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HYDROLOGICAL IMPACTS AFFECTING ENDANGERED FISH SPECIES: A SPANISH CASE STUDY

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ABSTRACT

The Júcar River Basin (Spain) harbours endemic aquatic species that are declining or going extinct at an alarming rate. After evaluating several possible stressors, flow modification is identified as the factor critically threatening one endemic cyprinid fish species *Chondrostoma arrigonis*. Physical habitat for this species is compared for river reaches with different flow modification histories to understand local extinctions across this species' historical range. Time-series of physical habitat, generated using PHABSIM, indicate a dramatic reduction in habitat area with flow modification. Our findings indicate that efforts to regulate and stabilize flows in the Júcar River Basin may cause the rapid extinction of the remaining populations. Copyright © 2007 John Wiley & Sons, Ltd.

KEY WORDS: hydrological alteration; habitat change; time series; fish conservation

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INTRODUCTION

The natural flow regimes of Mediterranean streams have strong seasonal and inter-annual flow variations. This pattern of flow contrasts with agricultural water needs which in the case of Spain represent nearly 80% of the overall water demand (MIMAM, 1997). Over 1200 major reservoirs have been built in Spain to overcome the problems of water scarcity and flood hazard, more than any other country in Europe (MIMAM, 1997). The Júcar River and its main tributary the Cabriel River provide a typical example of water management in Spain. The Alarcón Reservoir on the Júcar River and the Contreras Reservoir on the Cabriel River have been operated for irrigation water supply since 1954 and 1970, respectively. Flow regimes downstream of these reservoirs show an inverted seasonal pattern.

Changes in the magnitude, timing and frequency of river flow events can have a direct biologic and geomorphic impact, and geomorphic changes lead indirectly to ecological adjustments (Whiting, 2002). The otter (*Lutra lutra*) in this river basin has suffered in recent decades because of its dependence on fluvial ecosystems (Delibes, 1990; CHJ, 2004). The mollusc *Theodoxus velascoi* had a very restricted distribution and is now close to extinction (Robles *et al.*, 1996). Other examples of important losses are found in species such as the crayfish *Austropotamobius pallipes* and the freshwater mussel Anodonta cygnaea (CHJ, 2004). However, the impact of dam operations in aquatic ecosystems and related biota has not been documented (Elvira, 1995; Doadrio *et al.*, 2004).

The Júcar River Basin presented a rich and diverse ichthyofauna, including cyprinids of the genera *Barbus*, *Chondrostoma* and *Squalius*. Of the 29 Spanish native species and subspecies belonging to *Cyprinidae*, *Cobitidae* and *Cyprinodontidae*, 25 (i.e. 86%) are endemic (Blanco and González, 1992). *Chondrostoma arrigonis*

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(Steindachner, 1866), a freshwater fish species restricted to the Júcar River Basin, was locally common at the beginning of the 20th century. It was found mainly in the middle reaches (Doadrio *et al.*, 2004) with approximately 10 streams supporting this endemic species. By the late 1980s, this figure had dropped to approximately five streams. Individual population have recently gone extinct (or are about to go extinct) in three streams. The recent Technical Summary for this fish in the Júcar River Basin by the National Museum of Natural Sciences (CSIC) (Doadrio *et al.*, 2004), shows populations of *C. arrigonis* presently inhabit 5% or less of their historic range.

Unfortunately, the last stocks of the endangered fish populations continue to decline at an alarming rate and most of the remaining populations are small and fragmented (Blanco and González, 1992; Elvira, 1995; Doadrio *et al.*, 2004). Total population size has become very small and the loss of genetic diversity decreases the species' ability to adapt to changed environmental conditions, increasing the risk of genetic extinction. The Cabriel River supports the largest remaining population of *C. arrigonis* (Doadrio *et al.*, 2004). This population is considered a critical 'core population' of the cyprinid that may recolonize nearby tributaries and mainstem areas.

