    - 2: sand/clay
    - 3: small gravel
    - 4: medium-sized gravel
    - 5: large-sized gravel
    - 6: concrete
- 1: new value, after merging
- 0: old value, before merging
- V: percentage of vegetation cover

Substrate Index

In order to avoid an excessively disproportionate influence of the substrate on the GAM, a substrate index was calculated, thus reducing the number of substrate descriptor variables from five (vegetation, sand, fine gravel, medium gravel, and large gravel) to one (substrate index). This way, a total number of three predictor variables (mean velocity, depth and substrate) were available for the response variable (presence/absence).

The substrate index was calculated but the following equation:

$$SI = 1 \cdot VEG + 2 \cdot S + 3 \cdot F + 4 \cdot G + 5 \cdot C + 6 \cdot BR$$

Where,

- SI: substrate index
- VEG: percentage of vegetation
- S: percentage of sand / clay
- F: small-sized gravel percentage
- G: medium-sized gravel percentage
- C: percentage of large gravel
- BR: percentage of concrete coverage

In case of choosing a GAM using this substrate index as a predictor variable, it would be necessary to use it also for the transects later imported into SEFA, losing this way an important available information characterizing the river substrate

Habitat suitability curves

On one hand a model based on habitat suitability curves was developed, using a microhabitat data set, since this kind of models have the advantage of being quite simple to prepare and understand, in comparison with other models, such as generalized additive models.

The habitat suitability curves are functions that indicate the suitability, for each aquatic species, within each of their life stages, of each of the values taken by one of the evaluated habitat variables. They are usually developed for endemic and native species, by using diverse methods. The selection and use of the curves have a great influence in the planning and data collection, so they really affect the activities needed for their development, and also the results when working on ecological flows (Martinez-Capel, 2011)

A drawback to this method is that the presence / absence data for the studied species must have been taken in a river similar to the river of study. In this case, the data was taken from the Yagawa River itself, being thus suitable for the method.

At the beginning, the absolute frequency of the presence data was calculated for different mean velocity and depth ranges, as well as for the different types of substrate. Subsequently, a histogram was elaborated from the presence data, and also from the absence data, in order to compare the distribution of the data; and after standardizing the frequency data between 0 and 1, dividing both groups of data between their maximum values, and adjusting a curve to the mentioned histograms, a single graph was elaborated for each attribute, in which the said presence and absence curves were displayed, showing this way the difference between use and availability.

At the same time, a comparison based on the Mann-Whitney U test was made, to determinate whether the samples presented or not a significant statistical difference, between use and availability, namely if *Lefua echigonia* shows a selective use of the habitat. The test was carried for all the depth, velocity and substrate variables, using STATGRAPHICS Centurion XVII software (Version 17.2.04 (64-bit)). “To perform the test, the two samples are combined and ranked from smallest to largest, with any tied observations being given the average rank for the values in the tied group” (“Two Sample Comparison,” 2005). The premises for this test are the following:

- The samples are random
- The cases are independient within ech sample and between samples
- The measurement level is at least ordinal

Velocity

To obtain the velocity suitability curve, the presence data set was divided into intervals from 0 m / s to 1.1 m / s, with increments of 0.05 m / s, for which the absolute frequency of occurrence was calculated, obtaining subsequently a histogram of presence. Later on, a curve was adjusted to the histogram, and the frequency was standardized between values from 0 to 1, dividing by the maximum frequency value, being 1 the corresponding value to the highest frequency of appearance.

For the absence data set the same procedure was followed, in order to compare the distribution of the data and checking the possibility of establishing differences.

Depth

As for the depth suitability curve, for the presence data, the frequency was calculated by dividing in 0.025 m intervals, and a histogram based on these results was displayed. In the same way, a histogram of the absence data was made, segmented into identical depth intervals, and the trend of the absence data was compared with the presence data, after performing the same standardization as in the previous procedure for the velocity.

Substrate and vegetation

Regarding the substrate suitability curve, the whole substrate was divided into 8 different types, including vegetation as a part of the substrate, such as SEFA software does.

For this, the substrate was divided in the different groups the program uses, giving a number to each of them, as it is shown in the Table 2, below.

Table 2. Substrate codes

Attribute	Substrate type	Column
Vegetation	Vegetation	1
Mud	-	2
Sand	Sand	3
Fine gravel	Small gravel	4
Gravel	Medium-sized gravel	5
Cobble	Large gravel	6
Boulder	-	7
Bedrock	Concrete	8

On one hand, the data was divided according to the substrate index, by rounding its value to the closer value from the ones in the table above. As this index is more important to calculate for the generalized additive model, and not really relevant for this method, the procedure of obtaining it will be explained in that chapter. To merge the vegetation information together with the substrate, the procedure later explained in the GAMs chapter was followed, maintaining the original value of the vegetation cover percentage, and adapting the rest of percentages depending on this value. After dividing the data in the different categories, the frequency of occurrence was calculated for each of them, and the corresponding histogram was displayed.

On the other hand, the data was divided regarding a dominant substrate criterion, followed by the same steps taken for the substrate index.

In both cases, the frequency for each substrate type was adjusted, dividing by the maximum value of the frequency at each set, obtaining this way a standardized data within 0 and 1, making it possible to make a later comparison to one another, and with the corresponding absence data. Finally, the curve that offered a better representation of the reality was chosen.

Prior to the use, the substrate suitability curve was completed by adding values of 0 to the mud and boulder groups, as the manual specifies.

Generalized Additive Models

A multivariate habitat suitability model was adjusted with generalized additive models (GAMs), in order to understand the suitable habitats for *L. echigonia*. GAMs were selected to model the presence/absence of *L. echigonia,* using HabitatPref program (Milhous, Jowett, & Payne, 2012). Here presence of *L. echigonia* was considered to be a good estimator of potential habitat quality in the Yagawa River. GAMs have been previously used to assess habitat suitability for fish (e.g. Muñoz-Mas, Papadaki, et al., 2016).The advantage of this sort of models is that they allow developing nonlinear relationships among these variables, and in this kind of studies, this is particularly useful, since most of the habitat suitability functions are non-linear. The procedure of GAMs calibration is based on smoothing techniques and nonparametric regression, which relaxes the common assumption of linearity, and let you discover an underlying relationship structure, that could otherwise be overlooked. HabitatPref implements the generalized additive models developed by Hastie and Tibshirani (1990) in their Fortran GAMFIT programme (Milhous et al., 2012), which assume that the dependent variable can be connected to the predictor variables by a non-linear link function, that works as a data transformation (Milhous et al., 2012).

The assumptions were that we had non-linear relationships between the environmental variables and the response variable, and, due to the presence/absence nature of the available data, the response variable follows a Binomial distribution, constraining the output value to the range 0 and 1 (Muñoz-Mas, Lopez-Nicolas, Martínez-Capel, & Pulido-Velazquez, 2016), where 0 corresponds to absence and 1 to presence. The GAMs were developed with 3 and 4 degrees of freedom, so the partial dependence plots fitted well the ecological gradient theory (Austin, 2007), providing smooth curves without relevant irregularities (i.e., increases and decreases), which lack a clear ecological meaning. After producing models with the different combinations of microhabitat variables and with 3 and 4 degrees of freedom, the models showing the best performance for each of the fish species are supposed to be selected.

For the GAMs development two database were used. At first place we worked with data taken at a mesohabitat scale, which can bring problems while carrying a microhabitat study. Thus, we got a second data base, were the data were taken at a microhabitat scale.

Microhabitat data

This data set was specific for the adult stage, so the resulting GAM would only be applicable in the habitat assessment for adult individuals of Lefua echigonia, so the whole set of data was used to develop the GAM. Initially, diverse trials were carried out, in order to obtain a GAM with a good adjustment to the available data, being supposed to this way be able to be applied in the later analysis. The tool used for this was HabPref, a module available in SEFA (Jowett, 2011), in which different combinations of the variables were tried.

While presence/absence was the response variable of the model, the different available variables aforementioned were taken as predictor variables. The units of each of them were transformed to fit the units of the International System. The predictor variables used in the model were selected in two different ways, by including the whole set of data, namely mean flow velocity (m/s), mean water depth (m), percentage of vegetation coverage, total percentage of large-sized gravel, percentage of medium-sized gravel, percentage of small-sized gravel, percentage of sand and clay, and percent coverage of concrete lining, or by including velocity and depth, together with a calculated Substrate Index.

Mesohabitat data

The same procedure previously explained was followed for this new group of data, carrying out different trials in the same way as before.

Biological significant periods

Given to the fact that this database incorporates information related to all the life stages of the target species, the data were divided into three different groups, differentiated according to the different stages of life of *Lefua echigonia*, as follows:

- **April - June:** this period was identified to be the time in which the juveniles were distributed all over the river, being March/April the spawning season (Matsuzawa et al., 2017).
- **July - November:** in the same study it was mentioned that the distribution range was decreasing while the juveniles got closer to the adult stage (Matsuzawa et al., 2017).
- **December - March:** This stage was established as the representative one to the adult individuals, as in the previously mentioned study, it was emphasized that from this stage a stabilization of the distribution was reached, being the adult individuals the most selective in terms of habitat (Matsuzawa et al., 2017).

Several tests were carried out for each of these three biological significant periods of the life cycle, in order to obtain a total of three GAMs with the best adjustment.

5. Habitat simulation

The habitat simulation was made in SEFA, using the previously obtained suitability curves and a hydraulic model that was also developed in SEFA.

Hydraulic simulation

For the hydraulic model, the data taken during the field survey must be organized in a certain way that SEFA can understand. For this, and excel sheet was used.

Prior to the data use, some corrections had to be made, such as the elevation values. They were previously referred to the different stations were the optic level was set, and therefore the altitude elevation should be calculated.

Elevation

Initially, the lowest point was identified, in order to be the reference to the whole data. This point was placed in the first transect named as transect-0, which was not used in the model, for carrying a higher flow than the other ones.

At first place, this point was given a elevation of 0m, from which the elevation of the first station could be calculated, being supposed to be the height difference observed with the optic level. In case of the coming stations, the height was calculated from the reading obtained for the connecting points, from the prior and the next stations, as follows:

$$S_i = S_{i-1} - (R_{i-1} - R_i)$$

Where,

- S_i: Height of the new station
- S_{i-1}: Height of the previous station
- R_{i-1}: reading to the connecting point from the previous station
- R_i: reading to the connecting point to the new station

These calculations were made for the 21 stations used in the survey.

For the points, the elevation was calculated by getting the difference between the station from they were measured, and the relative elevation given by the reading. The equation below was used,

$$P_j = S_i - R_j$$

Where,

- P_j: elevation of the point
- S_i: elevation of the station from which the point was measured
- R_j: reading to the point, observed from the station *i*.

obtaining this way a coherent dataset to be used in the construction of the model.

Water Surface Elevation

Also, the water surface elevation (WSE from now on) had to be calculated, since it was not possible to take it for all the measured transects, due to the fact that some channelized reaches had a vertical wall where the stick could not be placed. To this aim, the available values of elevation and depth were used, as the WSE is the result of summing the elevation and depth values.

Then the data was organized in a format that SEFA could use, including the values of the water surface elevation for each transect, together with information about elevation, depth, velocity, substrate composition and location of each point in the transect.

Stage Zero Flow

The Stage Zero Flow (SZF) was identified for those transects whose deepest point is lower than the deepest point in a transect below, which is usually a section acting as a hydraulic control, i.e., producing a remnant water upstream, or backwater effect. To this aim, the value of the deepest point at the lower transect was set as SZF at the mentioned transects.

Calibration

Calibration Flow

The survey flow is calculated at each cross-section, in the software SEFA, by using the option Edit/View>Flows. “This calculates and displays a table of the flow, depth, velocity area and energy coefficient at each cross-section and the average of all.”(Milhous et al., 2012).

The flow was calculated at each cross-section, assuming that the velocities measured at each point were column mean velocities. Usually, single velocity measurements should be placed at 0.6 times the depth below the water surface, since, if velocities follow the "normal" logarithmic velocity profile, the average velocity is found close to that place (Milhous et al., 2012).

The average of the flows is the default estimate of the survey flow. However, in this case a further analysis of the calculated flows was carried, in order to set the best calibration flow, after removing the transects showing extreme values. After stablishing the calibration flow, this was set as the survey flow. "*When the survey flow is altered the ratings and velocity distribution factors (VDFs or point Manning's N values) are recalculated automatically*" (Milhous et al., 2012), and they can be displayed.

Roughness coefficients

To adjust the Manning's N, the module WSP is used, by selecting "fit roughness coefficients". "The various items on the spreadsheet are adjusted until an acceptable set of values of N are calculated. The main value that is adjusted is the stage adjustment. This raises or lowers the elevation of the cross-section. The justification for adjusting elevation is that heights of a mm or so can have a strong influence on values of Manning's N and the field measurement of water surface elevation is not that accurate." (Milhous et al., 2012).

Later, the Manning's N values were checked, to see if they were reliable or not. If the given value was not within the range from 0.03 and 0.15 (Chow, 1994), the loss of energy that occurs between those transects would probably be too low or too high, and thus the water surface elevation should be changed, increasing or decreasing its height in 2mm, as this is the value that could be misread during a field survey.

In this case, some N values were outside this range, so the explained modifications were carried, until a good N was obtained for each of the cases. When the N was not satisfactory corrected, the model was cut at that point to avoid later errors.

