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# VVF: integrating modelling and GIS in a software tool for habitat suitability assessment

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**Abstract**

A computer program, VVF, has been developed to assess the suitability of a territory as habitat for a species. It integrates several types of Habitat Suitability models into a Geographical Information System. In addition to standard GIS functions, VVF allows a user to create, modify and store new Habitat Suitability models for different species, to create Habitat Suitability maps by running Habitat Suitability models for specific areas, and to process these maps. The program requires only basic GIS knowledge and is very flexible, so as to guarantee a broad applicability. VVF is aimed at assisting public decision-makers and conservation biologists to assess the viability of endangered and threatened species, to evaluate policies and plans for wildlife management, as well as species translocations, reserve design and habitat protection. VVF can also be used in Environmental Impact Assessment. In this paper, VVF is demonstrated with an application for Ibex. © 1999 Elsevier Science Ltd. All rights reserved.

*Keywords:* Wildlife management; Habitat suitability model; Habitat suitability map; Geographical Information System

**Software availability**

Name of software: VVF—Valutazione della Vocazionalità Faunistica (Habitat Suitability Assessment)
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First available: 1997
Hardware required: IBM PC operating under Windows 95 or NT
Software required: GIS Grassland (LAS, Canada)
Program language: Tcl/Tk
Program size: 360 K
Availability and cost: freely available (by contacting the authors)

## 1. Introduction

Habitat loss, fragmentation and alteration due to pollution, change in land use and the introduction of invasive pests are seriously threatening the health and integrity of our fauna. In conjunction with excessive hunting and poaching, they are responsible in many places for the extinction or decline of several species (Dobson, 1995). Therefore, it is increasingly important to understand the habitat requirements of endangered species, delineate the remaining suitable habitat, and effectively manage these units of habitat for the species' survival (Duncan et al., 1995). Unfortunately, even though extinction processes are widely known, wildlife conservation policies in land planning and management practice have been rarely based on formalised and transparent considerations. However, habitat-based modelling techniques that can identify remaining potential habitat and predict spatial habitat suitability are now available (Morrison et al., 1992). They facilitate the use of standard procedures that are based on quantitative methods, are clearly stated and can be repeated.

A straightforward approach to modelling wildlife–habitat relationship is the use of Habitat Suitability (HS) models. These models assess the suitability of an area

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for the species of interest as a function of different environmental factors (such as terrain morphology, land use, vegetation cover, meteorological conditions and distribution of human activities) which most affect species presence, abundance and distribution (Morrison et al., 1992). The resulting habitat suitability value is usually expressed as either presence–absence of animals or species potential density or probability of species occurrence. The result of this analysis is a habitat suitability map that displays the potential geographic distribution of a species in a territory (Spagnesi and Toso, 1990; Buckland and Elston, 1993). Recent developments of wildlife management planning endeavour to integrate wildlife–habitat relationship models with Geographic Information Systems (GIS) incorporating relevant habitat characteristics (Laymon and Barrett, 1994). GIS are emerging as a new tool to assist in the resolution of land use conflict and the management of natural resources (Brown et al., 1994). In particular, GIS are playing an increasingly important role in conservation biology and wildlife management because they provide an efficient means for modelling potential distribution of species and habitats (Stoms et al., 1992). GIS are very useful tools in HS maps production: they can store maps that describe environmental variables, process these geographical data through spatial analysis, create and display new HS maps (Ormsby and Lunetta, 1987; Agee et al., 1989; Roseberry et al., 1994).

Until now, most attempts for integrating GIS into HS procedures were related to a single specific case, namely a restricted area and a particular species, and could not easily be applied or extended to wider or different areas (two partial exceptions are represented by the computer program created by Ferrier, 1991, and the software HAMS developed by Roseberry and Hao, 1996). Therefore, there was a need to create a software tool capable of linking GIS with HS models so as to develop a widely applicable database management system. To this purpose we have created a program that allows a user:

—to create, modify and store new Habitat Suitability models for different species;
—to manage and store geographical data (maps) of one or more territories;
—to create Habitat Suitability maps by running HS models for a specific area.

The resulting software VVF—‘Valutazione della Vocazionalità Faunistica’ (Habitat Suitability Assessment)—has been developed in such a way that only very limited GIS and computer experience is needed to perform all these operations.

The paper is organised as follows. First, we briefly introduce HS models, and outline pros and cons of different approaches in habitat suitability assessment. Then, we illustrate the design and development of VVF and point out the features that make this software tool very user-friendly and highly flexible. An application of the program to Ibex (*Capra ibex*) in an alpine area of northern Italy (Adamello Natural Park) is provided. Finally, we illustrate the role that VVF and similar software tools can play in evaluating policies and plans for wildlife management, reserve design, habitat protection and, more generally, land planning.

## 2. Habitat Suitability models

Fundamental elements of every HS model are the environmental variables (independent variables), the resulting habitat suitability values (dependent variables) and the classification function that links the two (Pedrotti and Preatoni, 1995) (Fig. 1). These functions commonly scale (both linearly and nonlinearly) each environmental variable between 0 and a maximum value (often 1) and then denote habitat suitability for a species as a function (more or less complicated) of these scaled values.

