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Chapter 12
Quantitative Habitat Models for the Conservation of the Endangered European Crayfish *Austropotamobius pallipes* Complex (Astacoidea: Astacidae)

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Abstract Crayfish are the largest mobile freshwater invertebrates and are keystone species in European aquatic ecosystems particularly in small streams and rivers. The white-clawed crayfish *Austropotamobius pallipes* (a species complex) is currently classified by the IUCN Red List as an endangered species (EN), because its populations have decreased significantly over the last decades in a number of European countries including Italy, due mainly to habitat modifications and the introduction and spread of alien species. Data on the ecological requirements of *A. pallipes* are needed to quantify the effects of habitat alteration, to simulate restoration scenarios, and to implement effective conservation measures for this species. We describe here a new methodology for modelling the habitat requirements for this endangered crayfish using the mesohabitat scale approach based on data from crayfish living in small streams draining the Italian foothills of the Alps (Lombardy region) and in streams in the mountainous areas of the Gran Sasso and Monti della Laga National Park (Abruzzo region). Data from seven morphologically different streams were used to train and validate the habitat models. The Random Forests algorithm was used to identify the best and most parsimonious habitat model, and to define the lowest number of variables to be surveyed in the future. The best habitat models were applied to each stream and used to classify each mesohabitat into suitability categories. Habitat flow-rating curves were developed to analyze spatio-temporal variation of habitat availability, and habitat time series analysis were used to define detailed management schemes for environmental river management. Flow releases and water

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temperature regimes were assessed for individual water diversions in order (1) to represent how physical habitat changes through time, and (2) to identify stress conditions for *A. pallipes* created by the persistent limitation of habitat availability. Results indicated that the kind of substrate in the stream bed (such as the proportion of fine-grained substrates), the water depth (whether shallow or deep), and the available cover (such as the presence of boulders, woody debris, and undercut banks) were all significant factors governing the occurrence of crayfish. The habitat models performed well in both calibration and validation phases (with accuracy ranging from 71 to 79 % in training and from 69 to 73 % in validation) and can be considered to be a valuable tool to predict the distribution of *A. pallipes* over a wide range of stream types. An example of how to establish environmental standards for small streams is presented. The proposed habitat model provides a useful tool that can be applied even when other commonly used methodologies are unsuitable. As such, this habitat model can be used to develop regional rules for the conservation of the endangered crayfish *A. pallipes* complex and for defining more site-specific management criteria.

Keywords Endangered crayfish · Mesohabitat · MesoHABSIM · *Austropotamobius pallipes* · Crayfish conservation

12.1 Introduction

The white-clawed crayfish, *Austropotamobius pallipes* (Lereboullet 1858) species complex, is indigenous to European freshwater ecosystems (Fig. 12.1) and it is considered a "flagship species", rather than indicative of good water quality (Füreder and Reynolds 2003).

Fig. 12.1 The white-clawed crayfish, *Austropotamobius pallipes* complex

Populations of *A. pallipes* complex have undergone a remarkable decline, and the extent of occurrence of this species in Europe has contracted sharply over the last 50 years (Souty-Grosset et al. 2006). In Italy declines in both crayfish numbers (down by 74 %), and in the distributional range have been reported over the last 10 years (Holdich et al. 2009). This has led to the species being listed in the EU Directive 92/43/EEC (Habitats Directive) as 'a species of community interest whose conservation requires the designation of special areas of conservation', and 'whose exploitation may be subject to management measures' (Annexes II and V, 92/43/EEC). This species is also listed as endangered (EN) by the IUCN (Füreder et al. 2010) due to habitat alteration, water diversion, water pollution, and the introduction of competitive North American freshwater crayfish species (*Procambarus clarkii* and *Orconectes limosus*) which are also carriers of the organism that causes the crayfish plague (the oomycete *Aphanomyces astaci* Schikora 1906) (Aquiloni et al. 2011). Habitat fragmentation has led to the geographic and genetic isolation of the remaining populations which are now confined to small streams in the headwaters of hydrographic basins (Nardi et al. 2004). In addition to the present threats, several hundred applications for new small hydropower plants (SHP) have been made across the whole Alpine and Apennine area (CIPRA 2010; CIRF 2014), and most of these are located in the small high gradient streams and headwaters which constitute the remaining unaltered habitat of the residual populations of *A. pallipes* complex.

Different management projects have been undertaken to prevent the extinction of native crayfish populations in European countries (Bernardo et al. 1997; Diéguez-Uribeondo et al. 1997; Holdich and Rogers 1997; Whitehouse et al. 2009; Berger and Füreder 2013; Ghia et al. 2015); but quantitative, predictive models and tools that can support the implementation of crayfish conservation actions are currently underdeveloped (Ghia et al. 2013). The prediction of crayfish distribution and abundance in relation to the stream habitat characteristics has multiple uses such as (1) planning reintroduction programmes, (2) assessing environmental flow releases from dams, and (3) evaluating and designing habitat restoration measures (Parasiewicz et al. 2012). Habitat simulation models are common tools used to perform stream habitat analyses and to demonstrate the effectiveness of the ecological management of watercourses (Maddock et al. 2013). These models use simulations of the spatio-temporal variation of habitat characteristics. The models aim to find the optimal hydro-morphological conditions needed to preserve aquatic communities and thereby avoid the decline of a selected group of target species beyond a determined conservation level. The meso-scale (or mesohabitat) approach is currently being used to model habitat changes in small high gradient streams in the Italian Alps and Apennine mountain ranges (Vezza et al. 2014a, b). These mesohabitats often correspond in size and location to hydro-morphological units (HMUs) such as pools, riffles, and rapids (Parasiewicz et al. 2013). Compared to the traditional micro-scale approach (e.g., Bovee 1982; Jorde et al. 2001) the mesohabitat scale allows for the surveying of longer portions of watercourses and involves a larger range of habitat descriptors in the analysis. As such it can be used to represent and model the complex morphology of high gradient mountain streams

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(Vezza et al. 2012a). In addition, traditional modeling approaches are mainly focused on the use of fish as indicator species, because fish have important touristic and economic benefits for the surrounding human population. However, fish are often absent from the small mountain streams where crayfish populations do well, so these crustaceans can be used as the target species for restoration actions. Currently no comprehensive methodology has been presented in the literature to model the habitat for crayfish. A few case studies (Foster 1995; Clavero et al. 2009; Favaro et al. 2011) have described the habitat preferences of *A. pallipes* at different spatial scales, but this has not been integrated into habitat simulation tools (e.g., CASiMiR, Jorde et al. 2001; MesoHABSIM; Parasiewicz 2007a) and remains unexploited for environmental flow assessment and the design of habitat restoration measures.