Calculate WSP

As for this study we could only accomplished one field survey, the module Water Surface Profile (WSP) turned out to be very useful.

The water surface profile model, called WSP, let the user model the water surface levels, based on the principles of conservation of energy and momentum between cross-sections. This approach is only possible with 'Representative reach' data, which is the method used for this study, and is most useful in low-gradient streams. The water surface elevation is calculated from the downstream cross-section and the simulated values are used to create another rating curve for all cross-sections. “This is particularly useful for rivers where the upstream cross-sections could not be surveyed more than once or where the ratings curves types […] for other reasons are unreliable”. (Milhous et al., 2012)

The velocity head coefficient (VHC) converts the mean velocity head ($Vm^2/2g$) to the true velocity head loss. If the velocity stays the same across the section, these values will be the same, but normally the true velocity head will be 1.5 to 3 times the mean velocity head. “It is calculated from the measured velocity by integrating the velocity head across the section:

$$VHC = Sum(V_i^3 \times A_i)/(V_m^3 \times A)$$

However, the integration method of calculating conveyance is used and the velocity head coefficient is calculated from the section geometry, rather than from measured velocities.

The velocity head coefficient (VHC) is:

$$VHC = (\text{Compartment conveyance}^3/\text{Compartment area}^2) \times (\text{Area}^2)/\text{Conveyance}^3$$

Integration methods for conveyance and velocity head are not used where the cross-section contains underwater overhangs. In fact, although cross-section data with overhangs can be processed habitat and velocity predictions will be incorrect if the overhang is underwater.

Conveyance can be calculated as an arithmetic or harmonic mean of two cross-sections." (Milhous et al., 2012).

After getting satisfactory values for Manning's N, these values were saved, and the WSP module was opened. In this module, several flows were simulated, similar to the ones that would be used afterwards to calculate the Weighted Usable Area/Flow curve. The first simulated flow was the calibration flow, in order to check that the water surface profile corresponds to the one measured in the field.

Later, different flows were simulated, saving the water surface profile, so that they can subsequently be used to obtain new rating curves. The simulated flows were selected after calculating the monthly average flow, out of the available flow data, included in the mesohabitat data file, and they were set from these average values.

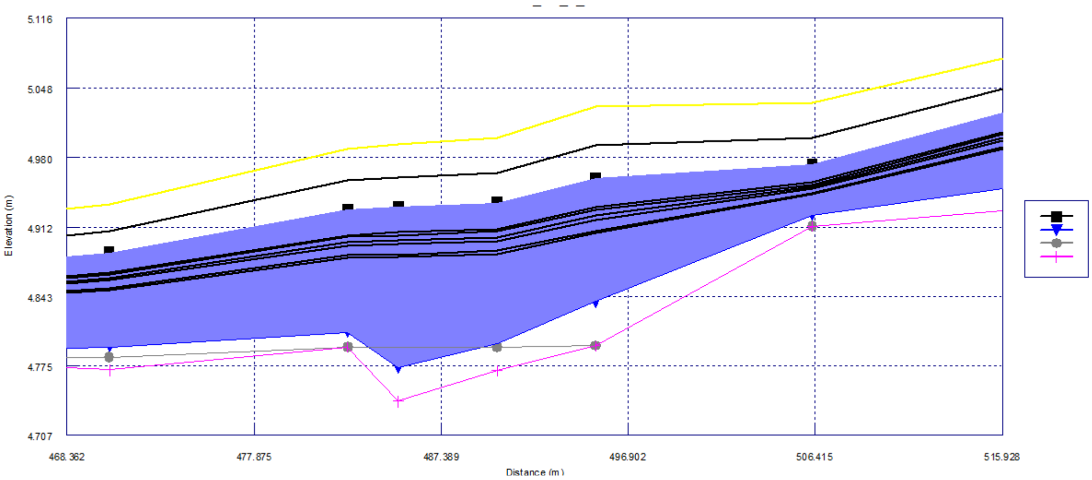


Figure 4. Simulating different flows

After simulating several flows, and saving their water surface profiles, new rating curves were calculated, that could be afterwards compared to the pre-existing ones.

Sensitivity analysis

A sensitivity analysis was done in order to identify the reach for which the sensitivity is not influencing the results, and so to select it as the simulation reach.

After being identified, the obtained results from the habitat simulations were divided so to keep the information regarding the selected reach, that was the one for which the simulation was done.

This sensitivity analysis is based on the existing differences between the hydraulic rating curve, calculated from the Manning's n, and the new calculated WSP-rating curve. The standard step method calculates from the lowest transect towards the upper ones, based on the fact that energy cannot disappear. The simulation of the WSP consists of going through this procedure several times, until the energy losses between the pair of transects are well fixed. Since this process starts from the lowest cross-section, the transects placed downstream are supposed to present a bigger sensitivity to method used, showing thus a greater difference between the two rating curves. As the transects get more distant to the first one, and the calculations are more based on the previous sections' simulated WSP, the effect of this sensitivity becomes lower, making the differences between both curves less important. The aim of this analysis is to identify the transect for which this difference gets lower, place where the sensitivity begins to be not so significant towards upstream. Later, the curves placed upstream should be selected, while rejecting the ones downstream, improving this way the quality of the model.

To measure the sensitivity of the WSP method, the WSP was simulated from the calibration flow, 0.044m^3/s, so it returns the Water Surface Profile measured in the field. Also with the calibration flow several WSP were simulated, but changing the water surface elevation for the first transect, which will trigger an error. The changes for the water surface elevation were carried so that they were 2, 4, and 6 cm upper or lower than the original value measured in the field. By setting this different level of water for the first transect, the simulations of the WSP will be different at the beginning, but getting closer while going upstream. The sensitivity was evaluated as the error occurring at each of the cross-sections, meaning a big error a high sensitivity. Once a transect with an enough small error was identified, the reach toward upstream was chosen to be the one for the habitat evaluation, not to be influenced by the sensitivity

Habitat evaluation

For the habitat evaluation, the chosen rating curve was the one based on the WSP simulation, since, although the difference between both curves were not big, this one seemed to be the best, as for this case the field survey was carried just once, what leads to a great influence of the one measurement, and probably to errors derived from the lack of further measurements.

This WSP-based curve was properly calculated, based on the standard step method, also called backwater step method, which computes “from one cross section to the next by solving the Energy equation with an iterative procedure” (Brunner, 2016), and thank to a sensitivity analysis, the error was minimized, by removing the transects subject to an influential error.

The program also asks for the flow range and increments that should be used. In this case, the highest available flow within the time series was a guide to set the highest flow, while the lowest available flow of this series helped in deciding the value to choose as the lowest.

- Highest flow: 0.2m^3/s
- Lowest flow: 0.01m^3/s
- Increment: 0.01 m^3/s

As to get around 20 intervals, an increment of 0.01m^3/s was used, obtaining this way a total of 19 calculation intervals.

For the habitat evaluation, the whole available information was used, by selecting all the attributes (depth, velocity and substrate). For the habitat evaluation, both the reach Area Weighted Suitability (m2/m) and the reach average Combined Suitability Index (CSI) were calculated. The CSI is calculated by multiplying the habitat suitability (between 0 and 1) for each of the criteria, usually depth, velocity, and substrate (if applied), at a measurement point (Milhous et al., 2012). And, the AWS is calculated by multiplying the CSI at each point by the proportion of the reach area represented by that point (i.e., the width and cross-section weight) and summing over the reach (Milhous et al., 2012).

Point suitability

The Habitat suitability is calculated from the water depth, velocity, and substrate between points and any other user variables that are specified in the suitability curves. And, the suitability of the value of each variable is determined from the selected habitat suitability curves. The suitability varies between 0 (unsuitable) and 1 (ideal). The overall suitability of a point (CSI) is the product of the suitability of depth, velocity, and substrate. This means that if any suitability is zero then the point is unsuitable for that habitat use (Milhous et al., 2012). As the SEFA substrate categories were used, substrate habitat suitability was calculated from the percentage of each of those substrate categories. “The substrate suitability at measurement point is the sum of the suitability for each category multiplied by the percentage of that substrate category at the point. Each measurement point represents a portion of the stream width and area. This is half the distance between the points on either side. SEFA interpolates linearly at 20 points between measurement points. The area of each interpolated point (compartment area) is the width multiplied by the percentage of reach that the cross-section represents.

Habitat suitability for a reach

“The total amount of habitat in the reach is summed for each flow and each point by multiplying the habitat suitability of a point by the area it represents and then by absolute value of the percentage of the reach represented by the cross-section.” (Milhous et al., 2012).

As previously explained, in this study a smaller reach was stablished, in order to minimize the error derived from the sensitivity of the standard step method, so a new value for the AWS had to be calculated, adjusted to this reach.

To this aim, the weights given for each section were recalculated, after removing the rejected cross-sections, so they summed 1, as explained below.

$$W_1 = \frac{W_0}{\sum W_{0,used}}$$

Where,

- W_1: new weight
- W_0: old weight
- $\sum W_{0,used}$: summation of the old weights of the transects included in the reach of evaluation.

Once the cross-sections had a new weight, the Area Weighted Suitability for the selected reach could be calculated as:

$$AWS_r = \sum AWS_i \cdot W_i$$

Where,

AWS: Area Weighted Suitability,

r: whole reach to evaluate,

i: each of the cross-sections included in the selected reach.

This way the AWS for the calibration flow in the reach was calculated.

AWS/Flow

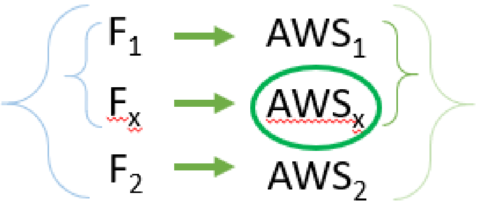
As the program includes a report where the different AWS for each of the transects is shown, for each of the different evaluated flows, the same procedure as explained above was followed, to calculate the AWS of the whole reach of study for each of the simulated flows, but excluding those transects subjected to a sensitivity error.

Time series

As for this study there were no long time series available, the flows measured together with in the meso-scale data of fish sampling were used in the habitat simulation. This period goes from June, 2015 to May, 2017. Actually, as it is shorter than usual, it can show a greater variability, being thus more representative of the flow and habitat changes that naturally happen in the river.

For each of the months a total of 15 values were given, corresponding to each of the 15 stations explained in the “mesohabitat data” section. The month flow was set as the average of these 15 values.

In order to see how the AWS is changing along time, the average flow was compared with the flows used by SEFA while evaluating the habitat. For each of the flows, the AWS was calculated as an interpolation based on proportionality, from the values of AWS corresponding to the more similar flow values.



$(F_2\text{-}F_1)/(F_x\text{-}F_1)=(AWS_2\text{-}AWS_2)/(\mathbf{AWS_x}\text{-}AWS_1)$

$$\frac{F_2 - F_1}{AWS_2 - AWS_1} = \frac{F_X - F_1}{AWS_x - AWS_1}$$

So,

$$AWS_x = \frac{F_x - F_1}{F_2 - F_1} \cdot (AWS_2 - AWS_1) + AWS_1$$

Where,

F_1: the value of flow that was evaluated by SEFA with the most similar value to Fx

F_2: the value of flow that was evaluated by SEFA with the second most similar value to F_x

F_x: the value of the evaluated flow for the month of study in the time series

AWS_1: the Area Weighted Suitability obtained for F1

AWS_2: the AWS obtained for F2

AWS_x: Area Weighted Suitability for each of the months evaluated in the time series

A graph was then displayed, to show the evolution of the Area Weighted Suitability in the reach of study.

4. RESULTS

6. Physical characterization of the river

The obtained box-plots for the width, depth and velocity in the target river reach are displayed in Fig. 3. The variability of flow rates in Yagawa River, together with the fact that the measurements taken in 2015 and 2017 did not cover the whole year, can explain the difference between width, depth and velocity in the different years. These attributes show a downward trend, which is logical, taking in count that in 2015 the data was obtained beginning from June, whose coming months are characterized by transporting more abundant flows. On the contrary, the data taken in the year 2017, between January and May, correspond to the months where the flow is usually lower. The data obtained throughout 2016 are very similar to those obtained for the entire period, given that measures have been taken throughout the year, collecting all the variability that the river presents.