Conservation efforts to address this massive decline of aquatic biodiversity should be informed by the precise identification of threats to aquatic fauna. Preliminary exploratory analyses were conducted by the Stressor Identification process (Cormier *et al.*, 2000) to assess evidence of various causes of biological impairment (Sánchez, 2005). After considering several candidate causes based on review of chemical data, biotic surveys, habitat analyses and hydrologic records, physical habitat condition was selected as the major factor limiting the fish populations. Following these general investigations, this study evaluates the specific impacts of flow regulations on physical habitat conditions of *C. arrigonis*.

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Following these general investigations, this study evaluates the specific impacts of flow regulations on physical habitat conditions of *C. arrigonis*, helping to identify effective protection, restoration and management alternatives.

METHODS AND STUDY DESIGN

Study area

The study area is the Júcar River and its tributary the Cabriel River (Eastern Spain) and is within the historical range of *C. arrigonis* (Figure 1). Total drainage area for the Júcar watershed is 21600 km^2 at the mouth, being approximately 500 km in length and with an average flow of $43 \text{ m}^3 \text{ s}^{-1}$. The Cabriel River is the largest tributary of the Júcar River, with an average flow of $12.2 \text{ m}^3 \text{ s}^{-1}$, a total river length of 262 km and a catchment area of 4750 km^2 at its confluence. For both rivers, annual discharges show low magnitude floods in spring and larger floods in fall, usually between October and November. The summer is normally a period of low-flow. The Alarcón Dam (1114 hm³ of storage capacity) and Contreras Dam (with 800 hm³ of storage capacity) are the major dams in the basin, allowing runoff to be retained for subsequent controlled release.

Hydrological dataset and sources

Streamflow data are needed to calculate metrics related to the magnitudes, timing, duration and frequency for particular flow events. Daily discharges were provided for this purpose by the Water Agency (Confederación Hidrográfica del Júcar) for gauging stations selected according to the study needs and availability of good-quality streamflow data.

To represent the natural flow regime, data were obtained for the period prior to regulation by large dams. Gauges and the historic periods were selected to minimize effects of surface-water diversions, regulation of streamflow or reduction of base flow due to ground-water pumping. Two streamflow-gauging stations met the selection criteria: streamflow records from the 08033 gauging station for the Júcar River near Alarcón (period of analysis is 1916–1931), and 08021 for the Cabriel River at Enguidanos (period of analysis is 1944–70). Two gauging stations



Figure 1. Study area location

and historic periods were also selected to represent the period after construction of the major dams. These are gauging station 08129 for the Júcar River at El Picazo (period of analysis is 1970–2003) and 08130 for the Cabriel River at Contreras (period of analysis is 1986–2003).

Habitat modelling sites, transect selection and measurements

The Physical Habitat Simulation Model (PHABSIM) was selected as the best method for predicting available fish habitat in response to incremental changes in streamflow (Bovee, 1982). Potential sites for simulating habitat availability were selected after defining homogenous hydrological regions. Two study sites in both rivers representing these homogenous hydrological regions were selected based on an on-ground reconnaissance. Transects were selected to represent the longitudinal distribution of different habitat types within the stream. Cross-sections were surveyed perpendicular to flow across each major habitat type. The number of cross sections varied for each site from 15 to 19.

Field data were collected using standard surveying equipment. Measurements of water depth, water velocity and substrate composition were made at various intervals along each transect. Substrate composition was assessed by visually estimating the per cent of the two main particle size classes and type of cover.

There is little quantitative knowledge of habitat preferences of *C. arrigonis*. Habitat Suitability Curves have not been developed, partly due to difficulties associated with the species' declining numbers. In order to apply PHABSIM models, habitat preferences for velocity, water depth and substrate size were developed by modifying preference data for the closely-related *Chondrostoma polylepis* (Martínez-Capel, 2000), derived from expert opinion. Species transferability testing was not used, but the confidence level from the new suitability criteria (category I curves in Bovee, 1986) was considered good enough in the context of this study, which is oriented to accurately identify major stressors affecting the status of the Júcar nase.

