

Article

Geo-Spatial Support for Assessment of Anthropic Impact on Biodiversity

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Abstract: This paper discusses a methodology where geo-spatial analysis tools are used to quantify risk derived from anthropic activities on habitats and species. The method has been developed with a focus on simplification and the quality of standard procedures set on flora and fauna protected by the European Directives. In this study case, the DPSIR (Drivers, Pressures, State, Impacts, Responses) is applied using spatial procedures in a geographical information system (GIS) framework. This approach can be inserted in a multidimensional space as the analysis is applied to each threat, pressure and activity and also to each habitat and species, at the spatial and temporal scale. Threats, pressures and activities, stress and indicators can be managed by means of a geo-database and analyzed using spatial analysis functions in a tested GIS workflow environment. The method applies a matrix with risk values, and the final product is a geo-spatial representation of impact indicators, which can be used as a support for decision-makers at various levels (regional, national and European).

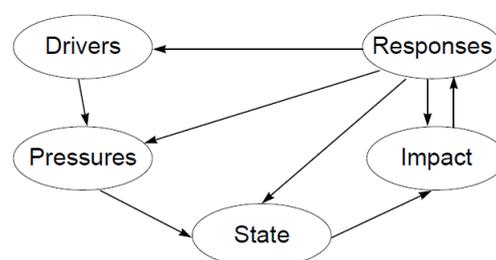
Keywords: hazard; impact analysis; spatial infrastructure; temporal scale; DPSIR model; EIA; support decision system; ecosystem; environment; biodiversity

1. Introduction

This paper reports on a specific approach to a method for ecological and environmental risk assessment, which leverages the potential of geographic information systems (GIS) for processing related geo-spatial data. Habitats and species are protected by the following European Directives: 92/43/EEC (on the conservation of natural habitats (listed in Annex I and II)) [1] and 2009/147/EC (on wild fauna, flora and wild birds (listed in Annex I) [2]. The elements in the Natura 2000 network are influenced by several factors, derived from natural and anthropic sources that originate directly or indirectly from human activities in the territory. They are defined as threats, pressures and activities with impact on a site [3] and are listed in tabular format in a specific document by the European Environmental Agency (EEA) [4]. Human activities that legally register for land-use change are defined in official projects, which have several spatial components (e.g., building plans) and, thus, intrinsically contain information on potential threats, pressures and activities; plans and project must be evaluated to avoid risk for habitats and species. Risk can be defined as the product of the likelihood that something will happen and the consequence suffered if it happens [5]. In this sense, risk is correlated to the expected number of injuries, damages or harm due to a particular phenomenon [6]. It is a product of a specific hazard, vulnerability and element of risk [7–9]; it is a function between indicators regarding exposure and effects [10], which may impact on habitats and species. Each of these elements is commonly analyzed using indicators.

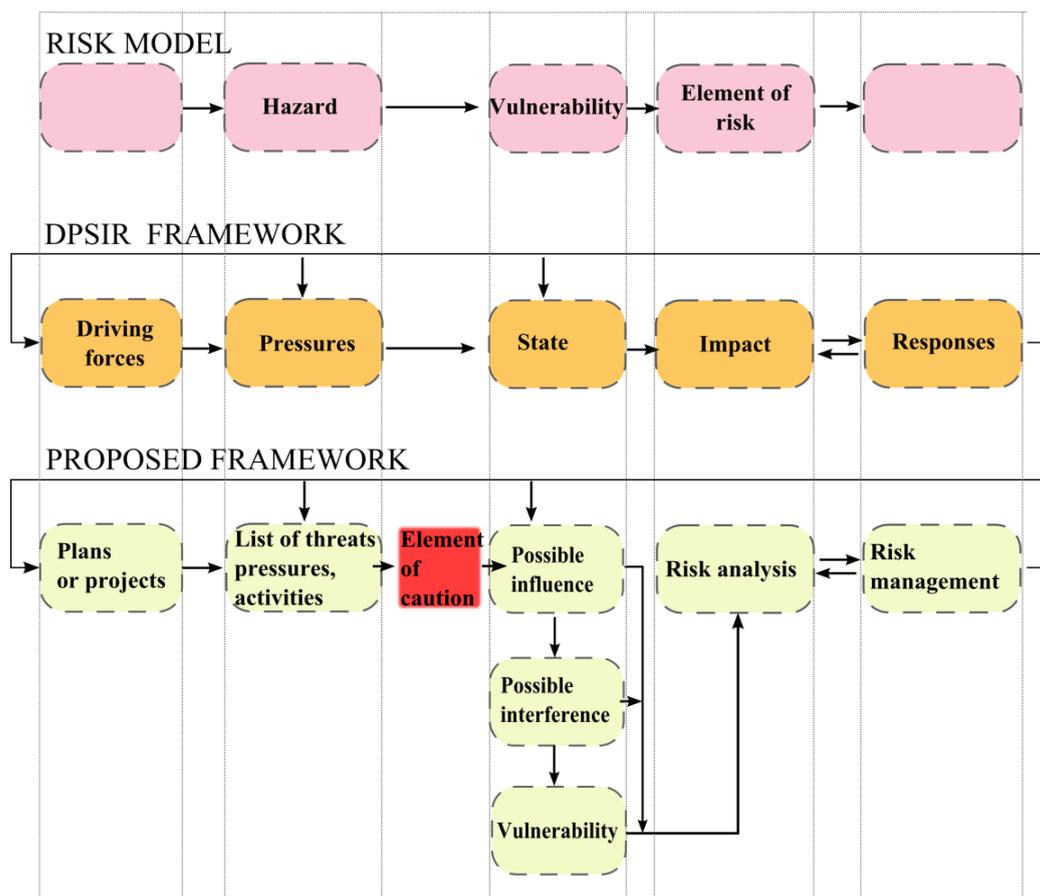
A wide variety of environmental indicators, representing physical, biological or chemical factors, are currently in use. They support analysis on trends in the state of the environment, and they monitor the progress of the effects of environmental policies; they are therefore deemed indispensable for policy and decision-makers. Indicators reflect a series of causes and effects on network-made relations between two systems: anthropological and environmental. According to this systems' analysis, EEA in 1999 introduced the DPSIR (Drivers, Pressures, State, Impacts, Responses) framework, in order to analyze cause-effect relationships between these parts and managing the information flow [11]. Many studies about ecology, environmental and sustainability management of socio-economic activities apply the DPSIR framework [12–22]. This framework helps to structure a paradigm about the interplay between the environment and socio-economic activities [13]. In the DPSIR framework, social and economic developments are the drivers (D) that exert pressure (P) on the environment. Pressure produces, as a consequence, the changes of state (S) of the environment. Finally, this leads to impacts (I) on human health, ecosystems and materials that may elicit a societal response (R) that feeds back on the driving (D) forces or on the state (S) or impacts (I) directly, through adaptation or curative action (Figure 1).