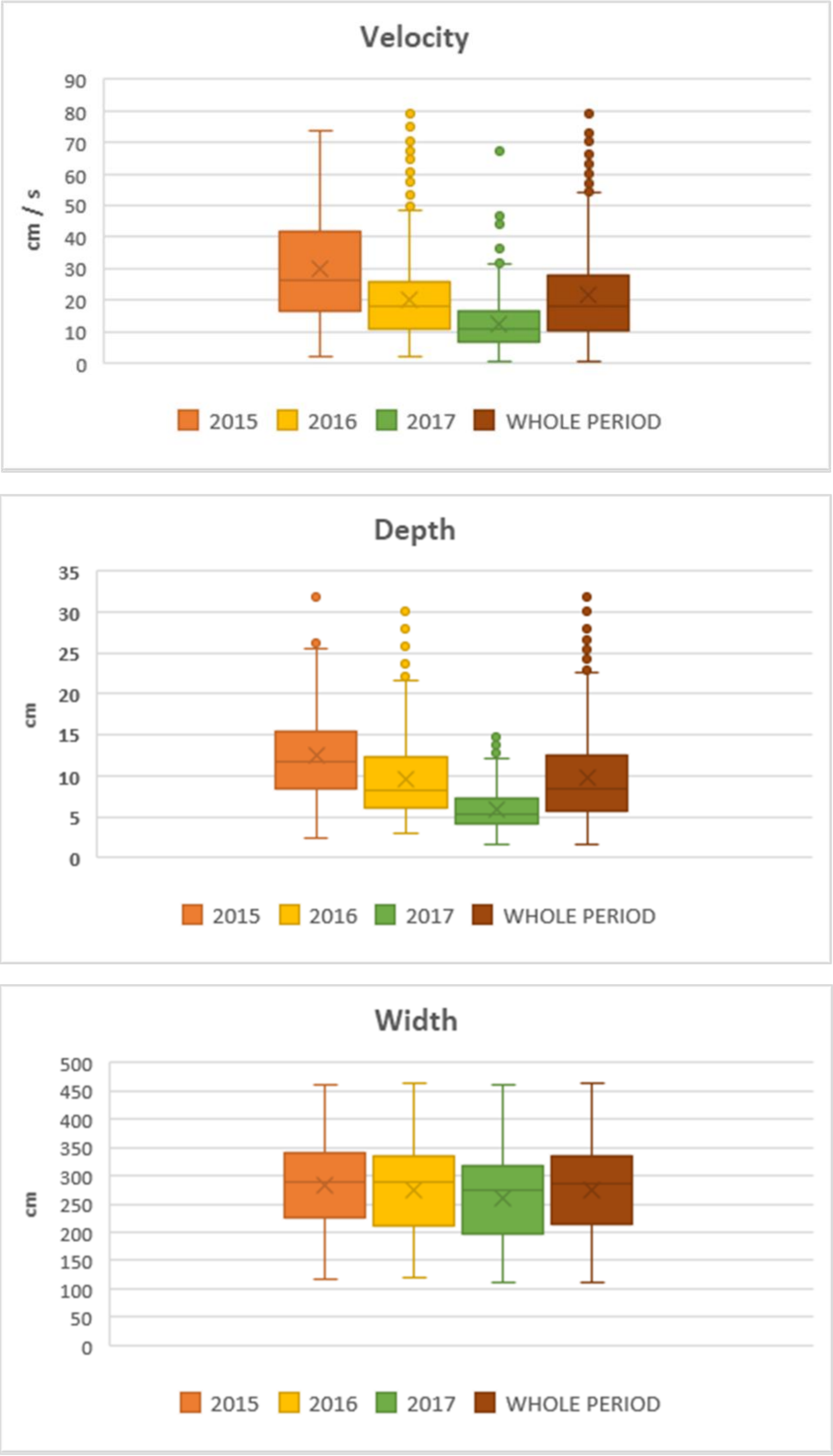


Figure 5. Yagawa River variability. Data provided by Dr. Fukuda, from Tokyo University of Agriculture and Technology

7. Habitat suitability curves

For the elaboration of this model, the microhabitat data were used, for presenting the advantages previously explained.

Mann-Whitney W test

The results of the Mann-Whitney W tests showed a significative statistical difference (used *versus* available) in both depth and velocity with a confidence of 95,0%, as it is explained in the annex of Mann-Whitney test. That means, these two fundamental variables for microhabitat use by the fish were selected in a non-random manner. In other words, the fish does not select different microhabitats randomly, or in similar proportion as they are available; on the contrary, the fish select the microhabitats based on specific behaviour of habitat selection. Even though the histogram showed clear differences between the use and availability, no significant statistical difference was demonstrated for the ordinal variable of substrate, with the Mann-Whitney test. This test is only valid for variables ordinal or continuous; however, in the case of the substrate, as only 5 classes were stablished, it is conceptually ordinal, but it behaves as a qualitative variable. Nevertheless, as the substrate histogram shows, and the results for the Mann-Whitney test for velocity ad depth indicate, the species chooses the microhabitat depending on various variables at the same time. This way, the results demonstrate that, combining the three variables, there is a non-aleatory use of the microhabitats by the fish.

Depth

From now and on, the figures show the standardized frequency or standardized frequency for each of the three microhabitat variables. As shown in the Fig. 8, for depth, the distributions of the presence and absence data are relatively similar, although there is a more abrupt decrease in the presence data as the depth increases from 0.125m. A predominance of the presence data can be also observed for the range between 0.075 and 0.1 m. The maximum depth measured within the reach of study was that of 0.4 m.

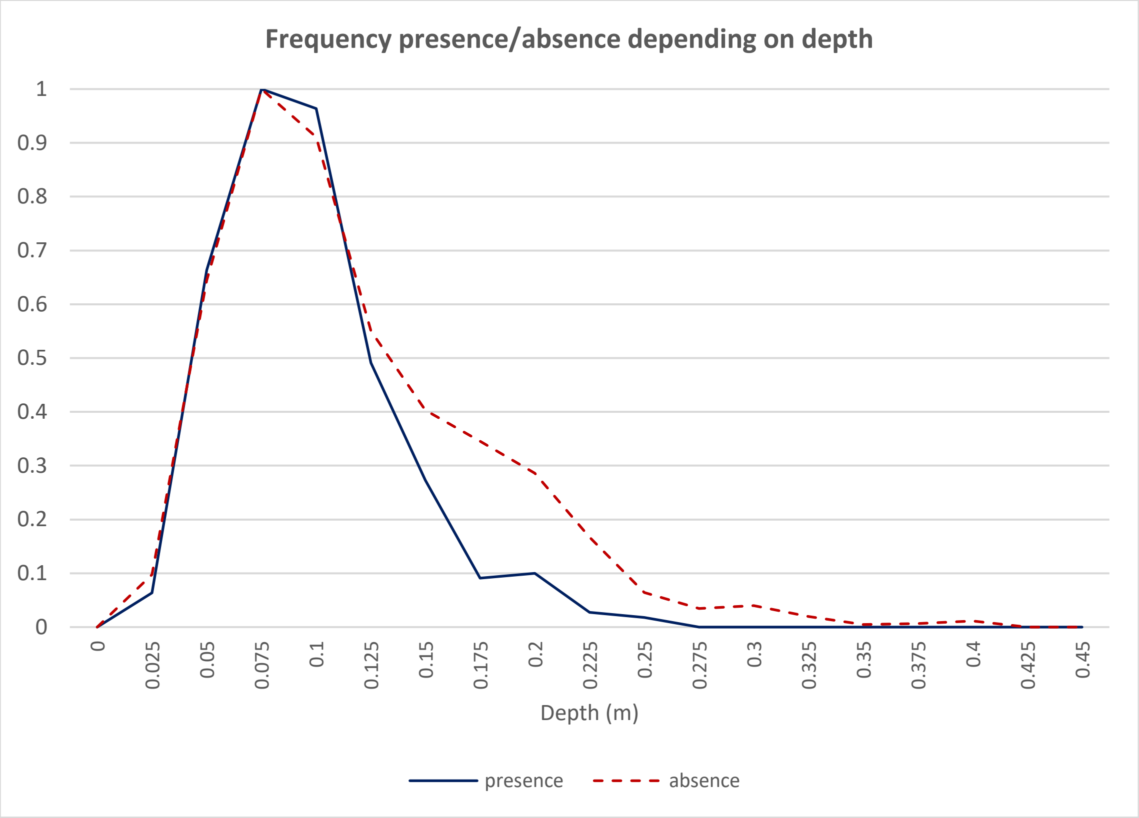


Figure 6. Standarized frequency of presence and absence data, depending on depth

Mean Water Column Velocity

As it is shown in Fig.9, the range in which the presence data are found is much narrower than the one within the absence data extends, which makes velocity seem to be a more restrictive factor to the habitat than the depth in this case study, according to the characteristics of the Yagawa River and the preferences of the adult individuals of *Lefua echigonia* in the same river. The maximum measured mean velocity for this reach of study had a value of 1.068 m/s.

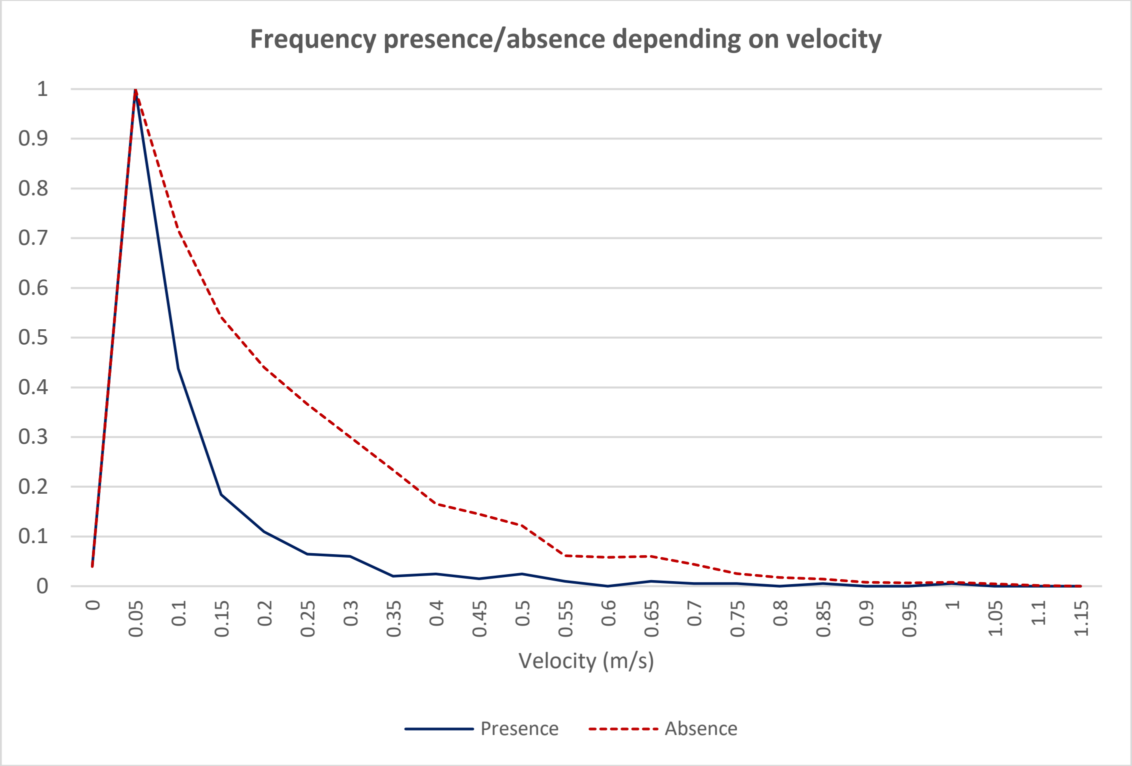


Figure 7. Standarized histogram of presences and absences for velocity

Substrate and vegetation

After the frequency calculations, certain significant differences can be observed between the presence and absence data.

Here is also a comparison of the suitability curve for substrate, between the data obtained as dominant substrate, and with the substrate index. By looking at the graph, we could highlight the importance of having good data, since in this case, the mathematical transformation of the substrate information into a substrate index show a fake of the results, due to the loss of information during the convergence. This is especially notable for the large-sized gravel type, that shows the best suitability regarding the dominant substrate curve, while showing the worst suitability for the substrate index curve. As it is known that the dominant substrate would fit better to reality, this is the chosen attribute to be used in the model. At the same time, *Lefua echigonia* is known to like the large-sized gravel, as it can use the holes in between as a refuge or shelter.

In the same way, a difference regarding vegetation can be found, showing that substrate index without vegetation was not suitable alone in this study. Therefore, the dominant substrate fits better to reality, in which vegetation results to be the best substrate type for *Lefua echigonia*.

Likewise, an analysis of the dataset given as the dominant substrate is included, prior to the inclusion of the vegetation as part of the substrate, thus allowing a better understanding of the influence of the different types of substrate on the preferences of *Lefua echigonia*. By observing the resulting histogram for this data set, more differences can be established between the different types of substrate, and their suitability for *Lefua echigonia*. This way, substrate number 5, corresponding to large-sized gravel type, proves itself to be the best one, while suitability gradually decreases for smaller substrate types.