Hydro-morphological and biological data from seven reference mountain streams in Italy have been used to develop a comprehensive habitat simulation methodology to describe and predict habitat requirements for the endangered crayfish *A. pallipes* complex. Streams were selected based on (1) the natural conditions of the habitat, (2) the absence of water abstraction, and (3) the presence of a native crayfish population with a well-structured age-class composition (Ghia et al. 2015). The Mesohabitat Simulation Model—MesoHABSIM (Parasiewicz et al. 2013) describes the natural spatio-temporal variation of habitat characteristics analyzed under reference conditions and quantifies habitat alteration, assesses environmental flow releases from existing and new water abstractions, and proposes habitat restoration measures for *A. pallipes* complex.

12.2 Study Area

The study was carried out in seven small streams, five of them were in the foothills of the Italian Alps in the Po River basin (Lombardy region, northern Italy), and two of them in the mountainous areas of the Gran Sasso and Monti della Laga National Park (Abruzzo region, central Italy) in the Saline and Tordino River basins (Fig. 12.2).

Each study stream has a stable population of white-clawed crayfish (*A. pallipes* complex), a moderate current velocity, generally high inorganic substrate heterogeneity, and woody debris, leaves, and detritus are all present. These study sites are located in the altitudinal range typical for *A. pallipes* complex (Fea et al. 2006) and each has the optimal value for the annual mean water temperature of the species (Souty-Grosset et al. 2006). Moreover, these streams were chosen within European protected sites (Natura 2000) and are surrounded by woodland in order to minimize anthropic disturbance including the poaching of crayfish. Each high-gradient stream site was characterized by a different morphological type (ranging from cascade, to step-pool, to plane bed type) (Montgomery and Buffington 1997; Vezza et al. 2014b). The length of the analyzed stretch was from 15 to 30 times the width of the stream, so that the hydro-morphological unit of distribution in small mountain

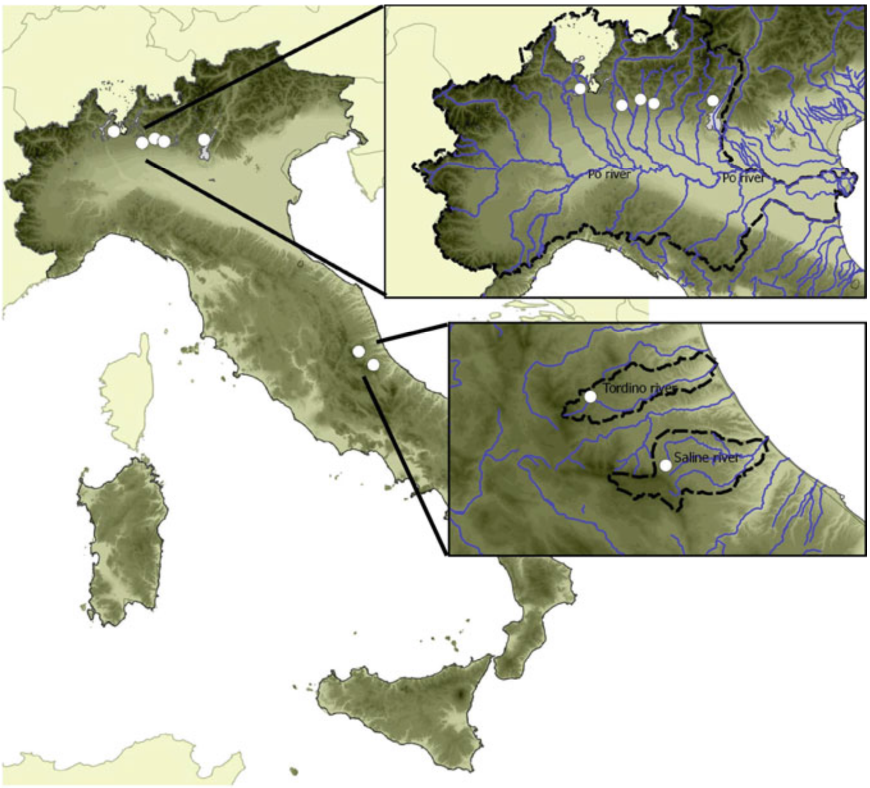

Fig. 12.2 Study sites selected in reference streams in the foothills of the Italian Alps in the Po River basin (Lombardy region, northern Italy) and in the Gran Sasso and Monti della Laga National Park (Abruzzo region, central Italy)

watercourses could be described (as mentioned in the system for morphological unit classification published by the Italian National Institute for Environmental Protection and Research, Rinaldi et al. 2015).

12.3 A Mesohabitat Simulation Model for the Endangered *A. pallipes* Complex

12.3.1 Habitat Description

Vezza et al. (2014b) described the changes in mesohabitat distribution over a selected range of stream discharges. The survey of mesohabitat characteristics was carried out with a rangefinder (Trupulse 360B, Laser Technology, Centennial, Colorado, USA) and a rugged field computer (e.g., Nomad TDS [tripod data system], Field Environmental Instruments, Sunnyvale, California, USA) along with a global positioning system [GPS]. The GPS was used to capture the starting point of the survey, defined as a nearby opening with good satellite coverage, or from a clearly identifiable ground control point. The HMU polygons were delineated using the rangefinder and both mesohabitat-scale features (e.g., HMU type, gradient, cover sources). Random samples of water depth, flow velocity, and substrate composition were recorded for each of the mapped mesohabitats. In particular for each HMU we collected from 7 to 30 mean water column velocity values (by using the flowmeter Marsh—McBirney Flo-Mate; Hach Company, Loveland, Colorado, USA), and carried out depth measurements and substrate estimates in order to describe the frequency distribution of these physical variables and to describe the entire HMU area. Flow velocity, water depth, and substrate type were then divided into frequency classes as a percentage of the random samples. The complete list of habitat descriptors collected during a habitat survey for crayfish is reported in Table 12.1. This HMU survey was repeated over a range of flows, between the minimum low flows and the medium/high flows that would be expected on these watercourses.

Table 12.1 Physical habitat attributes used to describe hydro-morphological units for *A. pallipes* complex

Variable name	Unit	Classes	Categories/description
Hydro-morphological unit (HMUs)	Yes/no	12	Photole, pool, plunge pool, glide, rock glide, riffle, rapid, cascade, step, waterfall, backwater pool, dune system
HMU length	m	1	Longitudinal length of the HMU
HMU width	m	1	Mean width of the HMU
HMU gradient	%	1	Longitudinal mean slope of the water surface
Cover	Yes/no	8	Boulders; canopy shading; woody debris; overhanging Vegetation; submerged vegetation; emergent vegetation; undercut bank, exposed tree roots
Flow velocity	Percentage of at least 7 random samples	9	Classes in 15-cm increments (range 0–120 cm and above)
Water depth	Percentage of at least 7 random samples	9	Classes in 15-cm/s increments (range 0–120 cm/s and above)
Substrate	Percentage of at least 7	12	Gigalithal (roks); Megalithal (>40 cm); Macrolithal (20–40 cm); Mesolithal (6–20 cm); Microlithal

(continued)

Table 12.1 (continued)