Different categories of HS models can be distinguished according to the approach used in their development and to their classification functions (Morrison et al., 1992). Firstly, models can be founded on a set of field observations or can be based on the experience and knowledge of the author and on bibliographic data. Secondly, the classification function can be estimated in different ways: it can express a subjective opinion of the author or be the result of mathematical and statistical analyses of a dataset or derived from the record of different scholars’ opinions. The statistical methods most commonly used include linear regression (Lindenmayer et al., 1997), generalised linear modelling (e.g. logistic regression) (Brennan et al., 1994; Smith and Connors, 1994; Lindenmayer et al., 1997), discriminant function analysis (Dueser and Shugart, 1978; Meriggi et al., 1992a,b), principal component analysis (Smith, 1977; Collins, 1983), and Bayesian approaches (Holl, 1982; Milne et al., 1989; Aspinall and Veitch, 1993).

As an example, a simple HS model for *Capra ibex*

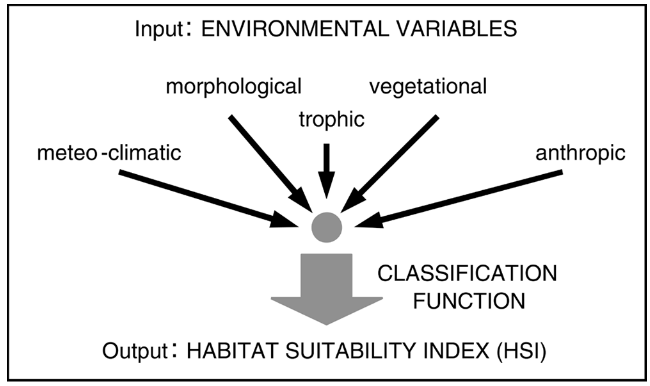
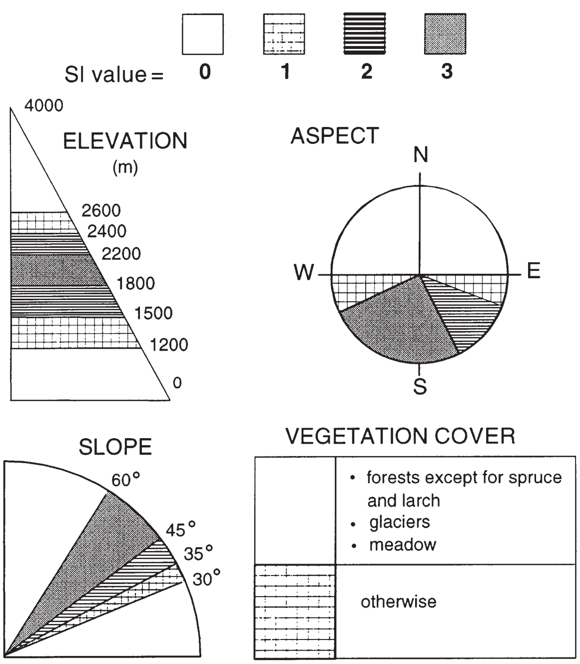



Fig. 1. Fundamental elements of a Habitat Suitability (HS) model.

(Pedrotti and Tosi, 1996) is illustrated in Fig. 2. This model was developed for the Adamello Natural Park (Brescia, northern Italy) by adapting an earlier model by Tosi et al. (1986), which was derived from census and environmental data of 6 colonies located in Italy, Switzerland and France. Pedrotti and Tosi's model is divided into two submodels: one for assessing winter areas (shown in Fig. 2) and one for summer areas. The winter model takes into account 4 environmental variables (altitude, slope, aspect and vegetation cover) while the summer model considers altitude only. The winter model assigns each single variable a partial Suitability Index (SI) scaled from 0 to 3 (Fig. 2(a)). SIs are then combined together to give the overall Habitat Suitability Index (HSI) value (Fig. 2(b)). From the HSI one can derive four Habitat Suitability classes (optimum, good, suitable, not suitable) each of them being characterised by a potential animal density (Fig. 2(c)).

An impressive number of HS models has been developed for a variety of species and many others are currently under development. The most readily available models are the HSI models for North-American vertebrate species (more than 350) (Edwards and Twomey, 1982; Allen, 1985; USDI Fish and Wildlife Service, 1986) extensively utilised by the USDI Fish and Wildlife Service. The situation is different in other countries. In southern Europe, for instance, HS models have been developed only for a few species of avian fauna (Meriggi et al., 1992a,b) and mammals, in particular ungulates (Felettig, 1976; Perco 1976, 1990; Apollonio and Grimod, 1984; Tosi et al., 1986; Hofer et al., 1987; Tosi and Pedrotti, 1996) and large carnivores like bear, wolf and lynx (Boitani et al., 1995; Boitani, 1998; Dupré et al., 1998). Most of these models are not published in scientific journals, but as internal reports of many different national or regional wildlife offices. Thus their availability is limited. It's also noticeable that only few HS models have been tested and validated against field data (Cook and Irwin, 1985; Duncan et al., 1995).

