Carrying Capacity Estimation for Small Hydro Plant Located in Torrential Rivers

Elena Carcano, James Ball, Betty Tiko

***Abstract*—**Carrying capacity refers to the maximum population that a given level of resources can sustain over a specific period. In undisturbed environments, the maximum population is determined by the availability and distribution of resources, as well as the competition for their utilization. This information is typically obtained through long-term data collection. In regulated environments, where resources are artificially modified, populations must adapt to changing conditions, which can lead to additional challenges due to fluctuations in resource availability over time and throughout development. An example of this is observed in hydropower plants, which alter water flow and impact fish migration patterns and behaviors. To assess how fish species can adapt to these changes, specialized surveys are conducted, which provide valuable information on fish populations, sample sizes, and density before and after flow modifications. In such situations, it is highly recommended to conduct hydrological and biological monitoring to gain insight into how flow reductions affect species adaptability and to prevent unfavorable exploitation conditions. This analysis involves several planned steps that help designing appropriate hydropower production while simultaneously addressing environmental needs. Consequently, the study aims to strike a balance between technical assessment, biological requirements, and societal expectations. Beginning with a small hydro project that requires restoration, this analysis focuses on the lower tail of the Flow Duration Curve (FDC), where both hydrological and environmental goals can be met. The proposed approach involves determining the threshold condition that is tolerable for the most vulnerable species sampled (*Telestes muticellus*) by identifying a low flow value from the long-term FDC. The results establish a practical connection between hydrological and environmental information and simplify the process by establishing a single reference flow value that represents the minimum environmental flow that should be maintained.

***Keywords*—**Carrying capacity, fish bypass ladder, long-term streamflow duration curve, eta-beta method, environmental flow.

I. Introduction

A. Hydrological Prelude

THE knowledge of watercourse regimes, particularly regarding low flows and droughts, is essential in the design of hydropower plants and the establishment of qualitative standards for ecosystems [10]. While this information is ideally obtained directly from hydrometrical gauges, in practice, it often relies on regionalization procedures to extend data from specific sites to ungauged sites. By ranking observed or modeled flows in a descending sequence, the percentage of time that specific discharge levels are equaled or exceeded during a given period can be determined. This process results in the construction of a FDC, which represents the cumulative frequency distribution of discharges and provides probabilistic information for defining future water scenarios. FDCs can be expressed at different time scales, such as daily, weekly, or monthly, but hourly scale curves are most commonly used in various applications, such as water power production, stream pollution evaluation, and data quality studies. These curves offer a convenient tool for analyzing the flow characteristics of streams and facilitating comparisons between basins. The development of FDCs has been significantly advanced by researchers such as Hickox (1933) [12], Searcy (1959) [21], LeBoutillier (1993) [15], and Vogel and Fennessey (1994, 1995) [24], [25]. These studies have emphasized that the flow characteristics of streams, across the entire range of discharge, are effectively encapsulated within the curves, even though the chronological sequence of data is disregarded.

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B. Hydrological and Environmental Connection through the FDCs

In the case of water power projects, the assessment of both design flow and environmental release is based on the daily FDC for the long-term period. To create the curve at a specific section of the river, flow data recorded at the hydrometric section are extrapolated to an ungauged section using sub-catchment sizes and precipitation patterns. The target flow for the power plant typically falls within the range of Q (45)-Q (60), which represents the streamflow available for 45-60 days per year. Environmental flows, on the other hand, range between Q (330)-Q (365) and vary depending on the necessary precautions for the species in question.

The focus of this analysis is on the tail of the FDC, specifically the values in the range of Q (330)-Q (365). This approach assumes that all flows within this range are consecutive, belonging to the same drought period, and are likely to be preceded and succeeded by their temporally adjacent values. By studying the flow hydrograph, the temporal sequence of flows is now incorporated into this specific part of the FDC, indicating that low flows tend to follow one another. Consequently, the flows within the range Q (330)-Q (365) represent the limited tolerable environmental conditions for the fishery in question. In contrast, the peak and middle parts of the FDC contain high and ordinary flows that are unrelated to consecutive events.

By selecting an appropriate flow target on the FDC, the designer can gain a preliminary understanding of the duration during which a species can survive under tolerable conditions and when it begins to experience adverse conditions. In this study, the target value has been set to Q(335), considering that its associated complementary duration in a year (one month) is represented by all consecutive natural flows, while any alterations to the water are prohibited. After sorting the drought month within a hydrological year of the long-term period, it becomes evident that the tail of the FDC (Q(330-Q(335)) contains numerous values, particularly if the month consists entirely of non-rainy days.