Variable name	Unit	Classes	Categories/description
	random samples		(2–6 cm); Akal (gravel); Psammal (sand); Pelal (silt, clay), Detritus (organic matter); Xylal (woody debris, roots); Sapropel (dark anoxic mud); Phytal (submerged plants)
Froude number	(flow velocity)/(9.81 depth)^0.5	1	Average value over the HMU area
Flow velocity standard deviation (SD)	cm/s	1	Flow velocity SD over the HMU area

12.3.2 Biological Data Collection

Crayfish (*A. pallipes*) were collected in each stream at night when these animals are most active in order to define the habitat requirements and to build mesohabitat suitability models (Barbaresi and Gherardi 2001). During summer 2012 and 2013 crayfish were quantitatively sampled by hand by walking upstream in each previously mapped HMU (Smith et al. 1996; Ghia et al. 2015). The gender of each crayfish was recorded. The cephalothorax length (CL = from the tip of the rostrum to the posterior median edge of the cephalothorax) was measured using digital calipers. CL was used as a reliable measurement of length due to the rigid structure of the cephalothorax. All crayfish that either lacked a rostrum or had a mutated rostrum were excluded from the length-frequency distributions. Wet weight was determined using a handy spring balance and any morphological mutilations were recorded. After measurement, crayfish were returned to the same sampled HMU part of the stream. Then, each crayfish was classified as adults or juveniles using size-frequency distributions to estimate the age composition (Ghia et al. 2015).

12.3.3 Defining Mesohabitat Suitability Criteria for A. pallipes *Complex*

Data from five reference streams in the foothills of the Italian Alps, which comprised 130 sampled HMUs, were used for *A. pallipes* model training. An independent dataset was collected in the two reference streams in the Gran Sasso and Monti della Laga National Park (65 HMUs, 50 % of the training data-set) and was used for model validation. In terms of crayfish presence the proportion of occurrence (i.e., model prevalence) of adult *A. pallipes* was 0.49 in training, and 0.46 in validation, whereas the proportion of occurrence of juveniles was 0.56 in training and 0.34 in validation. Abundance thresholds for crayfish were assessed as

1.5 ind/m^2 for adults and as 2.0 ind/m^2 for juveniles, whereas the presence/abundance model prevalence in training was 0.21 for adults and 0.28 for juveniles. The low density values of crayfish found in the validation sites (<0.8 ind/m^2) meant that only absence/presence models could be validated using an independent dataset.

To find effective mesohabitat suitability criteria the relationship between habitat variables and crayfish distribution was explored by Random Forests (Breiman 2001) as implemented in R (Liaw and Wiener 2002). RF is an ensemble learning technique based on the combination of a large set of decision trees (i.e., Classification and Regression Trees—CART, Breiman et al. 1984).

In RF, each tree is trained by selecting a random bootstrap subset Xi (i = bootstrap iteration which ranges from 1 to t, maximum number of trees) of the original dataset X and a random set of predictive variables (Liaw and Wiener 2002). Breiman (2001) provides details of the algorithm for growing a RF of decision trees. Following the MesoHABSIM approach two binary models were built as follows: a suitable habitat model (to distinguish between the absence and presence of crayfish) and an optimal habitat model (to distinguish between the presence and abundance of crayfish). The cutoff value for low and high abundance was determined as the inflection point of the envelope curve of the crayfish density histograms (Vezza et al. 2014b). As the response variable was categorical (crayfish absence/presence and presence/abundance), we therefore confined our attention to classification RF models.

To improve model parsimony the minimum number of variables was identified by the Model Improvement Ratio (MIR, Murphy et al. 2010) technique. The improvement ratio was calculated as [In/Imax], where In is the importance of a given variable and Imax is the maximum variable importance. To carry out this analysis the conditional variable importance was used to avoid RF bias towards correlated predictor variables (see, Strobl et al. 2008). Starting from MIR = 0, we then iterated through MIR thresholds (i.e., 0.02 increments), with all variables above the threshold retained for each model. Models corresponding to different subsets were compared and the model exhibiting the minimum EOOB and the lowest maximum EClass (j) was selected. Lastly, to avoid collinearity effects on the model performance, the correlation among the selected variables was tested using a correlation matrix. Crayfish habitat models were developed for both adults and juveniles.

The performance of the predictive models was evaluated using six performance metrics, i.e., accuracy, sensitivity, specificity, Cohen’s kappa (k), area under Receiver Operating Characteristic (ROC) curve (AUC), and true skill statistic (TSS), which are commonly used in ecological modelling (Vezza et al. 2015). The partial dependence plots provided a way to visualize the marginal effect of the selected independent variables on the probability of crayfish presence or abundance. Specifically, these plots can be used to characterize graphically the relationship between habitat variables and the predicted probabilities of fish presence obtained by RF (Cutler et al. 2007).

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12.3.4 Modelling Spatio-temporal Variation of Habitat Availability

The obtained mesohabitat suitability criteria were then applied to all HMUs mapped at each flow to calculate the probability of presence and high abundance and to classify mesohabitat into suitability categories (not suitable, suitable, or optimal). A probability equal to 0.5 is commonly used by RF to define the probability threshold and to determine the best separation of not-suitable/suitable (or suitable/optimal) habitat units. To develop habitat-flow rating curves, the area of HMUs with suitable and optimal habitats was summarized for every site by weighting suitable habitat area by 25 % and optimal habitat area by 75 %, and was plotted against the wetted area at the highest measured flow (Parasiewicz 2007a). To represent the habitat rating curve, the habitat values were interpolated using a mathematical spline function for the target species and the considered life stages (Vezza et al. 2014b).

In addition to habitat-flow rating curves, the definition of the reference habitat time series is an important final element needed for the full determination of environmental standards for watercourses (Milhous et al. 1990). The MesoHABSIM model emphasizes the temporal scale by statistically analysing habitat time series to detect stress periods due to limited habitat availability. This analysis is based on the assumption that habitat availability is a limiting factor, and events occurring rarely in nature create stress to aquatic fauna and shape the community. The identification of periods of stress has to not only consider the magnitude of a possible impact (i.e., the amount of diverted water), but also needs to provide a means of quantitatively measuring duration and frequency of stress events.

The habitat time series is calculated by converting the stream flow time series using the habitat flow rating curve (Milhous et al. 1990). Unfortunately, hydrological information and the stream flow time series are usually not available for small mountain streams. Therefore, the water levels and water temperatures of streams were continuously measured using HOBO © pressure transducers (Onset Computer Corporation, Bourne, Massachusetts, USA) and the mean daily discharge was calculated using discharge versus stage curves calibrated in stable regular cross-sections. The obtained habitat time series was then statistically analyzed using the uniform continuous under thresholds (UCUTs) methodology. The UCUT-curves are considered projected contours of a habitat surface area in the three dimensional space of duration, frequency, and habitat quantity (Vezza et al. 2012b). They are defined as the sum length of all events of the same duration, computed as a ratio of a total duration of the considered bioperiod, where proportions are plotted as a cumulative frequency. This procedure is repeated for an entire set of possible thresholds (e.g., from 2 % to the maximum value of available habitat). The UCUTs for very low frequency are located in the bottom left corner of the UCUT graph (Fig. 15.5). As habitat level continues to increase, this pattern of UCUTs rapidly changes and the distance between the curves increases. The highest curve is usually selected in the rare-event group of curves, as the rare-event level threshold. The distance between the lines after exceeding the rare-event level are

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usually greater than in the previous group, but are still close to each other. The next outstanding curve, demarcating a rapid change in the frequency of events (i.e., an increase in distance between curves), is assumed to mark the stage at which the common under-threshold events begin (Parasiewicz 2007b).