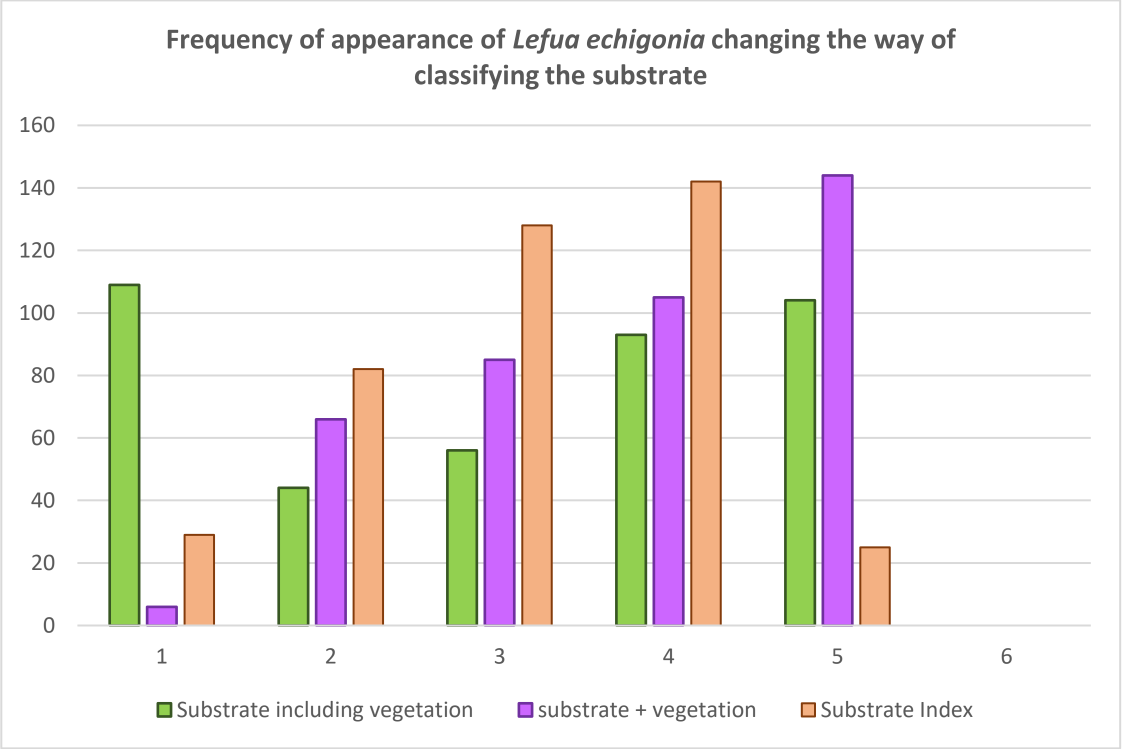


Figure 8. Comparison of the suitability results by using substrate index or dominant substrate, both keeping vegetation apart, or merging with the substrate. Meaning of the codes: 1-vegetation; 2-sand; 3-small gravel; 4-medium-sized gravel; 5-large gravel; 6-concrete.

It is remarkable that, thanks to the use of suitability curves, the problem of reality distortion, due to the substrate index, has been avoided.

The database provided by Tokyo University of Agriculture and Technology presents no data corresponding to substrate type number 6, namely concrete, what makes it work as a non-suitable substrate type. This is usually true, as concrete is an artificial substrate that most of the times turns to be harmful. Nevertheless, in this case of study, concrete was limited to the lateral walls of the channelized reaches, without directly affecting the bottom of the river.

Comparing the histograms of dominant substrate, it is clear that, in case of including vegetation as a part of the substrate, the highest suitability it is reached for this type of substrate; on the contrary, when the dominant substrate is analyzed keeping the vegetation apart, the best suitability occurs for the large-sized gravel. Looking at the curve including vegetation in the substrate, a quick decrease of the suitability takes place, to later increase as the substrate size does. As opposed to that, the curve keeping vegetation apart from substrate shows a low suitability for vegetation, which would lead to some problems in the model, as it is actually a favoring substrate to *Lefua echigonia*. In this last case, the tendency observed for the rest of the substrate types is similar, showing how the suitability increases together with the substrate size. However, the difference of suitability between the diverse groups of substrate can be better observed in the curve keeping vegetation away from the substrate, as when merging them together, the major part of the suitability that goes to the vegetation comes from the large gravel, resulting into a equalization of the suitability for medium-sized gravel and large-sized gravel.

Therefore, it is possible to conclude the importance of designing the work procedure, and the format of the data to be used, since the existing differences can greatly affect the final results of the study.

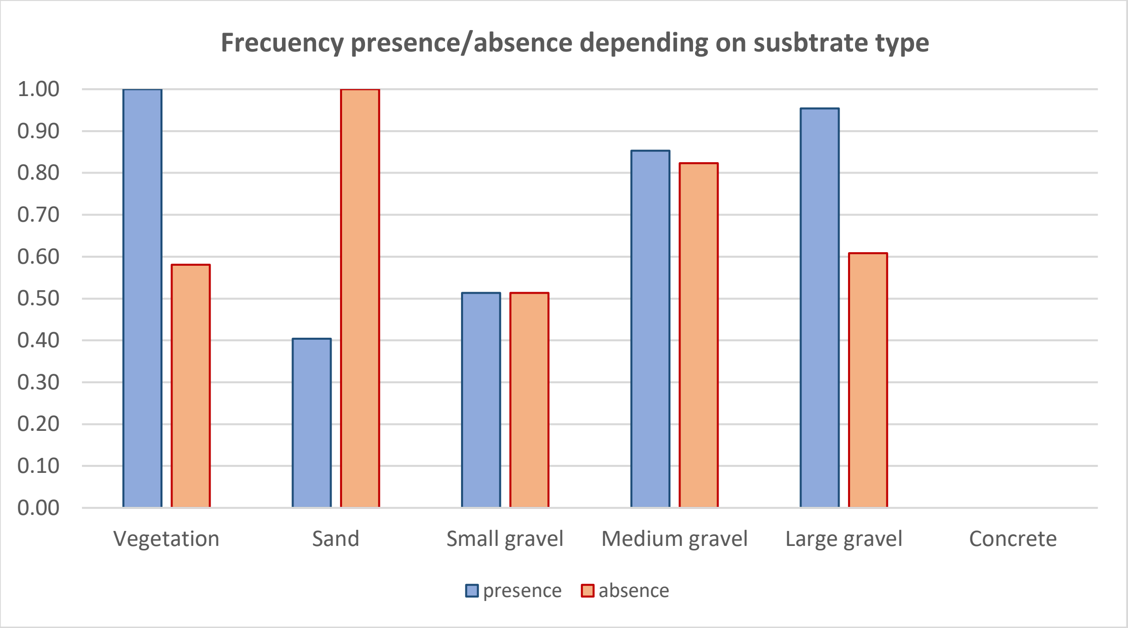


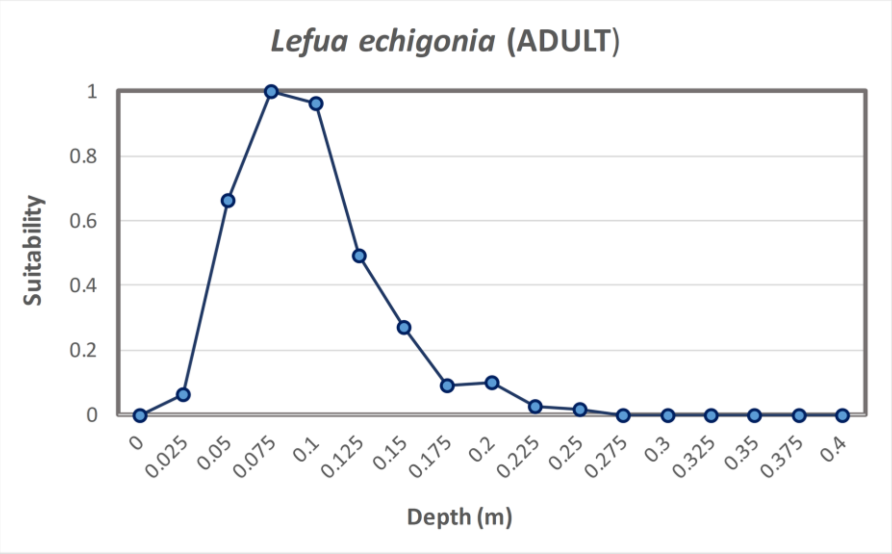
Figure 9. Presence/absence comparison regarding substrate categories, calculated as the ones used in the suitability model

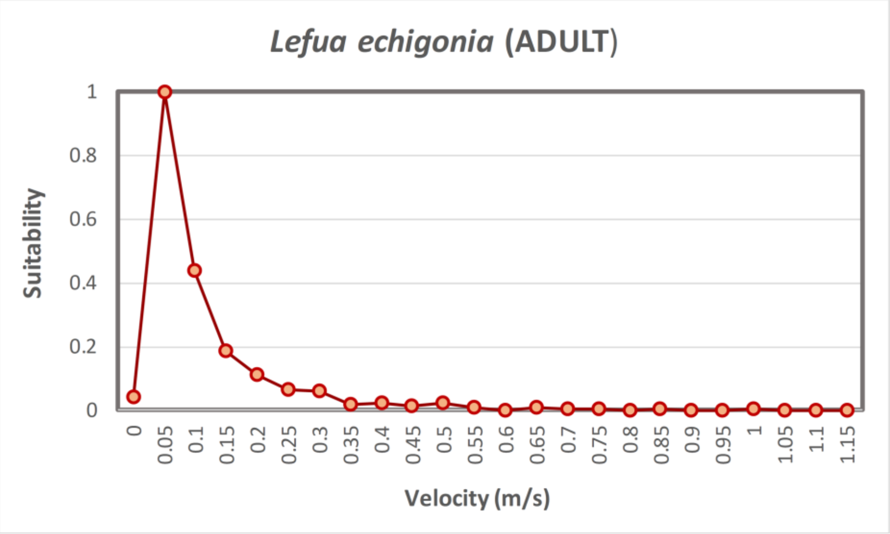
If we observe the distribution of presence and absence data, standardized to offer a better comparison, it can be determined that the most suitable substrates are vegetation and large gravel, as previously mentioned, presenting a proportion of presences significantly greater than absences. On the other hand, for the sand, a large concentration of absence data can be observed, in detriment of the presence data, which indicates that this type of substrate is non-convenient for *Lefua echigonia*. This could be explained by the fact that this species uses the holes between the large gravel as a refuge, and a high presence of sand could collapse these spaces, preventing them to be used by the fish. Regarding the small gravel and the average gravel, no significant differences can be highlighted, following a similar distribution for presence and absence.

The codes explained in Table 3 are the ones used in the model.

Table 3. Substrate codes

Code	Substrate ype	SEFA categories
1	**vegetation**	vegetation
2	-	mud
3	**sand/clay**	sand
4	**small gravel**	fine gravel
5	**medium gravel**	gravel
6	**large gravel**	cobble
7	-	boulder
8	**concrete**	bedrock





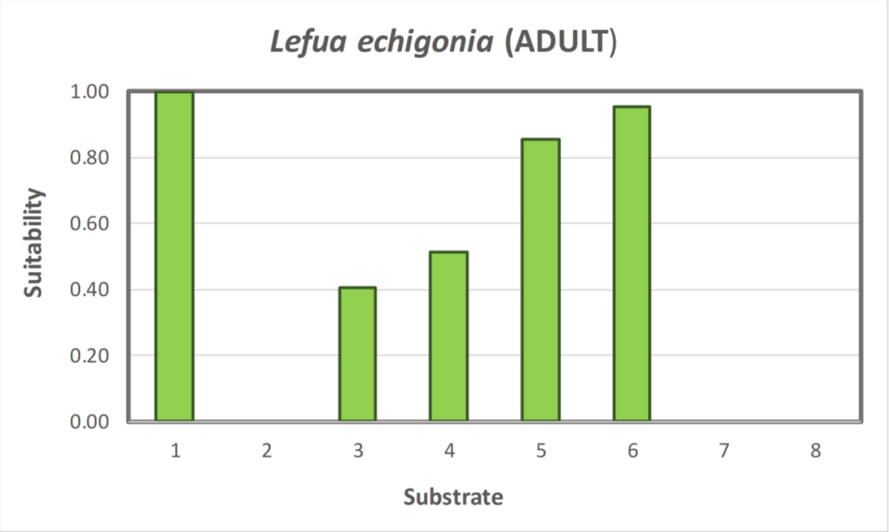


Figure 10. Habitat Suitability Curves of three microhabitat variables used in the physical habitat simulation of the Yagawa River.

After choosing the curves to be used in the physical habitat simulation, and observing them carefully, the best ranges for velocity and depth, as well as the most suitable substrate for this study case can be identified. Likewise, the presences of *Lefua echigonia* are mostly placed in the depth range between 0.025 m and 0.175 m, reaching the maximum suitability at a depth of 0.075 m, standing until the level of 0.1m is reached, and decreasing sharply, as the frequency did.

In the same way, an acceptable range of mean velocity can be established, being in this case very restricted, and located around 0.075 m/s (i.e., the interval between 0.05 and 0.1 m/s), value for which the suitability is 1, but sharply decreasing until reaching a suitability of 0.2 for a velocity of 0.15 m/s, and getting worse as the velocity increases.

In terms of substrate, as mentioned above, it seems that vegetation and large gravel are the most appropriate types, perhaps because they can be used as a refuge. Whilst, sand is understood to be a harmful type of substrate, probably ow to the fact that it is capable to fill the existing holes in between the large-sized gravels, preventing them from being used by *Lefua echigonia*. The small gravel and the medium gravel do not seem to have a significant influence, although in this case the use coincides with the availability, and therefore the medium-sized gravel will be wider used by the species.

It is also remarkable the fact that, most of the times, fishes need from a specific microhabitat characteristics, combining velocity, depth, vegetation and substrate, among other attributes not considered in this study, and that their evaluation as independent variables may lead to a loss of functionality.

8. Generalized Additive Models

Microhabitat scale

Despite the fact that these data regarded only adult individuals, this data group presents different advantages over the mesohabitat-scale one. The most important difference is that the data were collected at a microhabitat scale, what makes them suitable for a microhabitat study, which is the aim of this work. At the same time, additional information regarding dominant substrate for each point was included, letting this way avoid a fake of the data that could have occurred in the previous case when using the calculated substrate index.