C. Carrying Capacity and Precipitation Pattern

Following Hilborn [13], the concept of carrying capacity has played a significant role in the management of fish species and plant populations and has been the determining factor in exploited renewable projects. Despite its importance, estimating carrying capacity is rarely done due to its controversial definition and challenging quantification [15]. The traditional approach to determining carrying capacity involves analyzing stock data, which requires long-term data series and encompasses a wide range of run sizes and trials. Carrying capacity is the fundamental idea that a maximum population can be sustained over a certain period, given a specific level of resources [18]. This means that in reality, there is not enough space or sufficient resources for a natural population to continue growing indefinitely. Constraints such as food availability, predation effects, and diseases prevent a population from becoming too large. Population changes can also be attributed to unfavorable natural conditions. For example, a severe and prolonged drought can lead to the extinction of species with poor skills and adaptability. In such cases, fish repopulation campaigns have often failed to replenish the fishery to its normal flow conditions. Furthermore, to prevent a complete collapse of carrying capacity, additional man-made pressures should be avoided. This is the case with hydro-plant components, as they further limit the fishery during already stressful meteorological periods. Plant production should be evaluated in terms of the minimum environmental release necessary to ensure fishery survival.

II. Study Case

A small hydroelectric power plant located in northwestern Italy, near the French border, is scheduled for restoration.

Fig. 1 Hydropower plant

Solution consists in a short-subtended path, (which stretches from the capture's weir to the restitution opera), so to limit suffering conditions for the watercourse and offering a scheduled and controlled repopulation of the most fragile species.

The plant is located in Nervia's catchment and stretches from 69 $km^2$of size at the withdrawing section to 126 km^2 at the hydrometrical section. The installation has worked continuously from 1901 to 1965 with a sawmill aside facing risky droughts during summer European periods. Low flows have always occurred from end of June till mid-September. In recent years, however, due to climatic changes and additional water withdrawals, the droughts have become more severe and have deep question a proper water concession and its corresponding plant's production.

A purifier has been installed in 1985 over the installation subtended path. The adopted solution entails an upgrading of the ancient building (namely the restitution opera) uniquely distinguished by its architectural specificity and the concession of 15% of the achievable power production to public use.

III. Technical Details

The plant exhibits a total production of P = 66 kW and an associated annual energy E of 286,000 kWh/year, with an average power of P2 = 32 kW. The maximum water concession is Q = 1 m^3/s, and the Water Concession Bureau [25] has established a basic environmental flow (EF) of 100 l/s as the starting reference value. The average flow withdrawn amounts to 480 l/s, and the total topographical head is 8.69 m. Following the previous version, the plant's additional benefit is provided by a bypass device, which serves as a simplified "fish ladder" to facilitate the migration and reproduction of species. The dimensions of the bypass device are tailored to the swimming capabilities of the slowest surveyed species, in this case, the vairon (*Telestes muticellus*). Fig. 2 depicts an example of such a passageway.

Fig. 2 By-pass device as designed fish passage

Slits are 3.5 meters in height and 1.10 meters in width with hammer-shaped cells. The total distance covered by the flow is 700 meters and the village purifier is located 150 meters before the restitution opera. To ensure equal water dilution conditions in the absence of the plant's withdrawal, the basic environmental flow (EF) has been adjusted seasonally, taking into account both biological (purifier) and ecological (fish species) constraints. A Banki Mitchell turbine has been selected for its versatility in handling a wide range of flows, specifically suited for this scenario. The length of the pipe is approximately 350 meters and its diameter is less than 1 meter. Specific details of the plant can be found in Table I.

The overall financial repayment of the plant is anticipated to occur within a period ranging from 7 to 9 years.

IV. Flow Regime

The river Nervia exhibits a highly variable flow pattern, characterized by torrential flows. Significant flood events typically occur in November and April, while prolonged periods of low flow persist from June until the first half of September, often leading to drought conditions. Snowfall, primarily observed in January and February, contributes approximately 10% of the total water outflow. Information on daily stream flows at the Isolabona hydrometric station is available from 1929 to 1975, while only sub-hourly water level data are available from January 2016 onwards. Unfortunately, no updates have been made to the rating curve since the dismantlement of the hydrometric station in 1975. Fig. 3 illustrates the most recent water levels, with observations recorded every 15 minutes.

TABLE I
Plant's Pipe Characteristics

	Pipe	UM
Number	1	Unitless
Diameter	0.70	M
Length	350	M
Roughness	110	m 1/3/s
Roughness (2)	0.011	Nondim
Local Head Losses	0.50	Nondim
Total Head Losses	2.17	s/m^2