This analysis helps to identify the longest period that under-threshold events are allowed to continue before reaching catastrophic conditions (Parasiewicz et al. 2013). The results of habitat and water temperature time series analyses were used to define natural conditions and environmental standards, aimed at reducing or excluding continuous duration of events that are stressful for *A. pallipes*.

12.4 The Application of the Results to the Mesohabitat Suitability Models

A total of 1033 crayfish (538 females and 495 males) were collected at both of the locations used here (the model training and validation sites). Using the cross-validation procedure embedded in RF, model training performances were found to be high for both adult and juvenile crayfish absence/presence models (Table 12.2). In model training the lower value for accuracy was 0.71, 0.76 for AUC, and 0.46 for TSS.

Table 12.2 Performance metrics of the mesohabitat suitability models for both adult (Ad.) and juvenile (Juv.) *A. pallipes* complex. Two binary classification models were built: the absence/presence model and the presence/abundance model. Only the absence/presence model was validated using an independent data sets due to low density values in the validation sites

	Model training		Model validation	
	Ad. *A. pallipes*	Juv. *A. pallipes*	Ad. *A. pallipes*	Juv. *A. pallipes*
Absence/presence model				
Accuracy	0.75	0.75	0.69	0.73
Sensitivity	0.75	0.73	0.80	0.83
Specificity	0.74	0.76	0.61	0.67
Cohen's kappa	0.51	0.49	0.39	0.47
Area under ROC curve	0.76	0.82	0.71	0.75
True skill statistics	0.49	0.49	0.41	0.50
Prevalence	0.49	0.56	0.45	0.34
Presence/abundance model				
Accuracy	0.79	0.71		
Sensitivity	0.77	0.75		
Specificity	0.79	0.71		
Cohen's kappa	0.47	0.39		
Area under ROC curve	0.83	0.82		
True skill statistics	0.56	0.46		
Prevalence	0.21	0.28		

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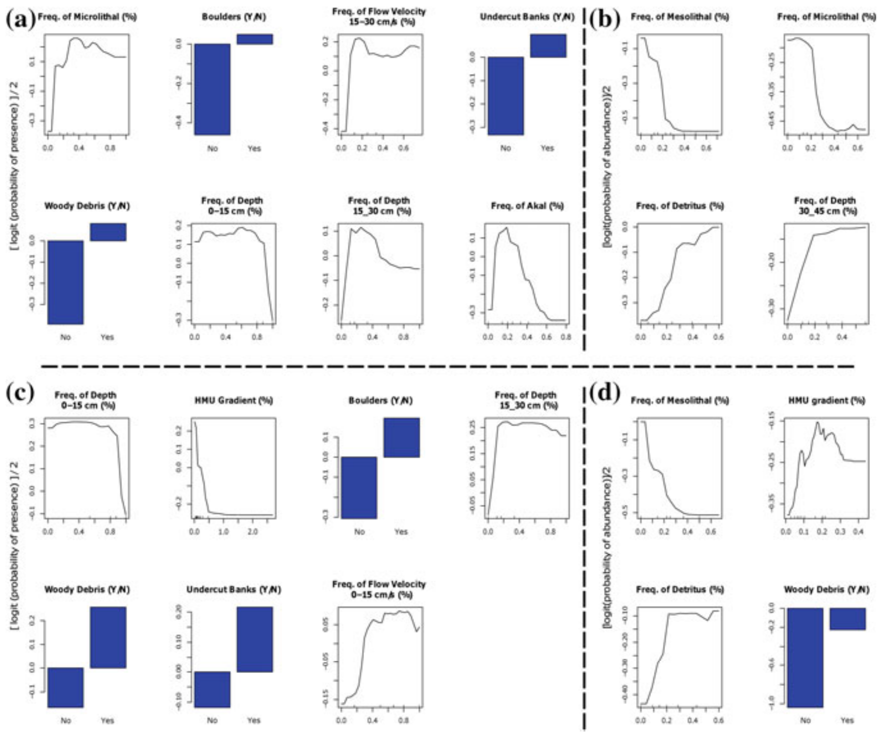

Fig. 12.3 Random forest model for crayfish to predict **a** adult presence, **b** adult abundance, **c** juvenile presence and **d** juvenile abundance. Selected variables are reported in order of importance. A detailed description of considered habitat attributes is reported in Table 12.1 and in Vezza et al. (2014b). The relationship between variables and probability is shown using partial dependence plots to investigate the marginal effect of the selected independent variable on the predicted probability of crayfish presence

Mesohabitat characteristics significantly affected the presence of crayfish ($\chi^2 = 43.582$, df = 9, $p = 0.000$). Crayfish occurred mostly in pools (58.1 %), riffles (14.3 %), and plunge-pools (13.1 %), and rarely in backwaters (1.5 %), shallow margins (0.5 %), and steps and waterfalls (0.3 %). The partial dependence plots (Fig. 12.3) indicated that the mesohabitat models provided similar sets for adults and juveniles although variables were ranked differently. Specifically, a microlithal substratum (grain size: 2–6 cm), akal (gravel), water depth up to 30 cm, and flow velocity up to 30 cm/s were selected as important for the presence of both adult and juvenile *A. pallipes*. In addition, mesohabitat features such as type of cover (boulders, woody debris and undercut banks) were important to these crayfish, and the presence of the cover positively correlates with the probability of presence.

Where crayfish was found as present, *A. pallipes* abundance models were calibrated. Low proportion of mesolithal, and high occurrence of detritus were selected

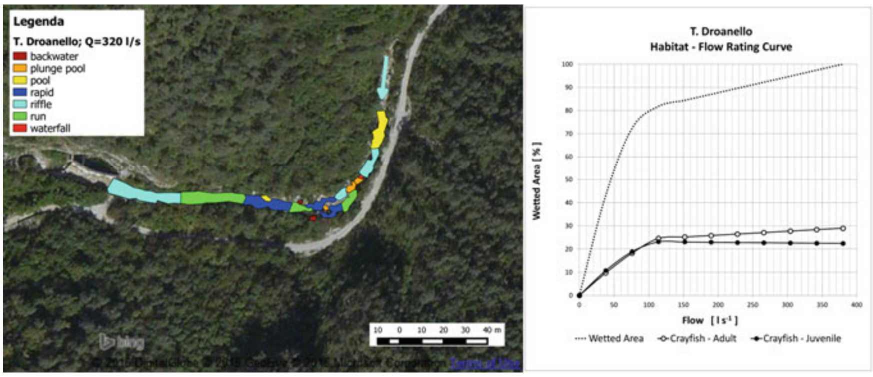

Fig. 12.4 The study site on the Droanello Creek (in the foothills of the Italian Alps, Lombardy region). MesoHABSIM model application to build habitat-flow rating curves for *A. pallipes* (adult and juvenile crayfish). Details of field data collection and model application are reported in Vezza et al. (2014b)

as important habitat characteristics for *A. pallipes* abundance. Furthermore for adults, high proportion of water depth between 30 and 45 cm are also positively correlated with the probability of abundance. Mesohabitat suitability models predicting crayfish presence and abundance are reported in Fig. 12.3 for both adults and juveniles.