(a)




(b) $$\mathbf{HSI} = (SI_{elevation} + SI_{aspect} + SI_{slope}) * SI_{vegetation}$$

(c)

| HSI | HSI classes | Potential density |
|---|---|---|
| < 3 | 0 not suitable | - |
| 4 - 5 | 1 suitable | 6 ibex/km$^2$ |
| 6 - 7 | 2 good | 25 ibex/km$^2$ |
| 8 - 9 | 3 optimum | 40 ibex/km$^2$ |

Fig. 2. HS model for assessing suitable winter areas for *Capra ibex* (Pedrotti and Tosi, 1996): (a) partial classification functions; (b) total classification function; (c) habitat suitability and potential density classes.

HS models are useful for representing, in a simple and understandable form, the major environmental factors that influence the occurrence and abundance of a wildlife species. However, they should be seen as hypotheses of species–habitat relationships rather than definitive statements of cause-and-effect relations or reliable predictions of species response (Morrison et al., 1992). They do not provide information on population dynamics or individuals' response to shifts in resource conditions. Their value lies in quantifying both the quality and quantity of remaining available habitat for selected wildlife species, and documenting a repeatable assessment procedure that can be used to compare different plans for land use and wildlife management. Because of HS models shortcomings, it would be useful for wildlife managers and land planners to use a specific software tool through which they can easily execute different HS models (either taken from the literature as-they-are or modified according to personal knowledge and experience) and compare their results. These comparisons would allow the software users to reject a model in favour of models that better fit field data, evidence key factors for habitat suitability and evaluate the robustness of results. As these analyses would give a decision-maker a deeper awareness of his/her choices, we have decided to create a new program, VVF, which meets these needs.

## 3. The design of program VVF

We developed VVF with two main characteristics in mind. First of all, VVF is very flexible. It allows for the easy modification of existing HS models, the introduction of a new HS model tuned to a specific territory and, subsequently, the recall and application of the model to a new study area with the production of a new HS map. This high degree of flexibility is guaranteed by the feature that HS models are stored separately from any maps related to their specific use for a given territory. Second, VVF does not require a specific experience with GIS. In fact, its interface consists of a principal menu and a series of submenus and windows that guide the user step by step in model development, input data import and processing, and habitat suitability maps creation.

The program VVF interacts with and is directly recalled from the GIS Grassland (LAS, 1996). Grassland is a version for Windows 95 and NT of the well-known GIS Grass, which operates under Unix. The main characteristics of Grassland, as compared with Grass, is its user-friendly interface. Grassland was chosen for our work primarily because it allows the performance of fundamental operations for HS maps creation. Furthermore, the presence of neighbourhood analysis functions permits the calculation of many diversity and fragmentation indices on different raster layers. Another advantage is that Grassland can be customised. New interfaces and users-defined programs can be developed by the program language Tcl/Tk (Tool Command Language/ToolKit) which was signed by John Ousterhout (1994) at UC Berkeley and is freely available on the Internet. In particular Tcl is the basic programming language and Tk has commands for the creation of menus, buttons and many other graphic objects.

The main structure of VVF is shown in Fig. 3. There are four basic modules. The “Models” module manages all that concerns HS model creation, storage, visualisation and modification. The “Maps” module manages the import and processing of maps (both raster and vector) representing geo-morphological and environmental variables (such as elevation, vegetation cover, land use) of the studied territory. These maps will be the input data to HS models. The “Execute Model” module allows the association of an HS model (which was developed for a certain species by the “Models” module) to a specific territory thus producing the HS map for that species in that territory. The last module called “Operations on HS maps” allows for the execution of many useful operations on existing HS maps, such as the calculation of the area and number of animals for each suitability class and each patch, the elimination of patches that are too small to maintain any viable population, the comparison of different HS maps, etc. The program is also provided with an on-line help and a user’s manual (in Italian at the moment, but we are producing an English version).

### 3.1. *The “Models” module*

The “Models” module contains all the procedures necessary for HS models creation, storage and modification. To guarantee flexibility, these models are defined in terms of environmental variables but do not depend on any particular map that describes these characteristics in a specific territory. The values for the variables are provided when maps are associated to the model during the “Execute model” phase. The “Models” module does not perform standard GIS procedure or spatial analyses, but is a completely original and independent module specifically tailored to HS model management. It consists of two main submodules. The first allows the creation of new HS models step-by-step. The second (Model Database) manages the storage, editing and display of previously created HS models.

#### 3.1.1. *Creating a new model*

The process to create a new model is divided into four principal phases:

1. input of general information about the new model;
2. choice of environmental variables;
3. definition of partial classification functions;
4. definition of total classification function.