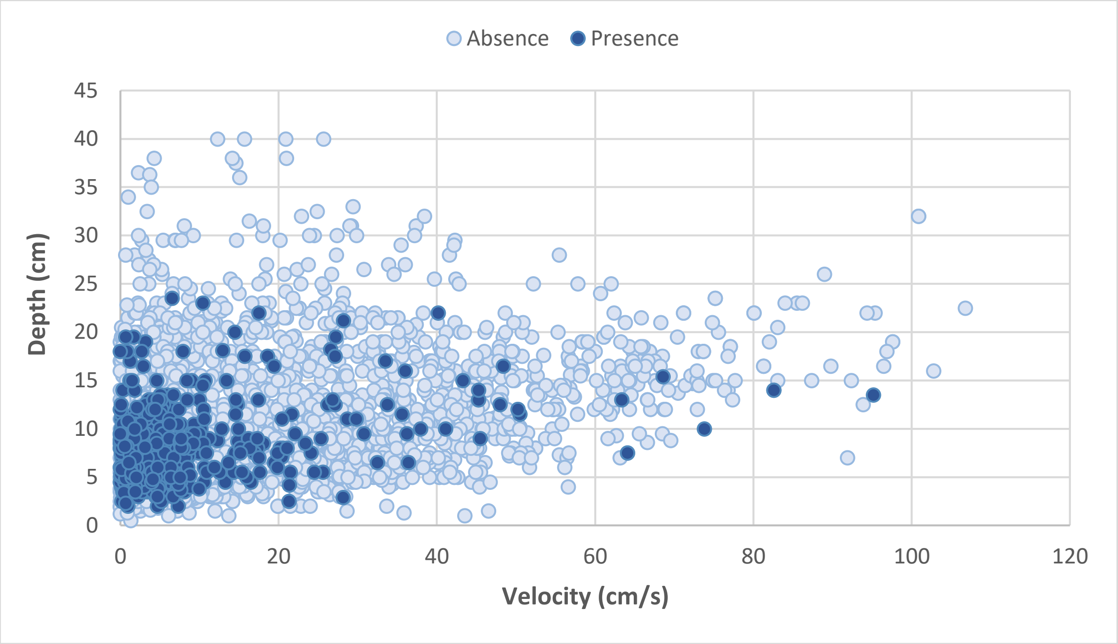


Figure 11. Presence/absence microhabitat data distribution for depth and velocity

Fig. 12 shows the new distribution of the presence and absence data, letting discover a similarity between them, even if the presence data were more constrained for both velocity and depth. After carrying out some trials, it was not possible to get a satisfactory GAM, with a high performance (fitting), probably because of a great overlap of the presence *versus* absence data, so a model based on habitat suitability curves was developed.

Mesohabitat scale

After carrying out several trials with the mesohabitat data, as explained previously, the overlap of the presence and absence was observed, making it impossible to develop a good GAM for this case of study. In the coming pages, a comparison between the presence and absence data of *Lefua echigonia* for the different stablished periods is presented.

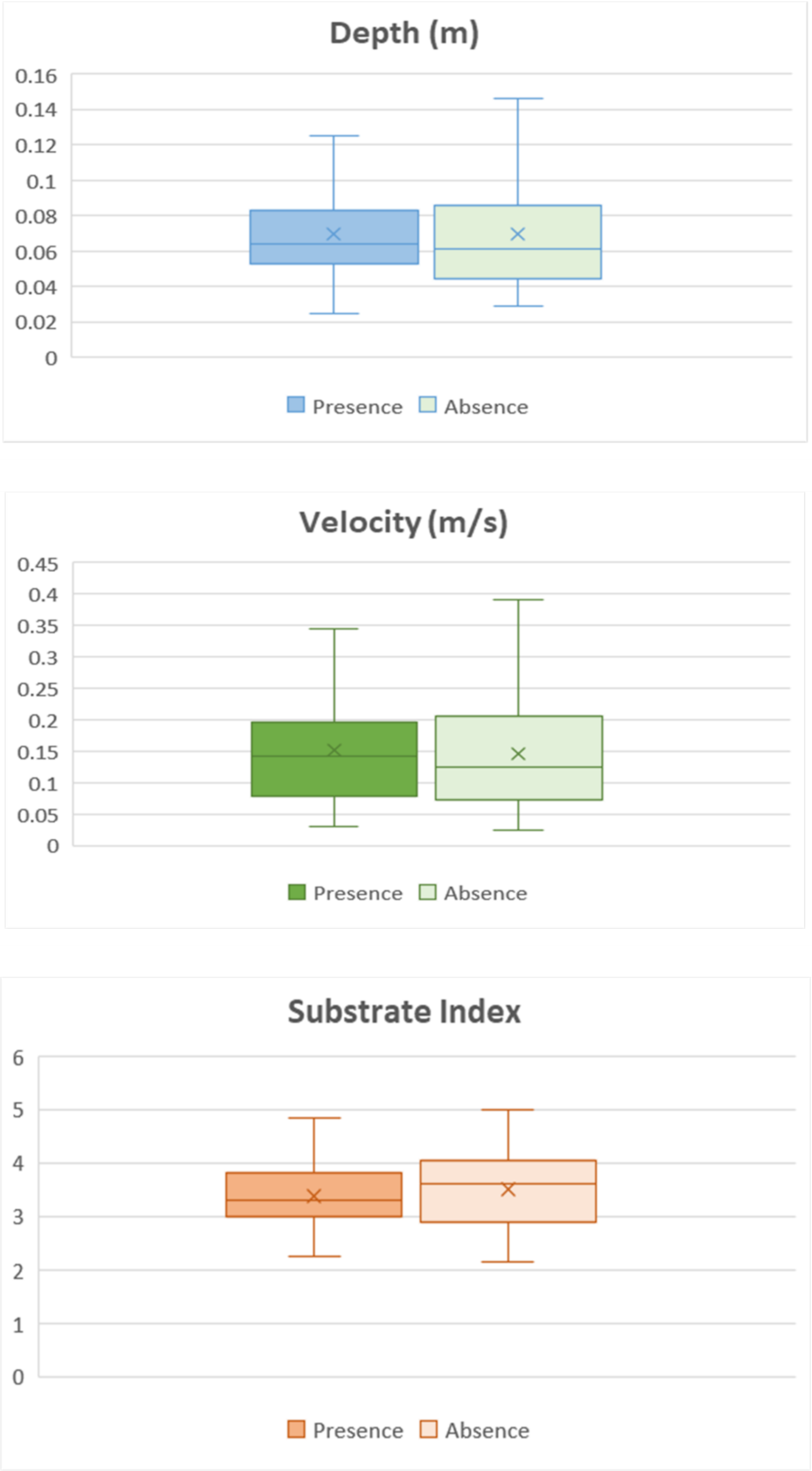


Figure 12 Presence/absence data distribution of Lefua echigonia between April and June, regarding depth, velocity and substrate index

Observing the graphs displayed in Fig. 13, it is possible to confirm that the distribution of presence and absence data is nearly the same for this period, being in the three cases slightly wider for the absence data, without being able to establish significant differences that could translate into a good adjustment of the GAM. This period was selected to be representative for the alevins, since April was identified as the spawning season.

Below it is shown the comparison of data for the period between July and December.

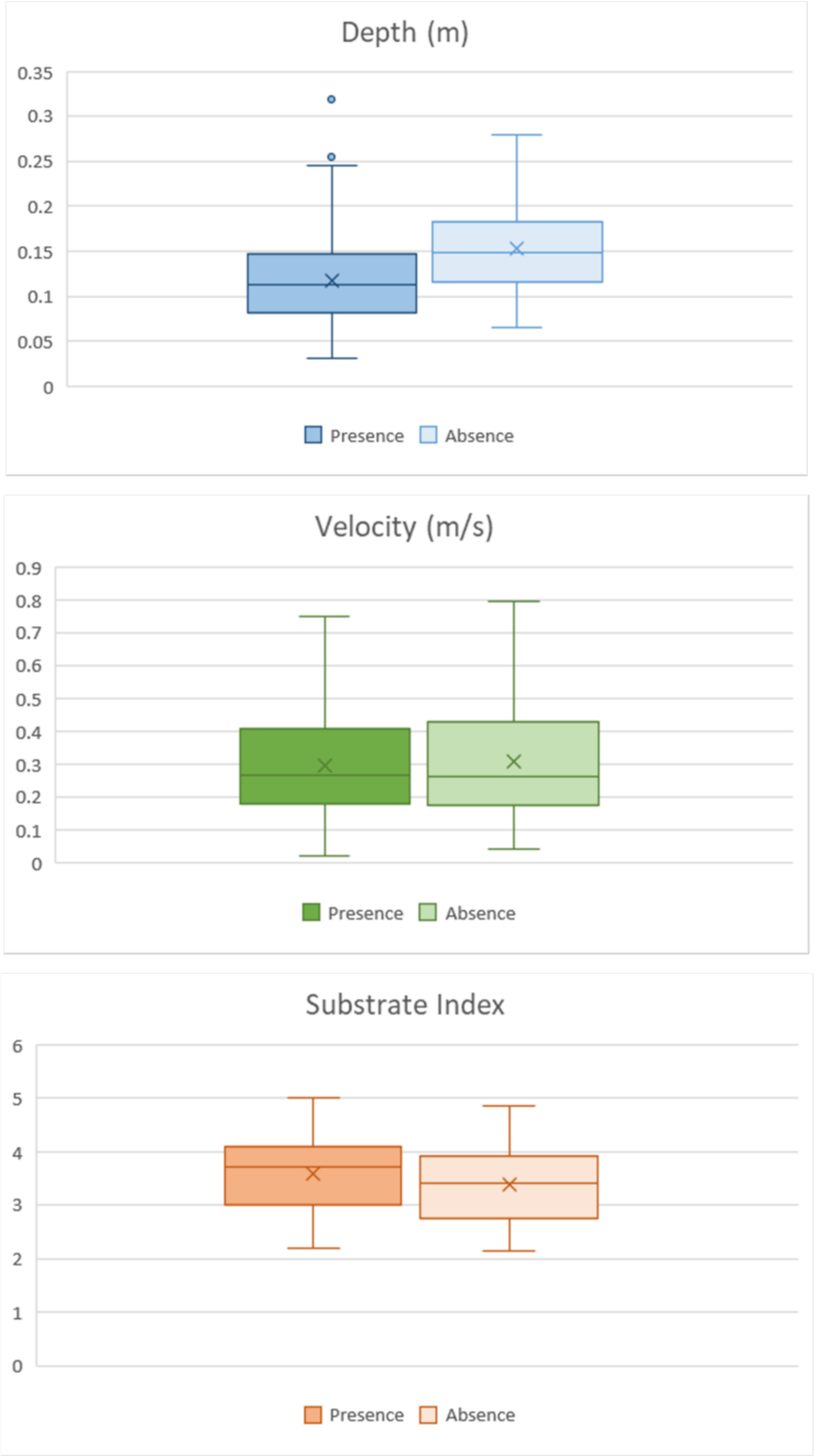


Figure 13. Lefua echigonia's presence/absence data distribution between July and December, regarding depth, velocity and substrate index

In this stage a slightly more differentiated distribution can be observed, especially regarding the depth data, showing a slight preference for shallower locations. This period was stablished as representative one for the juvenils.

Below it is shown the comparison of data for the period between December and March.

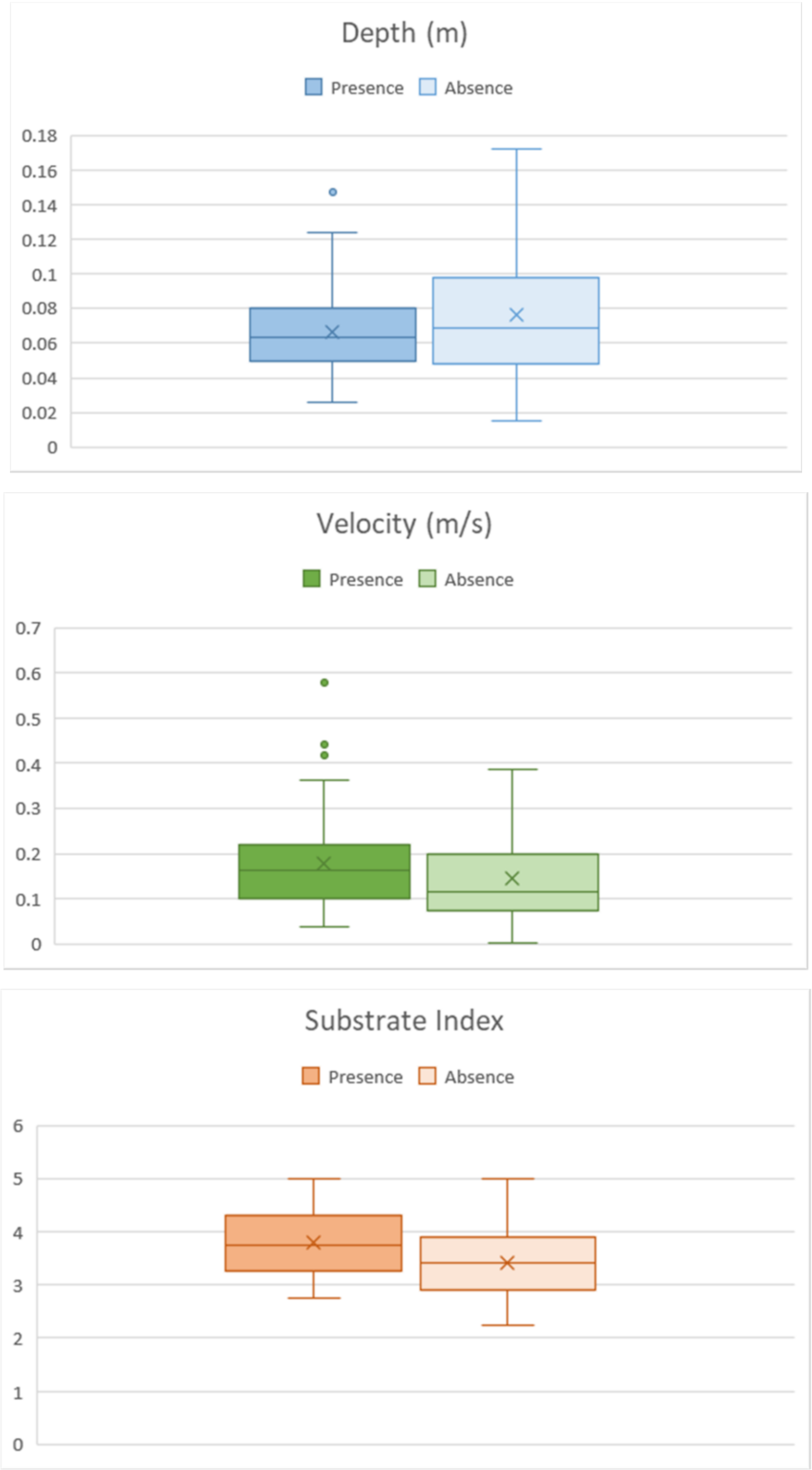


Figure 14. Lefua echigonia's presence/absence data distribution between December and March, regarding depth, velocity and substrate index