Data analysis

Olden and Poff (2003) identified 171 time-series statistics used in the literature to characterize flow series for ecological studies. These same statistics can be applied to habitat time-series. These authors showed substantial redundancy in these statistics, indicated by cross-correlations, and that a somewhat smaller set of statistics would be sufficient in most cases. One approach to selecting statistics is to calculate a vast number of statistics and use a data reduction exercise to identify a subset of relatively independent statistics characterizing different aspects of the flow regime (Clausen and Biggs, 1997; Olden and Poff, 2003). However this approach may fail to select the most meaningful statistics from an ecological perspective. We use an alternative in which statistics are selected based on understanding of the influence of flow-related variation in habitat on stream biota (Stewardson and Gippel, 2003).

To clarify the cause-effect relationships of human impacts and habitat responses (as well as ecosystem processes that maintain these habitats), we developed a broad conceptual model based on that of Burkhardt-Holm *et al.* (2002) (Figure 2). Using this conceptual framework, we focused our analysis on the particular aspects of hydrologic, geomorphology and physical habitat of importance to *C. arrigonis*.

In the first instance, this study focuses on general features of river flow regime theoretically needed to maintain ecological conditions. Hydrological analysis can be related to general indicators of biological function. Indicators of Hydrologic Alteration (IHA, Richter *et al.*, 1996) include a set of hydrologic summary statistics that characterize natural flow regimes and the types and degree of hydrologic change associated with an altered watershed condition. The IHA-variables include measures of seasonality (occurrence of minima and maxima in the year), magnitudes of high and low flows, frequency and duration of high and low pulses and rates of change (rise and fall). Components of the natural variation are quantified through hydrologic parameterization of the historical daily flow time-series.

In addition, to evaluate the disruption of geomorphologic and ecological processes we have used a specific hydrological indicator related to high discharges. The significance of high discharges in controlling river channel morphology and floodplain processes has been suggested by many authors (Wolman and Leopold, 1957; Wolman and Miller, 1960; Schmidt and Potyondy, 2004). Significant bedload transport in gravel bed-rivers typically begins at intermediate discharges approaching bankfull flow (Carling and McCahon, 1987). In our case, bankfull flows were determined using hydraulic outputs from the Physical Habitat Simulation System (PHABSIM) at the two study sites.



Figure 2. Conceptual framework linking flow modification and fish population (based on model proposed by Burkhardt-Holm et al. (2002))

Knowledge of any limiting habitat conditions is required for an understanding of fish population dynamics (Gerdeaux, 1984). We integrated habitat simulation results from PHABSIM with hydrological time-series (Habitat Time-series) to identify habitat-bottleneck periods induced by flow management. Relations between physical habitat availability and discharge were calculated for the Júcar and Cabriel Rivers. Time-series of habitat suitability were calculated for the range of streamflows between 0.5 and 50 m³ s⁻¹. Linear extrapolation was used for daily discharges larger than 50 m³ s⁻¹. The physical habitat model does not consider changes in substrate composition or modifications in the cross sections shape. In the case of *C. arrigonis* we have considered habitat requirements for each life stage: Adult from September to February; Spawning from February to May; and Young of the Year from May to September.

We use three methods to characterize changes in the temporal habitat distribution for *C. arrigonis*. The first method is an evolution of the Continuous Under Threshold curves methodology (Capra *et al.*, 1995), that plots periods during which habitat availability exceed a given threshold. According to these authors, two different thresholds have been defined corresponding to transitions between suitability habitat conditions: 75% of the maximum habitat availability is the lower limit of *suitable* habitat condition whilst 50% of the maximum habitat availability is considered the upper limit of *unsuitable* habitat conditions. Class frequencies of these durations are computed from the habitat time-series and plotted against the cumulative per cent of time. A comparison of the resulting curves for pre- and post-dam implementation indicates which part of the temporal habitat durations are most affected by flow management.