Special windows have been created for each of these phases. These windows are connected to each other in sequential order so that, when one phase is completed, the user automatically proceeds to the following one. In the first phase of model creation the user is requested to insert some general information (model name and author, species, date of creation) about the model she/he is going to build. In the second phase the user has to choose the environmental characteristics that she/he

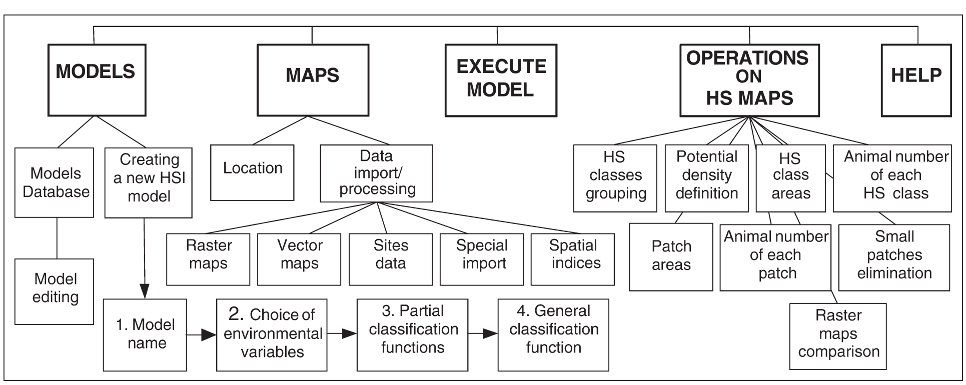



Fig. 3. The structure of program VVF.

wants to insert as model variables (Fig. 4). 73 environmental variables are pre-defined. They are divided into five main groups:

—morphological (e.g. altitude, slope, aspect, geology);
—vegetational (e.g. vegetation cover, land use, forest composition, tree height);
—trophic (e.g. prey, predator or competitor abundance and distribution, primary productivity, plant biomass);
—meteo-climatic (e.g. mean annual temperature and rainfall);
—anthropic (e.g. skiing area, pasture distribution, roads, hunting activity, urban areas, noise distribution).

Pre-defined variables have been chosen by comparing numerous HS models found in the literature and analysing, from a biological point of view, all the factors that can influence the vital cycle of vertebrates (fishes excluded). Moreover, the user can enter any new variable she/he wishes.

To help the user, classification function implementation has been divided into two phases. During the first (phase 3 of model creation) the user is required to define partial classification functions that depend on a single environmental variable. Then (phase 4) partial classification functions are combined together in a total classification function. Partial classification functions are defined for any input variable and associate each possible value of that variable to a suitability degree that expresses how much that value is positive for the species. These functions are classified in five types (scores, piece-wise linear, Gaussian, buffer and user-defined) and each of them can be defined in VVF specific windows. Examples of classification functions from the different classes are shown in Fig. 5. The buffer function makes it possible to assign specific suitability values to areas whose distance from particular sites (such as, for instance, rivers, roads, tourist areas) is less than an assigned threshold. Suppose, for example, that areas closer to rivers and lakes are more suitable for deer. Then we can define a buffer classification function which assigns a different suitability value to each pixel depending on its distance from rivers or lakes: typically higher for closer areas, lower for areas that are further away, and nil for areas far enough not to be influenced by water proximity. Buffer functions can also be defined for sites (like roads, industrial areas, pollution or noise sources) that cause disturbance to animals. Their negative effect on habitat suitability can be considered in the model by subtracting the buffer function values from the final HS value.


Fig. 4. VVF window “Choice of environmental variables” in “Creating a new HS model” procedure.

During the last phase of HS model creation, partial classification functions are combined together in the total classification function by logical and mathematical operators. The output variable of the total classification function represents the habitat suitability index of each cell for the species and will be represented on the HS map.

### 3.1.2. Model Database

The “Model Database” is where all created HS models are stored. The search key for models is the species, which is defined during model creation (Fig. 6(a)). The “Model Database” allows the display of all the parameters of an existing model and, if necessary, its modification. Figure 6(b) shows the VVF window that allows the user to modify an HS model. Through buttons located at the bottom of the window one can modify a model in three different ways:

—by changing its partial or total classification functions;
—by adding a variable and defining its classification function;
—by deleting a variable.

This feature guarantees the flexibility required for adapting a model to a different geographic situation or evaluating the sensitivity of an HS map to changes in parameter values (Stoms et al., 1992). In this sense the “Models” module is the core of the VVF program.

## 3.2. The “Maps” module

The “Maps” module manages import, processing and conversion (vector to raster) of maps that describe the geo-morphological and environmental characteristics of a territory. This module facilitates access to all Grassland import and conversion functions thanks to a user-friendly window that orientates users in selecting the right function according to the input map format and

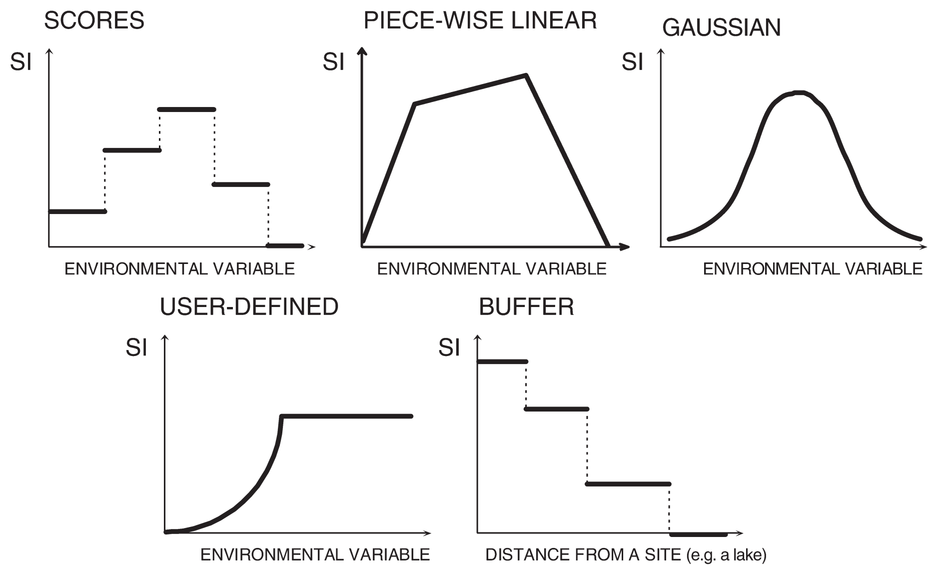



Fig. 5. Types of partial classification functions used in VVF.