Again, a greater difference for the depth attribute can be observed, being in this case the widest difference, both for depth, velocity and substrate index, what leads to the conclusion, previously found (Matsuzawa et al., 2017) that the adults are the most selective individuals of the species. This justifies the fact that the study focuses in adults, as the microhabitat data were available just for this life stage.

The velocity seems to be, in all cases, the most limiting characteristic, obtaining in all cases a smaller distribution range for the presence data than for the absence, while the presence/absence distribution for the depth and the substrate index is much more similar. After seeing these results, it seems that it is not possible to develop a good generalized additive model out of this data, maybe due to the fact that the data were taken at a mesohabitat scale, which may be blurring the ecological information, avoiding its utilization in certain studies.

9. Habitat evaluation

Hydraulic modelling

Calibration flow

During the survey, the whole set of 108 transects resulted into an average flow of 0.046m3/s, but, as it is shown in graph of Fig. 16, the data were very scattered, so a new calibration flow was stablished.

To set the calibration flow, the data from transects 8, 21, 35, 42, 67, 83, 98 and 99 were removed, as they presented extreme values that can strongly affect the average value, removing this way an eighth part out of the 108 transects. Thus, the calibration flow was the one calculated as the average of the 100 leftover transects, being 0.044m^3/s. As the graph shows, the error of the data is quite big, which would probably be due to the fact that the measurements were carried in a deficient way, to accomplish the whole survey within the limited time. Less points than the recommended were taken, since the measured ones represent more than the 10% of the whole flow for the section, leading to greater error. At the same time, the survey was carried with a lower flow, that can also translate into a bigger error.

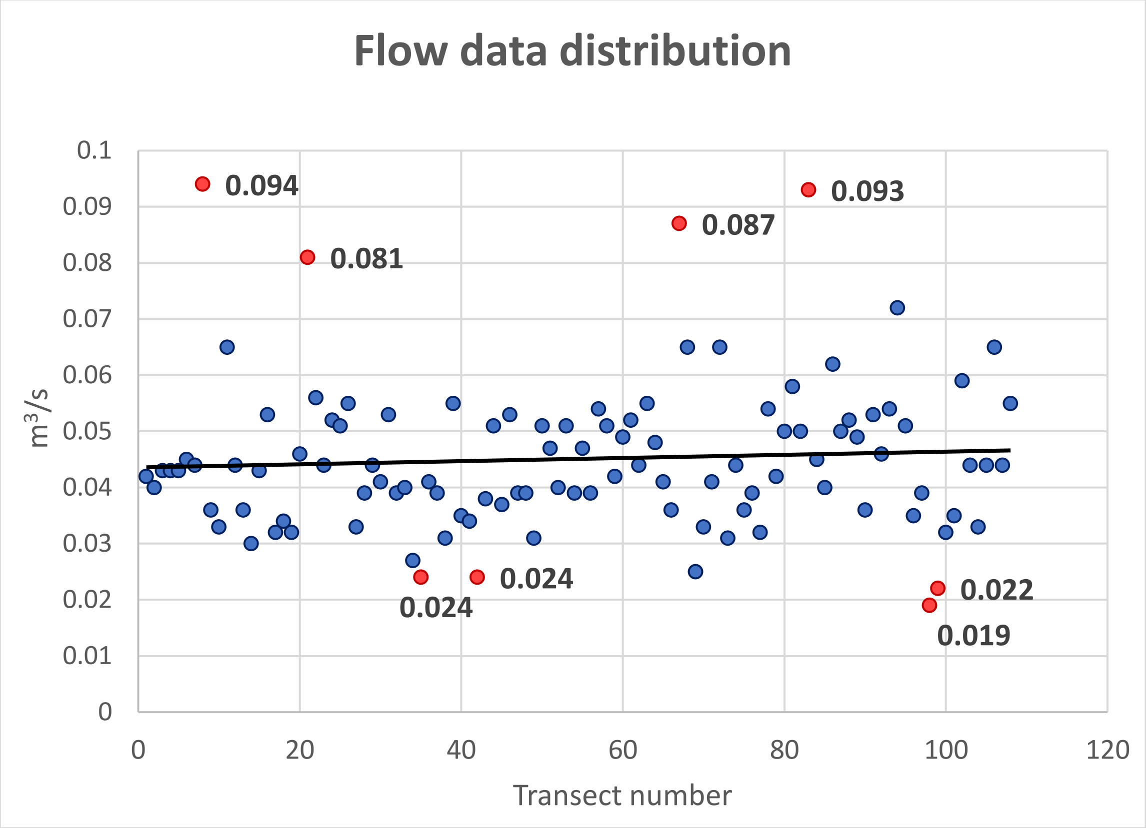


Figure 15. Measured flows

Roughness coefficients

After checking the roughness coefficients, a great jump was observed from transect 8 to transect 9, and as this cannot be well simulated, the model was cut, so it began from transect 9. Also great values of Manning's N could be shown from transect 76 to transect 79, so transect 76 was selected as the last one. Therefore, the total length of the reach taken for the hydraulic simulation reach was of 836,8m, what represents a 62,25% of the total measured length, of 1338 m, which corresponded to the total length of the river. This is still representative of the river, as it cover a larger percentage than the one usually taken for this sort of studies.

Water Surface Profile

In order to calculate the Water Surface Profile (WSP) rating curve, the average monthly flows were simulated. The obtained flows from the mesohabitat file were the ones shown in Table 4.

Table 4. Monthly flow average, calculated from the mesohabitat data given by Tokyo University of Agriculture and Technology

Month	**Average flow (m^3/s)**
January	0.0285
February	0.0172
March	0.0186
April	0.0246
May	0.0228
June	0.0273
July	0.0663
August	0.0985
September	0.1754
October	0.1563
November	0.0902
December	0.0587

This way, a total of 6 lower flows, together with 6 higher flows than the calibration flow, of 0.044m^3/s (supposed to have been flowing during the survey), were simulated.

Sensitivity analysis to the WSP method

During the sensitivity analysis, the transect number 12 could be stablished as the one for which the sensitivity to the errors in water level in the lowest transect was not detected, therefore the cross-sections from 12 and above were selected to evaluate habitat in the last phase of the study. For this purpose, the transects selected for the reach were renamed as XS-n, being n the new number assigned to each of them, beginning from transect 9 as XS-1. The sensitivity analysis is here explained with the following figures.

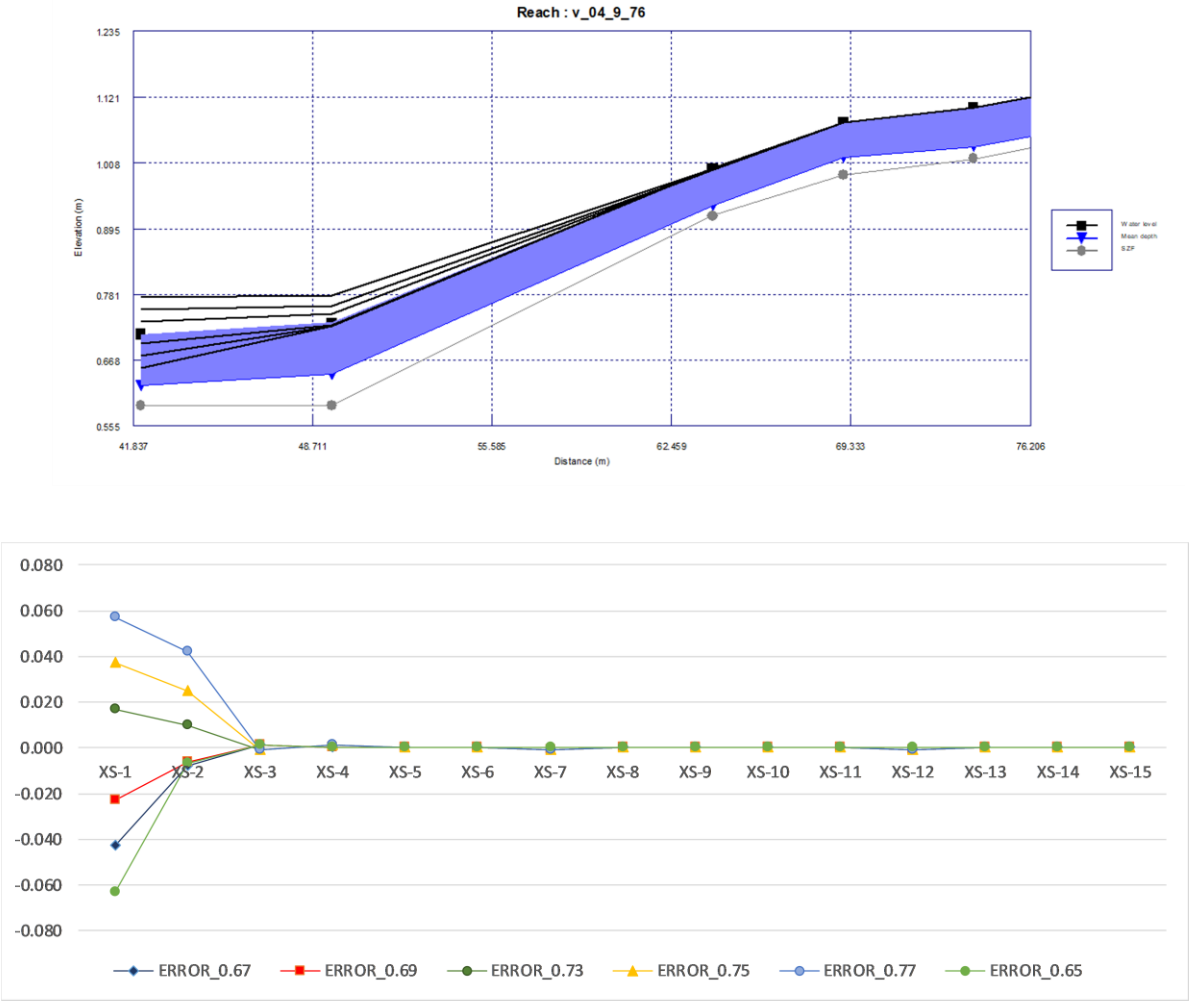


Figure 16. Sensitivity analysis based on the potential error in the water surface elevation (WSE) at the first transect.

In the two plots, positive and negative errors can be observed, since the value of water surface elevation was set both higher and lower than the measured value. The model was simulated (standard-step calculation method) to observe the propagation of negative and positive errors of the water surface towards the cross sections upstream.

Looking at the graph displayed in Fig. 15, we can see how the absolute value of the error for the simulated WSP decreases until they come together in the transect number 12, renamed as XS-4. Thus, the cross section 5, corresponding to the measured transect number 13, was chosen to be the beginning of the reach for which the habitat suitability would be evaluated, since the sensitivity to these water surface level fluctuations, or to measuring errors, is supposed to decrease while moving upwards in the calculation.

This allows us getting a model with a really high representativity of the river, using a reach of 805m out of the total 1338m (60,16%).

Habitat evaluation

After calculating the Area Weighted Suitability (AWS) and the Combined Suitability Index for the selected reach, without the rejected transects that still presented sensitivity, the results obtained for the calibration flow of 0.044m^3/s were 0.293m^2/m for the AWS, and a total of 0.108 for the CSI. These are the values supposed to be true for the day the survey was made, this means the week from 28th May to 3rd June, 2018.