The second method is a new tool that we have named the Impact Time-series technique (Figure 3). This methodology evaluates habitat impacts of modified flows in comparison with habitat availability under natural flow conditions. Habitat Reference Levels (HRLs) are estimated considering the hydrological reference conditions (pre-dam hydrology characterized using 10th percentile daily flows). In a second step, both habitat modelling sites subject to flow modification histories are compared with the predefined HRL. Based on habitat reduction respect the defined HRL, a threshold analysis is developed to estimate habitat impact levels in two different categories:



Figure 3. Steps within the Impact Time-series technique: (a) Pre-dam frequency analysis showing the range between 10th and 90th percentiles (black). (b) Weighted Usable Area (WUA) corresponding to the 10th percentile. (c) Habitat Reference Level and threshold categories indicating stress situations (grey clear) and critical impacts (grey dark). (d) Modified flow regime (pointed line) and habitat levels (dark line) compared with the habitat impact categories

River. Res. Applic. **23**: 511–523 (2007) DOI: 10.1002/rra reduction in a 50% or more is considered a 'critical impact', whilst a reduction up to 50% is considered a 'stress situation'. Adapted from results of *Capra et al.*, we have selected these class boundaries as meaningful thresholds, but biological validation is very difficult due to the declining numbers of *C. arrigonis*.

The third method is Habitat Spell Analysis calculated using the River Analysis Package (Marsh, 2003). This method characterizes changes in the duration of low flow spells, defined as continuous periods during which habitat availability is less than 50% of the maximum. The maximum low-flow spell duration for each biological season is obtained from the historical record. The distribution of these durations can be plotted in a similar way to flood frequency plots where the X-axis shows the average recurrence interval between years in which spell durations (the Y-axis) are exceeded. Spell analysis is carried out for each of the three life-stages, in the two rivers under natural (pre-regulation) and modified (post-regulation) conditions.

RESULTS

Hydrological analysis

The hydrological alterations caused by dam operations have changed the magnitude, timing and duration of stream flows (Figures 4, 5 and 6). The Alarcón Reservoir has reduced average flows in the months of October to



Figure 4. Range of daily variation at 90 and 10 percentages (grey dark) and at 25 and 75 percentages (black). Figures show results for (a) natural and (b) modified in Júcar River and (c) natural and (d) modified for Cabriel River



Figure 5. Daily hydrographs and bankfull flows (pointed line) for the Júcar (left) and Cabriel Rivers. After dam operations, magnitude and frequency of high discharges are drastically reduced

May from about 7 to $2.5 \text{ m}^3 \text{ s}^{-1}$ and has increased average flows in the month of August from about 12 to $20 \text{ m}^3 \text{ s}^{-1}$. Magnitudes of high flows are altered (Figure 5) and the day of the maximum flow has moved later in the year (Figure 6). Before dam development discharges greater than $100 \text{ m}^3 \text{ s}^{-1}$ occurred in the Júcar River every 1.2 years with an average duration of 2.5 days (ranging from 1 to 8 days). In contrast, since operation of Alarcón dam commenced, there has been only 1 year (in 54 years of recorded flow) with river flows greater than $100 \text{ m}^3 \text{ s}^{-1}$.

The number and the duration of low flow periods has increased and the annual minimum flow occurs earlier in the year since regulation (Figure 6). The annual minimum flows have been drastically reduced. Downstream of the dam, flows below $2 \text{ m}^3 \text{ s}^{-1}$ occurred 30% of the time with a minimum of 0.15 m³ s⁻¹ whilst in natural conditions the minimum flow recorded was $4.5 \text{ m}^3 \text{ s}^{-1}$ and flows were in excess of $5 \text{ m}^3 \text{ s}^{-1}$ for 92% of the time.