Figure 1. The DPSIR (Drivers, Pressures, State, Impacts, Responses) framework [11].



Applying the DPSIR framework in ecological and environmental risk assessment, the drivers can be modeled by plans and projects (e.g., an urban development plan or a project for a new road track). They can potentially produce pressures on habitats and species, called threats, pressures and activities by the Commission Implementing Decision 2011/484/EU [3]. Each of them may have a possible influence and interference on the state and have an impact, which is verified with the risk assessment. Whenever the interference cannot be determined with sufficient significance or the lack of scientific data do not allow the evaluation, the “element of caution principle” is applied, as in Point 4 [23] (Figure 2).

Figure 2. Comparison of the risk model between the proposed framework with the DPSIR framework.

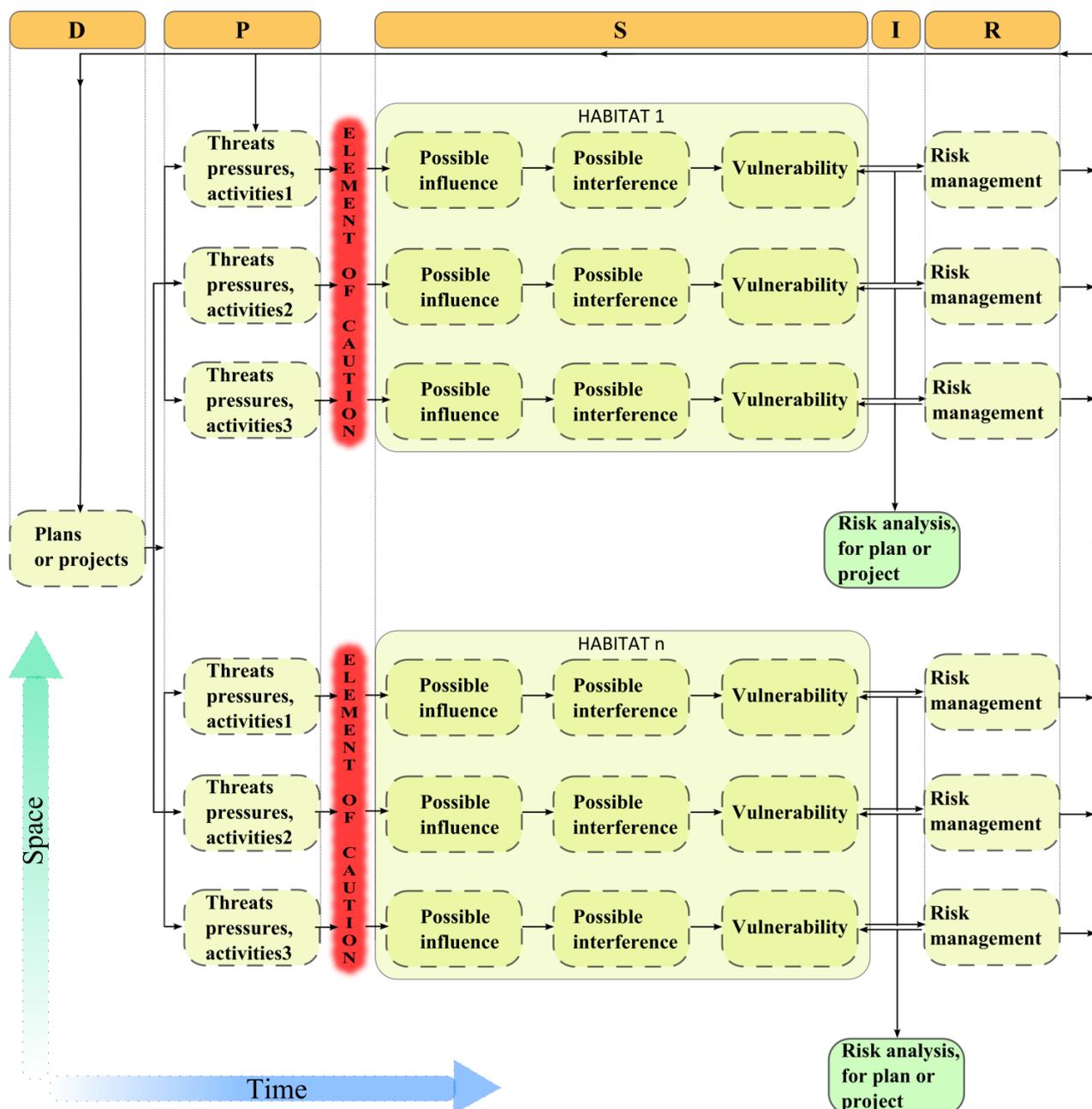


Using the list in [4] and defining threats, pressures and activities as pressure in the DPSIR framework, the analysis is not one dimensional, but it is multidimensional, because it must be applied for each element of threats, pressures and activities that could affect each single habitat or species (Figure 3). This is one of the aspects where geo-spatial tools are able to bring significant added value, as the dimensionality can be stored and represented as joins between tables related to a certain reference on the Earth’s surface (point, line or area).

The measures taken for the conservation of habitats and species are spatially defined in the Special Areas of Conservation (SACs) and in the Special Protection Areas (SPAs), but other measures may need to be implemented outside such areas, for example, in the case of a pressure, whose source is external to an SAC or an SPA, but has an important effect, due to it being spatially near to such areas. All measures taken should avoid the deterioration of the habitat and the disturbance of the species that

are present in the area. Deterioration is a physical degradation affecting habitat and must be avoided. Disturbance concerns species, and it occurs at the spatial or temporal scale. It is often limited and has characteristics of intensity, duration and frequency, and it might or might not be significant. In order to be significant, a disturbance must affect the conservation status [24]. The protection of valuable natural resources requires a better understanding of how the scale of the environmental hazard affects ecological processes and over what time the effects should be monitored and examined [14]. The assessment of plans and projects significantly affecting the Natura 2000 network is also compatible with general Environmental Impact Assessment (EIA) procedures and can be easily integrated into the Strategic Environmental Assessment (SEA) [25].

Figure 3. Multidimensional analysis by application of ecological risk assessment in the DPSIR framework.



Ecological impact assessments need multidisciplinary skills and especially require geo-spatial data. For example, they need information about the environment, soil, geomorphology, ecology, toxicology and chemistry and how these factors are distributed over the Earth's surface (as well as below and above it in some cases), and so on. Sometimes, the data are open, thus easily accessible and of good quality; in other cases, they are partial, incomplete or not accessible. In this case, we suggest applying an element of caution, because the decision-makers are faced with the dilemma of balancing the freedom and the rights of the individual with the necessity of reducing the risk of adverse effects on both the environment and on human, animal or plant health. All should be considered within a structured approach to the analysis of risk [23]. It is important to also consider a degree of uncertainty about the data as the starting point for risk management purposes [26]. Many studies were done to assess the risk for the ecosystem, and it is crucial to know the spatial distribution of the species and population or community at risk [27]. Populations are what are taken into account in this study, as they are the elements used in the Natura 2000 documents [3]. The U.S. EPA uses the term Ecological Risk Assessment (ERA) to define a process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more "stressors" and evaluates human-induced changes that are considered undesirable [28]. The EPA uses the term, stressor, to describe any chemical, physical or biological entity that can induce adverse effects on individuals, populations, communities or ecosystems [29,30]. Habitat and species are vulnerable to a certain degree to threats, pressures and activities, and such vulnerability is an intrinsic property, resulting in susceptibility to a risk source that brings about an event that has a consequence [7].