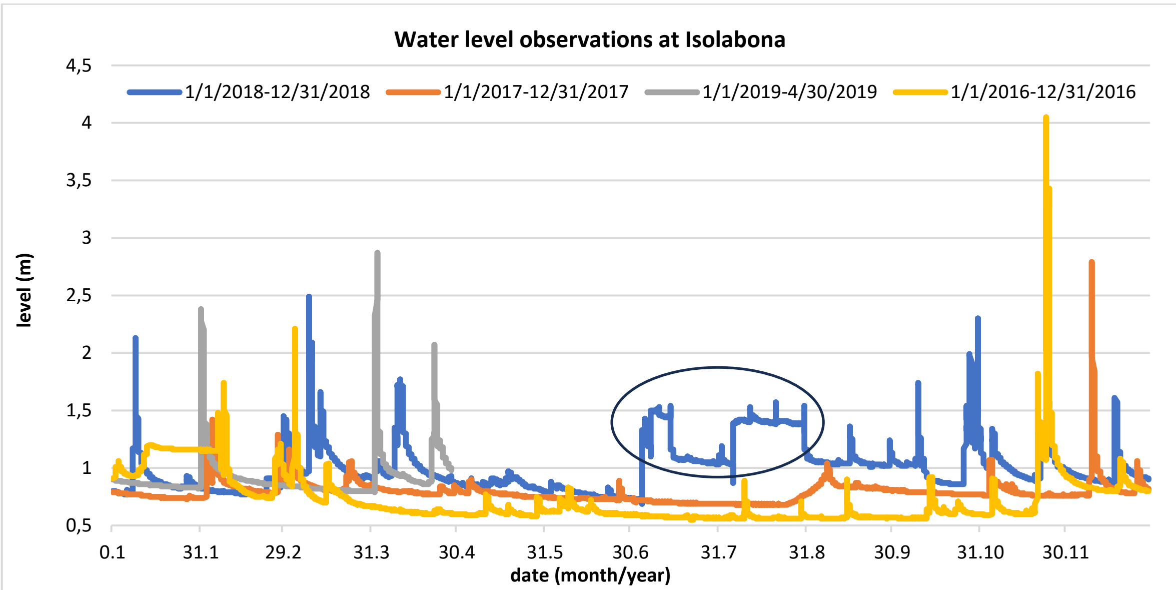

Fig. 3 Recent water levels observed at Isolabona

As can be observed, certain signals exhibit noise effects, particularly during the summer period of 2018, which is highlighted by a circle. These noise effects must be filtered before implementing any inflow streamflow modeling. However, despite the availability of recent information, it is undeniably evident from tangible evidence that all water levels should display flat signals from July until the first half of September, due to extended periods of no rainfall.

In terms of rainfall data, recent observations are accessible for the Rocchetta Nervina station, located 8 kilometers west of Isolabona. However, information regarding rainfall sequences in Isolabona and Pigna is only available starting from April 2021.

Conversely, when examining historical precipitation patterns and specifically focusing on the months characterized by drought (data collected from: 1929-1939; 1941-1943; 1955; 1957-1974 and June to September), the existing records indicate the pattern shown in Table II.

TABLE II
Historical Precipitation Data for Hydrometrical and Closing Section

Cumulative rainfall (mm)	June	July	August	September
Isolabona	68.6	33.5	77.4	81.1
Pigna observed	28.8	25	38	56
Pigna expected	37.6	18.35	42.38	44.41
Ratio R (observed/expected)	0.77	1.36	0.89	1.26