Operation of the Contreras Dam (Figure 4) has lead to considerable change in the seasonal pattern of discharge in the Cabriel River. There has been a large increase in mean summer flows (from 8 to $20 \text{ m}^3 \text{ s}^{-1}$) and reduced mean flows in the months of October to May. Upstream of the dam, flows in excess of $4 \text{ m}^3 \text{ s}^{-1}$ occurred 95% of the time (the minimum recorded flow is $2.8 \text{ m}^3 \text{ s}^{-1}$). The river can be dewatered immediately below this dam; flows below $1 \text{ m}^3 \text{ s}^{-1}$ occur for 65% of days, with 5% of zero flows. In the modified condition, magnitudes of high flows are altered (e.g. annual maximum flow, see Figure 5) and the duration of high pulses has increased and become more variable. The number and the duration of low pulses has also increased. The day of the minimum flow has moved earlier in the year and become more variable (Figure 6). There have also been increased rates of flow rise and fall.

Habitat analysis

Habitat duration curve analysis. The results of habitat duration curve analysis are presented in Figure 7. In Júcar River, unsuitable habitat durations for the young stage (less than the 50% habitat threshold) never occur with natural flows but represents 35% of the total time with modified flows. Considering the adult life stage, the lack of unsuitable habitat during the pre-dam period contrast with the 55% of the total time during the post-dam period, with some repeated durations over 200 days. Considering the range of 120–320 days for unsuitable modified habitat, it accounts for almost 60% of the total time, meaning these long durations would occur each 2 years on average.

In Cabriel River, suitable habitat in modified conditions for the young stage falls from 15 to 5% of the total time (see black arrows). Unsuitable habitat jumps from 60 to 100 days in upper limits and account for 30% instead of 15% of the total time with natural flows (see grey arrows). The 50% habitat curves also exhibits that long durations of 200 days of unsuitable conditions can artificially occur several times, when they do not exceed 160 days once a



Figure 6. Day of maximum (a) and minimum flow (b) starting in 1st January

decade with natural flows. Suitable habitat curves for adult stage indicate a severe decrease in total time from 72% in natural conditions to 22% with modified flows and complete elimination of long suitable habitat durations exceeding 100 days.

Impact time-series analysis. Alarcón dam operations in the Júcar River have substantially decreased the availability of suitable habitat for 10 months of the year (Figure 8). Impact time-series analysis shows that critical impacts have occurred for 33% of the time for the adult stage. If we consider the spawning period (from February to May), habitat conditions have been unsuitable for *C. arrigonis* for 70% of the time, with critical impacts for 45% of the time. From May to September (period considered more restrictive for the YOY stage), habitat availability is within the natural range for only 39% of the time, whilst the habitat conditions have been critical for 9% of the time and stressed for 52% of the time.



Figure 7. Habitat duration curves for under natural and modified (M) flows. The horizontal axis is the continuous periods (in days) of suitable-unsuitable conditions, and the vertical axis is the cumulative distribution of each duration. Horizontal arrows indicate total shifts in larger durations and vertical arrows show the proportion of total time from natural to modified flow regimes. Figures correspond to (a) adult stage in Júcar River; (b) young stage in Júcar River; (c) adult stage in Cabriel River; and (d) young stage in Cabriel River

In the case of the Cabriel River, habitat availability for *C. arrigonis* has been drastically reduced for all the periods and stages. Critical impacts for young and adult stages occur 45% of the time for the whole period of record, with habitat availability within the natural range for only 12 and 18% of the time, respectively. Habitat availability for spawning has been widely affected; *C. arrigonis* suffered critical impacts with the lack of habitat availability (50% respect minimum of the HRLs) for more than 73% of the time. In this spawning period, only 21% of the time is considered as having favourable conditions. For the YOY period, habitat loss was considered critical for 32% of the time (related to high discharges in the summer period and inversion of the natural seasonal pattern). There was a reduction in habitat availability that produced stress situations for the YOY for the 36% of the time, whilst for more than 32% of the time, habitat availability was inside the natural range.