The paper is organized with the following structure: (i) the Methodology Section describes the theoretical aspect of anthropic risk assessment on biodiversity; (ii) the Results Section describes a simulation of the method for defining the impact of new buildings on a specific habitat and species, shows the practical results, which are reported as spatially-explicit overlapping areas, highlighting the major risk areas; and (iii) finally, the conclusions will define the future applications and potential benefits of the approach.

2. Methodology

2.1. Definition of Anthropic Risk Assessment on Biodiversity

In an ecological context, we define risk as a function of pressure (P) and the ecological vulnerability of habitat and species (V):

$$R = f(P, V) \quad (1)$$

Pressure (P) is the probability that threats, pressures or activities may have a significant negative influence, in a spatial and temporal context, on a habitat or species. It is the product of influence (IN) and interference (IT). Influence means the intensity of threats, pressures or activities that occur on habitats and species. Interference means the spatial and temporal overlap of threats, pressures or activities with habitat and species.

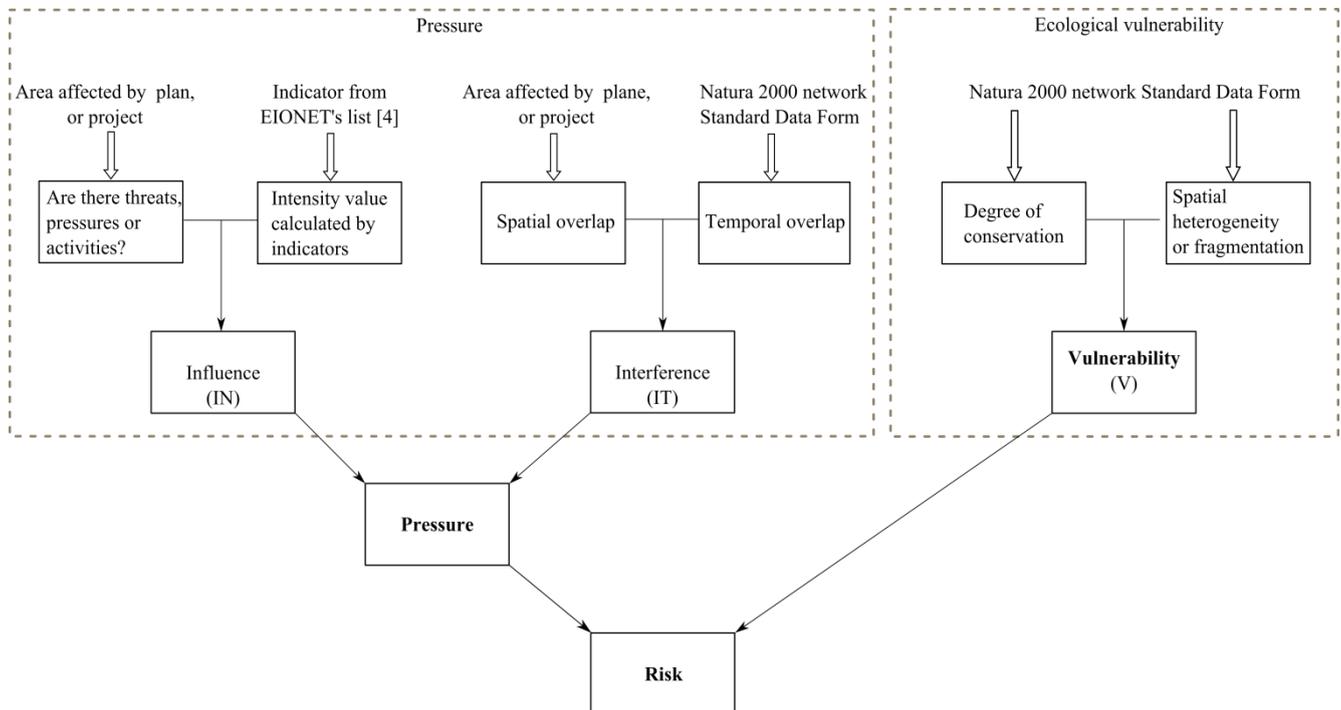
Ecological vulnerability (V) is a function of exposure (also referred to as potential impact and sensitivity) and recovery capacity (resilience or adaptive capacity) [31,32] of a habitat or a species to a

specific stressor listed as a threat, pressure or activity by the Commission Implementing Decision 2011/484/EU [3].

$$R = f(IN, IT, V) \tag{2}$$

The flow chart in Figure 4 describes these elements.

Figure 4. Flow chart of anthropic risk assessment.



2.2. Assessment of the Influence

Human processes operate in a geo-spatial context. The spatial domain describes where threats, pressures and activities do overlap somehow with the geo-spatial distribution of the habitats. If such elements are not present in our area of interest, the analysis will not proceed further, as it is obvious that there is no impact on our area of interest. If we are not sure, the element of caution is applied; the probability of occurrence of an event is always 100%, and thus, we hypothesize that it always occurs (Figure 5).

2.3. Check Temporal Interference (Elements of Risk)

Human processes operate not only in a geo-spatial scale, but also in a temporal scale and, most times, in both scales [33,34]. The temporal scale describes when threats, pressures and activities occur (their frequency, duration), but also when the ecosystem is more vulnerable [35]. A temporal example can be where the presence of a species is seasonal, and the pressure does not temporally overlap with such presence (e.g., maybe the pressure exists only in the building phase). If the spatial and temporal assessment are not verified positively, then the process ends; otherwise, we assign a value of 1 in case there is the presence of only a habitat and the value of 2 in case there is the presence of both a habitat and a species (Figure 6).

Figure 5. Assessment of the influence class.