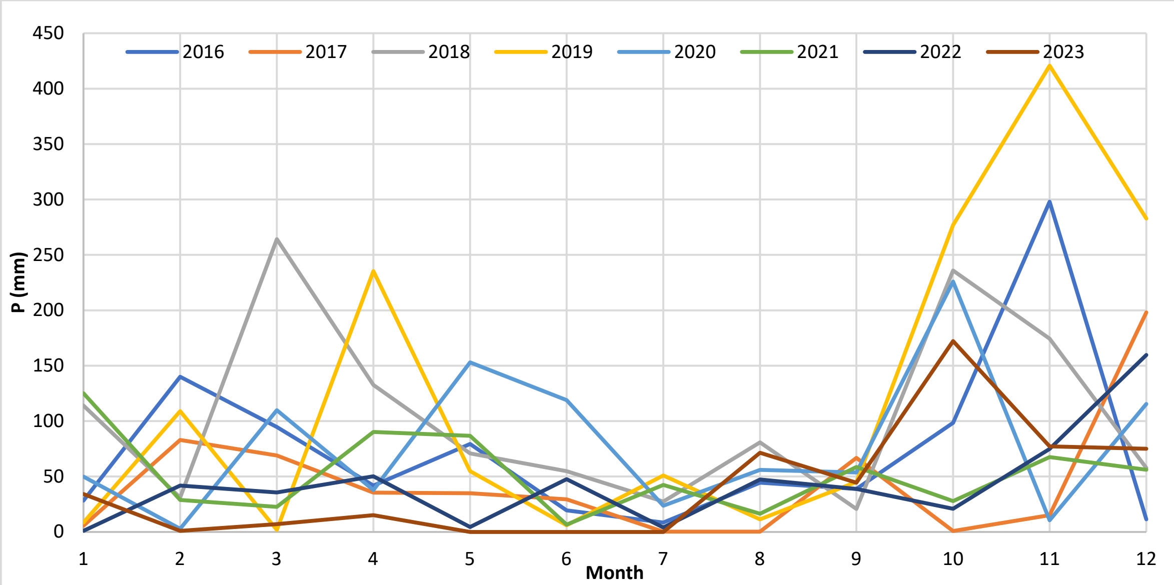

Fig. 4 (a) Monthly cumulative rainfall for Rocchetta Nervina

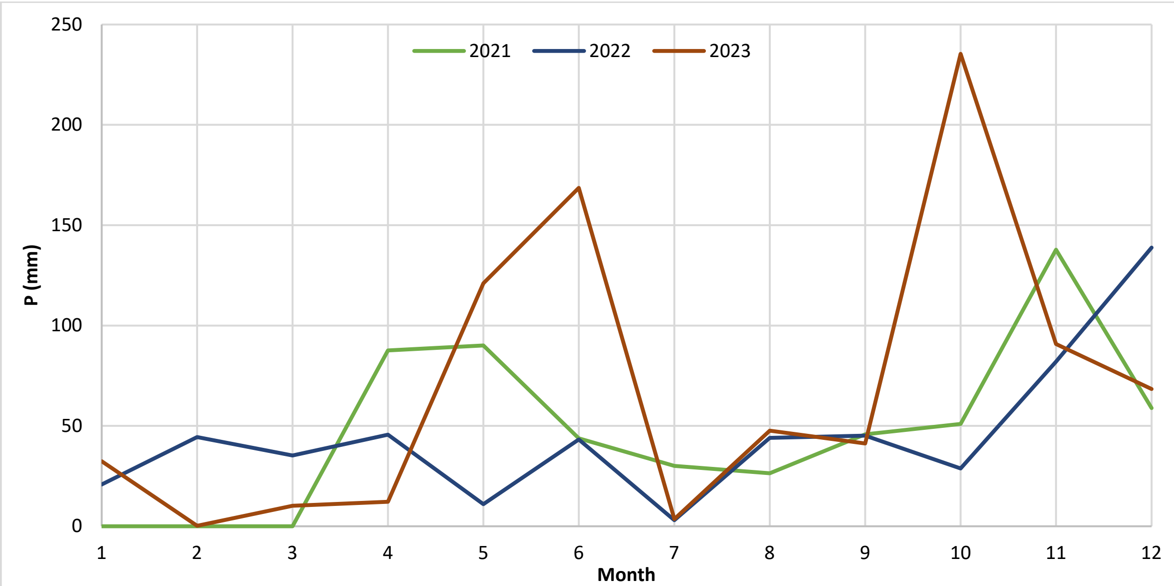

Fig. 4 (b) Monthly cumulative rainfall for Pigna

In Table II, the expected precipitation levels at Pigna, derived from the corresponding values recorded at Isolabona, are presented in blue. The ratio R is used to assess the deviation between the actual precipitation in Pigna and the expected values. Since R fluctuates around 1 and no other historical precipitation data are available for the basin, a preliminary estimation of water availability is made by shifting the daily historical stream flows from the hydrometric section (Isolabona) to the closing section (Pigna), assuming uniform rainfall distribution across the basin. This approach can be applied to the remaining months of the year, with R showing only slight deviations from 1.5.

Table III displays the average historical flows for the two aforementioned sections. The data are averaged for each month based on the original daily observations recorded from January 1, 1929, to December 31, 1975.

Still, a comprehensive understanding of water availability is typically derived from stream FDCs, which are considered to be fundamental in assessing a plant's production. FDCs directly illustrate the number of days per year that a given flow is available or exceeded [20]. In the FDC constructed over a long-term period using a calendar-based approach, both the plant's designed flow and basic EF are typically sorted.

In this study, flows corresponding to characteristic durations are introduced for practical purposes, providing a synthetic representation of the river's flow regime. The flows observed at the hydrometric station of River Nervia and extracted from the FDC of the long-term period (1929-1975) are as shown in Table IV.

TABLE III
WATER AVAILABILITY AT THE TWO CLOSING SECTIONS

Averaged Q (m^3/s)	Hydrometrical section (Isolabona)	Closing section (Pigna)
Q January	3.01	1.49
Q February	4.07	2.08
Q March	4.59	2.28
Q April	2.74	1.36
Q May	2.48	1.23
Q June	0.88	0.44
Q July	0.46	0.23
Q August	0.57	0.28
Q September	0.63	0.31
Q October	0.44	0.22
Q November	3.73	1.85
Q December	5.49	2.67

TABLE IV
FLOWS SET AT CHARACTERISTIC DURATIONS

Nervia at Isolabona	Q(10)	Q(30)	Q(60)	Q(91)	Q(135)	Q, mean	Q(182)	Q(274)	Q(355)
m^3/s	19.60	6.41	3.12	2.07	1.38	2.77	0.87	0.39	0.16

Considering the aforementioned condition, which is predicated on a nearly homogeneous distribution of precipitation across the basin (a hypothesis that has been sufficiently upheld to historical low flow measurements), the resultant low flows observed at the downstream section of Pigna are as shown in Table V.

TABLE V
ENVIRONMENTAL RELEASES FOR THE CLOSING SECTION AT PIGNA

Nervia at Pigna	EF/ Q (335)	EF1~Q (327)	EF2~Q (319)
m^3/s	0.14	0.15	0.17

EF represents the fundamental environmental flow to be released, chosen to be equal to Q (335). Its associated duration, namely 335 days/year, is complementary to 30 days, which represents the driest month of the year on the corresponding FDC. The selection of the basic EF is thus based on ensuring that the most vulnerable species can survive costly throughout the driest month of the year (August), while additional modulations of the initial release, EF1 and EF2, are set according to overwintering and reproduction needs. EF1 and EF2 correspond to additional values of 10% and 20% of the basic environmental flow EF and need to be released in March_April (EF1) and May to July (EF2), respectively.