Habitat spell analysis. The habitat spells analysis characterizes the frequency of long-duration spells when habitat availability is relatively low (i.e. less than 50% of the maximum). Results indicate there has been an increase in the frequency of long-duration spells with reduced habitat (Figure 9). The most severe impacts correspond to Adult spawning habitat in the Cabriel River where spells with reduced habitat availability of greater than 10 days duration only occurred on average every 10 years. Since regulation, spells with reduced habitat availability with a duration of more than 10 days occur in most years (in both rivers) and duration of more than 65 days are exceeded with an average recurrence interval of 2 years.

Severe impacts are also observed for Adult habitat between September and February, particularly in the Cabriel River where spells with limited habitat available with duration of greater than 20 days only occurred on average every 10 years. Since regulation, spells with duration of greater than 80 days occur every year. In fact in most years, adult habitat availability is less than 50% of the maximum for the entire period September to February. Longer durations of spells with reduced habitat were more frequent in the Júcar River under natural conditions with spell

Figure 8. Distribution of daily habitat impact. Figures correspond to (a) adult stage in Júcar River; (b) young stage in Júcar River; (c) adult stage in Cabriel River; and (d) young stage in Cabriel River. Black area indicates critical impacts, area with horizontal bars indicates stress situations and the clear stippled area indicates inside the natural range

duration of 30 days and 90 days exceed with average recurrence intervals of 2 and 5 years, respectively. However, regulation has increased the frequency of these longer duration spells with duration greater than 30 days in every year and duration of greater than 90 days with an average recurrence interval of 1.5 years.

Young of the year habitat has also been affected by regulation in both rivers. Prior to regulation spells with limited habitat availability of duration greater than 30 days occurred with an average recurrence interval of close to 3 years in both rivers. Since regulation 30 day spells occur almost every year in both rivers.

DISCUSSION

There has been a 95% reduction of the historical range of *C. arrigonis* in the Júcar River basin. Effective recovery planning must address all human-induced limiting factors that have contributed to fish declines, but linking biological effects with their causes is particularly complex when multiple stressors affect a waterbody. Our ability to accurately identify stressors is a critical first step in developing strategies that will improve the status of the Júcar nase.

Overexploitation, water pollution, invasion by exotic species, destruction of habitat and flow modification have been categorized as the ultimate forcing factors that threaten global freshwater biodiversity (e.g. Naiman *et al.*, 1995; Jackson *et al.*, 2001; Malmqvist and Rundle, 2002; Rahel, 2002; Dudgeon *et al.*, 2006). In our study, we propose that flow modification is the major stressor responsible for the severely restricted distribution of *C. arrigonis*.

Despite capture fishery data for *C. arrigonis* are lacking, there is no evidence that overfishing was a significant factor in the fish decline because it does not represent a high value target species. In the same way, water pollution is not considered a significant causal factor. Following the provisions of the Water Framework Directive, most

Figure 9. Results of low-flow spell analysis showing the average recurrence intervals for the annual maximum low flow spell durations for three habitats. Figures show results for (a) natural and (b) modified in Cabriel River and (c) natural and (d) modified for Júcar River

important parameters related to the suitability of the water for fish life were specifically analysed by the Júcar Water Agency to determine a preliminary status. The results show that the Júcar and Cabriel River, particularly the middle and upper reaches, did not present water quality problems (CHJ, 2004).

In contrast, we have no objective means to quantify effects of widespread invasive species on *C. arrigonis*. Operational since 1979, the inter-basin water transfer from the Atlantic River basin of the Tajo to the Mediterranean River basin of the Segura (through the Júcar River) diverts between 100 and $350 \times 10^6 \text{ m}^3 \text{ yr}^{-1}$ of water. After this scheme commenced, *C. polylepis* (fish species coming from the donor watershed) was increasingly encountered in the Júcar River (Elvira and Almodóvar, 2001). As some authors have mentioned (in Doadrio *et al.*, 2004), there is a risk of hybridizing between both species, but the most severe consequence could be the disappearance of the endangered species triggered by superior competitive ability of *C. polylepis*. The last remaining populations of the endemic fish located downstream of Contreras dam are found in areas lacking this invasive species, but the issue of introduced biota remains unresolved, and the future of the *C. arrigonis* remains threatened.