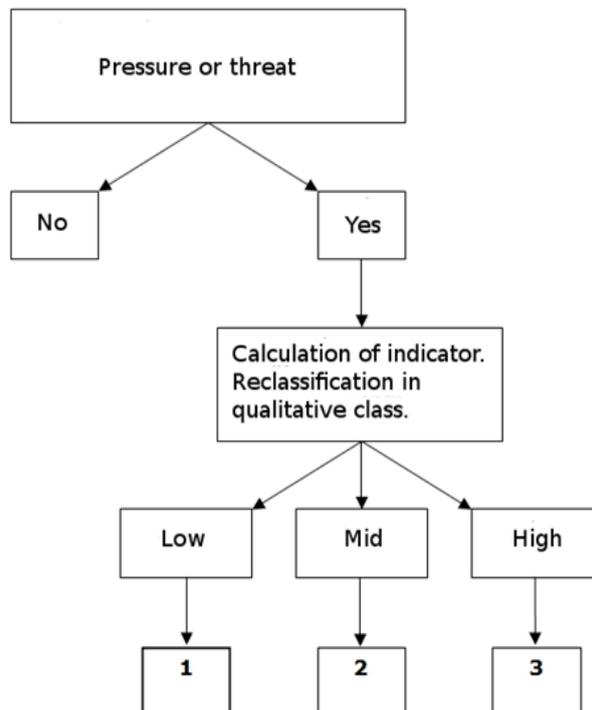
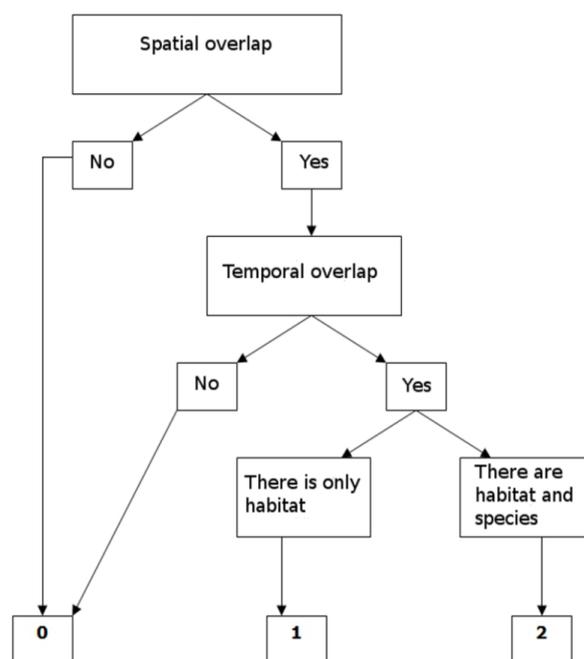


Figure 6. Flow chart for spatial and temporal interference.



2.4. Pressure Assessment

The method described is based on a semi-automatic interpretation of all factors in a matrix structure, applied by means of attributes linked to a geo-spatial representation of the phenomena. The format and application of the matrix depend on the context, and they are used with a wide variety of project types [5,8,36]. Pressure is the combination of influence and interference; this means that we assess the degree of influence of pressures and threats and we combine them with the degree of the

interference with habitats and species. We use a matrix (Table 1) that assigns a value between 0 and 3. In the X axis, there is the influence, and in the Y axis, there is the interference. If there is only the presence of the habitat of the species (value of influence = 1) and the species has not been positively found in the area, the element of caution assigns to the pressure the same value of the intensity. If there are both habitat and species (value of influence = 2), the matrix assigns to the pressure the maximum value of the intensity (3). There is only one case in which the matrix assigns a value of 0, and it is when there is no spatial and temporal overlap between pressure or threat and habitat or species. In this case, the procedure ends, and we have verified that there are no significant negative impacts in such a case.

Table 1. Matrix of pressure as a function of interference and influence.

		Influence		
		1	2	3
Interference	0	0	0	0
	1	1	2	3
	2	3	3	3

2.5. Assessment of Vulnerability

Vulnerability is the intrinsic property of something resulting in susceptibility to a risk source that can lead to an event with a consequence [7]. In our context, this means the sensitivity to the threats, pressures and activities, and it depends mainly on the biological and ecological properties. The analysis of vulnerability is made using the Natura 2000 Standard Data Form [3] that describes the conservation and isolation of habitat and species. The conservation codes in the Standard Data Form are A, B, C, where A is excellent conservation and C limited conservation. For isolation, the codes of the Standard Data Form are A, B, C, where A is an isolated population or habitat and C is not isolated and placed in a wide range of territory. Landscape fragmentation increases the risk of populations becoming extinct, and fragmented natural habitats are less able to support wildlife [37]. Isolated populations are more vulnerable to natural stress factors. It is a major cause of the rapid decline of many wildlife populations [13,38]. The conservation code is combined with isolation, and we obtain six intermediate classes (Figure 7). To use this value in the risk matrix, we need to reclassify again in order to obtain three classes with values of 1, 2 and 3.

3. Results

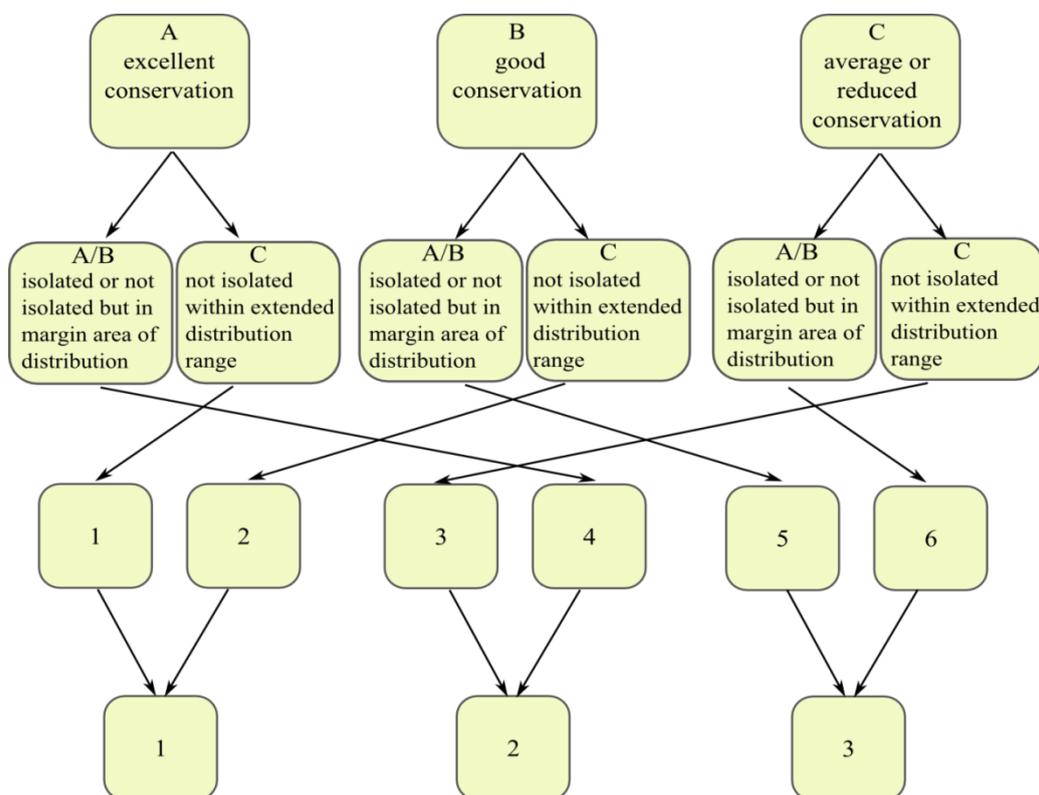
3.1. Simulation of Pressure and Land-cover Change