Habitat-flow rate curves for both adult and juvenile *A. pallipes* were built by applying mesohabitat suitability models to mapped HMUs (Fig. 12.4). These curves define the habitat variation at the selected range of flows and are plotted together with the wetted area curve. The distance between the wetted area and the habitat curves represents the amount of river channel that is not available for *A. pallipes* complex.

Flow and water temperature data collected at the study sites were used to generate the reference habitat and water temperature time series and to calculate the uniform continuous under threshold (UCUT) curves for the spring/summer period (May–July, Figs. 12.5 and 12.6). This period was the most critical bioperiod for crayfish due to flow recession, low flow occurrence, and increased water temperatures. Each curve on the diagram represents the cumulative duration of under-threshold events (ranging between 2 and 30 % of the channel area for habitat availability, and from 10 to 19 °C for water temperature). The reduction in slope, as well as the increase of spacing between the two curves, indicate the increase in the frequency of under-threshold events (Parasiewicz 2007b). Thresholds that identify rare under-threshold events (i.e., habitat availability equal to 16 % of the channel area and water temperature equal to 13 °C) and common under-threshold events (26 % of the channel area and 18 °C for water temperature) were selected and used to demarcate the references for the frequency and duration of events that were allowable (green area), critical (yellow area), or catastrophic and not allowable (red area) in the Droanello Creek.

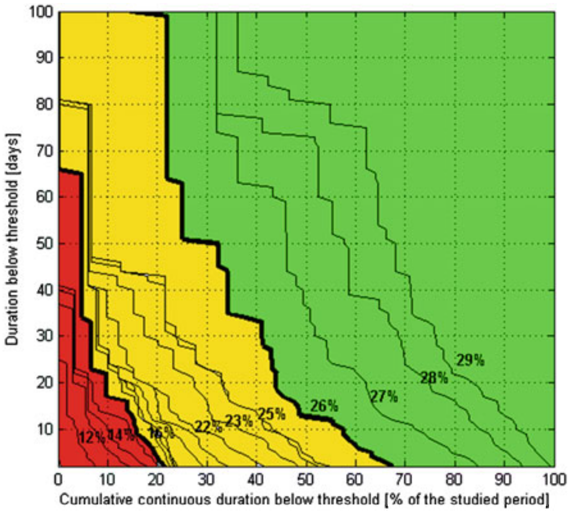

Fig. 12.5 The application of uniform continuous under threshold (UCUT) curves for Droanello Creek, Lombardy, Italy, to determine habitat stressor thresholds. Events between 2 and 29 % of channel area available for *A. pallipes* were analyzed referring to spring/summer low-flow periods (1 May–31 July). Increase of spacing between two curves, indicate an increase in the frequency of under-threshold events and rare (16 %) and common (26 %) habitat thresholds were selected and used to demarcate associated allowable (*green*), critical (*yellow*) and catastrophic (*red*) frequency-durations areas in the graph

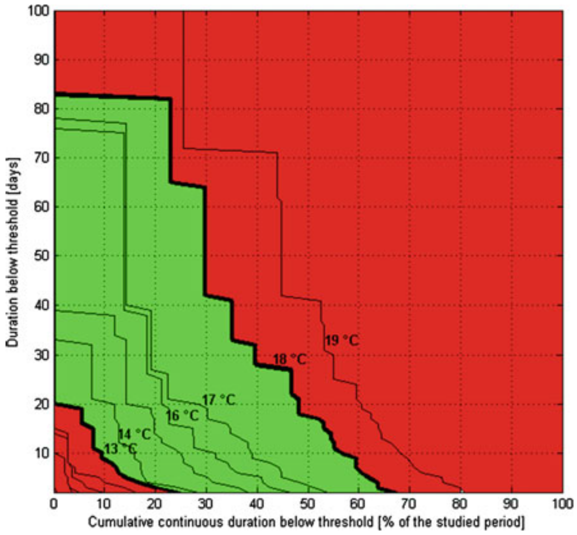

Fig. 12.6 The application of uniform continuous under threshold (UCUT) curves for Droanello Creek, Lombardy, Italy, to determine water temperature stressor thresholds during spring/summer (1 May–31 July). Events between 8 and 19 °C were analyzed. As for habitat availability, rare (13 °C) and common (18 °C) temperature thresholds were selected and used to demarcate associated allowable (*green*) and catastrophic (*red*) frequency-durations areas in the graph

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12.5 Discussion

To date habitat simulation models have been mostly built to identify the habitat characteristics used by target fish species (Vezza et al. 2014b). The research presented here provides a comprehensive methodology to model habitat for freshwater crayfish in small, high gradient mountain streams. Specifically, the mesohabitat scale was used to link in-stream environmental conditions to crayfish presence and abundance. The mesohabitat scale adapts well to the description of crayfish habitat use and distribution, and demonstrates great potential for the environmental management of watercourses (Fig. 12.7).

Mesohabitats as reference units for the analyses are useful ways to capture the confounding effects of different environmental variables (i.e., channel geometry, cover availability, flow velocity, water depth, substrate composition), focussing on how crayfish interact with the spatial arrangement of habitat characteristics. Random Forests (RF) was also effective in predicting the probability of crayfish presence and abundance in response to habitat variables. The conditional variable importance (Strobl et al. 2008) was used together with the Model Improvement Ratio (MIR) technique (Murphy et al. 2010) and the procedure allowed us to minimize noise and to improve model performance. RF is robust to overfitting when the number of noise variables increases and, together with the MIR procedure, is appropriate for parsimonious model construction (Vezza et al. 2015). A balanced species prevalence (i.e., presence, or abundance, frequency equal to 50 %) was not used to build mesohabitat suitability models due to its negligible