Fig. 5 illustrates the tails of the FDCs for the two selected sections, which were built for the long-term period (Table IV) and have flow thresholds set at 5 m^3/s.

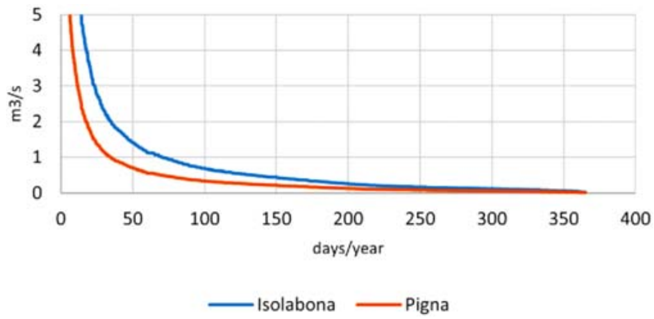

Fig. 5 FDCs of long-term period: sections of reference

As evident from the observation, the curves exhibit comparable shapes, particularly in the lower section of the tails where they converge to the same minimum flow level. This suggests that the basin retains consistent geological attributes, independent of the precipitation pattern, and evenly stores water irrespective of the size of the catchment area.

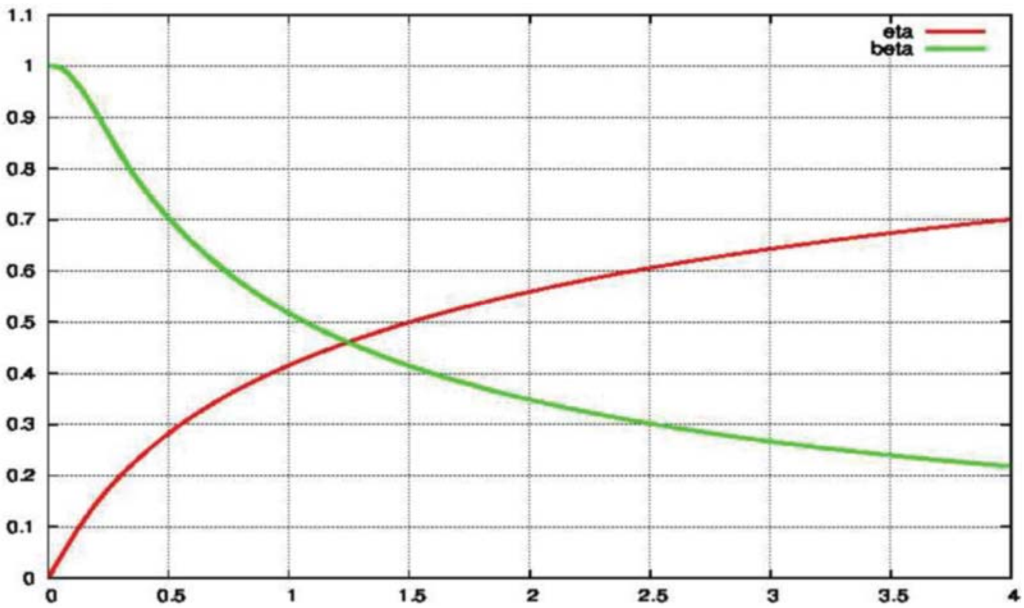

Fig. 6 Eta Beta method: The intersection of the two curves identifies the optimum withdrawal of reference

The plant's specified flow rate (referred to as the maximum withdrawn flow) can be accurately determined using the Eta beta method. Here, the Eta curve represents the ratio of the derived volume to the total volume available, while the beta curve represents the ratio of the derived volume to the volume that would be accessible if the maximum streamflow were maintained throughout the year.

The Eta and Beta curves intersect at a value of 1.225 m^3/s, which is associated with a duration of 76 days per year (see Fig. 5, Pigna section). If the chosen design flow is Q = 850 l/s, the complementary minimum suggested environmental flow (EF = 140 l/s, see Table V) results in an associated duration of 90 days per year (see Fig. 5, Pigna section). These duration values exceed the typical reference duration, which typically ranges from 45 to 60 days per year.

V. Surveys

A. Hydrological Survey

To gain a comprehensive understanding of the current availability of water and its biological condition, annual hydrological and biological surveys have been conducted. In terms of hydrology, information has been collected by indirectly measuring the flow using a SIAP BOLOGNA current meter equipped with a 6 cm propeller ratio. The measurements have been taken at two reference sections, allowing for the sporadic data from the latter section to be placed within the historical sequence of reference. Table VI presents the data obtained during the direct survey conducted from 2018 to 2019. The table consists of two Sub-tables: VI A and VI B, which respectively represent the observed and modeled flows.

The three remaining flows are assessed using the emptying formula of a linear reservoir.