Area Weighted Suitability vs. flow

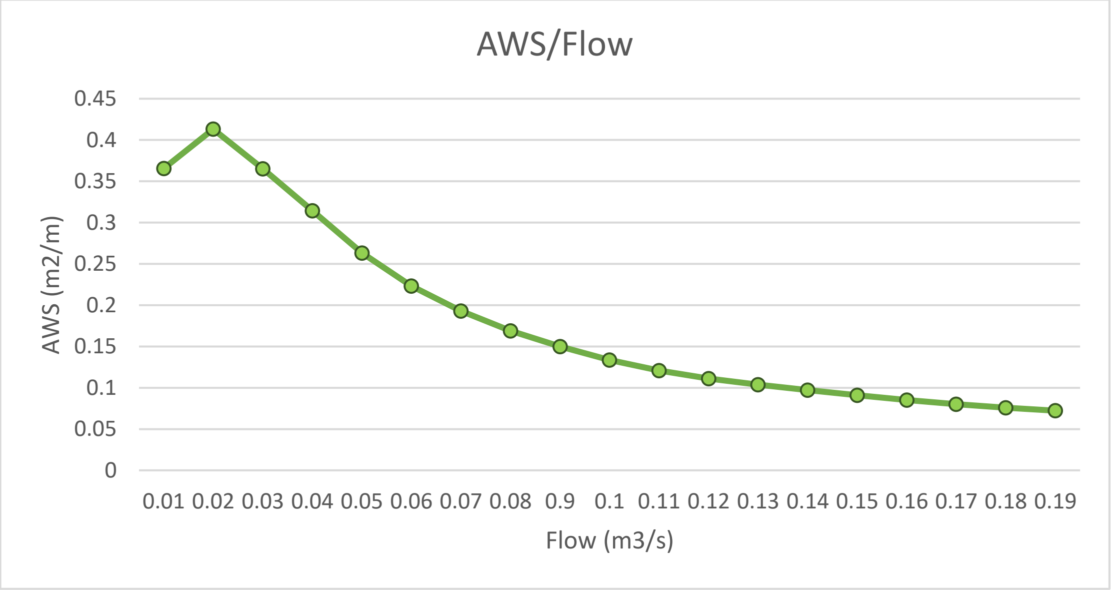


Figure 17. Area Weighted Suitability changing with the flow

Regarding the change of the habitat suitability with the different flows, it seems to reach the best value for a flow of 0.02 m^3/s, for which the AWS representing the whole reach gets a value of 0.41 m^2/m, for descending to the lowest value, of 0.07 m^2/m, obtained for the highest simulated flow, of 0.19m^3/s.

At the same time, it can be highlighted that, when the flow is higher, small increments do not translate into a quick loss of available habitat, but when the flows are closer to the optimum one, the differences are sharper, which can mean either that the optimum range for *Lefua echigonia* is too small, or that the taken microhabitat preferences do not cover the whole range.

By displaying the AWS for every transect with the different flows (Figure 19), it is clear that the value for the habitat suitability changes on a different way, probably depending on the condition of the transect, namely whether it is covered by concrete or not. As Figure 19 shows, the cross sections placed upstream get a smaller AWS for higher flows, while higher values can be observed for the cross sections placed downstream in the same condition, and vice versa.

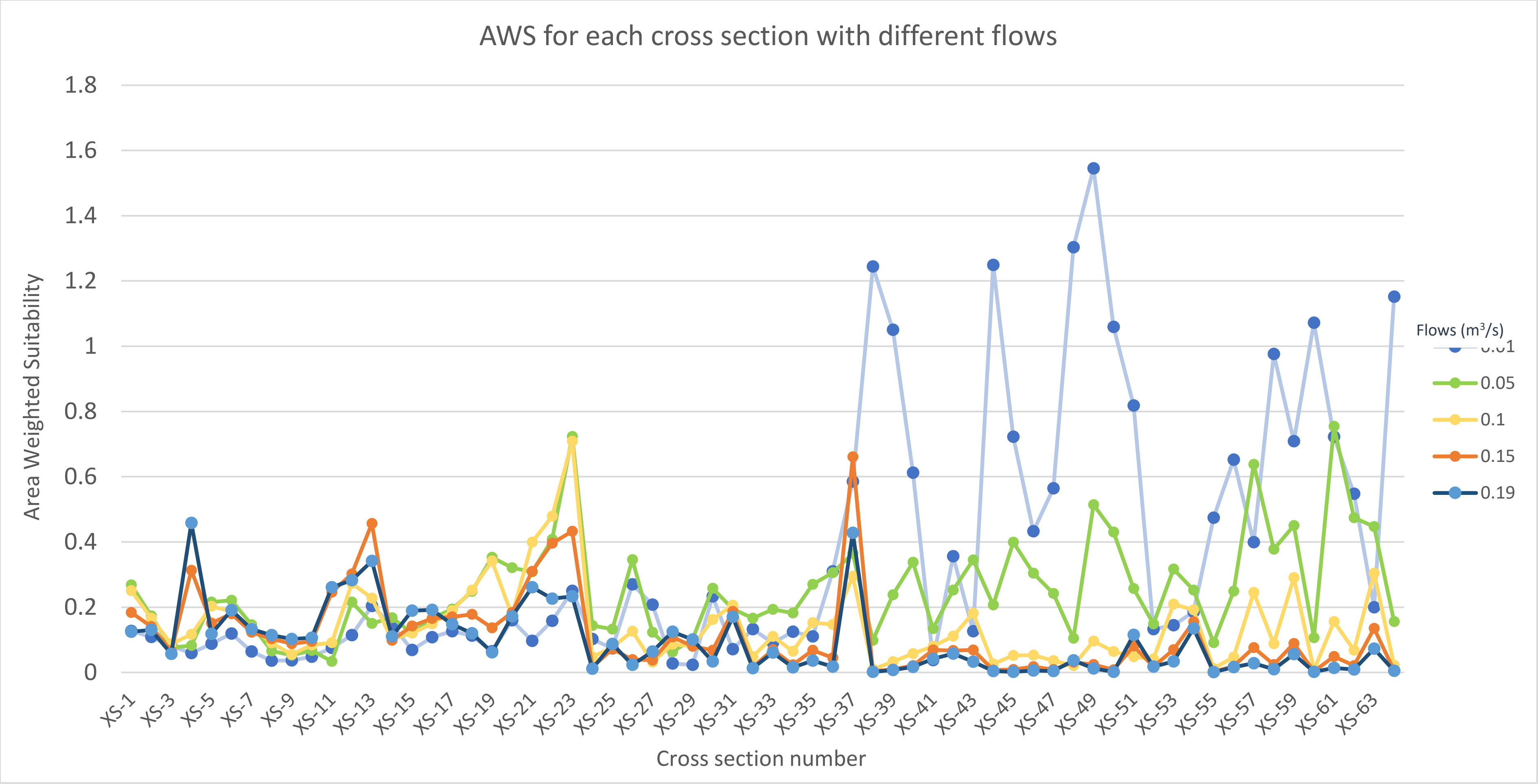


Figure 18. Local AWS changing with the flow

Habitat time series

After plotting the evolution of the Area Weighted Suitability (AWS) along the time series, it seems clear that the best conditions for *Lefua echigonia* adults are likely to occur during the period between January and July, being the worst months the ones between July and December. This could happen either because the highest flows affect *Lefua echigonia* in a negative way, causing critical velocities and depths that are unlikely to be used, or because the sampling was made with a low flow than could be faking the results. When the whole microhabitat data is collected with very low flows, high flows could seem to be negative, but sometimes this is due to the fact that the flow rank for the survey was too narrow. In this case the survey was carried monthly, ergo the results should be adjusted to the real preferences of the fish.

In the graph, the lowest value for the AWS is 0.074, in September, 2015, which is still far form 0, letting the species survive even under the worst conditions. On the other hand, the best observed value is the one corresponding to February, 2016, with a flow of 0,02m^3/s and a weighted suitability of 0.412. This means that for the range of flows, the value of suitability can improve so the lowest one can get almost 6 times better while decreasing the flow.

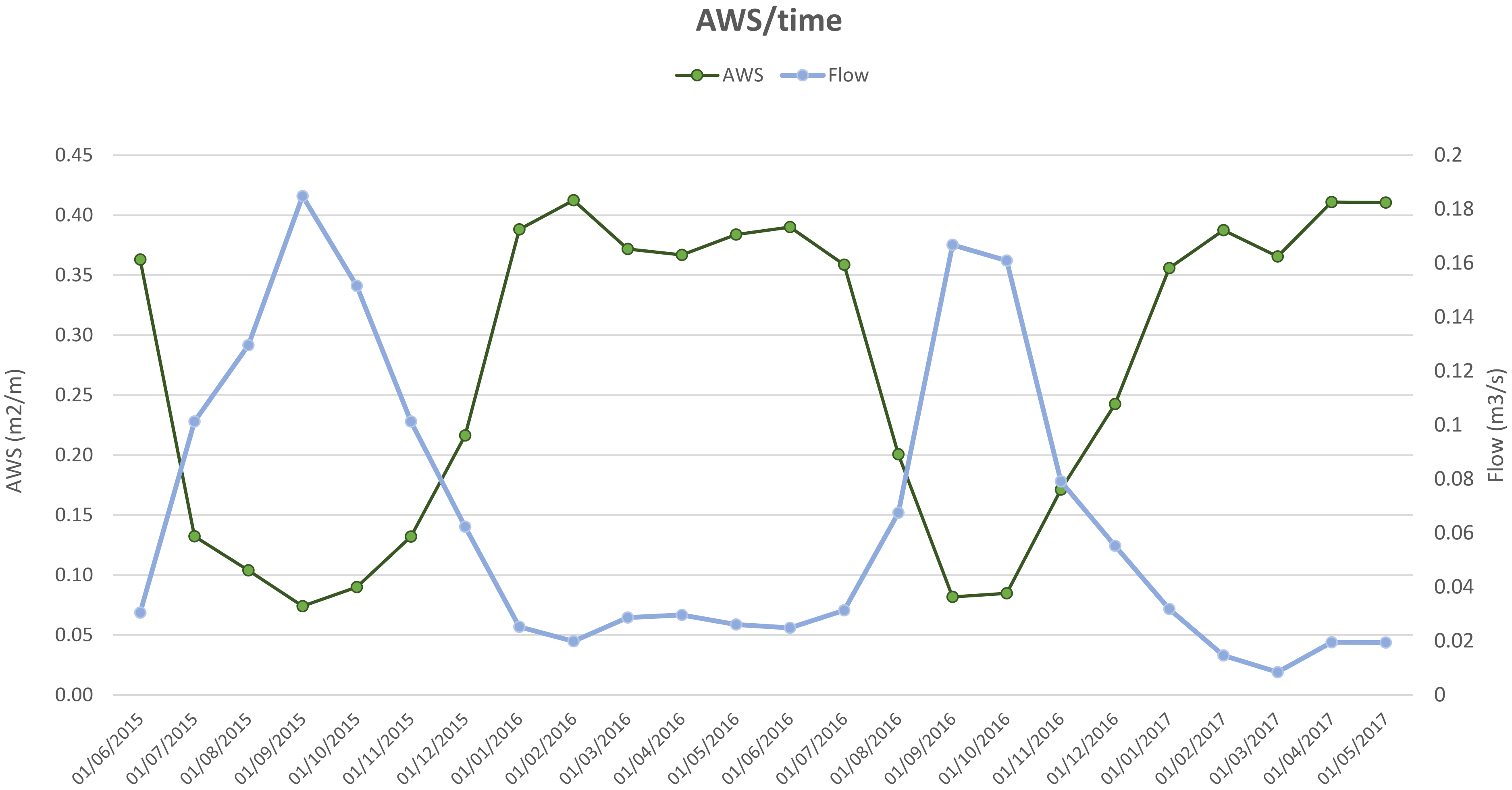


Figure 19 Area Weighted Suitability calculated for the period between June, 2015 and May, 2017.

When the habitat suitability curves are working fine and not faked by a small-ranged measurement, this could be explained because, as most of the river is under channelized conditions, the increment of the flow could come along with high velocities and depths, that seem unlikely to the species, but without leaving quiet areas on the bank sides, that would probably exist under natural conditions, where vegetation could provide a good refuge, while slowing the velocity.

In this case of study, the best managing alternative to keep the best possible conditions in order to protect *Lefua echigonia* would be trying to keep the flow at lower values, during the analysed season, between April and June. Since the flow is not directly affected by human activity (the regulation is not relevant, so far), the key action to enhance the river habitats would be the removal of the concrete from the banks, by either removing it and naturalize the river channel, or covering it with a substrate that would allow the growth of vegetation. In this direction, some works adding a suitable substrate and a fastening mesh, such as coco fiber, could be done, in order to provide a suitable substrate where the native vegetation could root and grow.

An important factor that may have a huge impact on the habitat is concrete lining on the channelized reaches, that affects not only the substrate, eliminating the refuge, but also velocities, making the impact of heavy rains larger, by transporting the whole flow downstream, preventing it to percolate into the ground, due to the lack of vertical connectivity. This may result into critical conditions for *Lefua echigonia*, since, as this study shows, high velocities specially affect the individuals in a negative way, by degrading the habitat just with small increments over the optimal value, as shown in the habitat suitability curves developed in this work. The cover of concrete also prevents vegetation from growing in the banks, preventing a potential refuge to be formed, that could be very useful in order to create areas with lower values of velocity.