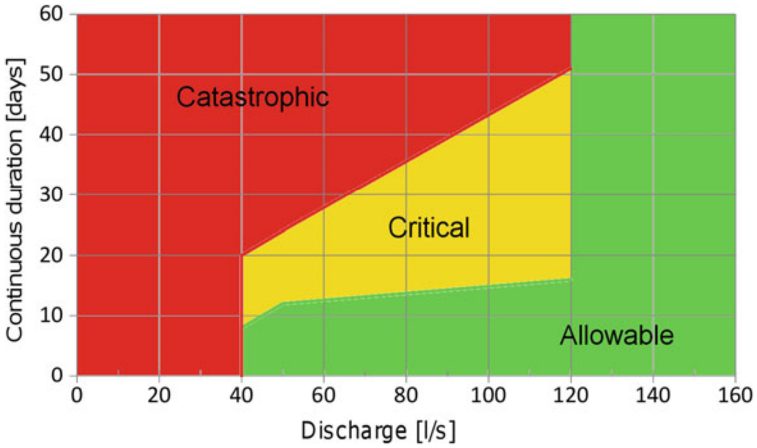

Fig. 12.7 E-flow scheme for the Droanello Creek, Lombardy, Italy. A possible e-flow option would be to allow hydropower generation with environmental flow release in the bypass section of 50 l/s with two-day interruptions every three weeks (catastrophic duration, *red area* in the graph). Once the inflow drops below this discharge value, the operation would cease until there is an increase to 120 l/s for two consecutive days. This conservative scenario, which aims to avoid subsistence flow, is one of the available options

influence on RF results (Freeman et al. 2012). All models developed for crayfish showed high accuracy, high sensitivity/specificity values, and strong Cohen's kappa statistics, indicating a very good to excellent model performance (Allouche et al. 2006). The area under ROC curve (AUC) and the true skill statistic (TSS), which are considered independent of prevalence (Vaughan and Ormerod 2005), also suggested low cross-classification errors and reliable predictions of crayfish distribution.

The high preference of *A. pallipes* for pools is in accordance with the findings of Englund and Krupa (2000) and Clavero et al. (2009). Crayfish were also found in mesohabitats characterized by moderate flow velocity (e.g., plunge-pools and riffles with velocity values of up to 40 cm/s). All the selected habitat variables in the models are features already reported to be important for microhabitat use by white-clawed crayfish in Mediterranean streams (Benvenuto et al. 2008; Clavero et al. 2009). Specifically, deep water plays an important role in decreasing the risk of predation by terrestrial and aquatic predators (Smith et al. 1996). Adult crayfish were found in deep pools with a water depth up to 50 cm. In addition, the availability of shelters for the crayfish reduces the risk of predation. In areas where crayfish density was high, crayfish often shifted towards shallow water if there was abundant cover, which served to reduce cannibalism after moult among adult crayfish (Ackerfors 1996). In the mesohabitat suitability models developed here (Fig. 12.3), the presence of refuges (mostly boulders, undercut banks and woody debris) was found to be a crucial factor that allows this species to inhabit a stream. This is confirmed by previous research (Foster 1993), in which the size of hidden crayfish was shown to be positively correlated to the size of the shelter stones. Woody debris and detritus also represent the main sources of energy and proteins available for *A. pallipes* which mostly acts as a detritus consumer (Gherardi et al. 2004). The fine-grained sediment (microlithal and akal) is the most suitable medium for macroinvertebrates and for the growth of the periphyton that constitutes the main food source for the white-clawed crayfish (Foster 1995; Naura and Robinson 1998). It is important to note that in this study we collected crayfish during the night because that is when they showed the most foraging activity (Barbaresi and Gherardi 2001; Gherardi et al. 2001). This nocturnal behavior can be considered one of the main reasons why the presence of woody debris and detritus significantly affects the presence of *A. pallipes*.

The high model performance in validation (Table 12.2) demonstrated the ecological relevance of the selected variables in predicting crayfish presence. As reported in Vezza et al. (2015), the use of independent data for validation is not a common procedure and it is often omitted when researchers build predictive models of species distribution (Elith and Leathwick 2009). Current practice usually involves testing predictive performance using data resampling (e.g., split-sample or cross-validation procedures, Favaro et al. 2011). Testing modelled crayfish-habitat relationships with independent data collected in different regions with different environmental conditions can provide valuable insights into model effectiveness and transferability (Bennett et al. 2013). Although we did not validate our presence/abundance models our results showed that absence/presence data would be promising, and future model validation tests are already planned.

The influence of different habitat variables (which can be either categorical or continuous) was captured by the modeling technique used here, which uses an ecologically relevant spatial scale. Indeed, the present approach substantially differs from traditional and more commonly used micro-scale analyses (Bovee 1982; Jorde et al. 2001) which are limited in including a large range of habitat variables (Vezza et al. 2012a), and when working on mountain streams that have a complex morphology and high gradient (Vezza et al. 2014b). In addition, collecting observational data across large spatial extents (e.g., several streams each with different morpho-climatic characteristics) is more useful when investigating the effect of habitat variables (Vezza et al. 2015). Apart from its ecological relevance, our regional predictive model builds in reference conditions based on reference variables that can be objectively measured and used as references for the effective environmental management of watercourses.

A recent guidance published by the European Union (Petitguyot et al. 2015) stressed the urgent need to better address over abstraction of water, the second most common pressure on the ecological status of rivers in the EU. The guidance identified possible methods that should be used to calculate ecological flows for the implementation of the European Water Framework Directive (WFD, 2000/60/CEE). The proposed mesohabitat modeling approach is recognized by the EU guidance as a reference method to achieve the WFD's environmental objectives, and as a specific application for crayfish.

The case study of crayfish from the Droanello Creek described here used the habitat time series analysis as a key component for the definition of environmental flows. This analysis demonstrates how physical habitat changes through time, and identifies stress conditions created by persistent limitation in habitat availability. The reference habitat time series uses UCUT curves to establish frequency and duration of events that characterized natural habitat conditions (Fig. 15.5). These highly informative diagrams allow the approximation of an envelope of typically occurring habitat events that are harmless to the fauna, so any environmental flows recommended for specific water abstractions should fall within this envelope. Catastrophically low habitat quantity can be identified by this method and although these events occur under natural conditions, they are not common. Consequently, environmental flow management offers one way to avoid increasing the frequency of such disturbances (Vezza et al. 2014b).

UCUTs help to identify the longest period that a habitat event is allowed to continue before reaching catastrophic/not allowable conditions (Parasiewicz et al. 2013). Once the allowable duration of released flow is exceeded the strategy calls for the release of water for a few consecutive days so that the amount of habitat increases and the continuous stress is stopped. This strategy can be summarized in operational rules and used for individual hydropower facilities. Figure 15.7 simplifies and summarizes the UCUT graph reported in Fig. 12.5.