Habitat destruction includes two main anthropogenic pressures: impoundments and morphological alterations. Surface water resources in the Júcar basin are regulated through 17 large dams. The Júcar nase will not successfully colonize a reservoir because this species present reofile reproductive adaptations (Doadrio, 2001). Despite the unfavourable effects of reservoirs in the cyprinid, more than 60% and 80% of the Júcar and Cabriel Rivers reaches are still unimpounded, respectively. Morphological alteration (artificially straightening the river channel or changing the morphology of riverbanks) also destroy habitats. Some river reaches in both rivers have been

canalized although most of those modified reaches in the upper and middle portions of the basin are not subjected to significant morphological pressures and impacts (CHJ, 2004).

The dramatic hydrological changes that have occurred over the last decades in the Júcar and Cabriel Rivers is evidence supporting flow modification as the major stressor affecting *C. arrigonis*. Our results are coincident with global species assessments. Analyses of the data on threats to biodiversity evaluated for the 2004 *IUCN Red List* show that the most pervasive threat is habitat destruction and degradation (Baillie *et al.*, 2004). Harrison and Stiassny (1999) found that whilst many factors can simultaneously contribute to extinctions, habitat alteration was the major cause driving the extinction of fish species. Surface water diversions is the major cause of stress, imperiling 74% of all threatened and endangered fish species in the United States (Reed and Czech, 2005).

Heterogeneity and complexity of physical structure, their connectivity and variability are environmental factors closely related with the flow regime. As many stream organisms are adapted to predictable flow changes associated with natural seasonal events, deviations from this pattern may act as disturbance (Poff *et al.*, 1997; Dudgeon, 2000; Bunn and Arthington, 2002). It seems reasonable to assume that hydrological alteration changes the full range of environmental conditions under which *C. arrigonis* was locally common at the beginning of the twentieth century.

To assess the potential flow modification impact, we have compared historical and current habitat conditions, making observations about the expected habitat-bottleneck periods. In these flow modified reaches, the Júcar nase have suffered habitat losses in two ways: lost of suitable habitat and gain for unsuitable habitat. For comparison between rivers, habitat losses for young and adult stages in Júcar River occur for 60% of the time and 77% of time for young stage in Cabriel River. Habitat availability for the spawning period since regulation is respectively 30% and 55% of habitat availability corresponding to natural low flow conditions (flows exceeded 90% of the time in the pre-dam period). Even considering the uncertainty in physical habitat modelling, these dramatic reductions in habitat should impact the fish reproduction cycle and the class population distribution. Then, it seems reasonable to hypothesize that a significant enough reduction in the amount of spawning habitat could result in a reproductive failure and the accelerated decline of the endangered species. Our results are consistent with the observed pattern of population (Doadrio *et al.*, 2004). In this study, the fish survey data exhibit a highly skewed distribution with a high proportion of populations having no YOY.

The methodologies reported here allow accurate prediction of shifts in habitat availability in response to human-induced alterations in river flow regimes. Under these flow modified reaches, *C. arrigonis* have suffered habitat losses in a double meaning: lost for suitable habitat and gain for unsuitable habitat. On the basis of these results, we conclude that the main identified pressure causing the Júcar nase decline is habitat modification through dam operation and consequent downstream flow modifications. The absence of a comprehensive environmental flow regime to protect and restore the aquatic ecosystem will probably cause the extinction of this species in the short term. To provide conservation and protection of those remaining populations, the most effective management action is obvious: a new flow regime to restore the disrupted ecological, hydrological and geomorphologic processes.

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