We here report a simulation of the method described in the previous section, where we simulated an urbanization project, which would produce a change of the land-cover, due to the transformation of a part of agricultural land to an urbanized area. We used a framework of open-source software; PostgreSQL was used as the relational database engine, with geo-spatial support of the PostGIS format and spatial functions, like in [39], whereas QGIS version 2 was used to view the data and add thematic mapping in order to increase the degree of comprehension by fine portrayal of the data. We consider

the threat for a single species, and we calculate the probability of its distribution in the Veneto area (Figure 8). The species taken into consideration in this specific case is the Yellow-Bellied Toad, *Bombina variegata* (Linneaus, 1758) [40]. Its presence decreased dramatically in the lowlands, probably because of intensive cultivation and urbanization and because of the elimination of hedgerows and the increase in the presence of the drainage of the water bodies where it lives. Breeding begins in April and goes until August. Hibernation begins in September/October and ends in March/May; the toads pass winter in burrows, holes and under stones. *Bombina variegata* is present for all the year in the same area. In mapping the distribution of *Bombina variegata*, some anthropic barriers, like roads and railways, are also considered in the process [41]. Areas with a high value indicate a high suitability for *Bombina variegata*, but not its actual presence, which is often not actively monitored to such a spatial scale.

Using the spatial tools in the GIS framework, we verify if the plan or project overlaps the habitats inside the Natura 2000 network (Figure 9). All uncertainties related to the spatial scale and the temporal scales are important, and they are combined in the final risk assessment [42]. This method may be applied for creating a support decision system in order to simplify the EIA procedure [43].

Figure 7. The conservation code combined with the isolation code gives the vulnerability class value.



Notes: **A:** population (almost) isolated; **B:** population not-isolated, but no margins of area of distribution; **C:** population not-isolated within extended distribution range.

Figure 8. Potential distribution of the habitat of the Yellow-Bellied Toad (*Bombina variegata*) in Veneto. Areas with a value of three indicate high suitability; areas with a value of 0.5 indicate low suitability.

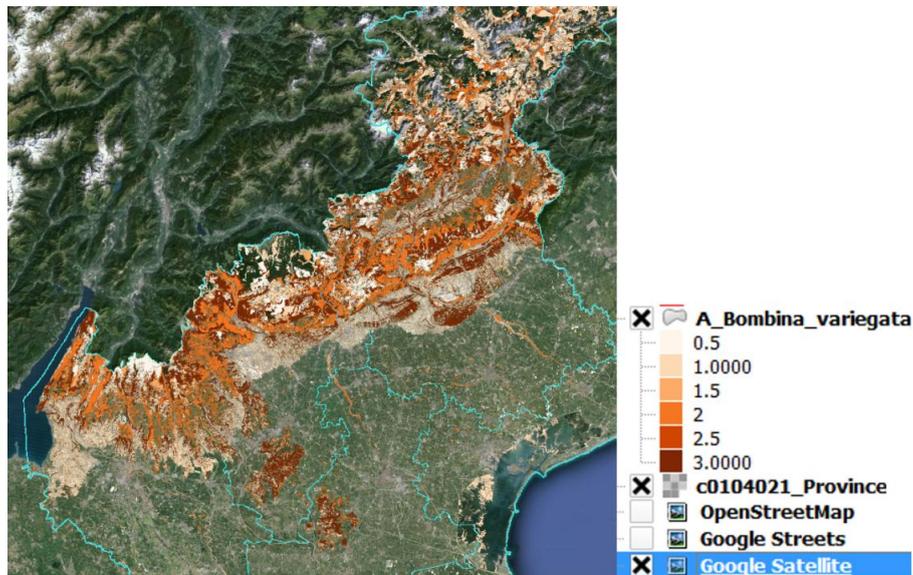
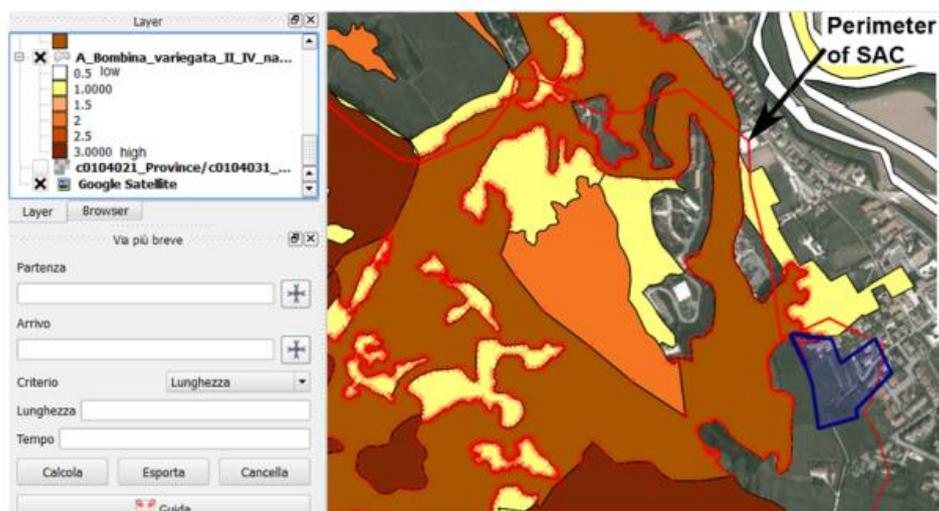


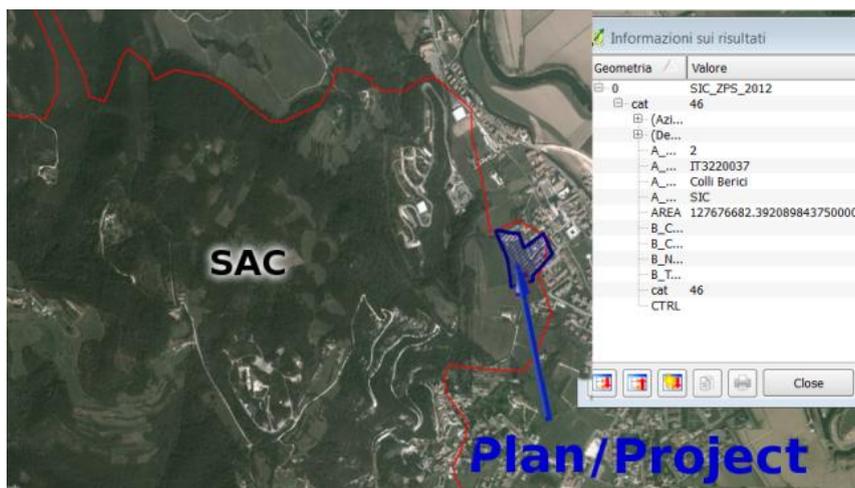
Figure 9. Example of the overlap of an area with a plan and project (blue) with areas of the potential distribution map (color map) and the Natura 2000 network (red perimeter). Distribution areas with a value of three (dark brown) indicate high suitability. Areas with a value of 0.5 (white) indicate low suitability. SAC, Special Area of Conservation.