Using the Droanello Creek as an example of a mountain stream in northern Italy it may be possible to allow hydropower generation in May–July (i.e., the flow

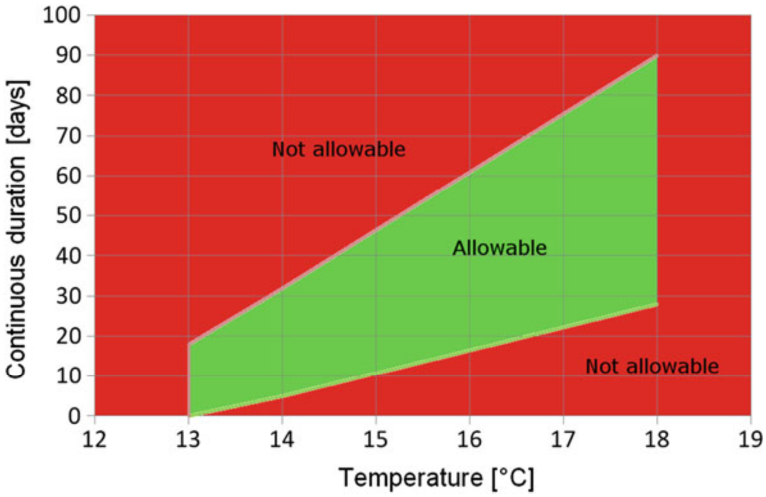

Fig. 12.8 Water temperature reference scheme for the Droanello Creek, Lombardy, Italy. The increase in temperature from 13 to 18 °C should be maintained in the spring/summer period. In July the water temperature is commonly below 18 °C, whereas the trend in increasing water temperatures can be maintained by following the continuous duration under-threshold (represented by the *green area* in the graph)

recession and low flow period) by releasing 50 l/s as e-flows in the bypass section with two-day interruptions every three weeks. Once the inflow drops below 50 l/s, the operation would cease until there is an increase to at least 120 l/s for two consecutive days. This conservative scenario aims to avoid continuously constant subsistence flow and continuous low habitat availability. The same concept can be used to define natural reference conditions for the water temperature. The results of this UCUT analysis are reported in Figs. 12.6 and 12.8.

The natural water temperature in May–July typically increases from 13 to 18 °C and this would not be affected by water abstractions. In July, it is common for water temperature to stay below 19 °C, and increases in the frequency and duration of these warm water events may lead to catastrophic changes in the composition of local crayfish populations. It is important to say that the trend in naturally increasing water temperatures between spring and summer should be maintained by respecting the continuous duration under-thresholds scheme reported in Fig. 15.8 (green area). For example, water temperatures of less than or equal to 14 °C cannot be maintained in the stream for more than one month (30 days). If the period started on May 1st, then June temperatures would be maintained higher than this value.

The methodological approach described here for Italian mountain streams can support e-flow implementation and habitat restoration actions and is critically needed to (1) protect local populations of endangered species of crayfish, (2) implement recent water laws, such as the European Water Framework Directive, and (3) address the present lack of intervention methods. Specific negative impacts on

A. pallipes can be detected before modifying the hydrological regime or morphological conditions. For existing water abstractions different restoration strategies can be compared using the proposed approach, and cost-effectiveness analyses can be carried out by decision makers to select the best restoration alternative.

References

Ackerfors, H. (1996). The development of crayfish culture in Sweden during the last decade. *Freshwater Crayfish, 11*, 627–654.

Allouche, O., Tsoar, A., & Kadmon, R. (2006). Assessing the accuracy of species distribution models: Prevalence, kappa and the true skill statistic (TSS). *Journal of Applied Ecology, 43*, 1223–1232.

Aquiloni, L., Martín, M. P., Gherardi, F., & Diéguez-Uribeondo, J. (2011). The North American crayfish *Procambarus clarkii* is the carrier of the oomycete *Aphanomyces astaci* in Italy. *Biological Invasions, 13*, 359–367.

Barbaresi, S., & Gherardi, F. (2001). Daily activity of the white-clawed crayfish, *Austropotamobius pallipes* (Lereboullet): A comparison between field and laboratory studies. *Journal of Natural History, 35*, 1861–1871.

Bennett, N. D., Croke, B. F. W., Guariso, G., Guillaume, J. H. A., Hamilton, S. H., Jakeman, A. J., et al. (2013). Characterising performance of environmental models. *Environmental Modelling and Software, 40*, 1–20.

Benvenuto, C., Gherardi, F., & Ilhéu, M. (2008). Microhabitat use by the white-clawed crayfish in a Tuscan stream. *Journal of Natural History, 42*, 21–33.

Berger, C., & Füreder, L. (2013). Linking species conservation management and legal species protection: A case study on stone crayfish. *Freshwater Crayfish, 19*, 161–175.

Bernardo, J. M., Ilhéu, M., & Costa, A. M. (1997). Distribution, population structure and conservation of *Austropotamobius pallipes* in Portugal. *Bulletin Français de la Pêche et de la Pisciculture, 347*, 617–624.

Bovee, K. D. (1982). *A guide to stream habitat analysis using the instream flow incremental methodology*. Fort Collins: U.S. Fish and Wildlife Service.

Breiman, L. (2001). Random forest. *Machine Learning, 45*, 5–32.

Breiman, L., Friedman, J. H., Olshen, R., & Stone, C. J. (1984). *Classification and regression trees*. Monterey: Wadsworth and Brooks.

CIPRA [International Commission for the Protection of the Alps]. (2010). *Situation Report on Hydropower Generation in the Alpine Region focusing on Small Hydropower*.

CIRF [Italian Center for River Restoration]. (2014). L'energia "verde" che fa male ai fiumi. CIRF, Mestre.

Clavero, M., Benejam, L., & Seglar, A. (2009). Microhabitat use by foraging white-clawed crayfish (*Austropotamobius pallipes*) in stream pools in the NE Iberian Peninsula. *Ecological Research, 24*, 771–779.

Cutler, D. R., Edwards, T. C., Beard, K. H., Cutler, A., Hess, K. T., Gibson, J., et al. (2007). Random forests for classification in ecology. *Ecology, 88*, 2783–2792.

Diéguez-Uribeondo, J., Rueda, A., Castien, E., & Bascones, J. C. (1997). A plan of restoration in Navarra for the native freshwater crayfish species of Spain, *Austropotamobius pallipes*. *Bulletin Francais de la Peche et de la Pisciculture, 347*, 625–637.

Elith, J., & Leathwick, J. R. (2009). Species distribution models: Ecological explanation and prediction across space and time. *Annual Review of Ecology Evolution and Systematics, 40*, 677–697.

Englund, G., & Krupa, J. J. (2000). Habitat use by crayfish in stream pools: Influence of predators, depth and body size. *Freshwater Biology, 43*, 75–83.

Favaro, L., Tirelli, T., & Pessani, D. (2011). Modelling habitat requirements of white-clawed crayfish (*Austropotamobius pallipes*) using support vector machines. *Knowledge and Management of Aquatic Ecosystems, 401*, 21.

Fea, G., Nardi, P. A., Ghia, D., Spairani, M., Manenti, R., Rossi, S., et al. (2006). Dati preliminari sulla distribuzione in Lombardia dei gamberi d'acqua dolce autoctoni e alloctoni. Atti Soc. it. Sci. nat. *Museo civ. Stor. nat. Milano, 147*, 201–210.

Foster, J. (1993). The relationship between refuge size and body size in the crayfish *Austropotamobius pallipes* (Lereboullet). *Freshwater Crayfish, 9*, 345–349.

Foster, J. (1995). Factors influencing the distribution and abundance of the crayfish *Austropotamobius pallipes* (Lereboullet) in Wales and the Marches, UK. *Freshwater Crayfish, 8*, 78–98.