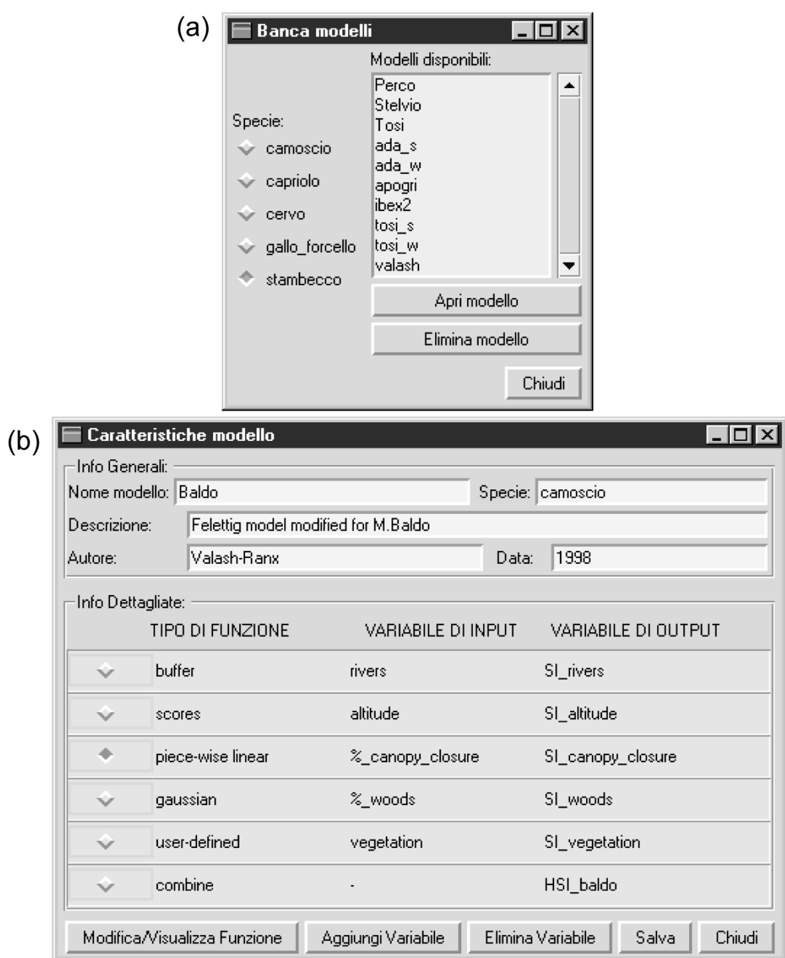



Fig. 6. VVF windows “Models Database” (a) and “Model Summary” (b).

type (raster, vector, sites list). In addition, it is possible to process these maps to produce new useful maps: for instance it is possible to get aspect and slope maps from the digital elevation model (DEM) or from contour lines. Mapping different indices (e.g. Shannon–Wiener diversity index, fragmentation index) is also possible. All the maps imported and processed with this module are stored in the Grassland Librarian and can be displayed by dragging and dropping them to the Grassland Mapviewer window.

### 3.3. The "Execute Model" module

The "Execute Model" module presides over the creation of HS maps. An HS map relative to one species and a specific area can be created by running any of the models stored in the Model Database. The execution of a model is performed by associating each input environmental variable of the model to the map that describes that variable in the area. Obviously these input maps should be previously imported and processed by the "Maps" module. During model execution HS maps are created and stored in Grassland Librarian so that they can easily be viewed in Grassland Mapviewer.

It is possible to produce many HS maps relevant to the same species and geographic area by executing different HS models available for that species in the Model Database. Comparison of these maps is often useful for better assessing habitat suitability of a territory. Furthermore, once an HS model stored in Model Database has been modified the corresponding HS map can be updated by running the modified model.

### 3.4. The "Operations on HS maps" module

The "Operations on HS maps" module meets the need to elaborate on already produced HS maps to make them more meaningful from an ecological point of view. This module allows the user to execute many useful operations on maps. First of all, it is possible to group all the habitat suitability classes represented in an HS map into fewer classes, as in Pedrotti and Tosi's (1996) model for Ibex (Fig. 2(c)). Secondly, the area of each HS class can be calculated and the result stored in a text file or a map, in which each pixel value represents the area of the HS class to which that pixel belongs. In addition, each habitat suitability class can be associated to a value of the species potential density so that the total animal number in each HS class can be estimated. Very often, cells of HS maps belonging to the same HS class do not constitute a unique and continuous area, but consist of disconnected patches. VVF allows the user to calculate the area for each patch and the total animal number it can support.