5. DISCUSSION

Even with the limitations and difficulties of being in a foreign country we could successfully accomplish the study, by completing the different objectives we set at the beginning. We measured a great part of the river, and properly calibrated the model, using the standard step method, with the water surface profile module available in SEFA. We obtained a highly representative model of the river, covering more than a 60% of the total length of the river for the habitat, which is significantly higher than the proportion covered by a normal study.

In order to complete a very representative study reach, we considered the alternatives we had, and since we had a limited time of one week to do the survey, we had to make a balance to represent more the longitudinal variability (i.e., more cross-sections or transects) or the transversal one (i.e., with more points per transect). As the river is somehow similar to a channel, and the transversal variability is not remarkable, we decided to focus on measuring a higher number of transects, instead of measuring too much detail for each transect. Some other limitations took place regarding the survey, since the period of my grant in Japan coincided with the irrigation season, which made it dangerous to measure the first target river (Mie prefecture), and forced us to find another site (in Tokyo); however, the coordination between the teams in Spain and Tokyo allowed me to make a complete study based on the data from Tokyo.

The target species *Lefua echigonia* is an endangered endemic species, which can be a key of the biodiversity protection. By using data referred to this species we could see how the suitability changes along the river with different flow conditions, and we can better understand how to improve the habitat conditions in order to maintain the biodiversity, currently affected by significant pressures.

The habitat suitability curves (univariate habitat suitability model) were obtained from the microhabitat data set, using only the information referring to presence, obtaining this way a use curve. Since the presence/absence data were taken in the same river of the study, the use of these curves is justified, even when the GAMs would have caught underlying relations between the different variables, making this way a better estimation of the suitable habitat. Habitat suitability curves have thus proof themselves to be useful as a suitable alternative when Generalize Additive Models do not perform well; the GAMs have been successfully used in previous studies, but they did not fit well in the case of the available database. The curves present the advantage of being really transparent, making it easy to understand, and to explain to non-expert people, which is actually very important; on the contrary, with the use of GAMs it is difficult to know how each factor affects the model, and review if there is any kind of mistake. Although the results of habitat simulation were reasonable and satisfactory, it would be advisable to carry out further studies, in different rivers showing a greater variability, in order to evaluate more widely the preferences of *Lefua echigonia*.

As the microhabitat data was just available for adult individuals, the habitat suitability curves were only calculated for this group, that, according to previous studies, seemed to be the most selective.

Regarding generalized additive models, the problem of the data it is probably due to the presence data overlap with the absence data, fact that may not allow the model to make good predictions. For the mesohabitat data set, even if this problem would not have existed, a possible difficulty would have occurred, due to the blurring that exists when using mesohabitat scale data in a microhabitat study.

As for calibration, SEFA offers the possibility to calculate the water surface profile of the reach, from an estimation of the water surface elevation at the first cross-section (this means the one downstream), calculating towards the coming transects. This is the classic hydraulic method of the standard step method. An alternative method, very common in studies of physical habitat simulation, requires more field surveys with different flows, to confer a better quality to the model. After comparing the hydraulic rating automatically obtained from the field data, and the one obtained from the different WSP simulated, we could observe that they were actually very similar to one another. Even though, the WSP-rating curves was chosen for the habitat simulation, as the calculations were properly done, removing the part of the reach susceptible to be affected by errors.

The results showed the great influence of including the vegetation as a part of the substrate, showing this substrate habitat suitability curve a greater vegetation suitability than in the one where it was not included. The one keeping the vegetation apart from the substrate was obtained by using the data directly as they were given, showing a low suitability for the vegetation, being this wrong. Thereby, we selected the curve with the previously merged vegetation, as it represented the reality in a better way. In spite of this, some relevant information that foregrounded the large-sized gravel as the best sort of substrate was lost, since for the selected curve, the suitability difference for the medium and the large-sized gravel was strongly reduced.

The results obtained in this study seem to indicate a preference for lower flows, related to the fact that this species does not use microhabitats with high velocities. The fact that a great part of the river is channelized could aggravate this problem, preventing vegetation from growing. An improvement of the natural substrate with some aquatic vegetation, and possibly reed plants, could help this fish species by reducing the velocities during high flows, thus creating important shelter for the fish. It is worth mentioning that some transects show a greater weighted usable area with higher flows, while others follow the opposite tendency. This is probably because, due to the longitudinal variability that we have previously mentioned, the river has some areas with a more natural aspect, while some of them are just like a channel. We can imagine that the increment of this weighted usable area takes place whenever the flow rises for the more natural transects, while the opposite is happening in the channelized transects.

As to improve the habitat conditions of the Yagawa River, it would be very advisable to remove the concrete (at least in some areas where bank failure is not probable and bank protection is not a priority), returning the natural river forms (lower lateral slope in the banks, with natural vegetation) and the natural variability to provide different microhabitats that could be used by the different species in the different moments of the day and of their life. The protection of the forested areas that still remain around the river is also important, to provide shaded areas with a lower temperature in the extremely hot months of summer. Helping vegetation to grow in the banks is essential in order to provide shelter and increase the system resilience, while stabilizing the banks. In order to modify the river morphology, the use of woody debris may be an ally, helping into create pools and rapids, which could increase the variability of mesohabitat morphological units in the river.

Other measures that could be taken are:

- Placing groups of boulder in the base of the river, to create areas of reduced velocity and scour holes (Leopold, 1998).
- Constructing heavy wooden planks and blocks, imbedded into the toe of streambanks at channel bed level to provide covered compartments for fish shelter, habitat and prevention of streambank erosion (Leopold, 1998).
- Shaping and planting the banks for regrading streambanks to a stable slope, helping plant growth by selecting, installing and establishing appropriate plant species (Leopold, 1998).

These are only examples among others, and can be seen in Figure 21. The specific actions to be done should be decided in a further stage, after evaluating the different alternatives that would work in a better way in the Yagawa River.

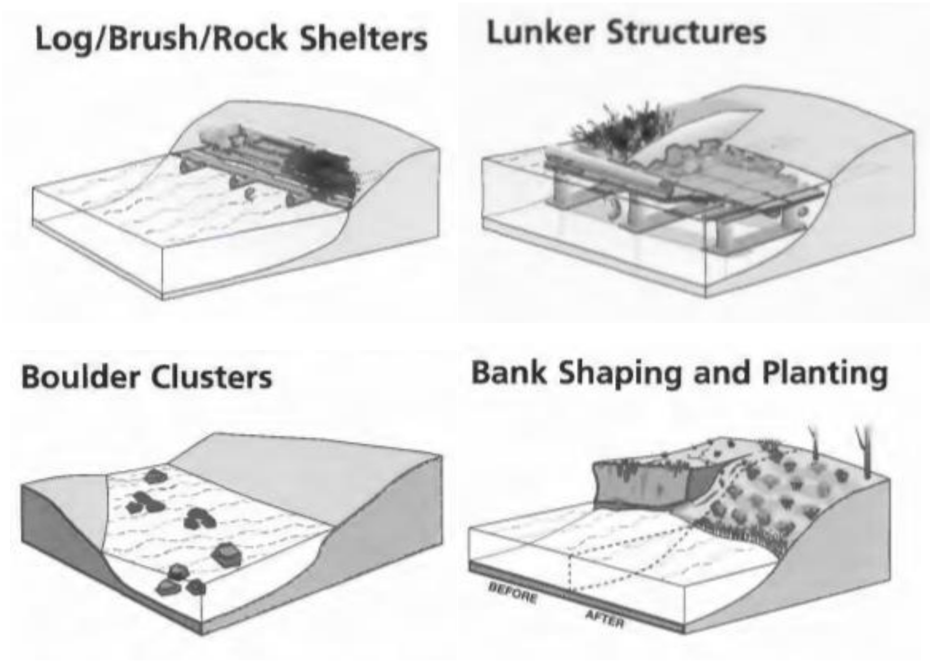


Figure 20. Restoration measures. Source: Stream Corridor Restoration

Ecological flows are a very important factor to consider, even if in the Yagawa River the maximum WUA was reached for a low flow and no regulation is applied. It is very probable that, after applying the improving measures, this condition would change, and a higher WUA would come for higher flows, whenever the number and quality of the shelters was increased. It is also important to foresee possible future demands on the water resources, and to protect the river from water abstractions that could significantly harm the ecosystem. According to the Spanish norm of hydrological planning, the minimum flow would correspond to the 50% of the maximum AWS. In this case, the highest AWS has a value of 0.41, corresponding to a flow of 0.02m3/s, which would lead to set a minimum flow of 0.01 m3/s. This flow is suspiciously small, but looking at the time series, the minimum flow, in March 2017, has this value, showing a relatively high AWS. As previously explained, in this river the main critical factor is the high flow, causing high velocities that seriously affect the microhabitat, not existing vegetation that provides refuge for the species, so following this rule would not be the best option. This proofs the importance of adapting the possible recommendations to the study river, and not just blindly follow the general recommendations, that may not be applicable in certain situations. After applying the improving measurements, the AWS is likely to increase for the flow rates above 0.02, and a new evaluation of the physical habitat would be interesting.

6. CONCLUSIONS

The general conclusion is that, despite the difficulties found in the way, the main objective of this study was successfully completed; that is, the simulation of the habitat for the fish species *Lefua echigonia* in the Yagawa River. This is one of the first studies of habitat simulation in the urban rivers of Tokyo, which makes it relevant and interesting, in order to convert urban rivers (very abundant in the metropolitan area of Tokyo) in sustainable aquatic environments capable of shelter the native species, and therefore to maintain the biodiversity of the area. The specific conclusions of this study can be summarised in the following points:

- The Yagawa River shows a high longitudinal variability, compared to the low transversal variability, due to the morphological alteration (partial channelization). The proportion of river simulated in this work is very high compared to the normal simulations made in this kind of studies, because the simulated reach covers the 60,16% of the whole length of the Yagawa River. Therefore, the simulated river reach is fully representative of the Yagawa River.
- The standard step method for the 1-dimentional hydraulic simulation (named as Water Surface Profile in SEFA), and for generating rating curves for the cross-sections, was successfully used to calibrate the model in SEFA.
- New and first habitat suitability curves for adults of the endangered fish species *Lefua echigonia* were made for the habitat simulation; these curves have the advantage of being easy to explain and clear to understand and transfer to other researchers, in comparison with the generalised additive models that are somehow unclear to the modeller and so to the public, and with more difficulty to be incorporated in the habitat modelling process.
- Adult individuals of *Lefua echigonia* prefer large gravel and vegetation as substrate, low mean velocity and small depth, in coherence with his character of small benthic fish, with relatively low ability to swim in the water column or in swift waters.

- The highest value of the AWS or Weighted Usable Area (WUA) for the simulated reach was obtained for a flow of 0.02 m^3/s. The analysis by transects showed that some segments of the river show a higher weighted usable area with higher flows, whereas other segments show a decrease in this value while the flow increases. The highest value at low flow occurs because a high proportion of the river is like a channel, and extreme conditions are reached with higher flows, without any available refuge or shelter to protect the fish from high velocities.
- The time series of habitat in terms of AWS indicated that the critical period of habitat for adults of *Lefua echigonia* may take place between July/August and November/December, with the highest flows.
- Any improvement of the habitat condition will require direct actions concerning the river morphology and the physical habitat, such as removing small concrete walls (to be substituted with near-natural bank protections, or bioengineering solutions, where necessary) and naturalizing the substrate, in combination with the addition of shelter elements (made of rock or wood), in order to generate refuge for the high-flow events. A large-scale study of the river network focusing on habitat connectivity, altered by dams and weirs, would be also necessary due to the high sensitivity of benthic fish species to the barriers.
- Further studies on other native and endemic fish species should be carried out, since they represent a very important part of the biota in Japan, and they were not payed enough attention. Considering the large amount of urban rivers as potential usable habitat for these species, it is essential to manage urban river systems to achieve the survival of these species in the long term.

Finally, it is important to remark that human activities in the urban environments are the origin of the habitat degradation, and the prioritisation of habitat rehabilitation by environmental managers is the key for the future improvement. Therefore, working on citizen education, from the children to the adults, and specially the neighbours living in the vicinity of any target river, and helping them understand the importance of keeping the ecosystems in a healthy way, is a key approach to conserving and enhancing the ecosystems biodiversity.

7. FURTHER RESEARCH

Given he limitations, results and recommendations for the enhancement of the river habitats, the possible actions of future research can be summarized as follows.

Further studies on this species, by sampling in different rivers could be really useful, in order to obtain a complete data that can be used to improve the suitability model. In the same direction, testing the transferability of the suitability curves between different rivers, would allow to create a better model, that could be extrapolated to a various number of close rivers with similar characteristics regarding size and morphology, contributing thus with a really valuable ecological information that can be very useful while trying to hold biodiversity in this area.

An ample study of habitat suitability for *Lefua echigonia* in different rivers would also allow to validate the model of one river in another one and vice versa; and even obtain a general suitability model, with all the available data, for which a validation test within the studied rivers could be made. Testing and validating a multivariate habitat suitability model with different sorts of models (GAMs, Multi-Layer perceptron, etc.) would be also possible after getting this information.

Finally, a monitoring plan of the native species could be carried within the whole Tokyo metropolitan area, to make a distribution model of the species, that would let us know which are the used areas, and could show us the status of the population at larger scale. This way we could identify the best zones to collect data for the microhabitat studies, that later would allow us to take decisions in an efficient way, to improve the species conservation and propose certain actions to restore this rivers.

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