3.2. Verify if Risk Assessment is Necessary

The first step of this methodology is to verify if, according to existing legislation, the plans and projects submitted by the stakeholders require a risk assessment procedure. If the answer is negative, the assessment never starts. If the answer is positive, we proceed to the next step. The example shows a simple overlap between plan and project with the SAC area in the Colli Berici in the northeast of Italy, where the answer to the first verification is positive, and thus, the new project requires assessment (Figure 10).

Figure 10. Area overlap of plan and project with the SAC.



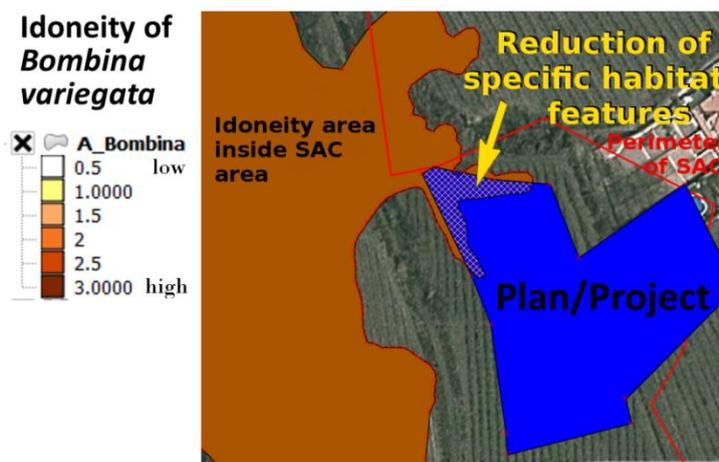
3.3. Identification of Threats, Pressures and Activities

The plans and projects need to be assessed to identify the pressures and threats that can potentially be derived from them. The risk assessment is based on specific threats, pressures and activities that could have a significant negative impact [3]. In terms of land use change and of landscape fragmentation, the replacement of a habitat with a certain matrix of cover types can create habitat loss and have negative consequences for populations and communities of existing species. It can create barriers or filters to the movement of individuals between habitat patches [3] and produce a number of detrimental effects on the environment, including the spread of noise and pollution from traffic, and effects on the local climate, reducing the size and persistence of wildlife populations [44].

Table 2. Threats, pressures and activities in the project area listed in specific document [4].

Code	Description
J.03.01	Reduction or loss of specific habitat features

Figure 11. Reduction of potential habitat area by the new plan and project.

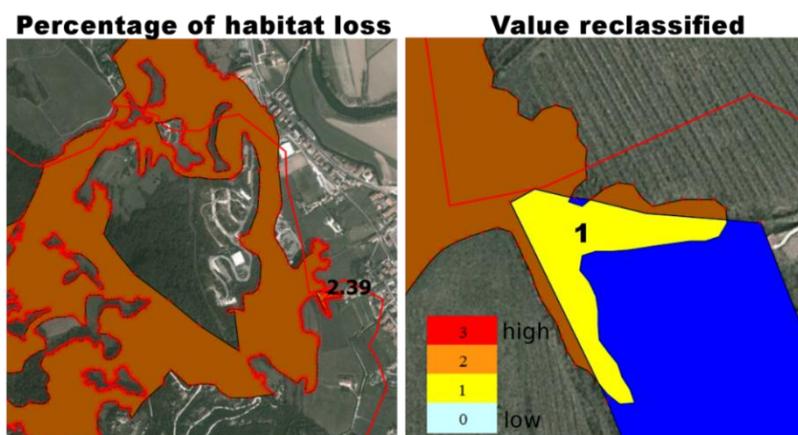


Threats, pressures and activities can be separated into two elements. The first element is the local component, which describes the object in the real world and the change of land-use derived from it, for example a new building, a new service area or a new road that connects areas create patches and fragmentation of existing habitats. Such elements can be represented in a geo-spatial domain using polygons. The second component is the pollution component. It is made of many sources, for example the emission, the noise, the drainage systems, *etc.* both during the realization of the project and afterwards, when the elements have been put into place. We need to identify specifically and clearly each threat, pressure and activity, in this step of the analysis. In the example, we identified and analyzed the reduction or loss of specific habitat features (Table 2, Figure 11). The procedure has to be applied to each component of threats, pressures and activities that are identified in the process.

3.4. Calculation of the Influence

Using QGIS Open Source software, we calculate specific indicators using a list of such indicators, stored in a geodatabase created by Regione Veneto in accordance with the Standard Data Form by the Commission Implementing Decision 2011/484/EU, 2011 [3], which assumes a range of possible values of low, mid and high. Then, we reclassify the three qualitative classes, and we assign numerical values of one, two and three (Figure 12).

Figure 12. Reclassified value of influence as a result of habitat loss.



3.5. Calculation of the Interference

The analysis finds a spatial overlap between the project area and a suitable area for *Bombina variegata* inside an SAC. Temporal assessment finds the presence of *Bombina variegata* all year. There is the presence of both a habitat and a species, and applying the methodology, the reclassified value is two (Figure 13).

3.6. Calculation of the Pressure

Using the matrix of pressure (Table 1), we combine the influence and interference to obtain the value of pressure (Figure 14).

Figure 13. The value of interference calculated from the spatial overlap of areas.