Freeman, E. A., Moisen, G. G., & Frescino, T. S. (2012). Evaluating effectiveness of down-sampling for stratified designs and unbalanced prevalence in Random Forest models of tree species distributions in Nevada. *Ecology Models, 233*, 1–10.

Füreder, L., Gherardi, F., Holdich, D., Reynolds, J., Sibley, P., & Souty-Grosset, C. (2010). *Austropotamobius pallipes*. The IUCN Red List of Threatened Species 2010: Public Internet. e. T2430A9438817. Accessed Feb 27, 2014.

Gherardi, F., Acquistapace, P., & Santini, G. (2001). Foraging by a threatened species: The white-clawed crayfish, *Austropotamobius pallipes*. *Archiv für Hydrobiologie, 152*, 339–351.

Gherardi, F., Acquistapace, P., & Santini, G. (2004). Food selection in omnivores: A case study of the *Austropotamobius pallipes*. *Archiv für Hydrobiologie, 159*, 357–376.

Ghia, D., Vezza, P., Fea, G., Spairani, M., & Sacchi, R. (2013) The meso-habitat scale as a new approach for the conservation of the endangered crayfish *Austropotamobius pallipes* complex in Northern Italy. In: *Regional European crayfish meeting, Croatia. Contribution awarded with the novelty award*.

Ghia, D., Fea, G., Conti, A., Sacchi, R., & Nardi, P. A. (2015). Estimating age composition in Alpine native populations of *Austropotamobius pallipes* complex. *Journal of Limnology, 74*, 501–511.

Holdich, D. M., & Rogers, W. D. (1997). The white-clawed crayfish, *Austropotamobius pallipes*, in Great Britain and Ireland with particular reference to its conservation in Great Britain. *Bulletin Français de la Pêche et de la Pisciculture, 347*, 597–616.

Holdich, D. M., Reynolds, J. D., Souty-Grosset, C., & Sibley, P. J. (2009). A review of the ever increasing threat to European crayfish from non-indigenous crayfish species. *Knowledge and Management of Aquatic Ecosystems, 394–395*, 11.

Jorde, K., Schneider, M., Peter, A., & Zöllner, F. (2001). Models for the evaluation of fish habitat quality and instream flow assessment. In: CD-ROM *Proceedings of third international symposium on environmental hydraulics*. Tempe, Arizona.

Liaw, A., & Wiener, M. (2002). Classification and regression by Random Forest. *R News, 2*, 18–22.

Maddock, I., Harby, A., Kemp, P., & Wood, P. J. (Eds.). (2013). *Ecohydraulics: an integrated approach*. West Sussex: Wiley-Blackwell.

Milhous, R., Bartholow, J., Updike, M., & Moos, A. (1990). *Reference manual for generation and analysis of habitat time series*. U.S. Fish and Wildlife Services: Fort Collins.

Montgomery, D., & Buffington, J. (1997). Channel-reach morphology in mountain drainage basins. *Geological Society of America Bulletin, 109*, 591–611.

Murphy, M. A., Evans, J. S., & Storfer, A. (2010). Quantifying *Bufo boreas* connectivity in Yellowstone National Park with landscape genetics. *Ecology, 91*, 252–261.

Naura, M., & Robinson, M. (1998). Principles of using River Habitat Survey to predict the distribution of aquatic species: An example applied to the native white-clawed crayfish *Austropotamobius pallipes*. *Aquatic Conservation: Marine and Freshwater Ecosystems, 8*, 515–527.

Parasiewicz, P. (2007a). The MesoHABSIM model revisited. *River Research and Applications, 23*, 893–903.

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Parasiewicz, P. (2007b). Using MesoHABSIM to develop reference habitat template and ecological management scenarios. *River Research and Applications, 23*, 924–932.

Parasiewicz, P., Ryan, K., Vezza, P., Comoglio, C., Ballestero, T., & Rogers, J. N. (2012). Use of quantitative habitat models for establishing performance metrics in river restoration planning. *Ecohydrology, 6*, 668–678.

Parasiewicz, P., Rogers, J. N., Vezza, P., Gortazar, J., Seager, T., Pegg, M., et al. (2013). Applications of the MesoHABSIM simulation model. In H. A. Maddock, P. Kemp, & P. Wood (Eds.), *Ecohydraulics: An integrated approach* (pp. 109–124). West Sussex: Wiley.

Petitguyot, T., Bussettini, M., Linsen, M., Schmidt, G., Arqued-Esquía, V. M., Smolar-Žvanut, N., et al. (2015). *Ecological flows in the implementation of the Water framework directive. Common Implementation Strategy (CIS) Guidance Document n 31*. European Union, Luxembourg.

Rinaldi, M., Belletti, B., Comiti, F., Nardi, L., Mao, L., & Bussettini, M. (2015). *Sviluppo di un sistema di rilevamento e classificazione delle Unità Morfologiche dei corsi d'acqua (SUM). Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA)*, Rome, Italy

Smith, G. R. T., Learner, M. A., Slater, F. M., & Foster, J. (1996). Habitat features important for the conservation of the native crayfish *Austropotamobius pallipes* in Britain. *Biological Conservation, 75*, 239–246.

Souty-Grosset, C., Holdich, D. M., Noel, P. Y., Reynolds, J. D., & Haffner, P. (2006). *Atlas of crayfish in Europe*. Paris: Museum National d'Histoire Naturelle.

Strobl, C., Boulesteix, A. L., Kneib, T., Augustin, T., & Zeileis, A. (2008). *Conditional variable importance for random forests*. *BMC Bioinformatics, 9*, 307.

Vaughan, I. P., & Ormerod, S. J. (2005). The continuing challenges of testing species distribution models. *Journal of Applied Ecology, 42*, 720–730.

Vezza, P., Parasiewicz, P., Rosso, M., & Comoglio, C. (2012a). Defining minimum environmental flows at regional scale: Application of mesoscale habitat models and catchments classification. *River research and applications, 28*, 675–792.

Vezza, P., Parasiewicz, P., Spairani, M., & Comoglio, C. (2012b). Meso-scale habitat modelling in Alpine high gradient streams. In H. Mader & J. Kraml (Eds.), *Proceeding of the 9th eco-hydraulics symposium*. Vienna: ISE 2012.

Vezza, P., Parasiewicz, P., Calles, O., Spairani, M., & Comoglio, C. (2014a). Modelling habitat requirements of bullhead (*Cottus gobio*) in alpine streams. *Aquatic Sciences, 76*, 1–15.

Vezza, P., Parasiewicz, P., Spairani, M., & Comoglio, C. (2014b). Habitat modelling in high gradient streams: The meso-scale approach and application. *Ecological Applications, 24*, 844–861.

Vezza, P., Muñoz-Mas, R., Martinez-Capel, F., & Mouton, A. (2015). Random forests to evaluate biotic interactions in fish distribution models. *Environmental Modelling and Software, 67*, 173–183.

Whitehouse, A. T., Peay, S., & Kindemba, V. (2009). Ark sites for white-clawed crayfish—guidance for the aggregates industry. In: *Buglife—The Invertebrate Conservation Trust,* UK.