All the recent recorded measures (Table VI A) are lower than the historical calculated measures (Table III, column 3). The connection between historical and recent flows should be thoroughly examined by expanding the recent flow dataset, specifically by relying on the water level registrations obtained from the gauge installed at the plant's capture weir.

TABLE VI A
Forded Observed Flows at the Closing Section

Date	Observed Q
27/6	Q = 0.19 m^3/s
17/7	Q = 0.24 m^3/s
16/8	Q = 0.14 m^3/s
26/10	Q = 0.29 m^3/s
22/12	Q = 0.73 m^3/s
28/2	Q = 1.25 m^3/s
4/3	Q = 0.71 m^3/s
29/3	Q = 0.91 m^3/s
7/4	Q = 0.68 m^3/s

TABLE VI B
Modeled Flows at the Closing Section

Date	Modeled Q
20/6	Q = 0.24 m^3/s
1/11	Q = 0.24 m^3/s
3/11	Q = 0.50 m^3/s

B. Biological Survey

The upper part of the basin exhibits samples of *Anguilla anguilla, Telestes muticellus,* and *Barbus plebejus*. Furthermore, evidence of crayfish has been discovered in the smallest tributaries due to their unpolluted environment and clear waters [11]-[13], [16].

In terms of direct biological assessments, three transects have been implemented: upstream, within, and downstream of the hydro plant, to examine the conditions of the fluvial continuum along the respective paths. Monitoring activities were carried out using an ELT 60 11 G1 Scubla instrument. These monitoring efforts have validated the species surveyed by the Local Fish and Hunting Bureau (Settore Caccia e Pesca Provincia di Imperia) inspections. The corresponding density and fish population are outlined in Table VII.

TABLE VII
Results of the Surveyed Species Campaign 2018

Path	*Anguilla Anguilla*			*Barbus Plebejus*			*Telestes Muticellus*			Density	Biomass
Upstream	2	0.013	0.0053	23	0.153	0.0015	24	0.163	0.0013	0.326	0.0081
Internal	----	------	-------	20	0.133	0.0003	13	0.087	0.0001	0.220	---------
Downstream	----	-------	-------	72	0.745	0.0026	2	0.020	0.0001	0.765	0.0027

Fig. 7 Second transept sampled specie

In the upper section, upstream the purifier, there is an intensive population of vairon, in the inner one and downstream the purifier, conversely, there is a population of *Barbus* with different size samples still living in poor favorable hygienic conditions. Fig. 7 shows a sample amongst the population of *Barbus plebejus.*

The three surveys conducted in 2018 have revealed distinct fish conditions, providing evidence that the purifier strongly affects the fish species by regulating the dissolved oxygen levels in the water.

Examination of the surveys administered by the Fish and Hunting Bureau, responsible for the 2015 biological monitoring, has yielded the findings reported in Table VIII for the *Telestes muticellus* species. Records of 2021 show the pattern reported in Table IX.

TABLE VIII
RESULTS OF THE SURVEYED *TELESTES MUTICELLUS*. CAMPAIGN 2015

Path	*Telestes Muticellus*	
Upstream	28	0.189
Internal	17	0.103
Downstream	8	0.050

TABLE IX
RESULTS OF THE SURVEYED *TELESTES MUTICELLUS*. CAMPAIGN 2021

Path	*Telestes muticellus*	
Upstream	20	0.158
Internal	21	0.160
Downstream	2	0.022

The recent data sets from 2018 to 2021 indicate a significant decline in the carrying capacity of *Telestes muticellus*. This decline may have occurred both over the years (2015-2021) and throughout ontogeny. To fully understand the reasons for the variation in carrying capacity over time, it is recommended to have complete and continuous data sets.

Currently, the Fish and Hunting Bureau conducts surveys every three years, and the impact of the project, including additional water withdrawal, cannot be assessed as the construction site is still ongoing.

Given this context, this analysis proposes a relationship between fish habitats and the changing hydrological conditions over the years. In essence, the reduction in fishery catches can be explained by a decrease in precipitation patterns from 2015 to 2022 (see Fig. 4 (a)).

C. Vegetational Survey

The impacts of eutrophication on surface water were examined through a study conducted on July 3, 2019, at a location 50 meters downstream from the point of discharge by the purifier. It is commonly acknowledged that a distance of 50 meters serves as a threshold beyond which the water should regain its pristine condition. The study assessed several parameters including pH, BOD5, COD, Ammonia Nitrogen, and *Escherichia coli*.

TABLE X
RESULTS OF THE CHEMICAL MONITORING ON SURFACE WATER

Parameter	U.M.
BOD5	< 4 mg/l O_2
COD	< 4 mg/l O_2
Ammonia Nitrogen	0.025 mg/l NH_4
pH	8.4
Total suspended solids	3 mg/l
Escherichia coli	3200 UFC/100 ml

The chemical monitoring provides a specific and limited overview of the water characteristics, rather than a comprehensive assessment of the overall river condition.

A comparison between the obtained results and the reference values of LIMECO indicates that both ammonia nitrogen and nitric ammonia parameters indicate exceptional water quality for the case study.