Certain areas that may appear as suitable habitat on a preliminary HS map should be discarded as unsuitable. For instance, small areas with a high HS value may be not suitable because they do not guarantee the minimum area necessary for vital activities (mainly feeding and breeding) of an animal. The minimum area required depends on the species, specifically on their home range, migration rate and ability to go across unsuitable areas. VVF lets the user eliminate patches whose areas are below a user-defined minimum, and produces a new HS map representing only patches that can sustain a viable population.

Finally, VVF allows a pixel by pixel comparison of two different raster maps. The output is a table showing the frequency of mutual occurrence of categories for two raster maps. This operation can be useful in the creation of HS maps. For instance, it can be used for comparing two HS maps produced by different HS models so as to evaluate their differences in estimating suitability for the same area. Also, whenever geo-referenced data on the presence of a species are available, this operation allows the user to compare an HS map (which expresses the potential presence of a species) with a map that expresses the actual presence of a species. This is quite useful for validating the model (Duncan et al., 1995).

## 4. An example: Ibex (*Capra ibex*) in Adamello Natural Park

This section presents an example of application: the use of VVF to assess habitat suitability for an ungulate species (the Ibex—*Capra ibex*) in Adamello Natural Park. This area (481 $Km^2$) is typical alpine habitat located in northern Italy and constitutes, together with two other Italian parks (Adamello–Brenta Regional Park and Stelvio National Park) and Switzerland's National Park, the biggest protected area in the Alps (2,500 $Km^2$).

Ibex, once widely spread over all alpine areas in Europe, was facing extinction. This species has always been hunted, not only for its meat, but also because its horns are a valuable trophy and because some parts of its body were believed to have therapeutic properties (Toso et al., 1989). A very high hunting effort dramatically reduced the presence of this ungulate in the past century: in 1820 only a population of less than 100 animals survived in the area of Gran Paradiso, Italy. Fortunately, nowadays *Capra ibex* is spread again over many alpine areas thanks to protection policy and intentional release. Its overall population now exceeds 21,000 animals (Toso et al., 1989). In the Adamello Park, Ibex, once extinct, is now present again thanks to relocation of some animals from other alpine areas: 55 ibexes were released in the park area during 1995 and 1996. Although an evaluation is still premature, these releases appear to be successful and the Ibex population is slowly growing. An HS map for this area can be useful for evaluating the potential population the park can sustain, identifying areas suitable for Ibex release, planning land use for wildlife conservation and habitat protection.

### 4.1. The Habitat Suitability model

The HS model used in this application was developed by Pedrotti and Tosi (1996) with the main purpose of determining the best areas for Ibex release. This model was already presented in Section 2 (Fig. 2). The two submodels that compose the model (one for identifying suitable winter areas, the other for summer areas) were created in VVF and stored in the Model Database by using the procedure "Create new model" in the "Models" module.

### 4.2. Available data

The Adamello Natural Park authority has collected digital maps of the area characteristics and Ibex location data by radio-telemetry (fixes). In particular the following data were used for this application:

—vector map of altitude (contour lines every 50 meters), scale 1:10,000 in ARC/INFO ungenerate format;
—vector map of vegetation cover, scale 1:10,000 in ARC/INFO ungenerate format;
—2,933 *Capra ibex* fixes (946 in winter, 1,987 in summer) taken in the park area during the period 1995–1997 (text file).

The available data were processed to get the maps necessary for running the HS model. First, both altitude and vegetation vector maps were imported to Grassland and rasterized by adopting a cell resolution of 50 meters. Then elevation, aspect and slope maps were derived from the raster contour-line map by interpolation and neighbourhood analysis. The digital elevation model (DEM) and the vegetation map are shown in Fig. 7. Radio telemetry data were used for HS model validation. They were imported into Grassland as two different site lists (respectively summer and winter fixes) and then transformed into raster maps in which each cell value represents the number of fixes that are inside that cell. All these operations were easily executed by using VVF "Maps" module.

### 4.3. The habitat suitability maps

Once the HS model for Ibex was edited and stored in the VVF Model Database and once the maps necessary to describe the model's input variables were imported into the Grassland Librarian, it was easy to execute both winter and summer models by associating input variables to maps. Two (one for each season) habitat suitability maps were produced. The winter HS map was reclassed into 3 suitability classes (optimum, good, suitable) and is shown in Fig. 8.

The total number of ibexes that the park can sustain (1,500 animals) was estimated after assigning the potential density of animals to each class according to the model, and eliminating patches too small to guarantee the minimum area necessary to support a viable subpopulation (400 ha according to Tosi et al., 1986). At present, the ibexes in the Adamello Park are 60–65 individuals only. Therefore, the model shows that there exist plenty of resources for a much larger population.