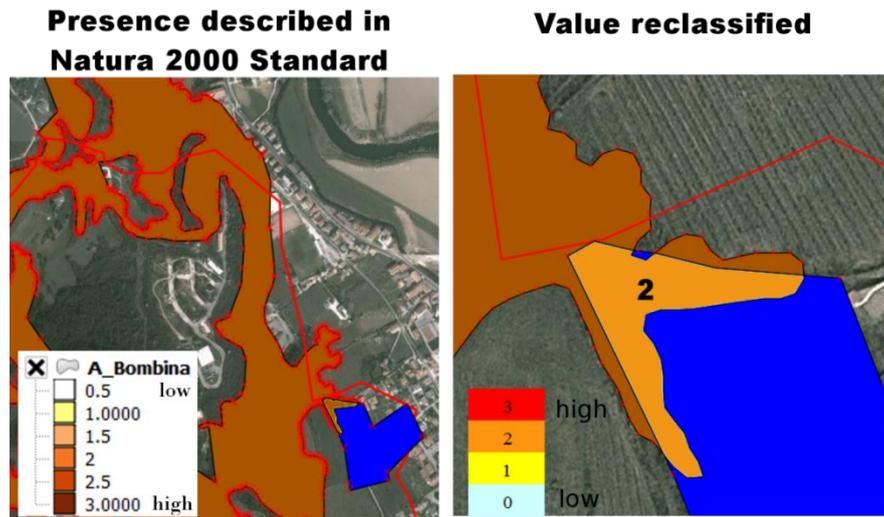
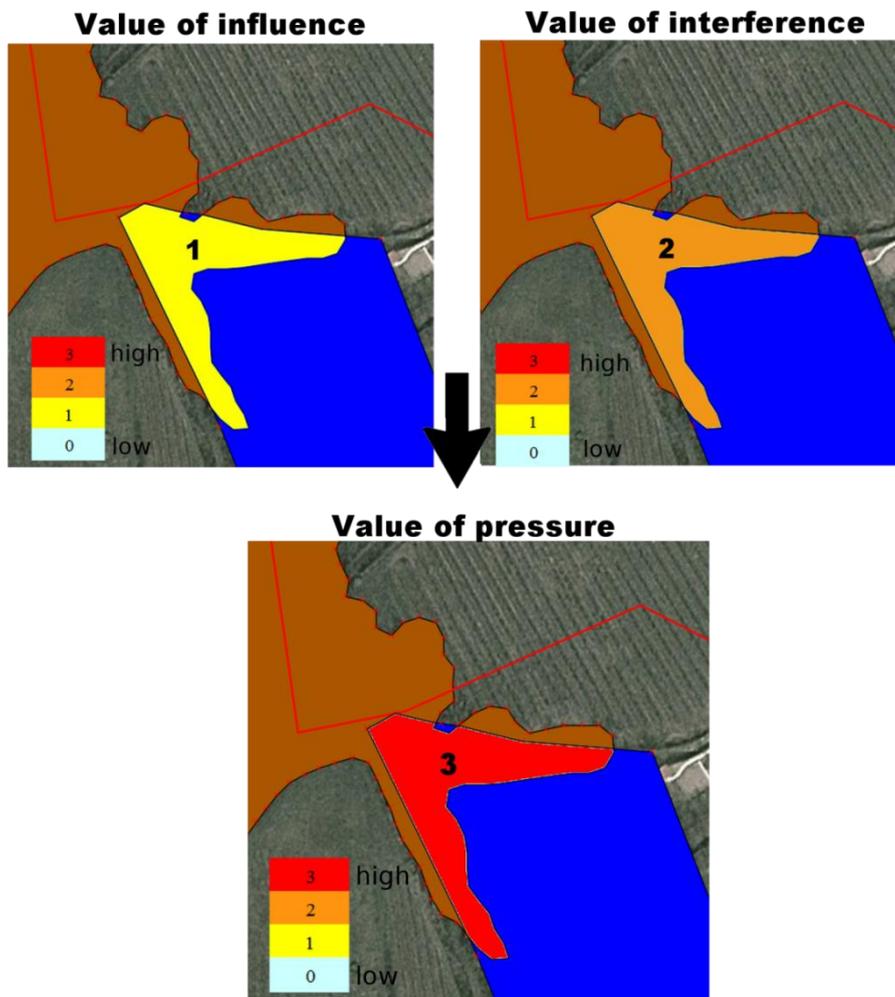


Figure 14. Value of pressure.

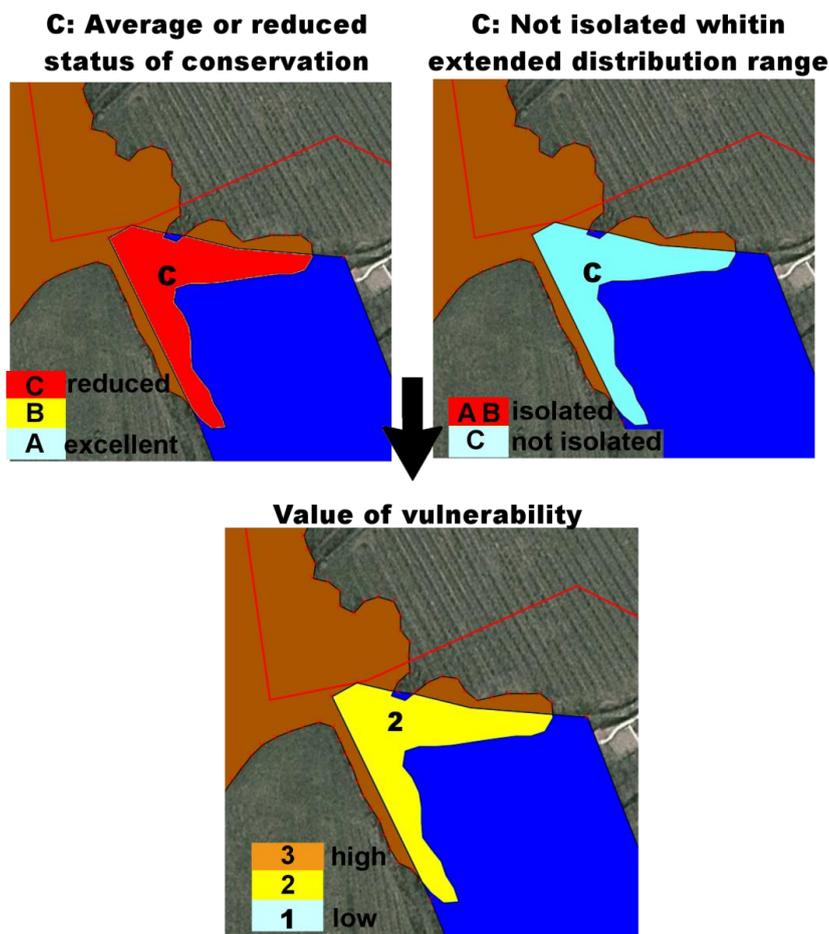


3.7. Calculation of Vulnerability

The Natura 2000 Standard Data Form [3,45] describes the conservation and isolation of habitat and species. The conservation codes of the Standard Data Form are A, B, C, where A is excellent

conservation and C limited conservation. For isolation, the codes of the Standard Data Form are A, B, C, where A is an isolated population or habitat and C is not isolated and placed in a wide range of territory. The conservation code is combined with isolation to obtain six intermediate classes, which are reclassified, applying the schema in Figure 15, to obtain the three final classes of pressure value: 1 (low)–3 (high).

Figure 15. Vulnerability value from a combination of information from conservation and isolation.



3.8. Calculation of Risk

The risk is assessed using a matrix (Table 3) that multiplies the pressure and vulnerability values.

In order to protect habitat and species, it is simple to notice that the susceptibility of an area to the presence of a particular species is sufficient to produce a low risk. The matrix can be read using the next table that describes the action to be taken in the case of each risk value (Figure 16, Table 4).

Table 3. Matrix of risk as a function of vulnerability and pressure information.

		Vulnerability		
		1	2	3
Pressure	1	1	2	3
	2	2	4	6
	3	3	6	9

Figure 16. Risk map calculated using the risk matrix.