TABLE XI
LIMECO TABLE: RECOMMENDED VALUES

	Score	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
		1	0.5	0.25	0.125	0
Parameter		< = 10				
100-O_2% sat.	Thresholds**	< = 10	< = 20	< = 40	< = 80	< = 80
N-NH_4 (mg/l)		< = 0.03	< = 0.06	< = 0.12	< = 0.24	>0.24
N-NO_3 (mg/l)		<0.6	< = 1.2	< = 2.4	< = 4.8	>4.8
Total P (μg/l)		<50	< = 100	< = 200	< = 400	>400

Referring to the *Escherichia coli* parameter (Table X), there is no established reference value for the internal superficial water. However, the LIM index (recently revoked by the D.Lgs 152/06 law) indicates that an optimum value to strive for is 100 CFU/100 ml, while a moderate stage of pollution is indicated by 3200 CFU/100 ml.

Fig. 8 Foams caused by the purifier's release

The high value is most likely attributable to the release of the purifier, which has a significant impact on local water flows. Therefore, to determine the actual distance at which the purifier can distort the water quality, it is necessary to conduct a comprehensive evaluation of the *Escherichia coli* index along the river path, taking into account the theoretical value of 50 m.

In terms of vegetation monitoring, the current species composition is mainly characterized by dense areas and clusters of scotch brooms, ashes, and oaks, while olive trees and thyme are prevalent throughout the basin.

Fig. 9 Leaves and fruits of green alder

As the river approaches its delta (with Isolabona located 15 km upstream), urbanization becomes increasingly intensive. This leads to the formation of larger groups of mullets and a noticeable decrease in vegetative areas. Near the coast, the vegetative areas account for approximately 60% of the landscape, whereas in the upper part of the catchment, this percentage reaches as high as 90%.

VI. Fish Passage

Fish passages are designed to facilitate the migration of fish species to a designated point in the river, enabling them to bypass obstacles and access their desired destination more easily [4]. The movement of fish fauna encompasses various behaviors throughout their lifespan, with downstream migration being primarily driven by trophic and overwintering requirements.

The types of migrations typically observed include:

- Regular daily movements in search of food (downstream migration);
- Seasonal repositioning to locate deeper water bodies for shelter and overwintering purposes (downstream migration);
- Movements during the reproductive period;
- Extraordinary movements prompted by flood events.

Natural fishways, such as bypass or rustic fishways, are often preferred over technical ones. In this study, the most delicate species is *Barbus plebejus* from the Cyprinidae family, which tends to create multiple resting spots for food and shelter along the river. On the other hand, the slowest species, *Telestes muticellus* from the Leuciscidae family, is considered. A separate ramp for eels is not necessary as this species has better swimming ability compared to *Telestes muticellus*.

The designed bypass consists of five steps, each measuring an average of 2 m^2 (1.8 m wide and 1.10 m long) and 0.70 m in height. These steps are arranged like a waterfall to avoid abrupt changes in flow direction and pressure variations. The water depth within each step should not be less than 0.40 m. All sides of the bypass are lined with pebbles and cobbles to ensure a smooth passage and prevent injury or disruptions to the species due to sharp changes in flow direction or pressure.

The inlet of the downstream fishway is located near the right bank, opposite the pipeline and turbines. This area experiences higher average flows, as fish typically migrate along the main flow speed and move along the banks. The species have a tendency to freely reach higher locations and overcome full obstacles (weirs), unless they encounter hindrances such as excessive water turbulence or hydrodynamic conditions that require jumps or impede their progress.

The upstream outlet should be positioned away from hydraulic devices like spillways, which can increase local water speed. This is done to prevent the species from being carried downstream after surmounting the weir. The water should not be stagnant or excessively turbulent, and water whirlpools should be avoided. The location of the fish passage is determined based on local morphometric and bathymetric conditions, as well as where the flow remains relatively consistent throughout the year.

The fish passage is situated 2 m from the right bank of the weir, complying with the aforementioned requirements. It provides easy access and allows maintenance work to be carried out at least three times per year. Each species should be able to traverse the subsequent step in both descending and ascending directions, with the flow speed inside each step comparable to the species' speed (e.g., 1.70 m/s as the average for adult *Telestes muticellus*, which are 20 cm long).

During floods or high flows, excessive environmental releases must be avoided as the abundance of water and its resulting high speed ($v > 1.5$ m/s) can completely hinder the migratory process and have detrimental effects on the species. The risk of injury from turbines is minimal, as the passage is positioned opposite the restitution area and *Telestes muticellus* are gregarious species that tend to move together. Migration outside the passage should be strongly discouraged by employing electrical and acoustic barriers where the inlet passage conditions may appear passable.