### 4.4. HS model validation

The availability of Ibex location data taken over 3 years permits the validation of the HS models by comparing HS maps with species sightings in winter and summer. These two maps were compared by VVF as explained at the end of Section 3. If Ibex could not distinguish between different habitat suitability classes, we would expect sightings to be distributed in each HS class according to the percentage of the area of that class over the park total area (random distribution). To test this null hypothesis, we have performed Chi-square tests to explore whether observed frequencies significantly differ from expected frequencies (Table 1). According to the tests results (Summer model: Chi-square=1867.8; d.f.=1; $P<0.001$; Winter model: Chi-square=6421.6; d.f.=3; $P<0.001$ if 4 HS classes are considered; Chi-square=2485.1; d.f.=1; $P<0.001$ if only suitable–not suitable classes are considered), the null hypothesis is rejected. Also, observed frequencies for suitable areas are significantly higher than expected frequencies (one-tailed $Z$ test for percentage differences; $P<0.001$ both for summer model and winter model considering only suitable–not suitable classes). In conclusion, Ibex seems to significantly prefer habitat classified as suitable by the model and thus this HS model seems to predict winter and summer areas for Adamello Ibex population reasonably well.

## 5. Conclusions

Wildlife management and conservation are problematic because of the uncertainty of populations' responses to environmental factors, human disturbance and land use changes. Therefore, any plan and policy for wildlife management and habitat protection should be based on detailed studies of ecosystems status and trends, clearly stated and repeatable. The VVF program is an innovative tool for habitat suitability assessment that satisfies this need. It integrates GIS with Habitat Suitability models, thus facilitating the use of quantitative methods for wildlife management. In particular it makes the procedure of Habitat Suitability maps production transparent and

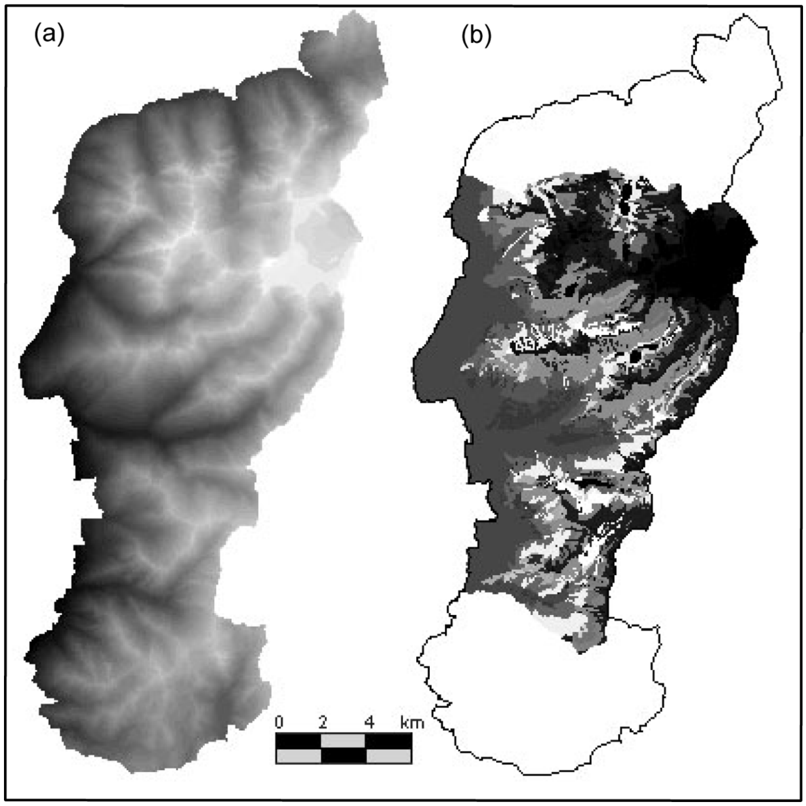



Fig. 7. Maps of (a) Digital Elevation Model (DEM), and (b) vegetation cover for Adamello Natural Park, Italy. (a) Low altitudes are represented with dark grey, high altitudes with lighter grey. (b) Different shades of grey represent different vegetation classes; e.g. the large light grey patch on the left is alpine and subalpine forest.

readily available to decision-makers and conservation biologists, because it requires only basic GIS knowledge.

VVF can be used to study many different cases. A large HS model database for several species can be created, a variety of maps describing different areas can be stored and, as a result, a number of HS maps can be produced and modified. This capability is probably the most innovative and original property of VVF and guarantees the flexibility necessary for a broad applicability. In fact, HS models may need modification for many different reasons. First, a model may need to be simplified by reducing or grouping its environmental variables to match the dataset available for the territory under study. Second, an HS model developed for an area can be adapted to another territory with different geomorphological and vegetational characteristics. Furthermore, model modification can be used to test HS map sensitivity. This is done by evaluating how an HS map varies when ranges of variable values are changed or a variable is added or eliminated. This process is useful to identify the most important variables that affect the suitability of a territory. Finally, an HS model derived for a species can be modified to obtain a new model for another species with similar habitat requirements (for instance, deer and roe deer), although this operation is not recommended and can be justified only as a preliminary approach in developing a new model. Needless to say, HS models cannot substitute field research and data collection. Field work is always necessary for a deep knowledge of wildlife in a territory, and data are the basis for both model creation and its validation and improvement. VVF can only help a wildlife biologist to organise his knowledge, identify patterns in a dataset, test hypotheses on habitat-species relationships, derive HS maps.