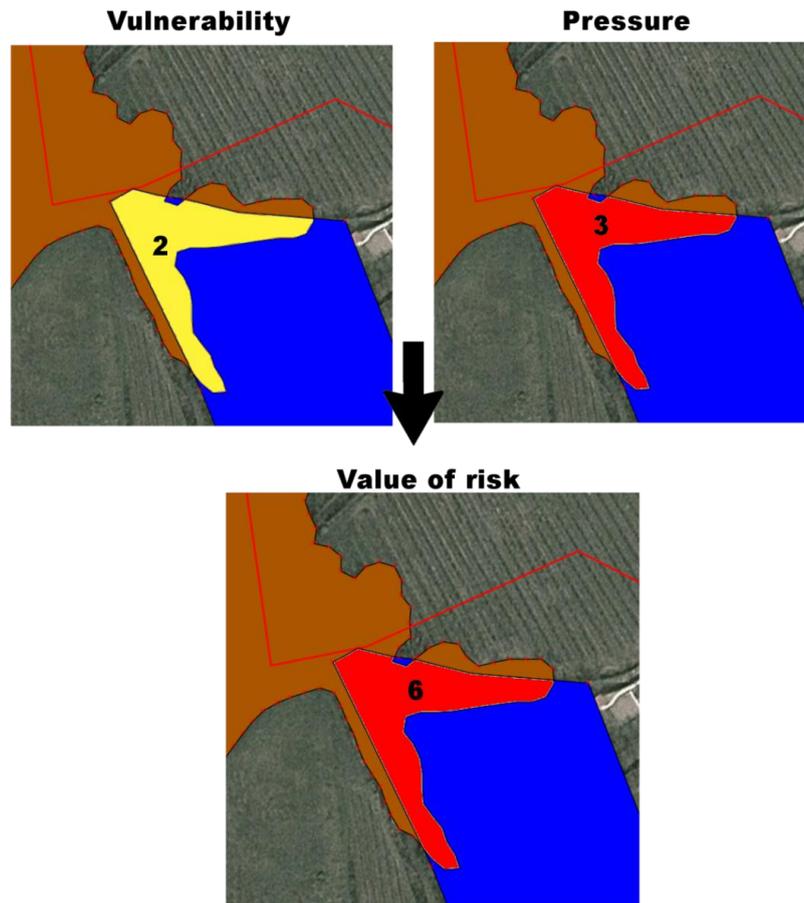


Table 4. Table for the interpretation of risk and relative action.

Value	Risk	Action
0	Null	Monitoring plan
1	Low: situation potentially stable	Monitoring plan: planning actions in case of an increase in the risk value
2	Mid: situation potentially unstable	Monitoring plan (high level of monitoring): planning actions in case of an increase in the risk value
3–4	High: situation potentially serious	Monitoring plan (high level of monitoring): immediate regulations and actions for active management
6	Very high: situation potentially critic	Monitoring plan (high level of monitoring): urgent regulations and actions for active management
9	Extreme: situation potentially irreversible	Monitoring plan (high level of monitoring): priority regulations and actions for active management

Color codes improve the readability for decision-makers, who are responsible for the last part of the process. Spatially explicit information is one of the main objectives of using a GIS procedure in informative and collaborative platforms [39]. This method will leverage this principle in the future to test a semi-automatic procedure for the assessment of anthropic impact on biodiversity in the sense of risk to habitats and species derived from multiple pressure sources.

4. Conclusions

The methodology proposed in this paper is in an experimental phase. It is a prototype and needs to be further tested in real test cases. Nevertheless, we have reported on the methodology to provide a roadmap to readers that might be interested in an implementation of the process with a wider array of data. Habitat and species, protected by European legislation, are a vulnerable element of the overall environment. The necessity to minimize risk created by anthropic activities has led to a definition of this procedure that includes the element of caution as an important part of the method. In classic risk analysis, the risk is the product of elements of risk, vulnerability and hazards. In an ecological context, the elements of risk are habitats and species, and we define the risk as the product of vulnerability and pressure. Vulnerability is an intrinsic property of habitats and species and denotes their susceptibility to suffer from specific threats, pressures or activities. Pressure means the probability that threats, pressures or activities may have a significantly negative influence, in a spatial and temporal context, on habitat or species. It is the product of influence (the intensity of a single threat, pressure or activity) and interference (the spatial and temporal overlap of threat, pressure or activity with habitat and species). The application of the DPSIR framework to ecological risk assessment shows clearly how the process is multidimensional, because it must be applied for each element of threats, pressures and activities that are identified and listed by European legislation [3,4] and that could affect each single habitat or species. The driving forces are the plans and projects that the public administration needs to assess. Plans and projects can potentially create many threats, pressures and activities. They have two components: the spatial extension of the object that produces the effects at a local spatial scale and a polluting component; both produce effects in both the spatial and temporal scale. Threats, pressures and activities could affect the ecological state of habitats and species and could produce an impact. The responses are expressed in actions (Table 4) to limit the impact for habitats and species. They are given at the risk management stage (Figures 2 and 3). The “element of caution” principle has been applied in the manner described in the method, and a general precautionary principle is used at the “risk management” stage (Figure 3) and is part of political choice, and is eminently a political responsibility [23], applicable if the uncertainty of risk assessment is too high and does not exclude the possibility of very high risk.

This analysis is always multidimensional, because it is applied to each single pollutant that manifests its effects in the spatial and temporal context for each single habitat and species identified by the planner as an element of risk. The method requires information on the spatial area and localization of plans and projects in order to assess spatial and temporal overlap with habitats and species. It is important to note that the threats, pressures and activities may exist, but if they do not overlap with habitat and species, they do not produce risk. When a single threat, pressure or activity (also with low intensity) is identified, in conformity with the precautionary principle, risk always occurs. The method is developed for the public administration of the Veneto Region, with the scope of excluding significant negative impact, in order to simplify and improve the quality of European EIA. Further developments can be foreseen in the integration with collaborative web-GIS platforms [39] to include public participation fitting the view of Digital Earth (DE) [46]. Furthermore, a professional can use this instrument to simplify and improve his work. The future development may be improving the semi-automatic interpretation of the matrix in a full automatic procedure to build a full spatial data

infrastructure (SDI), actively online, to support the decision system process. In this method, there is only one case where the assessment will not reach the stage of “risk management”, that is where there is either no spatial overlap between polygons and/or no temporal overlap (Figure 6); all other cases produce a certain degree of risk, thus a certain relative action (Table 4).

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Author Contributions

Piragnolo Marco and Salogni Gianluca conceived the study and designed the analysis. Pirotti Francesco, Piragnolo Marco and Salogni Gianluca carried out its implementation and drafted the manuscript. Pirotti Francesco participated in the design and implementation of the study. Piragnolo Marco, Pirotti Francesco and Salogni Gianluca participated in the revision of the manuscript. All authors read and approved the final manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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