In general, the existing risks along the passage, particularly at the final gates (downstream and upstream inlets), depend on the species' length and the same speed conditions. Specifically, *Telestes muticellus* samples measuring 22 cm long have limited possibilities of injury if the final gates are appropriately designed. A technique to deter fish from crossing the inlet grid of the pipe is to reduce the space between rods, thus preventing the species from selecting that path. This paper suggests a distance between rods ranging from 1/8 to 1/10 of the species' length, with a space of 2.5-4 cm. The water speed along the grid is determined using the following equation:

$$V_{grill} = 0.15 + 0.24 * \text{fish length} \quad (1).$$

This speed should be lower than the swimming speed of the corresponding fish species (adult samples of *Anguilla* and

Barbus plebejus exhibit slightly higher swimming speeds compared to adult *Telestes muticellus* samples). Additionally, the grill should be inclined to facilitate easy entry into the opening for any fish attempting to pass through 7. Other mitigative interventions suggest no more than five people working continuously for a period of 3/4 months are recommended. To protect the fauna the construction site should be stopped during spring while it is favorably recommended during late summer, fall periods. Moreover, disorder caused by the construction site should be totally discouraged from March to July since the *Telestes muticellus* specie in particular is deeply committed to the reproductive phase and progeny nutrition. The real impacts which happen on the ecological connections are: workers break, human presence during working hours which can disturb the fauna migration. Another risk factor which can spur up degradation effects consists in abandoning refusals in the area at the end of the works. Referring to the vegetational scenario, man-made changes of the riverbed should be totally avoided, and the banks shall be naturally sodded. Rehabilitation to the access consists in reducing the allochthonous species, stabilizing the scarp with naturalist engineering interventions and replacing old deteriorating structures with only native vegetal material. Referring to the subtended path, in case the river's quality would have been found compromised, the proposed intervention can consist in limiting the water withdrawals or an improvement of the purifier depurative treatment without filtering of the incoming flows.

VII. Other Mitigative Interventions

When considering a construction site, it is recommended to have a continuous workforce of four to five individuals for a period of three to four months. To ensure the protection of the local fauna, construction activities should be halted during the spring season [21], while late summer and fall periods are considered more favorable. It is especially important to avoid any disturbances caused by the construction site from March to July, as this is the crucial reproductive and nutritional phase for the *Telestes muticellus* species. The main ecological impacts that occur are: workers' activities that may interrupt fauna migration and the presence of humans during working hours. Additionally, the abandonment of waste materials in the area after the completion of the construction may lead to further degradation effects. In terms of vegetation, any artificial change to the riverbed should be completely avoided, and the banks should be naturally covered with grass. Access rehabilitation should involve reducing the presence of non-native plant species, stabilizing slopes using natural engineering techniques, and replacing old deteriorating structures with native vegetation. In cases where the water quality of the river is compromised, the suggested intervention includes limiting water withdrawals or improving the efficiency of the purification treatment plant without filtering the incoming flows.

VIII. Conclusions

This paper presents the restoration of a small hydropower plant situated in the Nervia basin in Italy. The study serves as an exemplary demonstration of achieving a favorable balance between power generation, environmental requirements, and societal expectations [1], [3], [5]-[9], [17].

The plant was decommissioned in 1965, but with the new water concession, it is now permitted to have a design streamflow value (Qd) of 1 m^3/s, while the environmental flow (EF) starts at 140 l/s. Furthermore, additional adjustments to the minimum environmental flow, in response to biological demands, can be requested by the Water Bureau responsible for overseeing these matters. The Government Bureaus are accountable for assessing the environmental impacts of water withdrawal and ensuring compliance with environmental regulations. However, it is ultimately the responsibility of the designer to make suitable choices that effectively safeguard aquatic biodiversity. Consequently, two additional environmental flows, namely EF1 and EF2, have been implemented [19], [21], [22].

In addition to the annual hydrological campaign conducted concurrently at the capture weir and the reference hydrometric section, a separate biological campaign was specifically carried out in three transects to portray the biological conditions along the hydro-subtended path. The biological data collected between 2018 and 2019 were compared with the corresponding public information (2015; 2021) obtained from the local Fish and Hunting Bureau (Servizio Caccia e Pesca Provincia di Imperia). Unfortunately, the comparison of the hydrological datasets was not possible due to the absence of publicly available streamflow data.

It is well-known that any hydropower plant, irrespective of water withdrawals, disrupts the fluvial continuum and fragments the ecological connectivity crucial for the survival and reproduction of fish fauna thus affecting carrying capacity as considered to be the maximum population a given level of resources can sustain over a specific period [2]. To mitigate this interruption, the study proposes the implementation of a bypass device functioning as a natural fish passage. The fish passage consists of five steps measuring an average size of 2 m^2 each (1.8 m wide, 1.10 m long, and 0.70 m high). These steps are designed to overcome a 3.5 m difference in height between the capture weir and the downstream area. Each individual pool resembles a waterfall and is designed in a manner that prevents abrupt changes in flow direction and pressure variations. The water depth within each step is maintained at a minimum of 0.40 m. All surfaces are covered with pebbles and cobbles to ensure the passage remains as smooth as possible, preventing injury to the species and avoiding sharp changes in flow direction or pressure.

Other mitigation measures include the removal of all non-native species in the vicinity of the restoration site (Fig. 1) and improvements to the wastewater treatment plant's effluent discharges to minimize the presence of foam on the surface waters (Fig. 8).

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