A possible use for VVF is in Environmental Impact Assessment. In the United States the most frequently used habitat-based approach in environmental impact studies, the Habitat Evaluation Procedure (HEP) of the US Fish and Wildlife Service, is based on Habitat Suitability Index models (Canter, 1996). The main objectives of HEP are to provide a uniform system for predicting and comparing the beneficial and adverse impacts of proposed projects or activities on wildlife resources and, also, for recommending project alterations that would compensate for or mitigate these adverse effects. In HEP, impacts of new projects on wildlife are quantified by HSI models and, therefore, the reliability of HEP is directly dependent on the accuracy of HSI models used therein. VVF is a useful tool for Habitat Evaluation Procedure because:

—it can provide a wide HS models database;

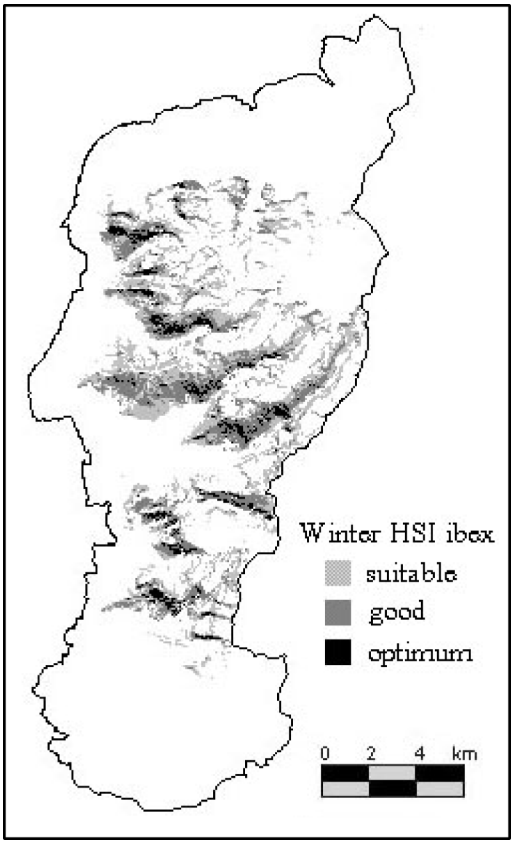



Fig. 8. Winter habitat suitability map for ibex in Adamello Natural Park, Italy.

—it can store coverages of the study area. The study area should include those areas where biological changes are expected as a result of the proposed project, either as a direct effect (i.e. of engineering structures) or an indirect effect (i.e. of human use trends);
—HS maps can be easily and quickly produced and compared to evaluate impacts of project alternatives and provide recommendations to mitigate adverse effects.

Therefore VVF could help decision-makers in the phase of evaluation and choice between different alternatives of land management or planning. However, the utility of VVF in HEP strongly depends on the availability of HS models that explicitly account for variables expressing human disturbance.

VVF will be easily improved in the future by adding new modules and functions. Our first goal will be to integrate VVF with multi-variate statistical modules that are useful for creating a new HS model. Also, it is our intention to include population dynamics modules. In fact, HS models cannot fully explain the presence and abundance of a species in a territory mainly because environmental characteristics are not the only factors that determine the occurrence of a species in an area. A more realistic prediction of the species necessitates the study of its demography. To this purpose Population Viability Analysis (PVA) procedures are particularly interesting: they try to evaluate a population's extinction probability in a determined time lag from its demographic characteristics. The integration of PVA procedures within VVF will improve its use for wildlife conservation and management: for instance, it will allow the evaluation of the success of a species release in an area identified as suitable on HS maps. It is to be remarked that VVF in its present version can provide HS models and maps useful for running programs that perform GIS-based PVAs such as RAMAS/GIS (Akçakaya, 1996), which is especially designed for building metapopulation models.

The usefulness of VVF is now limited mainly by data availability and quality and by the reliability of Habitat Suitability models. Fortunately, GIS technology is spreading quickly into the public administration and the environmental agencies, and this increases the number of available thematic maps. Furthermore, the number of species for which georeferenced data are available is increasing, mainly thanks to a wider diffusion of radiotracking technologies. Increasing thematic maps and data availability will allow the validation of existing HS

Table 1
Results of ibex HSI model (Pedrotti and Tosi, 1996) validation in Adamello Natural Park, Italy (absolute frequencies are expressed in number of elementary cells)

| | | Observed frequencies | | Expected frequencies | |
|---|---|---|---|---|---|
| Season | Habitat Suitability class | Absolute | Relative | Absolute | Relative |
| Summer | Suitable | 1947 | 0.980 | 984 | 0.495 |
| | Not suitable | 40 | 0.020 | 1003 | 0.505 |
| | Total | 1987 | 1.000 | 1987 | 1.000 |
| Winter | Optimum | 314 | 0.332 | 17 | 0.018 |
| | Good | 309 | 0.326 | 66 | 0.070 |
| | Suitable | 172 | 0.182 | 102 | 0.108 |
| | All suitable | 795 | 0.840 | 185 | 0.196 |
| | Not suitable | 151 | 0.160 | 761 | 0.804 |
| | Total | 946 | 1.000 | 946 | 1.000 |

models and the development of new HS models, and will likely speed up advances in Habitat Suitability assessment procedures.

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